NEW FRONTIERS

Proceedings of the 15th International Conference

on Computer- Aided Architectural Design in Asia

CAADRIA 2010

Edited by

Bharat Dave, Andrew I- kang Li, Ning Gu, and Hyoung- June Park

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FOREWORD

This volume of papers represents the culmination of a long and collaborative process. It also marks another forward step for CAADRIA, an association founded 15 years ago to foster a community of people with shared interests in Computer-Aided Architectural Design Research in Asia (www.caadria.org). Over the last 15 years, CAADRIA has continued to thrive, its regional base has grown from Asia to include the Pacific Rim, and the annual international conference now routinely includes scholars and practitioners, not just those based in Asia-Pacific countries but also from the rest of the world.

This volume of research papers is the tangible realisation of a process initiated nearly one year ago. The initial call for papers in early 2009 resulted in the submission of 177 abstracts from around the world. The Paper Selection Committee reviewed all the abstracts and invited 130 abstracts for further development and submission as full papers. Of these, 85 full papers were submitted and brought to final review stage. A rigorous and blind review of each paper was carried out by three reviewers drawn from an international review committee, resulting in nearly 260 separate reviews. Based on the combined recommendations of reviewers, 62 papers were finally accepted. This volume contains 58 papers that were subsequently revised and resubmitted for presentation at the 15th International Conference on Computer-Aided Architectural Design Research in Asia.

The long process leading up to the publication of this volume involved many scholars, practitioners, and reviewers distributed around the world, and conference organisers based in Hong Kong. The authors submitted their ideas and work for peer assessment and comments; the reviewers voluntarily devoted time and energy to critique and suggest improvements to papers; the Paper Selection Committee members stepped in where gaps appeared and coordinated this process as objectively as possible; a competent team of students (including Kevin Lau, Alexander Zipprich, Xia Heng, Lam Yim, Jason Lee, Kaman Tam, and Tan Ka Wai), assisted by Christine Ko, and led by Andrew Li managed digital typesetting and printing of this volume; and the conference hosts and organisers orchestrated and facilitated the coming together of the community at the 15th international conference of CAADRIA held at the Chinese University of Hong Kong 7–10 April 2010.

On the following pages, we acknowledge and thank the support and input by many individuals leading up to the production of this volume.

B. Dave, A. I. Li, N. Gu, H.-J. Park (editors), April 2010

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Editorial introduction

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It was nearly five decades ago that Ivan Sutherland laid the foundation for digitally expressing and reasoning with graphic shapes in the form of Sketchpad: a man–machine graphical communication system (1963), a foundation that has since provided inspiration and some challenges that are yet to be fulfilled by those who followed. Over the last five decades, research and developments in the field of computer aided design continue to draw upon Sutherland's original visions and explore what lies beyond the frontiers of known or established knowledge in the field. The research community keeps redefining and repositioning itself: computer-aided design, computer-aided design and drafting, computational design, digital design, computer modelling and design, algorithmic design, and other monikers, each one emphasising a particular facet related to design and its tractability using digital representations that is deemed significant by researchers. The multiple perspectives about what the field is about or what to call might reflect a degree of ambiguity or lack of clarity. However, we think it is a healthy sign of our research field that it continues to discover problems that are not yet addressed, rediscovers

new ways to approach problems that are already addressed, and continues to reflect on how digital tools redraw disciplinary and professional knowledge and practices.

The ideas and projects described in papers on the following pages provide one snapshot of current research in computer-aided architectural design from around the world. The papers explore the field from diverse perspectives, emphasise different foci, employ a range of methodologies, and demonstrate many different ways in which designs and designing can be construed, understood and supported using digital tools and technologies. The notion of frontiers in this collection of papers reflects not just a quest for new problems but also a reassessment of what we already know, not just what is conventionally understood as design in terms of tangible material configurations but also what may exist only as processes or as immaterial and virtual representations.

The diversity of research questions and approaches in the following pages reflects richness for a community that is relatively modest and unevenly distributed around the world. While there are no absolutely reliable data about the community of researchers in this field, an approximate and gross measure of its size can be surmised from CuminCad, an online cumulative index (cumincad.scix.net). Its records include approximately 7000 conference papers, 1000 journal papers, and over 200 PhD and 80 masters theses. If we use the founding of the Architecture Machine Group at MIT in 1967 as the threshold for developments in computer-aided design, the number of published outputs indicates a research community that has grown and sustained only modestly over the last four decades and a few years. Against this background, annual meetings and conferences organised around the world assume much bigger significance in that they allow the exchange and flow of ideas in a community that is both small and globally dispersed in terms of researchers, educators and research students.

This volume reports on current research from around the world. Each paper was selected by an international panel of peer reviewers and offers methods, insights, findings, or observations relevant to those involved in computer-aided architectural design research. The papers represent a diversity of focal interests, ranging from the search for original or novel approaches to support designing, to arguing for changes in established norms or practices, to highlighting how digital tools and technologies not just support but also fundamentally alter the very processes they are meant to facilitate, and many others. They also range in terms of scale of operation, typologies of design problems addressed, and methods employed. These range from research issues and approaches relevant at the scale of a single design idea, to configurations in 2D and 3D of various complexities, and to large-scale urban fabric. Some

papers also represent increasing interest in issues of multidisciplinary collaboration involving both complementary and divergent knowledge domains and ways of thinking. There are papers that focus on the flow of information from ideas to their realisation in material forms, and facilitated by structured protocols or seamless integration with new fabrication technologies. Other papers, in contrast, focus only on immaterial and virtual representations which, although existing only virtually, provide substance for embodied experiences and reflection about social and cultural dimensions of our lives. Among the diversity of research papers in this volume one will also find refreshing propositions and acknowledgement of the changing contexts in which designers and researchers operate. Parametric thinking and delivery of services in post-disaster regions, folding in sustainability issues with digital design approaches, reassessing design, construction and delivery processes, and others represent some of the most engaging research themes.

The papers collected together in this volume offer a snapshot of ideas that are being pursued around the world, by both established and emerging researchers in computer-aided design. Needless to say this is but one snapshot of the landscape of ideas at a particular moment in time and space. We hope researchers, educators, practitioners and technologists will find these papers stimulating and valuable, as a record of current knowledge and understanding and also as a jumping-off platform for future research and development in computer-aided design.

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VINE GRAMMAR GENERATIVE SYSTEM

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Abstract. Graphic designers always take both time and efforts when they are creating a decorative pattern with complicated curves and a great deal of motifs. Although there are many sourcebooks of decorative patterns, the satisfaction of the results couldn't accomplish with designer's requirements. Thus, graphic designers need a faster and easier system to create decorative patterns in classical style. There are a few effiencient methods to analysis curves and surfaces in the development of shape grammars. The purpose of this research is to develop *Vine Grammar* based on shape grammars. The vine grammar analyses principles hidden in the language of deisgn works to create the order, then generates design by using Bézier curves. This research also presents the development of a decorative pattern generative system called *Shlishi* by using FLASH Action Script 2.0. The grammar can be applied with computers and to verify rules quickly by *Shlishi.* The intention of this research is to make graphic designers to use these rules to create decorative patterns of plants in classic style and to produce satisfactory results for designer more efficiently or to make the results the source materials for the follow-up design works.

Keywords. Vine; *Shlishi;* decorative patterns; shape grammar; generative design system.

1. Introduction

The manufacturing of decorative patterns gets into computational period. From making by hand to duplicating by printing, a computer program of today has been able to analyse and interpret how designer think and create patterns automatically. With a generative design system, designers can set their concepts and conditions of design to generate all the computing results which

adapted to the rules they defined. Then designers can choose a satisfactory one. Comparing with a traditional design process that designers merely rely on their intuitive inspiration, this generation mechanism serves with an evaluative and selective way for designers to solve their time consuming in design processes.

Graphic designers always take both time and efforts when they are creating a decorative pattern with complicated curves and a great deal of motifs. Although there are many sourcebooks of decorative patterns, the satisfaction of the results couldn't accomplish with designer's requirements. Probably designers are unfamiliar with one style and couldn't describe the framework with the right concept. Even they make their works become skin-deep ones.

Shape grammars have the great power in generating language in the architecture and industrial design domains. But there are few efficiency methods to analysis or generate curves and surfaces since shape grammar being developed in 1972 (Gips, 1999).

This research makes use of shape grammars, which have great power in generating composition of lines, to develop "Vine Grammar". It analyses principles hidden in the language of design works in order to get criterions, then creates decorative pattern design of plant with curve elements by rules of the vine grammar.

Finally, the research develops a shape grammar interpreter uses a code, *Shlishi*, to be the name of system. The word *Shlishi* is number 3 in Hebrew, and God creating flowers and plants on the third day in world of Genesis. Graphic designers can operate *Shlishi* to create or modify decorative pattern in computational way to be the source materials for follow-up design works.

2. Shape grammar

Shape grammar is a computational design method by calculating shape in limitative conditions. Shape grammar has multiple capabilities like emergence, parameterisation, descriptions, labeling, weights, multiple drawings, and so on. A grammar is used to get the hypothesis of prediction and correct the grammar by elevating the style (Li and Lau, 2004).

A shape grammar interpreter can be separated into two main parts: determinism and indeterminism. A deterministic system generates automatically and an indeterministic (non-determinism) system is operated by designers. An automatic generating system sets the initial shape and terminal condition, and then the system will decide which rule to be applied automatically. An indeterministic interpreter usually has a user interface to consign the decision of ordering rules to designers. And, the results of generation will mainly depend on the designer's free mind.

3. Curves

A curve can identify an infinite number of points that are conformed to the definition of shape by Stiny (1980a), and the conception can extend to maximal lines and sub-shapes with collinear with not only a node but also the class of nodes that construct the curve.

In the past ten years, the development of shape grammar mainly aims at designs with straight line. There are few relative researches about analysing or producing curves or surfaces in shape grammars (Gips, 1999).

Stiny (2006) mentioned that there is a possible variation of generating curves without detailed examples. There are only predictions which a closed curve is able to change its forms by shape transformation.

Jowers (2010) uses a sub-shape idea to analyse curves. By applying shape algorithms which provide the mechanisms necessary to implement a shape grammar interpreter for shapes composed of parametric curves in two- or three-dimensional space.

There are sets of shape grammar for generating Chinese traditional patterns with curve elements. Unfortunately most of them are decided by the outline generated by rules, and then by replacing the straight line with curve elements. These grammars don't have a sub-shape, and they might belong to symbolic grammars. Design works generated by these grammars have less variation and have to increase the generative power by adding or replacing rules by human.

A parametric shape grammar of Hepplewhite-style chair-back design has been developed by Knight (1980). The constraints determining the design of a chair-back can be more succinctly rigorously expressed by triangles which generated by parametric shape grammar. At the final stage, a procedure for replacing straight lines with curves in any previously generated rectilinear design.

The intention of symbolic grammars is to attempt all compositions between elements. By replaying a single element to a composite element, rules can raise the diversity of design. There is a difference between shape grammars and symbolic grammars. The symbols are all human have to combine, and they can't change itself when they're put in place (Stiny, 2006). Language generated by shape grammars not only get the result from re-arranging symbols, but also change the form or attributes of element which blend the idea of designers. By manipulating the parameters and applying the ordering of rules, it make design varied.

4. Vine grammar

The vine grammar can use equations to replace polygons into curves. This study uses quadratic Bézier curve for an instance. According to the composition of the spatial relationships between Bézier polygons, the grammar could create various Bézier curves.

Polygons in the space have to be arranged in a specific way. In vine grammar, limited numbers of spatial relationships between polygons keep curves harmonious, and rules can produce these spatial relationships.

The vine grammar doesn't use a grid system to define a basic unit. Chinese lattice generation of Ice-ray grammar (Stiny, 1977) and axis of Palladian grammar (Sass, 2007; Stiny and Mitchell, 1978b) both use a grid system to define the parameter of distance in the space. Thus design that the vine grammar generates are decided by manipulating the apex of Bézier polygons.

4.1. SPATIAL RELATIONSHIPS

The goal of vine grammar rules is to produce new relationships of Bézier polygons. The left-hand shape (LHS) of one rule could be one labelled Bézier triangle or multiple triangles with specific relationships. And, the right-hand shape could be more Bézier triangles with more complex relationships.

As the vine grammar desires to generate one harmonious curve, there are two kinds of common relationships, C-type and S-type. As the vine grammar desires to generate a multiple curve with branches, there is also a Y-type relationship. And they are defined as below:

1. A Bézier triangle constructs from two locative-vertices and one controlled-vertex. A Bézier curve passes by these two locative-vertices. The controlled-vertex affects the value of curvature.
2. Two Bézier triangles only contact with a single point, a shared locative-vertex. This share locative-vertex is collinear with the other two unshared locative-vertices of Bézier triangles, and these vertices construct an axis.
3. As the figure shown below, two Bézier triangles both locate at the same side of the axis, one C-type curve could be generated.

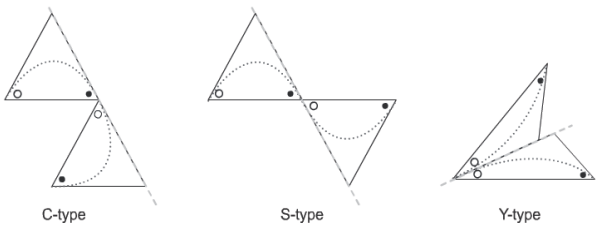

Figure 1. Spatial relationships and curves (a) C-type; (b) S-type; (c) Y-type.

4. In other words, when there are two Bézier triangles located at the different sides of axis, one S-type curve could be generated.
5. As the figure shown below, when shared vertex is collinear with controlled-vertex of both triangles, one Y-type curve could be generated.

4.2. GENERATION

The initial shape roughly decides the border and tendency of the generating result. Rules mentioned here produce Bézier triangles according as the scope of the initial shape. There are labels used to control application times and target shape which is going to apply rules. There are three stages of generative procedure: *trunk, branches,* and *leaves.*

4.2.1. The generating and modifying of trunk

Trunk is the main body of one decorative pattern of the plant. After defining scope and location of the initial shape, rules are defined to turn a single quadratic Bézier curve into multiple quadratic Bézier curve. And, specific spatial relationships are used to generate S-type or C-type curves shown in figure 2 below.

Rule r1 is applied to the initial shape and generates three Bézier triangles contacted with S-type relationship. And, the procedures of these three triangles apply rule r2 respectively as shown in figure 3.

4.2.2. Producing "branches" and modifications according to trunk

A Branch is a division of the Trunk, or division of other Branches. After two Bézier triangles are contacted with C-type relationship by applying rule r3, a new Bézier triangle with a right-angle label will be produced. And, rule r4 and r5 extend the result of rule r3 to generate C-type curves as shows in figure 4.

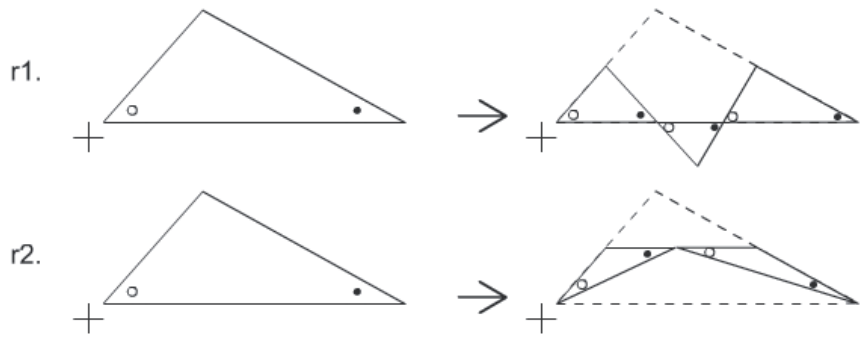

Figure 2. Rules which can generate trunk

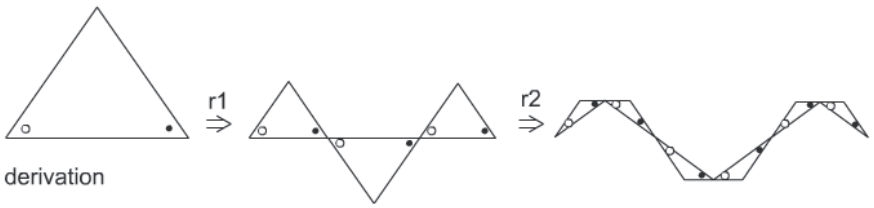

Figure 3. Derivation of generating trunk.

According to the generating result of the above derivation from last procedure, each set of Bézier triangles with C-type relationship apply rules r3 and r4 repeatedly to generate spiral curves. The derivation is shown in figure 5.

4.2.3. Producing "leaves" and modifications

After finishing generating trunk and branches, a rough framework of the decorative pattern is formed. Then, any one Bézier triangle applies rule r6 to generate a new Bézier triangle with a label of letters by using a Y-type relationship. A Bézier triangle with the label of a specific letter could be placed into a form element by applying rule r7. Rules r8 and r9 are used to erasing right-angles or equal-line labels. Rule r10 turn the labels of Bézier triangle into the same arrangement of the initial shape. Finally, rule r10 replaces all Bézier triangles into curves. The result is shown in figure 7 below:

4.3. INITIAL SHAPE

In order to generate a vine design repetitively or symmetrically, an initial shape could have multiple Bézier triangles. With the same ordering of rules being applied to Bézier triangles, curves reflecting each other.

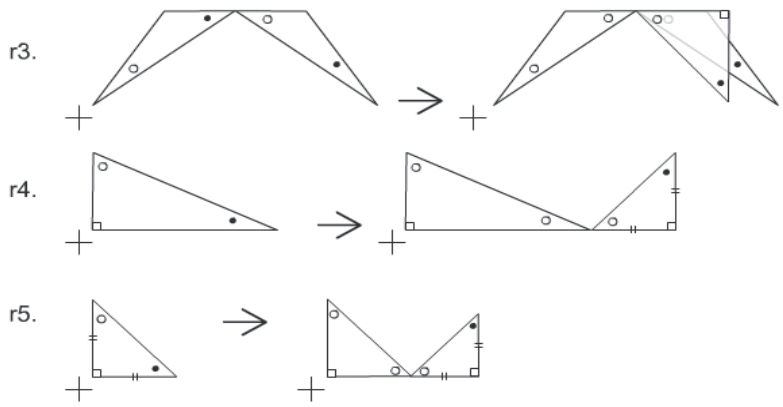

Figure 4. Rules which can generate branches.

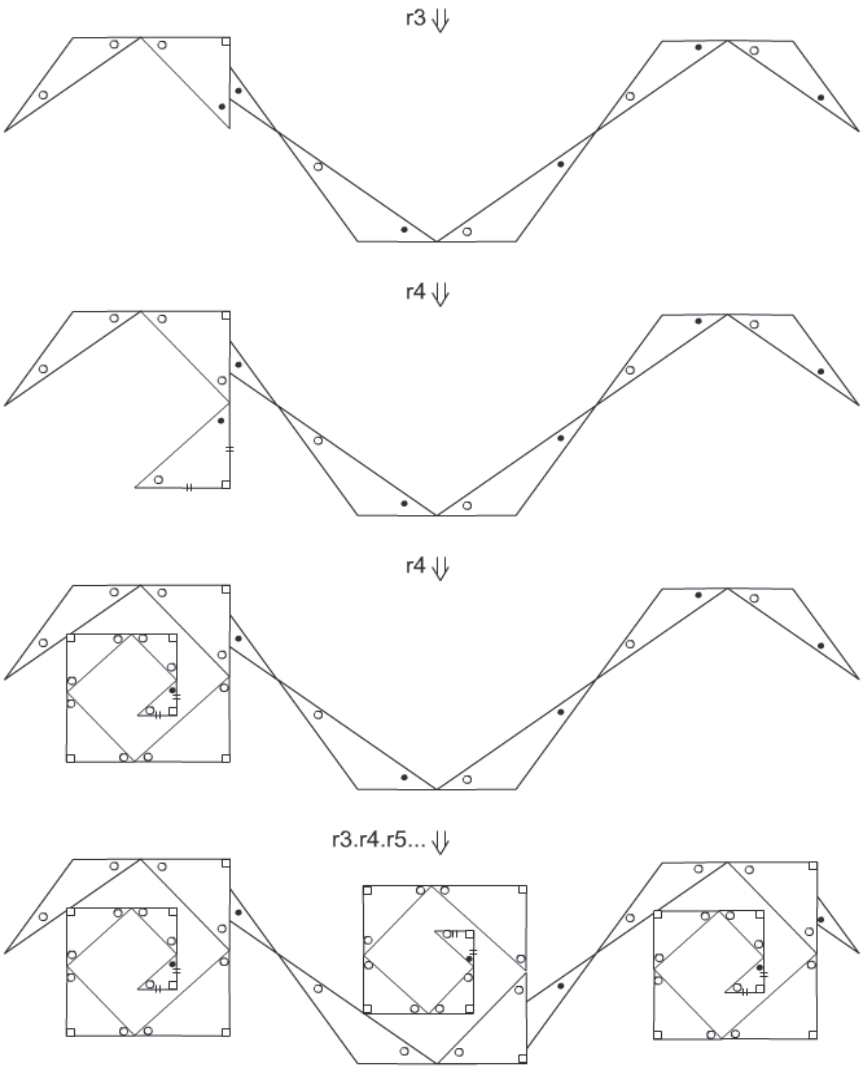

Figure 5. Derivation of generating branches by using rules r3, r4, and r5.

5. Discussion

This research studied the vine grammar based on shape grammars. A shape grammar study usually focuses on design works of straight line. According to the vine grammar, design works with curve could be generated. Rules of the vine grammar generate new spatial relationships of polygons, and then place the polygons into curves.

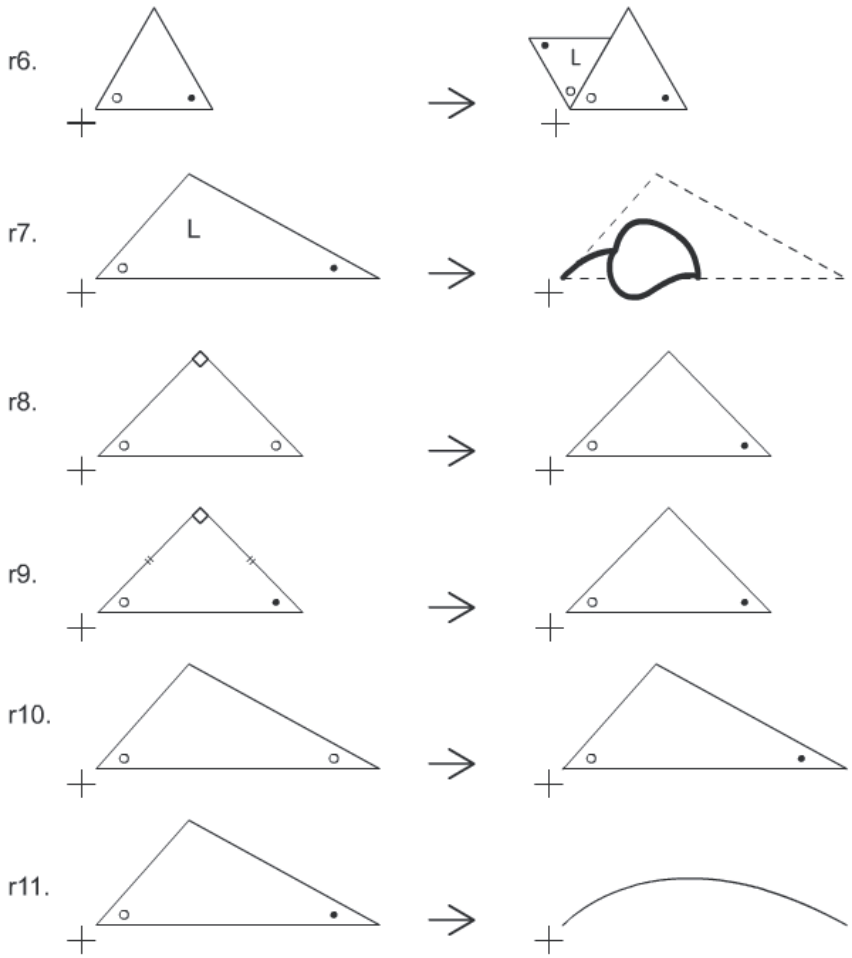

Figure 6. Rules for producing leaves and curves.

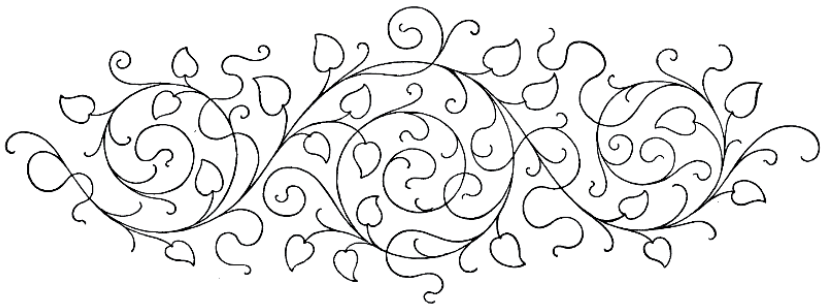

Figure 7. Decorative pattern generated after applying the rules repeatedly.

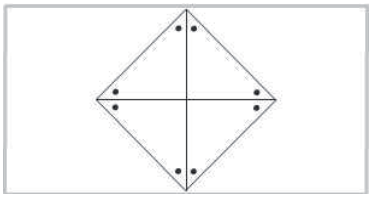

Figure 8. An initial shape with Bézier triangles arranged symmetrically.

Finally, *Shlishi*, a grammar interpreter system, provides an environment for testing rules for generating decorative patterns of plants. Graphic designers can quickly create or modify decorative patterns by manipulating the vine grammar.

In rules applying derivation, this research observes that indeterminism or determinism of shape grammars is decided by using designer's free mind or not being in a design process. For example, if someone operates on a set of determinative rules, the generating results will belong to the same style according to the ordering of applying the rules, format of the rules, or other restrictions. On the other hand, the various compositions of language are generated according to how the designer operates a set of non-determinative rules.

Free mind is defined as a designer's requirement and the notion for this design at the moment, and it contains creativity, knowledge, and experience of the designer. How do we get the balance between free mind and the restrictions of grammar? That will be another problem worth to confer.

References

Carlson, C., Woodbury, R. and McKelvey, R.: 1991, An introduction to structure and structure grammars, *Environment and planning B,* **18**, 417–426.

Chiou, S. C. and Krishnamurti, R.: 1995, The grammar of Taiwanese traditional vernacular dwellings, *Environment and planning B,* **22**, 689–720.

Gips, J.: 1999, Computer implementation of shape grammars, *Workshop on shape computation.*

Jowers, I. and Earl, C.: 2010, The construction of curved shapes, *Environment and planning B,* **37**, 42–58.

Knight, T. W.: 1980, The generation of Hepplewhite-style chair-back designs, *Environment and planning B,* **7**, 227–238.

Knight, T. W.: 1999, Shape grammars: six types, *Environment and planning B,* **26**, 15–31.

Li, A. I. and Lau, M. K.: 2004, A set-based shape grammar interpreter, with thoughts on emergence, *First international conference on design computing and cognition workshop.*

Sass, L.: 2007, A Palladian construction grammar: design reasoning with shape grammars and rapid prototyping. *Environment and planning B,* **34**, 87-106.

Stiny, G.: 1977, Ice-ray: a note on the generation of Chinese lattice designs, *Environment and planning B,* **4**, 89–98.

Stiny, G.: 1980a, Introduction to shape and shape grammars, *Environment and planning B,* **7**, 9.

Stiny, G.: 1980b, Kindergarten grammars: designing with Froebel's building gifts, *Environment and planning B,* **7**, 409–462.

Stiny, G.: 2006, *Shape: talking about seeing and doing*, MIT Press, Cambridge.
Stiny, G. and Mitchell, W. J.: 1978, The Palladian grammar, *Environment and planning B*, **5**, 5–18.

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A FORMAL APPROACH FOR THE INTERPRETATION OF CULTURAL CONTENT(S)

Evolution of a Korean traditional pattern, Bosangwhamun

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Abstract. This paper develops a formal approach to investigate the evolution of a Korean traditional pattern, *Bosangwhamun*. The approach employs the structure of symbolic memes embedded in the pattern as a framework of hierarchical decomposition of a pattern to describe an evolutionary development process of a given pattern with a set of rules in shape grammar as style changes. Further, the formal descriptions of the given pattern become the basis for generating its variations. With this process, the validity of the rules and their appropriateness in the representation of *Bosangwhamun* are examined.

Keywords. Culture; memes; shape grammar; hierarchical decomposition; Korean traditional patterns.

1. Introduction

There have been various formal approaches to performing content analysis on

visual records, especially on patterns. Shape grammars, one of many formal approaches used for the content analysis, are production systems that generate and analyse designs (Stiny, 2006) and are successfully employed for representing the formal structure of given visual records or artefacts with a series of shape rules (Knight, 1980; Cenani and Cagdas, 2007). Further, shape grammars have proved to be valuable for learning about styles and languages of designs (Stiny and Mitchell, 1978; Knight, 1981; Koning and Eizenberg, 1981; Buelinckx, 1993; Li, 2004). They are also descriptive enough to reveal simplicity or regularities behind designs.

In Korea, however, little research has focused on integrating computational or systematic approaches to find and capture unique cultural characteristics of Korean traditional patterns and to trace the hidden cultural identity from the shape and arrangement of the patterns. Moreover, in order to evaluate similarities and differences between two different styles which have symbolic memes in their structure, the grammar needs to be developed for explaining such meta-contents like semantics, functions or structures. That is, the interpretation of patterns with strong awareness of their cultural identity and the changes has been problematic in shape grammar so far.

As a method of explaining symbolic memes with shape grammar, we propose the structure of symbolic memes in a pattern as a place holder for delivering such meta-contents. Compared to Liew's (2004) meta-grammar, which adds more complexity to the description of the design, the structure becomes the apparatus for decomposing the given pattern with a hierarchical order for its analysis in the process of shape grammar formulation.

2. The study of Bosangwhamun

The study of culture provides substance for defining the identity of each human group. The identity becomes an essential component for maintaining the evolution of the group in various exchanges with other groups over history. As one of the approaches in cultural study, content analysis has been employed for finding significant relationships between the observed human behaviors, including words and artefacts, and the underlying constructs that explain a broad trend to prefer certain states of affairs over others (Hofstede, 2001). The representation of the outcomes from the analysis explains the cultural development of each group by characterising the commonality of the records in the group, by differentiating its records from the others and by providing substance for understanding mutual influences among different groups (Distin, 2005).

In this research, a Korean traditional pattern, *Bosangwhamun,* is selected for introducing the framework of hierarchical decomposition and its applica-

tion for conveying meta-contents in shape grammar. The framework is developed from the understanding of various symbolic memes of the pattern, which are stratified through the ages.

2.1. A BRIEF HISTORY OF BOSANGWHAMUN

Bosangwhamun (BSWM) translates to the pattern *(mun)* of an imaginary holy flower *(Bosangwha)*. It originates from the ancient Egyptian and Mesopotamian Palmette pattern shown in many western traditional patterns. In the 4C B.C, Greek Acanthus style was introduced to Eastern cultures as a source of Palmette, an artistic motif resembling the fan-shaped leaves of a palm tree, by Alexander the Great. In Eastern cultures, the variations of the original Palmette have specific 'regional characteristics,' including BSWM. During the Sassanian Persian Dynasty, the Palmette pattern was influenced by the Greek Acanthus. The normal Palmette motif was reconstructed into a newer one, the combination of the Half Palmette leaves. BSWM flourished in the Korean peninsula during the Early Unified Shilla Dynasty, transferred from the Tang dynasty of China with Buddhism and underwent numerous iterations of both form and meaning. BSWM and its components are believed to be transferred to some Japanese traditional artefacts later.

2.2. SELECTED BSWM PATTERNS

Four samples of BSWM were chosen according to their clarity in well preserved relics and topological coherence with stylistic shifts over time during which the pattern developed in Korea. The selection includes two tiles from the early Unified Shilla Dynasty (A.D. 7C), a circular tile from the late Unified Shilla Dynasty (A.D. 8C), and a musical instrument from the Korea Dynasty (A.D. 13C) as shown in figure 1.

(a) BSWM_A *(b) BSWM_B* *(c) BSWM_C* *(d) BSWM_D*

Figure 1. Four samples of Bosangwhamun.

3. A hierarchical decomposition of BSWM

The hierarchical decomposition starts from defining the metaphorical structure of the pattern. The symbolic memes in BSWM define the identity of the pattern as an ideal holy flower. The structure of the symbolic memes becomes

a template that allows us to decompose the pattern into typical components in the taxonomy of the flower. The hierarchical decomposition applies the construction method of BSWM to establish the morphological relationship among the components of the structure and to provide the sequential procedures of the transformation functions that organize the formation of the pattern. When the sequential procedures are laid out on the metaphorical structure as a set of rules, the structure becomes a *global geometry* that governs the formation of the pattern. Each place holder of the global geometry becomes an individual component of a local geometry that maintains the transformational functions among its contents.

3.1. METAPHORICAL STRUCTURE

The metaphorical structure of BSWM is based on the evolution of symbolic components in the pattern including Palmette, Lotus, and In-dong-dang-cho, a Korean vernacular plant motif frequently employed for various decorative patterns. The archetype of BSWM is the combination of two half Palmettes from Persian Empire. With the Buddhist influence from China, Lotus becomes the central component of BSWM between the Palmettes. As the pattern is employed for a tile design that requires the usage of four corners and their combinations, In-dong-dang-cho is added to the pattern to satisfy the requirement. The structure further develops into four components including *seed* (inner and outer), *calyx* (calyx and intermediate calyx), *flower* (inner, half Palmette, intermediate petal), and *corner* (flower, petal, band). The original Palmette and lotus components in BSWM disappeared or distorted due to the fall of Buddhism from the Korea Dynasty to the Joseon Dynasty. Each component of BSWM is replaced by a Korean vernacular motif with rough abstraction and generalization. The symbolic relationship among the components fell apart and only figurative aspects of the pattern were imitated in later periods of Korean history.

3.2. CONSTRUCTION METHOD

The construction method guides various transformational functions for organizing the contents of BSWM and provides the geometrical relationship within a metaphorical structure. It allows the consistent replication of the central portion of the pattern. An example of the process of constructing BSWM and its four corners in a traditional practice is shown in figure 2.

3.3. GLOBAL AND LOCAL GEOMETRY OF BSWM

The study of BSWM starts from the hierarchical decomposition of the pattern

into global and local geometry. Global geometry regulates the boundary condition of local geometry. On the basis of metaphorical structure and construction method of BSWM, the global geometry of the pattern is defined as a schema that can be referred to illustrate the basic elements of motif. The basic elements are employed for making the shape rules of BSWM (figure 3).

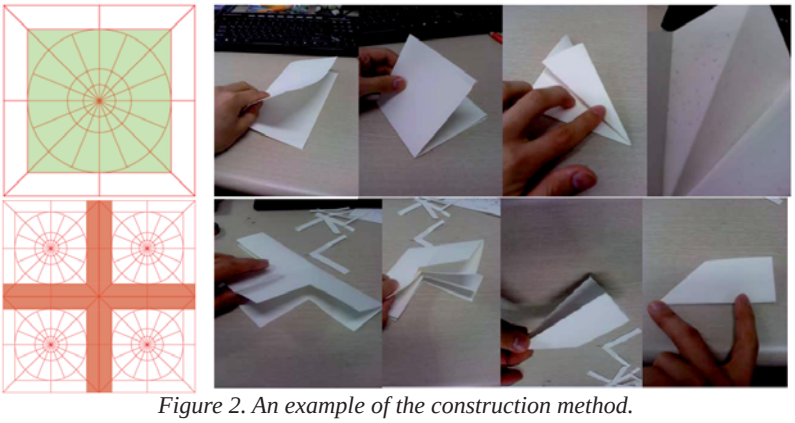


Figure 2. An example of the construction method.

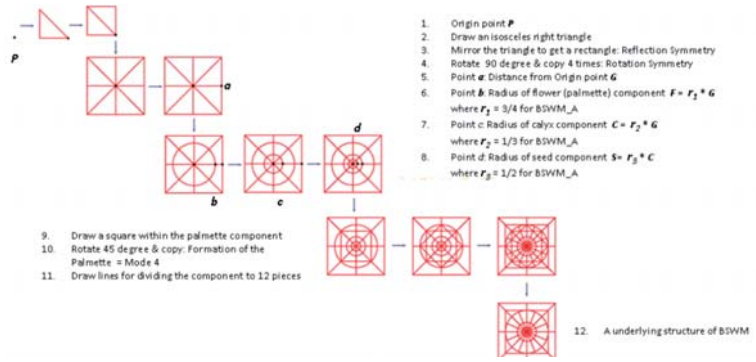


Figure 3. Global geometry as a schema in shape grammar.

Once the global geometry has been established, finer components within the major metaphorical categories can be described in figure 4.

Local geometry is a formal relationship among basic elements within each placeholder defined by the global geometry. The place holder consists of the sum of minimal divisions indexed by different colors as shown in figure 5.

4. Analysis in shape grammar formulation

Formulating a descriptive grammar of the decomposed patterns is a process of subdividing all the basic elements of the pattern into the local geometry of BSWM, confirming the global geometry. Shape grammar formulation also

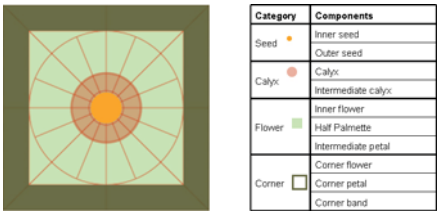


Figure 4. Metaphorical components of BSWM in global geometry.

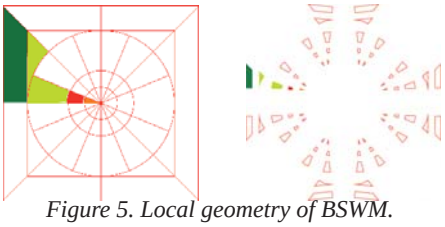


Figure 5. Local geometry of BSWM.

requires a registration process to establish a catalogue of the set of rules to describe the components of the global geometry before the contents of each component of selected BSWM samples, which belong to the same geometric structure, can be compared in depth (figure 6).

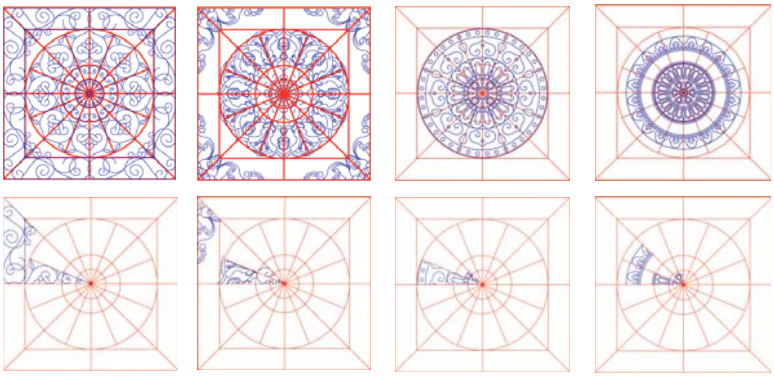


Figure 6. Minimal geometries for symmetric iterations for each pattern.

4.1. ANALYSIS OF BSWM_A AND ITS SHAPE RULES

After recogniing the global and local geometry of BSWM, the analysis of BSWM_A starts by decomposing basic elements of the artefacts into the global geometry as a template. The decomposition of the pattern into the geometry allows us to compare the elements belonging to a counterpart within the global geometry. By registering the formal relationship among the elements in the global geometry, the transformational functions employed for the relationship are rewritten as the series of the rules in shape grammar. The

registration processes for BSWM_A includes registration of the SEED, registration of Intermediate CALYX, registration of FLOWER (PALMETTE), and registration of CORNER. For example, figure 7 shows registration of FLOWER (PALMETTE). Having combined all registration processes, registration of BSWM_A is completed as shown in figure 8.

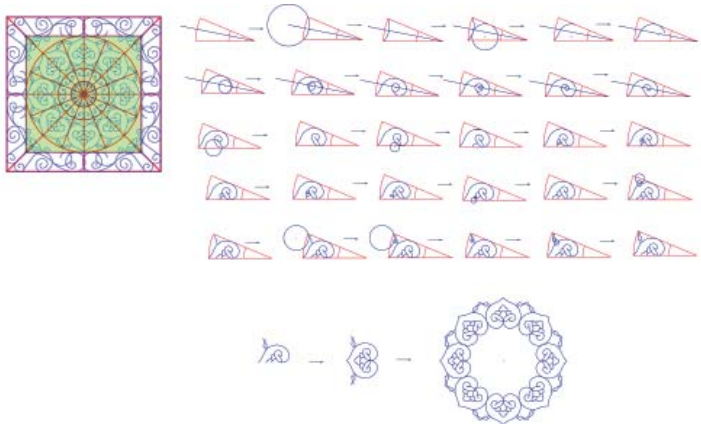


Figure 7. Registration of FLOWER (PALMETTE).

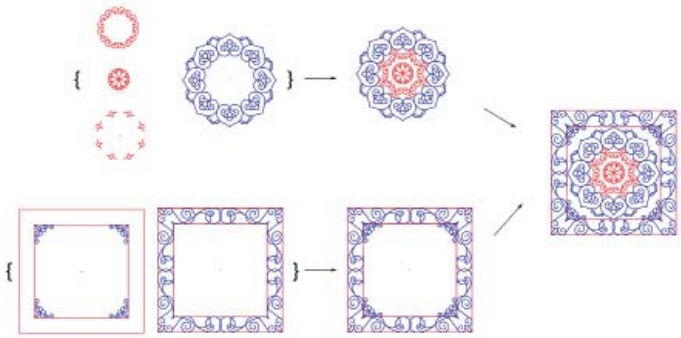


Figure 8. Registration of BSWM_A.

4.2. COMPARISON AMONG BSWM_A, BSWM_B, BSWM_C AND BSWM_D

Despite the topological coherence among four patterns, three noticeable evolutionary directions are observed through the hierarchical decomposition of the patterns as below:

1. The usage of a pattern in different artefacts is a critical factor to decide components of BSWM. The functionality of an artefact regulates formation of the global geometry. As an example, patterns in the early Unified Shilla Dynasty (A and B) have boundaries since many BSWM variations in the

period are represented on bricks and tiles, which requires consideration of four corners.

2. Due to the problem of transferring the pattern to next generation by copying the product, the construction method was distorted and reinterpreted arbitrarily. The patterns in the early Unified Shilla Dynasty (A and B) have a single symmetric shape in a same local geometry while the others have two different symmetric shapes. This breaks the efficiency of using transformational functions in the construction method.
3. Cultural changes cause different transformations of the symbolic memes in the pattern. The patterns in the Unified Shilla Dynasty (A, B and C) share similar degrees of symmetry, i.e. 22.5 and 45 degrees, while the last one has 60 degree of symmetry in the seed area. A lotus motif in the seed became less significant in BSWM due to the fall of Buddhism. Accordingly, the number of seed changes from multiples of eight to multiple of six.

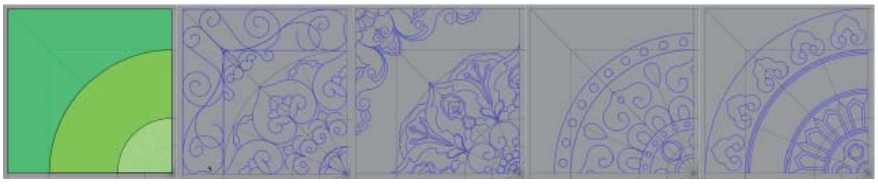
5. Synthesis in generative process

With the generative capabilities of shape grammar, the analysis of the selected BSWM examples provides the resources for producing morphological descendents of the selected BSWM. For this synthesis process, we implement SD2, a generative shape grammar tool developed as a part of the research project 'Design Synthesis and Shape Generation' (DSSG) (Lim, et al., 2008) in order to support shape synthesis in conceptual design (McKay et al., 2008). SD2 can create a shape rule, detect shapes from a design, replace them by pre-defined shapes in a given shape rule library, and automatically save the design history.

To make common basic elements for the four BSWM examples, which have different symmetries, a quarter of the global geometry was used as shown in Figure 9. The basic elements of each pattern are then defined and categorized into three sections as shown in the first picture in Figure 9. In our preliminary experiment, we defined 15 elements in the seed and calyx (yellow) areas, 19 elements in a part of flower (light green) area, and 14 elements in the corner and a part of flower (green) area from the four BSWM. This allows us create up to 4,800 combinations; however, many of these would not be recognizable as BSWM. Our trial of BSWM generation with design students indicates that around 200 combinations can be accepted as BSWM. The basic elements were considered as the partial elements of the motif of BSWM, which is a (lotus) flower.

With the basic elements of BSWM and SD2, we were able to generate new BSWMs that inherit geometric coherence from the existing ones. Some examples of new BSWM composited using the basic elements are shown in Figure 10, and they clearly show similarity with the original BSWM A to D.

The current SD2 system does not support a detection of scaled shapes. In theory, however, shape rules can be applied to scale shapes which allow broader detection of emergence. Thus, more combinations are possible if we consider scaling of the basic elements. For example, BSWM A and C can be merged and can simply substitute their scaled seed, calyx and boundary into the other patterns without losing its geometric coherence.



Global *BSWM_A* *BSWM_B* *BSWM_C* *BSWM_D*

Figure 9. Quarter part of global geometry and BSWM patterns A to D.

Figure 10. Three examples of new BSWM composited by the existing four BSWMs.

6. Discussion

The structure of symbolic memes embedded in the pattern that we have proposed here has not been applied to shape grammar so far. The place holder for delivering the meta-contents provides the framework of hierarchical decomposition for the given pattern to analyze it using the process of shape grammar rules, to produce the variation of it and to compare it with other patterns. The possible number of variations generated by the given four BSWM patterns shown in section 5 is approximately 4,800, which allows significant diversity to be considered. This suggests to us that our proposed structure is plausible enough for shape grammar to retain its generative power and significance.

Features of the shape grammar can also help us to find and describe unique cultural characteristics of Korean traditional patterns and to trace the hidden cultural identity from the shape and arrangement of the patterns. Most of the traditional patterns in Korea have been copied and transferred through the ages not by *copy-the-instruction,* how patterns are developed, but by *copy-the-product,* visual mimicry, within very exclusive apprenticeship without considering instrumental components of the patterns, which establish (1) their

identities, (2) the process constructing the patterns, and (3) the practical application of the patterns. Due to the lack of such documentation, the construction process of many Korean traditional patterns became extinct and distorted. Moreover, treating cultural elements with *copy-the-product* introduces the possibility of producing errors of interpretation, which are often problematic to isolate and remove later in the process. In contrast, shape grammar formalism, a kind of *copy-the-instruction* method, treats cultural subjects algorithmically and pragmatically, and thereby serves as a powerful tool for capturing the *ordering principles* and for constructing a systematic archive, with localized errors, that researchers could use to comprehend the subject at hand.

In our future work, we hope to analyze more BSWM patterns to validate the structure of symbolic memes we proposed here. Once the structure is shown to be generalized in Korean patterns, we aim to use the structure to compare with another culture's floral patterns to annotate the similarities and differences. We expect that the result will give us interesting insights to compare different cultures in general.

References

Buelinckx, H.: 1993, Wren's language of city church designs: a formal generative classification, *Environment and planning B: planning and design,* **20**, 645–676.

Cenani, S. and Cagdas, G: 2007, A shape grammar study: form generation with geometric Islamic patterns, *Proceedings of the 10th generative art conference,* December 12–14, Milan, Italy.

Distin, K.: 2005, *The selfish meme,* Cambridge University Press, Cambridge.

Hofstede, G.: 2001, *Culture's consequences,* 2nd ed., Sage Publications, Thousand Oaks, USA.

Knight, T.: 1994, *Transformations in design,* Cambridge University Press, Cambridge.

Koning, H. and Eizenberg, J.: 1981, The language of the prairie: Frank Lloyd Wright's prairie houses, *Environment and planning B: planning and design,* **8**(3), 295–323.

Knight, T.: 1981, The forty-one steps, *Environment and Planning B: planning and design,* **8**, 97–114.

Knight, T.: 1980, The generation of Hepplewhite-style chair-back designs, *Environment and planning B: planning and design,* **7**, 227–238.

Li, A.: 2004, Styles, grammars, authors, and users, *in* J. S. Gero (ed.), *Design computing and cognition '04,* Kluwer Academic Publishers, Dordrecht, 197–215.

Liew, H.: 2004, SGML: a meta-language for shape grammars, PhD dissertation, Department of Architecture, Massachusetts Institute of Technology, Cambridge, USA.

Lim, S., Prats, M., Jowers, I., Chase, S., Garner, S., and McKay, A.: 2008, Shape exploration in design: formalizing and supporting a transformational process, *International journal of architectural computing (IJAC),* **6**(4), 415–433.

Mckay, A., Jowers, I., Chau, H. H., De Pennington, A., and Hogg, D. C.: 2008, Computer aided design: an early shape synthesis system, *International conference in advanced engineering design and manufacture (ICADAM),* Sanya, China.

Stiny, G.: 2006, *Shape: talking about seeing and doing,* MIT Press, Cambridge, Mass.

Stiny, G. and Mitchell, W.: 1978, The Palladian grammar, *Environment and planning B: planning and design,* **5**, 5–18.

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REFINING A COMPUTATIONAL FRACTAL METHOD OF ANALYSIS

Testing Bovill's architectural data

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Abstract. In 1996 Bovill applied Mandelbrot's fractal method for calculating the approximate visual complexity of images to architecture. This method is one of only a limited number of quantifiable approaches to provide a measure of the relative complexity of an architectural form. However, the method has rarely been tested despite many scholars uncritically repeating Bovill's conclusions. While Bovill's original work was calculated manually, a software program, *Archimage*, is presently being developed by the authors as a tool to assist architectural designers and researchers to understand the visual complexity of building designs. The present research returns to Bovill's original architectural data (elevations of famous buildings) and re-calculates the results published therein using *Archimage* and the commercial software *Benoit.* These results are then compvared with those produced by Bovill (1996) and Lorenz (2003), to determine if any consistency can be found between the sets. The level of consistency will assist in determining the validity of Bovill's method and provide important data in the ongoing process to refine the *Archimage* software and the analytical method.

Keywords. Computational analysis tools; design analysis; visual complexity.

1. Introduction

In 1996 Carl Bovill published *Fractal geometry in architecture and design,* in which he expands upon Benoit Mandelbrot's fractal dimension calculations of the visual complexity of images (Mandelbrot 1982). The fractal dimension

approximates the visual complexity (degree of detail present) in an image as it is observed over multiple scales. Importantly, Bovill applies a box-counting method of fractal analysis to line drawings of elevations of iconic buildings by the architects Frank Lloyd Wright and Le Corbusier, determining their fractal dimensions and thereby comparing one measure of their visual complexity. Bovill's work is the first to apply the box-counting method to architecture on a broad scale and if valid, it could provide one of a limited number of quantifiable measures of the fractal dimension, also often called "characteristic complexity", of an architectural design. Since that time many scholars have reproduced Bovill's results but his method has rarely been the subject of intense scrutiny and his original results have never been consistently tested. Wolfgang Lorenz (2003) re-analysed several of Bovill's images. Even though the original data have since been used by many scholars, they have remained untested and no attempt has been made to quantify the difference between the computational and manual results produced by the method.

One reason why Bovill's original work has resisted testing is simply that his process was completely manual; a laborious process involving repeated drawing, counting and calculating. Because of the difficulty of achieving consistent results with this method a software program, *Archimage,* is being developed by the authors. Based on Bovill's box-counting method, this program is specifically intended to be a tool to assist architects to analyse the fractal dimension of buildings and thereby aid designers and researchers to understand the visual complexity of building forms. The *Archimage* software calculates the approximate fractal dimension of plans and elevations, producing comparable quantitative results, and the authors have developed and consistently tested this software previously on 160 elevations by notable architects.

This paper is part of ongoing research to determine the validity of Bovill's box-counting method and this present research aims to strengthen the calibration of the *Archimage* software by comparatively testing three variations of the method. These variations are:

1. Bovill's original manual method (with existing data provided by Bovill and Lorenz),
2. *Archimage,* a program developed by the authors.
3. *Benoit*, a TruSoft program designed for the general fractal analysis of images.

Significantly, all three of these approaches for calculating fractal dimension rely on subtle variations of the box-counting approach. The comparative study contained in the present paper uses the very first examples of architectural testing provided by Bovill; three images in total, comprising one elevation each of Frank Lloyd Wright's Unity Temple and Robie House and Le

Corbusier's Villa Savoye.

The paper will first provide a brief background of the use of the box-counting method, covering the common features of this method. Bovill's manual box-counting method, as repeated by Lorenz, will be described next, followed by an outline of any methodological variations present in the *Archimage* and *Benoit* programs. The set of architectural images which have been analysed for fractal dimensions by Bovill and Lorenz will then be re-tested by *Archimage* and *Benoit.* Finally, the paper compares and contrasts all four sets of results, providing an analysis of the accuracy of the results and any limitations and discrepancies, to determine if any consistency can be found between the three sets, and what importance these results could have for the architectural computational community.

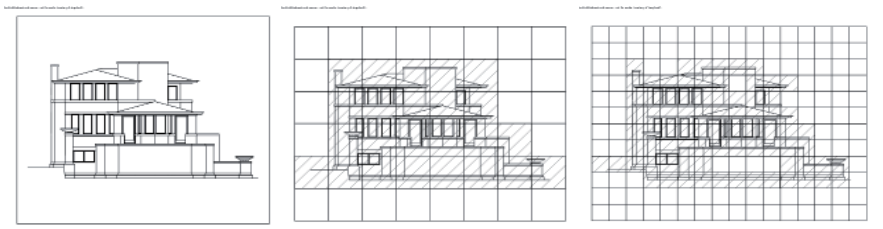
2. Fractal analysis of architecture

Bovill's 1996 work was the first major exploration of the relationship between fractal geometry and art, music, design and architecture. In particular, in this work Bovill demonstrates a mathematical way of measuring and comparing the fractal dimension of several important historical buildings. Bovill calculated the fractal dimension of these buildings using an application of Benoit Mandelbrot's box-counting technique, to determine the approximate fractal dimension, or characteristic visual complexity, of architectural plans and elevations. Bovill's box-counting method has since been employed to calculate the fractal dimension of a range of ancient buildings, including Mesoamerican pyramids (Burkle-Elizondo and Valdez-Cepeda, 2006) and the fractal dimensions of the Doric, Corinthian and Composite orders of architecture (Capo, 2004). Sala reproduces Bovill's work on Frank Lloyd Wright's Robie house without any additional interpretation (2002) and Gozubuyuk, Cagdas and Ediz (2006) apply the box-counting method to digital design methods to create a new building that might respond to existing architectural "languages" of a district. In the last two years a computational variation of the fractal analysis method has been developed and tested on the built works of Le Corbusier and Frank Lloyd Wright (Ostwald, Vaughan and Tucker, 2008) partially confirming Bovill's original results. This computational method has since been used to analyse the domestic architecture of Eileen Gray (Ostwald and Vaughan, 2008), Peter Eisenman (Ostwald and Vaughan, 2009) and Kazuyo Sejima (Ostwald, Vaughan and Chalup, 2009).

3. The Box-counting method

The process of box-counting any architectural form involves translating the

subject into a line drawing, such as the elevation of a building (figure 1a). A grid is placed over this image and the number of squares which contain part of the image are noted (figure 1b). This grid is then replaced by another with closer spacing, and the number of squares are counted once again (figure 1c). This sequence progresses for a set number of iterations. The decreasing grid size allows for levels of detail in the image over different scales to be discovered. By plotting a comparison of the grid sizes with the number of counted boxes on a log-log graph, the slope of the resulting graph provides the fractal dimension; in the case of an image, this is a number between 1.0 and 2.0 (Bovill, 1996; Lorenz, 2003). The higher this number is (that is, the closer the number is to 2.0) the closer the image is to appearing as a two-dimensional object and thus the higher the fractal dimension of the object.



Figures 1a, 1b and 1c (from left to right). The box-counting process.

4. Methods of Box-Counting

4.1 BOVILL'S MANUAL METHOD

Bovill undertakes the box-counting method manually in his 1996 publication. To determine the starting box size, Bovill considers the optical actions of the eye focusing at different scales and assumes the location of the standing viewer at an observation point somewhere between 40–80 feet away. Bovill calculates that the appropriate box-counting grid size for a building would range between 1.4′ and 29.1′. Bovill considers that "[t]he starting grid size should generally be small enough so that not all the boxes are counted" (1996: 121). For the Robie House analysis this translates to a starting grid size of 24′, for the unity temple: 15′ and the Villa Savoye: 8′. Beyond the visual range proposal, Bovill does not clarify why this initial box dimension is selected for each building. Presumably it relates to the actual size of the elevation. The south elevation of the Robie House is actually 161′6″ long, while Bovill's 8 box-row starting grid provides 192′ (8 × 24′) to fit the elevation, leaving approximately 15′ of white space on each side of the elevation to create a starting image, which matches the image provided by Bovill. However, for the Unity Temple North elevation, the starting grid provided is a total of 150′ wide

(10 box row × 15′ grid size), and the width of the actual northern elevation is only 91′6″, providing nearly 30′ on each side of the temple as white space, which does not match Bovill's image. Likewise the Villa Savoye is accorded 5′ of white space on each side, which is not clearly repeated in Bovill's drawings, and confusingly, the placement of the Villa Savoye in the grid is offset to the left, providing no white space on that side and only a small amount on the right. As Bovill progresses in the scale change of the calculations, the successive grid size is always half the size of the previous, and a total of 2 to 3 iterations are calculated for each image. It is not clear why Bovill stops at this point, when he does mention that for the Robie house calculations "[t]he design interest of the Robie House does not stop at […this] scanning range […]. The window mullion pattern has not affected the box count yet."(1996, 124). It is possible that the small scale required for these further grid sizes would prove very difficult to reproduce manually.

In 2003 Lorenz produced an in-depth study re-testing and expanding Bovill's work. In order to re-calculate several of Bovill's original images, Lorenz uses the same manual method as Bovill, however, some of the images are analysed at different scales of observation, and Lorenz occasionally calculates an additional iteration. It is assumed that Lorenz calculated these results directly from copies of Bovill's original published images.

4.2 *ARCHIMAGE*

Archimage software was developed primarily to analyse line drawings of buildings, although a variation for analysing photographs is also under development. The original version (1.0) was authored in 2005 and it has been tested, refined and expanded since that time. The current version (2.1) uses a range of mathematical, geometric and computational approaches to provide quantitative information about architecture. One of the analytical approaches *Archimage* uses for line drawings is the box-counting method.

For *Archimage* to undertake a box-counting analysis, line drawings are imported into the program. The first stage scales the imported image to a certain pixel length and then uses a Sobel line detection algorithm to convert the imported image into a line drawing, with no lines wider than a single pixel. The Sobel algorithm is used to ensure consistency for the images loaded into *Archimage.* Once images have been converted to consistent line drawings, the program assesses them to determine the size of the image in pixels (length × height). *Archimage* then uses an aspect ratio system to regulate this initial image size in order to determine the starting box size ratio required to calculate the image's fractal dimension, ensuring an equal division of whole boxes. Starting aspect ratios of 4:4, 4:3, 3:2 or 4:2 are determined by an algorithm

which adds, if necessary, white space around the figure in order to grow it to conform to one of these starting ratios. If the image must be expanded in size to conform to a starting ratio, the shorter dimension of the image is expanded evenly on both sides with white space. While Bovill halves the size of each grid being used for the analysis, *Archimage* decreases the box dimension by a coefficient of $\sqrt{2}$; this provides a much higher degree of accuracy. The process continues until a minimum box dimension of 5×5 or 4×4 pixels is reached.

The approximate fractal dimension is calculated from these box counts using a linear regression algorithm in much the same way that Bovill's method does. However, unlike Bovill's method in which only 2–3 calculations are performed per image, *Archimage* typically produces 10–15 results per image. *Archimage*'s adjustment of the imported image's scale does allow for a consistent number of iterations across the different imported images, however the final number of iterations for each image does vary due to the combination of the scaled image and the aspect ratio. The resulting fractal dimension is presented numerically (to three decimal places) and graphically. The graphical form shows the box count (log) values in the y-axis and the box size in pixels (log scale) on the x-axis. A blue and red line on this fractal dimension graph show the actual results and the fractal dimension slope respectively. These lines are important because they demonstrate the limits of the calculation. The points of the graph which do not closely approximate the slope of the line generated by them determine the limits of the accuracy of the result. The largest grid sizes tend to produce the greatest divergences from the line if there are any at all. Intermediate grid sizes are typically more closely aligned with the overall result.

4.3 *BENOIT*

Benoit is a commercial program that was developed by TruSoft in the late 1990s for the computational analysis of the fractal dimension of complex natural features. *Benoit* (1.31) uses the most complex version of the box-counting method applied in any available software tool today, but this very complexity means that to develop consistent results can be difficult. Moreover, *Benoit* is not well optimized for architecture; a subject matter which is much simpler that the natural forms *Benoit* was designed to investigate.

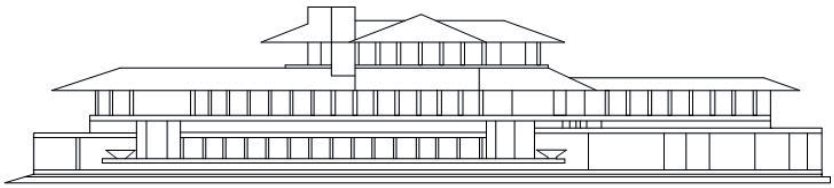
Benoit has a wide range of flexible scaling ratios meaning that comparisons between grids can be made at an extremely fine scale and the analysis parameters were set to match those of *Archimage* for the present paper. *Benoit* also uses an innovative grid rotation system to reduce the impact of "double-counting lines" (Ostwald, Vaughan and Tucker, 2008). One major difference between *Benoit* and *Archimage* is that while the latter adds white space

to the starting image to achieve an optimal grid, the former appears to clip white space to achieve an appropriate starting grid. This difference in tactics is expected to produce a subtle variation in the results. The *Benoit* results are included in this paper because the software to replicate the results is relatively accessible and this means that the result of the present paper can be independently tested.

5. Method of comparison

Four sources of data, generated from the same three images, are used in this present study. The three architectural images published in Bovill's 1996 publication are redrawn for analysis by *Archimage* and *Benoit,* and it is presumed Lorenz followed the same procedure in his 2003 study. However, it is not known at what line thickness Lorenz reproduced Bovill's original images. Bovill's images vary in their line width and when redrawn for testing by *Archimage* and *Benoit* in this research, all image lines were reduced to 1 pixel width (figures 2–4).

Bovill presents 2–3 calculations per image, without an overall result for each image. To find a comparative figure for this study, Bovill's results are averaged into one final composite result for each particular image. The same process is undertaken on Lorenz's results. *Archimage* and *Benoit* produce a single result from several iterations (10–13), and these single results are used in the comparison.



Figures 2. Robie House.

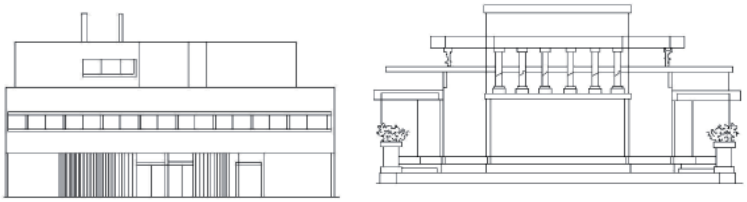


Figure 3, Villa Savoye (left). Figure 4, Unity Temple (right). All images are redrawn from Bovill's originals at 1 pixel line weight.

6. Results and Discussion

6.1 LE CORBUSIER'S VILLA SAVOYE (1928)

Bovill undertakes two calculations on the northern elevation of the Villa Savoye (figure 3), ($D_{(14\text{-}28)}$=1.42; $D_{(28\text{-}56)}$=1.33). Lorenz uses a different set of scales to achieve an identical result: $D_{(16\text{-}32)}$=1.42; $D_{(32\text{-}64)}$=1.33 (see table 1); and includes an additional calculation: $D_{(64\text{-}128)}$=1.17. The average results for Bovill and Lorenz are therefore close, whereas the result for the Villa Savoye using *Benoit* and *Archimage* are significantly higher; respectively D = 1.433 and D = 1.544.

Table 1. Comparison of results.

Results	**Bovill (1996)**	**Lorenz (2003)**	***Archimage* (2009)**	***Benoit* (2009)**	**$D_{(range)}$**	**%gap**
$D_{(\text{Villa Savoye})}$	1.3775	1.306	1.544	1.433	0.238	11.9%
$D_{(\text{Unity Temple})}$	1.550	1.513	1.574	1.506	0.068	3.4%
$D_{(\text{Robie House})}$	1.520	1.575	1.689	1.620	0.169	8.45%

6.2 FRANK LLOYD WRIGHT'S UNITY TEMPLE (1908)

Bovill uses the northern elevation of the Temple (figure 4) for his analysis, undertaking 2 calculations to produce an average result of D = 1.550. Lorenz uses 3 grids, with different scales to Bovill (D = 1.513) and, as seen from the log-log scale graph, *Archimage* processed 13 iterations, resulting in a fractal dimension of 1.574 (figure 5). The Unity Temple calculations from all methods show a great coherence of results with a percentage gap difference of all the results at around 3%.

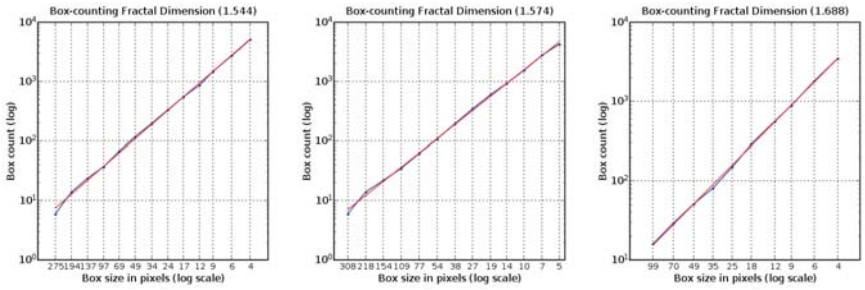


Figure 5. Archimage log-log scale graphs showing the fractal dimensions for, from left to right, the Villa Savoy (north elev.), Unity Temple (north elev.), and of the Robie House (south elev.).

6.3 FRANK LLOYD WRIGHT'S ROBIE HOUSE (1910)

Bovill undertakes 3 calculations for the south elevation of the Robie house (figure 2), with an average result of D = 1.520. Lorenz also provides three measurements, additionally including an overall calculation of D = 1.57, which matches the average of his results D = 1.575.

6.4 COMPARATIVE ANALYSIS

The comparative graph (figure 6) shows variation between the three methods, with tight clustering of results for the Unity Temple ($1.506 < D < 1.574$) and the wider ranges for the Villa Savoye ($1.306 < D < 1.544$) and the Robie House ($1.520 < D < 1.689$). The grouped results for each building do match the historically proposed level of complexity for each building: that the Robie house with its progression of detail is the most complex, and the Villa Savoye, with its plain, geometric exterior, has the lowest visual detail of the three images. The graph shows that for these three images, *Archimage* produces a higher result than the other methods, and that this result is consistently higher than that of *Benoit.* This may be due to the smaller final grid size that *Archimage* calculates to, since with a smaller grid size, increased detail can be captured. It is most likely Lorenz's utilization of Bovill's manual method and images that produce the similarity with their results, with a difference in scale and hand production explaining the slight variation. Likewise, the greater variation in the two computational programs may be based on several of the differences in method, such as line width, number of iterations, and image placement.

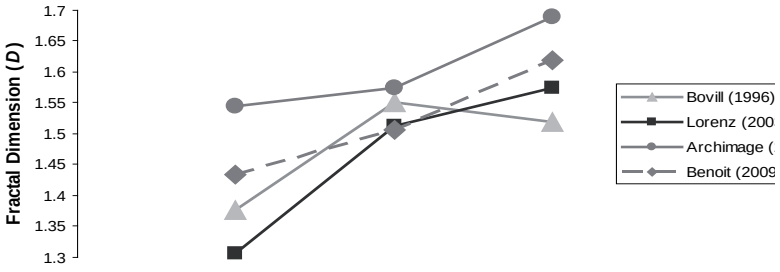


Figure 6. Comparative graph

7. Conclusion

Comparing the results produced by Bovill's three elevations of iconic buildings is useful to demonstrate the subtle variations in the box-counting method. Generally, the results from the three methods do contribute to the credibility of the box-counting approach for fractal analysis of architecture. Although the

Archimage results fit into a numerical cluster, they do show a consistent difference to the other methods, yet it is not clear if this is due to increased accuracy or whether fine-tuning may be required. Further testing which isolates aspects of the box-counting method such as line thickness, image placement and the statistical divergence of results is necessary to refine this program for use by the architectural computing community.

Acknowledgements

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References

Bovill C.: 1996, *Fractal geometry in architecture and design,* Birkhäuser, Boston.

Burkle-Elizondo, G. and Valdez-Cepeda, R. D.: 2006, Fractal analysis of Mesoamerican pyramids, *Nonlinear dynamics, psychology, and life sciences,* **10**,105–122.

Capo, D.: 2004, The fractal nature of the architectural orders, *Nexus network journal,* **6**, 30–40.

Gozubuyuk, G., Cagdas, G. and Ediz, O.: 2006, Fractal based design model for different architectural languages, *in* K. Oosterhuis and L. Feireiss (eds.), *The architecture co-laboratory: GameSetandMatch II,* Episode Publishers, Rotterdam, 280–286.

Lorenz, W. E.: 2003, *Fractals and fractal architecture,* Department of Computer Aided Planning and Architecture, Vienna University of Technology, Vienna.

Mandelbrot, B. B.: 1982, *The fractal geometry of nature,* Freeman, San Francisco.

Ostwald, M. J., and Vaughan, J.: 2009, Calculating visual complexity in Peter Eisenman's architecture, *CAADRIA 2009,* Taiwan, 75–84.

Ostwald, M. J., and Vaughan, J.: 2008, Determining the fractal dimension of the architecture of Eileen Gray, *ANZAScA 2008,* Newcastle, Australia, 9–16.

Ostwald, M. J., Vaughan, J. and Chalup, S.: 2009, A computational investigation into the fractal dimensions of the architecture of Kazuyo Sejima, *Design principles and practices: an international journal,* **3**, 231–244.

Ostwald, M. J., Vaughan, J. and Tucker, C.: 2008, Characteristic visual complexity: fractal dimensions in the architecture of Frank Lloyd Wright and Le Corbusier, *in* K. Williams (ed.), *Nexus VII: architecture and mathematics,* Kim Williams Books, Turin, 217–231.

Sala, N.: 2002, Fractals in architecture: some examples, *in* G. A. Losa, T. F. Nonnenmacher, D. Merlini and E. R. Weibel (eds.), *Fractals in biology and medicine volume III,* Birkhäuser, Basel, 347–358.

Vaughan, J. and Ostwald, M. J.: 2009, A quantitative comparison between the formal complexity of Le Corbusier's pre-modern (1905–1912) and early modern (1922–1928) architecture, *Design principles and practices: an international journal,* **3**, 359–372.

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A STUDY OF EMERGENCE IN THE GENERATION OF ISLAMIC GEOMETRIC PATTERNS

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Abstract. Generative design is concerned with the definition and exploration of design spaces, and it has been suggested that emergence plays a key role in this process. In this paper, the impact of emergence on a design space is explored via consideration of different methods used to generate designs in a particular style. Three distinct methods of generating Islamic geometric patterns have been investigated and the extent to which emergence is employed in these methods has been explored. This research supports a discussion on the role of emergence in generative design, and an investigation into how design spaces are affected by the type of emergence employed in a generative process.

Keywords. Islamic geometric patterns; emergence; design space; design generation

1. Introduction

The definition and exploration of design spaces is a fundamental activity in generative design (Prats et al., 2006). As a result, the design space is a primary object for research intended to realise computational systems that support generative design (Woodbury and Burrow, 2006). This paper presents a discus-

sion on the relation between emergence in a generative system of design and the resulting design space. Intuitively, a relation does exist, since emergence in a generative process is likely to result in the generation of a broader range of designs, thereby expanding the boundaries of a design space. However, the extent to which this intuitive understanding is true remains to be seen.

Here, an exploration of this issue is presented which is based on consideration of different approaches to generating designs within the same style. Three different methods of generating Islamic geometric patterns are investigated, and because the different methods generate designs in the same style they provide a common ground from which to explore the relation between the use of emergence in a generative process, and the resulting design space. The aim of this exploration is to achieve a deeper understanding of the role of emergence in design generation and hence inform future development of computational systems intended to support generative design.

2. Islamic geometric patterns

Throughout the world, the artistic traditions of Islam are apparent in a rich system of ornamentation applied to art and architecture. Islamic ornamentation consists of combinations of three predominant types of decoration – calligraphy, vegetal motifs and geometric patterns. Figural forms of humans or animals are not typical, in response to Qur'anic commandments against idolatry. Instead, abstract forms of decoration are used to create visual statements about religious ideas and express the logic and order inherent in the Islamic vision of the universe.

In this paper, methods for constructing Islamic geometric patterns are investigated as illustrations of generative methods of design. The patterns can be seen to be composed of simple polygons such as squares, triangles and stars, as illustrated in figure 1. However, from the combination and repetition of these polygons complex forms emerge which exhibit properties of symmetry, scalability and movement. As such, the patterns support exploration into philosophical aspects of Islamic faith, such as the relationship between unity and multiplicity.

In section 4 three methods for generating Islamic geometric patterns are presented. Two of these are based on historical techniques of construction, while the third is based on the shape grammar formalism (Stiny, 2006). The role of emergence in the three methods is discussed, and in order to support this discussion section 3 explores the concept of emergence in generative design. Finally, section 5 explores the relation between the role of emergence in a generative design process and the resulting design space.

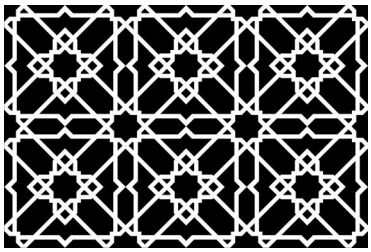

Figure 1. An Islamic geometric pattern.

3. Emergence in Islamic geometric patterns

On comparing the three methods of construction introduced in the next section, one differentiating factor that can be highlighted is the extent to which emergence plays a role. The concept of emergence is not always easy to define. For example, in complexity theory emergence "refers to the property of a collection of subunits that comes about through the interactions of the subunits and is not a property of any single subunit" (Flake, 1998, p. 449). With respect to geometric design, emergence can be defined as the construction of a shape that is not explicitly represented or identified in the method used to construct it. In this mode, it has been suggested that emergence plays a key role in design generation and exploration, as discussed by Schön and Wiggins (1992), Gross (2001) and Knight (2003). Consequently, it is of interest to support the recognition and use of emergence in computer based representations of shape. However, the problem of supporting emergence is exacerbated by the fact that it has many different guises.

Gross (2001) identified three types of emergence that should be supported in computer representations of shape. These are type 1) emergence that results from intersecting shapes, type 2) emergence that results from alternative configurations of parts of shapes, and type 3) emergence that results from figure-ground reversal. The methods for generating Islamic geometric patterns presented in the next section provide illustrations of all three of these types. However, before exploring these in detail it is beneficial to introduce a further distinction. This is the distinction between emergence as *process* and emergence as *product,* which Knight (2003) explores at length.

Emergence as process is characterised by emergent forms that are both recognised *and* used. For example, a foundational feature of the shape grammar formalism is that emergent shape is recognised and used in the process of generating designs (Stiny, 2006). Emergence as product on the other hand is characterised by emergent forms that are recognised but are *not* used. For example, cellular automata are often cited as examples of emergence since they are defined by simple rules but give rise to complex forms (Flake, 1998).

However, the emergence in a cellular automaton does not inform the process of defining the resultant form – it is emergence that is seen and not used, i.e. it is emergence as product.

With respect to Islamic geometric patterns, both emergence as process and emergence as product are apparent. For example, a key characteristic of Islamic geometric patterns lies in the fact that they can be read in an unlimited number of ways. Ultimately, they can be seen to be composed of a set of simple polygons, but in the combination and repetition of these polygons there emerges an infinite range of complex geometric forms. This is illustrated in figure 1, where the combination of simple polygons results in the emergence of forms such as crosses and rosettes. Indeed, the range of forms that can be recognised in Islamic geometric patterns is limited only by the eye of the viewer. Some of these forms are intended by the designer, are included in the construction process, and result from emergence as process. The remaining forms are not included in the construction process and are emergence as product. In the next section three methods of generating Islamic geometric patterns are introduced, and for each method the type of emergence employed is identified by considering the underlying structure of generated patterns.

4. Generating Islamic geometric patterns

4.1. COMPASS AND RULER CONSTRUCTION

Very little information about the historical techniques for constructing Islamic geometric patterns survives to the present day. However, explorations into the geometrical properties of the patterns have resulted in a wide variety of different graphical techniques, including the use of set squares, grids and stencils, e.g., El-Said (1993). Fundamentally, each of these can be reduced to a method of construction using a compass and ruler. This method has its roots in the mathematics of ancient Greece, as recorded in Euclid's *Elements,* which was translated into Arabic by early Islamic scholars. In this ancient geometry, the straight-edge is an abstraction of a ruler – it being infinitely long, one-sided and having no markings. As a result it cannot be used for measurement but can be used to draw straight lines. Similarly, the abstraction of the compass can be opened arbitrarily wide, but when not in use it collapses. As a result it too cannot be used for measurement, but it can be used to draw circles. In practice the compass and ruler define operations that result in the creation of points, lines or circles. A point is created at the intersection of two lines, or at the intersection of two circles, or at the intersection of a line and a circle. A line is created by connecting two existing points, and a circle is created through one point with a second point as its centre.

In the construction of Islamic geometric patterns, these simple operations are applied repeatedly, as illustrated in figure 2. Here, in the first image, a simple initial construction is presented, composed of a circle and two lines. The intersections of the lines and circles define points which in turn are used to define new circles. Creation of the circles in turn results in the definition of new intersection points which are then used to define additional lines or circles. And the process can continue ad infinitum. As more lines and circles are added, a complex and intricate grid is defined. An Islamic geometric pattern is then derived from this grid by systematically selecting a set of line segments and circular arcs that are sub-sets of the grid lines.

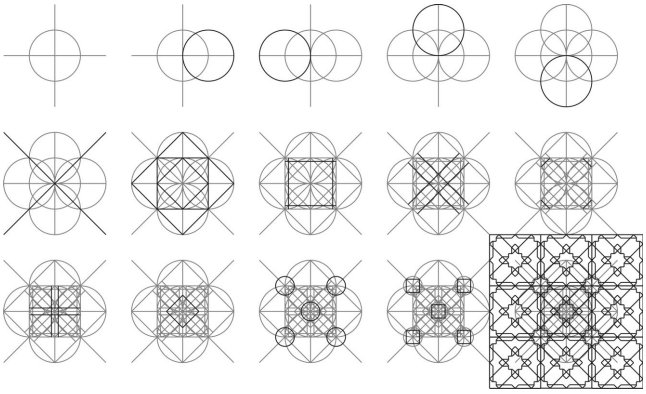

Figure 2. Compass and ruler construction of an Islamic geometric pattern.

In compass and ruler construction the structure of a pattern is defined by the grid which results from the geometric operations of creating lines or circles. Emergence is fundamental in the process of defining this grid and in particular emergence type 1) – emergence that results from intersecting shapes – is predominant. As discussed, the grid is created according to points that emerge at the intersection of lines and circles. These emergent intersection points are then used to create new lines and circles. The final form of the grid is not predefined but has infinite variety that emerges as a result of the construction process. The final form of a geometric pattern is defined by systematically selecting emergent forms in the grid, such as lines or polygons. If the designer intends the pattern to be symmetric, then the construction will also incorporate emergence type 2) – emergence that results from alternative configurations of parts of shapes. This results from the designer seeing in part of the grid an emergent configuration that can be repeated, and then evolving the rest of the grid so that the configuration is repeated under symmetry transformations.

4.2. SET-BASED CONSTRUCTION

The Islamic architecture of Spain and Morocco is distinctive in its ornamentation, since it makes use of monochrome mosaic tiles which are combined in a tessellation of the plane. This tile work, or *Zillij,* recreates Islamic geometric patterns by combining sets of small enamel hand-cut tiles called *furmah.* The *furmah* are defined according to the simple polygons that can be seen to compose the geometric patterns. For example, figure 3 illustrates a set of fifteen *furmah* that were identified in the analysis of a corpus of eight patterns, and named according to Hedgecoe and Damluji (1992). The variety of *furmah* used in *Zillij* far exceeds the examples illustrated here. For example, it is estimated there are 360 *furmah* in common use, but uncountable more are apparent in historical examples of *Zillij.* While the great masters of *Zillij* continue to practice their trade, the secret to their art remains a mystery. No instructive or analytical writings about the art are known of, and instead the secret is passed on only from master to apprentice (Hedgecoe and Damluji, 1992). However, the mysteries can be discovered, to a certain extent, via geometric study of *Zillij* themselves.

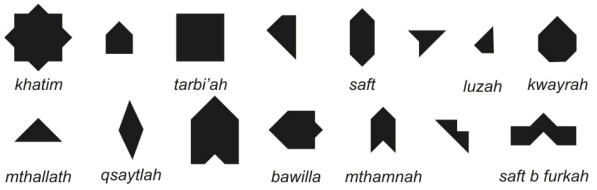

Figure 3. A set of fifteen furmah.

For the study presented in this paper, a method of constructing Islamic geometric patterns was defined based on *Zillij*. In the method geometric patterns are generated according to the set of fifteen *furmah* illustrated in figure 3. This choice of *furmah* is not unique but is a consequence of the eight tiles in the analysed corpus – analysis of an alternative corpus would likely lead to the selection of an alternative set of *furmah.* In generating a pattern, the *furmah* can be transformed according to similarity transformations – which are combinations of translation, rotation, reflection and isotropic scaling. However, a legal pattern can contain no holes, nor can it include parts of *furmah.* For example, figure 4 illustrates three designs generated using this set-based construction method.

In set-based construction the structure of a pattern evolves with the pattern itself – as new *furmah* are added to a design the structure grows accordingly. The structure is an emergent product of the construction process. As with compass and ruler construction this structure has an infinite variety, but here

it is limited according to the set of available *furmah.* In considering set-based construction two different types of emergence can be identified; neither is necessary in the construction of a pattern, and one is illegal. Firstly, type 2) emergence can be utilised in order to incorporate symmetry in a design, in a manner similar to that described for compass and ruler construction. Secondly, type 3) emergence – emergence that results from figure–ground reversal – can be identified in the recognition of holes that result from piecing *furmah* together. It is likely that figure–ground reversal is the reason for the uncountable number of *furmah* that are apparent in historical examples of *Zillij*. However, in the tiling–based construction this emergence is not allowed since it was specified that patterns must not contain any holes and they must be composed only of the *furmah* defined in figure 3.

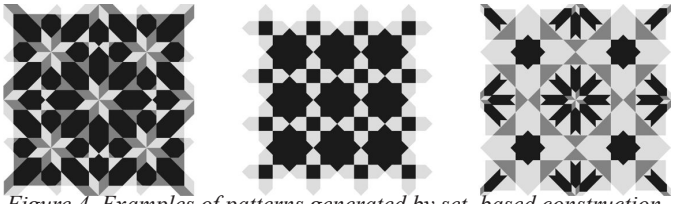

Figure 4. Examples of patterns generated by set–based construction.

4.3. MOTIF-BASED CONSTRUCTION

The geometry of Islamic patterns can also be rigorously described according to the shape grammar formalism (Stiny, 2006). A shape grammar consists of shape rules that define geometric properties of a particular style. The rules can then be applied to generate existing or new instances of the style.

For the purposes of this study, a corpus of eight Islamic geometric patterns was analysed (this was the same corpus used in defining the method of set-based construction). Each of the patterns in the corpus exhibited a repeating square pattern with an eight-fold rotational symmetry, and the underlying structure could be described according to a triangular region, the contents of which serve as the motif of the pattern. The resultant shape grammar, illustrated in figure 5, uses the symmetry of the patterns in order to remove any redundancy in the generative process, according to two types of rule. The first type, rules 1–8, is concerned with defining the geometric properties of the triangular motif. The second type, rules 9 and 10, is concerned with repeating the motif under symmetry transformations.

Application of a shape grammar is initialised by a seed shape, which for the Islamic geometric pattern grammar is a right-angled triangle, as illustrated in figure 6. Here, the step-by-step generation of an Islamic geometric pattern is presented, and the rules that are applied to move from one design to the next

are specified. Rule 1 adds a grid to the initial triangle, and rules 2–6 define line elements of the motif by recognising and replacing grid lines. The grid and the lines added by rules 2–6 were derived from the analysis of the eight patterns in the corpus. As a result, they cannot be claimed to universal since analysis of an alternative corpus would likely lead to the definition of an alternative rules. When the designer is satisfied with the generated motif he can prevent any further modification via application of rules 7 and 8, which remove grid lines and their associated end points.

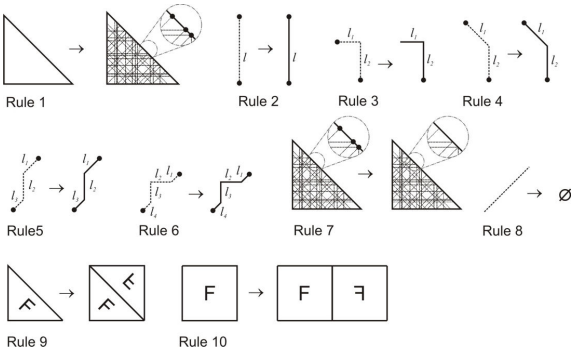

Figure 5. Shape rules of the Islamic geometric pattern grammar.

The last two rules in the grammar, rules 9 and 10, define how the generated motif is repeated under symmetry transformations. In these rules the F denotes any generated motif. Knight (2003) defines rules such as these as *emergence rules.* The rules are applied to an emergent design that has resulted from previous rule applications. Rule 9 recognises the triangular motif (including the pattern lines added by previous rules applications) and reflects this through the triangle's hypotenuse. The result is a square containing a pattern with a reflective symmetry. Rule 10 recognises the square pattern that results from the application of rule 9 and reflects this through an edge of the square. Repeated application of rule 10 results in a larger square pattern, with an eight-fold rotational symmetry.

Motif-based construction can be seen as a two stage process, where in the first stage the motif is defined, and in the second it is repeated under symmetry transformations. Definition of the motif does not incorporate any emergence since it is based on a fixed grid. However, the motif is an emergent product of this stage in the process, and according to type 2) emergence it is recognised and used in the second stage of the process.

5. Generating design spaces

Section 3 explored the concept of emergence in generative design and, based on previous research, three types were identified. In addition, a further distinction was made between emergence as process (where emergent forms are both recognised *and* used) and emergence as product (where emergent forms are recognised but *not* used). In generative design, emphasis is often placed on supporting emergence as process, e.g. it is a foundational feature of the shape grammar formalism (Stiny, 2006). However, emergence as product can also play a role in the generative process. For example, the discussion in section 4 revealed that emergence as product plays a role in the process of generating Islamic geometric patterns in two distinct ways.

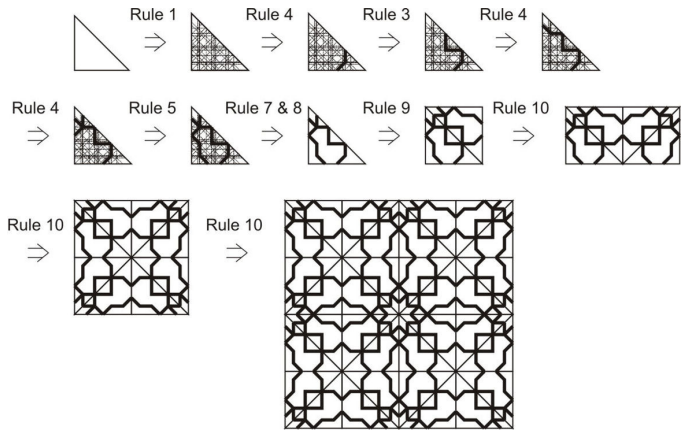

Figure 6. Motif-based construction of an Islamic geometric pattern.

Firstly, emergence as product can play a role when a generative process is a multi-stage process. For example, this was illustrated in motif-based construction (section 4.3), where the first stage of the process generates a motif as an emergent product; the second stage recognises this and uses it in the process of generating a pattern. Similarly, compass and ruler construction (section 4.1) can also be viewed as a two-stage process. Here, the first stage results in definition of a grid as an emergent product, from which design elements are selected in the second stage. The idea of emergence as product being used this way in design generation is not new and has been explored previously, for example in Knight (2003).

Secondly, emergence as product can play a role when a designer fixates on a particular aspect of a design. For example, this was illustrated in set-based construction (section 4.2) where, if a designer intends a generated design to be symmetric, a particular configuration of the parts in a design is recognised as

an emergent product. This product is then repeated under symmetry transformations to create a pattern. A similar method is also used to impose symmetry on patterns constructed using compass and ruler.

Interestingly, emergence as process, emergence as product, and emergence as product *in* process all have different properties with respect to the design space defined by a generative process. As mentioned, emergence as process is often emphasised in generative design, and this is because it can result in an expansion of the design space through the use of emergent forms. Emergence as product on the other hand is the output of generation and as a result has no effect on the design space. Emergence as product in process can have one of two different effects on the design space. Firstly, it can allow the design space to be populated, by enabling the design process to continue. This corresponds to emergence as product in a multi-stage generative process. Secondly, it can result in the shrinking of the design space. This corresponds to fixation on particular aspects of a design, resulting in a disregard for the alternatives.

The aim of this discussion was to inform future development of computational systems intended to support generative design, and to this end it has highlighted some of the complications that can arise when considering the concept of emergence in design generation. In particular, different types of emergence all have a significantly different impact on the design space defined by a generative process. Despite this, processes that incorporate different types of emergence can be used to generate designs within the same style, as illustrated in section 4. This suggests that the extent to which emergence needs to be supported in a system depends on the extent to which the defined design space will be explored. This merits further investigation.

References

El-Said, I.: 1993, *Islamic art and architecture: the system of geometric design,* in T. El-Bouri, and K. Crichlow (eds.), Garnet Publishing Ltd., Reading.

Flake, G. W.: 1998, *The computational beauty of nature,* MIT Press, Cambridge, Mass.

Gross, M. D.: 2001, Emergence in a recognition based drawing interface, *in* J. S. Gero, B. Tversky and T. Purcell (eds.), *Visual and spatial reasoning in design II,* 51–65.

Hedgecoe, J. and S. S. Damluji: 1992, *Zillij: the art of Moroccan ceramics,* Garnet Publishing Ltd., Reading, UK.

Knight, T. W.: 2003, Computing with emergence, *Environment and Planning B: planning and design,* **30**(1), 125–155.

Prats, M., Earl, C., Garner, S. and Jowers, I.: 2006, Shape exploration of designs in a style: toward generation of product designs, *Artificial intelligence for engineering design, analysis and manufacturing,* **20**(3), 201–215.

Schön, D. A. and Wiggins, G.: 1992, Kinds of seeing and their functions in designing, *Design studies,* **13**(2), 135–156.

Stiny, G.: 2006, *Shape: talking about seeing and doing,* MIT Press, Cambridge, Mass.

Woodbury, R. F. and Burrow, A. L.: 2006, Whither design space? *Artificial entelligence for engineering design, analysis and manufacturing,* **20**(2), 63–82.

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COMPUTATIONAL ASPECTS OF A DESIGN PROCESS

Mario Botta's single-family house in Breganzona

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Abstract. The present study aims to foreground and investigate computational aspects of the design process of Mario Botta's single-family house in Breganzona. Through the selected case, it mainly addresses the research question, "what are the computational aspects of the examined design process and what is the nature of such aspects?" or, otherwise formulated, "what aspects of such a design process could be formalised, and thus, represented or explained in computational terms?" The study primarily involves analysis and investigation of the "material"; the sketches and the drawings produced during the design process and through this material, reinterpretation, and hypothetical reconstruction of the process. The material is taken as the container of design ideas / concepts and operations, and a formal / conceptual analysis is employed to foreground and extract this content.

Keywords. Design process; design analysis; design computation; design knowledge.

1. Introduction

In architecture, examining past designs is a well-established strategy in studio teaching, carried out for various purposes. A past design might be useful for showing students what a design solution (Ledewitz, 1985), to that degree, a failure, or a non-solution was (Akın, 2002). Past designs are the containers and carriers of architectural knowledge: such content can be distilled, and help students in establishing their own schemata.[1] As it was emphasised by Bryan Lawson (2004) actually, "acquisition of design domain schemata," is one of the essentials of design education, and design expertise.

Within this context, the present study is based on the following hypotheses: examining a past design could also be useful for understanding computational aspects embedded within a work, and teaching or transmitting such content to the students. This is also true for the designs not originally designed by the help of computers; perhaps examining such designs from this point of view might be even more important to show students that every design has such content, and illustrate to them what content embedded within a design might be represented computationally and how.

From a wider perspective, the purpose of the present study is to question and illustrate how such an undertaking could be employed. The study primarily provides a theoretical and conceptual framework to be adapted to the present situation, and tries to illustrate and discuss how these could be utilised in examining architectural works.

In architectural design research, various inquiries seek models and formalisms for representing design process and design knowledge. A well-known example of such models or formalisms is shape grammars. Such models and formalisms are essential for formalisation, and consequent computational representation of architectural design knowledge and the processes. From a different angle, we may also say that computability of architectural design knowledge is highly dependent upon formalisation and formalisability of such knowledge. The present study may be evaluated within the context of this last issue. It foregrounds and investigates the computational aspects of the material produced throughout the design process of Mario Botta's Single-family house in Breganzona. The material produced in every stage of the design process is interpreted as embodying a "work" that is frozen in a certain stage of its evolution, with a body of "thought content," (architectural design knowledge if we prefer) embedded within. Through the examination of the selected case, the study mainly addresses the research questions, "what are the computational aspects of the examined material, and what is the nature of such aspects?" and "what aspects of such a material could be formalised, and thus represented or explained in computational terms?"

2. On the analysis of the design processes

The analysis of architectural design process, with its roots in earlier body of research in general human problem-solving (Newell and Simon, 1972) has been one of the main concerns of the design research society (Eastman, 1973; Akın, 1986). Common to these studies is the "protocol analysis," a well-established method which is often taken to be "the one that has received the most use and attention," among "of all empirical, observational research methods for the analysis of design activity" (Cross et al., 1996). The method

"has become regarded as the most likely method (perhaps the only method) to bring out into the open the somewhat mysterious cognitive abilities of designers" (Cross et al., 1996). It was no surprise that in 1994, a workshop on protocol analysis was held in Delft University of Technology,[2] and in 1995, a whole issue of the *Design studies journal* was reserved for discussions on protocol analysis studies.

Despite the popularity and the potentialities of the method, the present study follows a different path, by embracing a different approach. The motivation behind this is the hypothesis that rather than observing and analysing the "verbal reports," and interconnected behaviour and acts of the designer, examining and analysing the material (i.e., sketches, diagrams, drawings, and models) produced throughout the process might lead to a better, deeper, and more rigorous understanding of the examined materials themselves and the process itself.[3]

The epistemological basis of this argument is so-called evolutionary epistemology, and the proposed method (and approach) refers to Karl Popper's thoughts on "objective approach" in studying human-made objects.

3. Epistemological basis

To use Popper's (1972) terminology, every product of the human mind, including the works of architecture (or designs) possesses a "thought content" inherent in it. This is the "objective content," which resides in a design, carried by it, independent from one's experience of it, and even independent from its creator's original intentions and thoughts invested in it. Thought content is not the essence of a design, since a design may carry and yield "thought contents" which nobody has thought so far (including its creator), and perhaps nobody will ever think about; a content of a design may well go beyond what was operational in its creation. Such content is only accessible if one is able to read and understand a design, and one has the ability to decipher and grasp the content embedded within: one always comes with his or her horizon of expectations.[4] a frame of reference, to be applied to the present situation.

Popper distinguishes between two main categories of problems arising from the study of the products of the human mind. The first category is primarily related with the way the maker or creator of such products *behaves* while constructing the products. Apparently, here, the primary emphasis is on the methods, and the "problems concerned with the acts of production." On the other hand, the second category is primarily related with the things or objects themselves, and all the related attributes such an object might carry or subject to. This is what Popper (1972) calls an "objective approach," which puts the primary emphasis on the "objects themselves," isolated from their makers and

the acts and behavioural dispositions operational in their making. Popper's point is that such examination of objects themselves might lead us to develop a better (and objective) understanding of them; more important, it may shed a light on the way they were produced, and the methods, even the production behaviour operational in their production.

4. Assumed design model

In the analysis, the so-called conjecture / analysis model of design was assumed. The assumed model was first conceptualised in Bill Hillier, John Musgrove and Pat O'Sullivan's (1972) seminal paper titled "Knowledge and design." In their conceptualisation, design was viewed as "essentially a matter of pre-structuring problems either by a knowledge of solution types or by a knowledge of the latencies of the instrumental set in relation to the solution types." Conceiving approximate solutions early in the design process helps the designer to "understand the problem," and these approximate solutions work as departure points to initiate the design process, something to work with, to develop, and to evaluate. In their conception, one of the primary emphases was on the "developmental" aspect of the process: "The variety of possible solutions has been reduced to one unique solution by some means. The succession of documents produced during design reflects this progressive reduction of variety. More and more specific drawings for example exclude more and more detailed design possibilities" (1972). In this sense, the "solution in principle" conceived early in the process is "progressively developed and refined (or discarded)" (1972). Such an assumption was essential in the analysis, since it provided a basis, a set of preconceptions, a schema to carry out a structured analysis and understanding of the examined material, and hypothetical reconstruction of the process.

5. Investigation[5]

The selected case for the analysis is the single-family house in Breganzona, one of Botta's relatively late designs (figure 1). The primary rationale behind the selection of this design is that stages of its design process are recorded in the form of sketches and drawings, following a sequence, and the provided material is well enough and relevant to support and illustrate the present argument and in developing a fruitful, content-rich discussion.

The design of the single-family house in Breganzona begins in September 1983 and ends in October 1986. In the present analysis, the sketches and drawings; the "material" produced during the design process is investigated chronologically, each design variation, each design stage with reference to

each other and to the overall process, to reconstruct the design process, and to foreground and formalise the computational aspects within each stage, between the produced variations and between the stages.

Methodologically, in the study of the material, and in the examination and reconstruction of the formative processes operational throughout the process, a formal / conceptual analysis is employed. The primary reference of the formal / conceptual analysis refers to the line of thought beginning with Colin Rowe's (1977) "The mathematics of the ideal villa" of 1947, and Peter Eisenman's (2006) doctoral dissertation, *The formal basis of modern architecture,* of 1963.

Here, in the investigation, what is mainly important is to not only to determine how the form emerges or comes into existence through the process, but also to determine which factors contribute to this formation, in what respects. The findings can be summarised as follows:

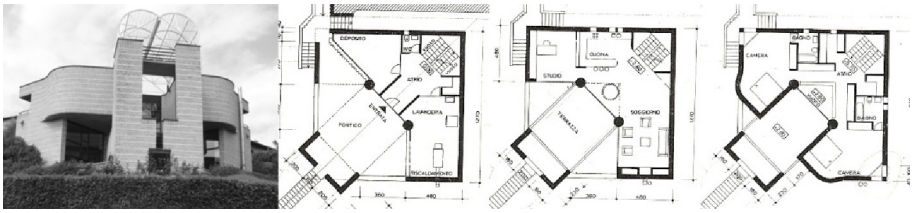

Figure 1. Single-family house in Breganzona, photograph and finalised plans.

5.1. GENERAL OBSERVATIONS ABOUT THE EXAMINED DESIGN PROCESS

Contrary to the often-accepted view, throughout the process, the design did not merely proceed from a less detailed to more detailed (or refined) version. Actually, each stage contained a set of less detailed and more detailed proposals. Otherwise formulated, we may say that the process does not refer to a single "developmental" line, from a less detailed towards a more detailed description of a design, but might also involve a series of interconnected parallel lines of search in various detail levels.

We may say that there are two categories of formative elements, concepts, or ideas operational in the observed process. The first category refers to the concepts, or ideas that are in formative control of the designed object and the subsequent set of elements and concepts. These might be named as "dominants" or "dominant formative elements." The rectangular solid controls the overall outer form (and the outer overall effect) of the design, the square frame controls the outer boundaries of the plan and the spatial organisation, and finally a grid structure (often a nine-square grid or a modified version of it) is in formative control of the inner order and the spatial organisation. The

second category refers to second-order (minor) elements, concepts, and ideas or elements, such as apertures, entrances, which have formative affect on the design, and such as the diagonal axis, which is in control of the circulatory spaces. Despite their formative contribution to the overall design, such entities are under the control of the dominants.

5.2. VARIATIONS AND INHERITANCE

Throughout the process, between the stages, many ideas, concepts, or elements, whether dominant or second-order, are inherited from one stage to another, sometimes kept as they were, sometimes modified. Conceptual inheritance, operational throughout the process, was an important finding of the investigation (figure 2).

Throughout the process, major or minor variations are produced to be integrated / incorporated into the design (figure 3). Such variations are controlled by the specificities (or conditions) provided by the problem situation, and the design itself. The minor variations do not refer to operations in the formative sense, but rather introduction of new minor ideas, concepts, or elements to the design. The elements are integrated to the overall configuration, if successful, to be inherited to the following design stages, while unsuitable (unfit) variations are filtered out to single out the preferred ones. Actually, this was an indication of the existence of "trial and error" (or, if we prefer, conjecture / analysis) process residing behind such a process. As one will recognise, the pattern is operational not only throughout the process between major trials (as the proponents of the conjecture / analysis model of design would accept), but also within each stage and variation whether minor or major. There were trials, in various levels and with different characteristics, such as introduction (and evaluation) of a number of entrance variations, spatial organisations, apertures, etc. superimposed on the overall design and evaluated by the conditions of the present design situation.

5.3. FORMATIVE PROCESSES WITHIN THE DESIGN STAGES

As it was argued by Eisenman (2006, 81), "all specific architectural form can be related to a generic antecedent." Here, generic antecedent or form refers to a universal, transcendent form with its own inherent laws. It is an absolute, which "cannot be considered subjectively" (2006, 81) Specific form, on the other hand, refers to the actual physical configuration, realised to be met a set of conditions relevant to a specific design situation, such as context, program, requirements, function, and so on. Consequently, determination of the generic antecedent is essential to determine the conditions within which

the design-under-investigation was embedded, and the way these conditions affect the formation of the design. As one would recognise, this is fundamental for the analysis of designs and the design process. Once a generic structure is determined, the formative process that transforms the generic to specific can be hypothetically reconstructed, and the conditions such a process is being affected, may be identified. Such a hypothetical reconstruction might not refer to the actual (trans)formation process. However, for that reason it may well go beyond the apparent content of the original material, and the reconstruction may become a creative act itself.

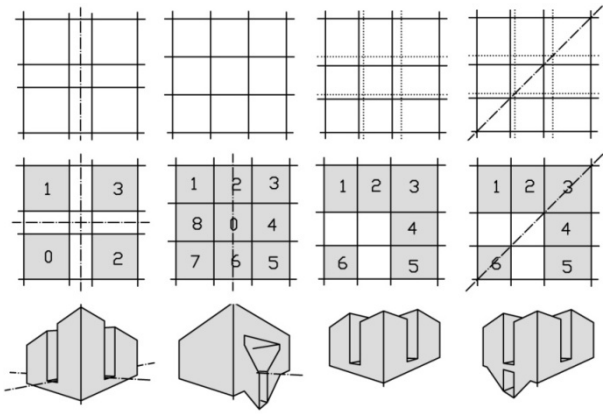

Figure 2. Transformation of the design from Sept. 1983 to Dec. 1983. Inheritance and transformation of the dominants.

In the investigation, all the stages are reconstructed, representing the transformation of the design(variation) from a generic state to a specific state (or, if we prefer from a generic form to a specific form) (figure 4). These reconstructions not only showed the computational (or algorithmic) nature of the transformations and formative operations but also the set of principles, rules, dimensions operational in this (trans)formation (figures 5 and 6). This was one of the important outcomes of the study as a means of illustration of the content embedded within the process, which can be formalised and computationally represented.

6. Final remarks

The outcome of the investigation yields a set of findings, some of which are related to the computational aspects of the process and the examined material. The primary outcome was that despite the fact that the computer is not used during the actual design process, the process and the material have strong

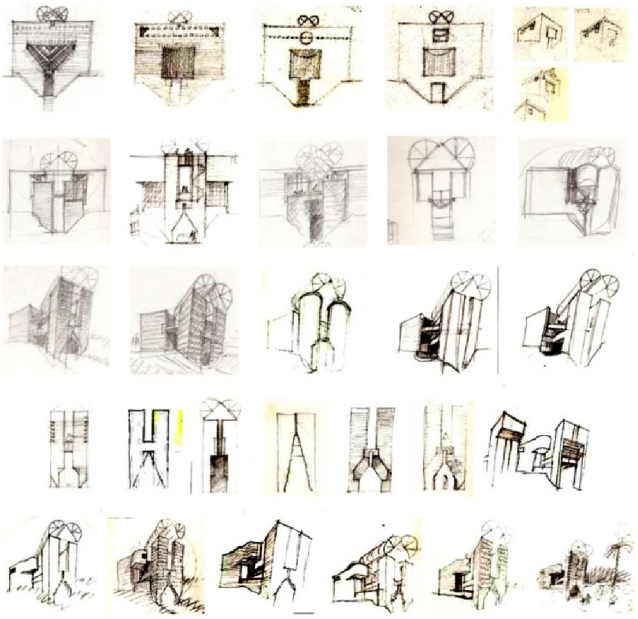

Figure 3. Variations: 1st row, Sept.–Oct. 1983; 2nd and 3rd rows, Feb. 1984; 4th and 5th rows, July 1984.

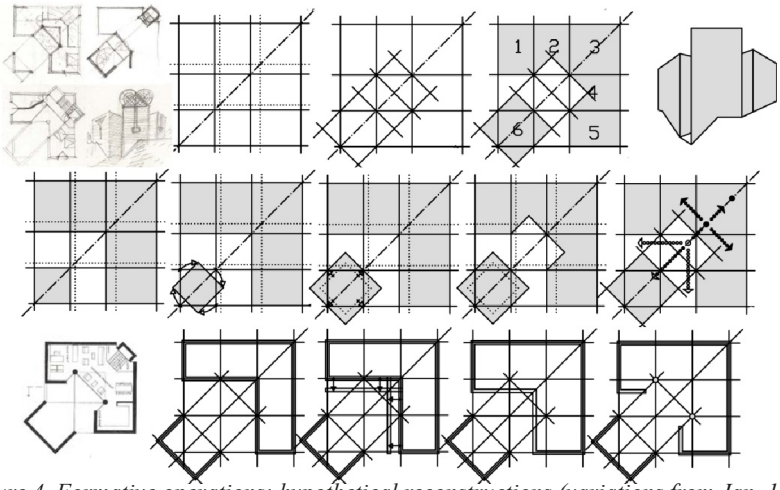

Figure 4. Formative operations: hypothetical reconstructions (variations from Jan. 1984 stage).

computational aspects, and actually, behind the process lies a design thinking / reasoning with a strong computational emphasis.

Perhaps the second important outcome was the implied framework, which comes out of the findings and observations summarised particularly in sec-

tions 5.1 and 5.2. The framework could be used as a basis for developing models and might be turned into a formalism that could be developed further and used for this purpose.

It may be said that the implications of the present study might well go beyond the scope of the present study that was set at the beginning of the paper. For example, the proposed and elaborated theoretical and conceptual framework could be used as a basis for developing CAAD software / tools.

Finally, it must be emphasised that the scope and limitations of the present study do not allow for more. However, it actually points to an epistemological, conceptual, and methodological framework, and a set of findings and issues to be questioned and reconsidered as a basis for further research.

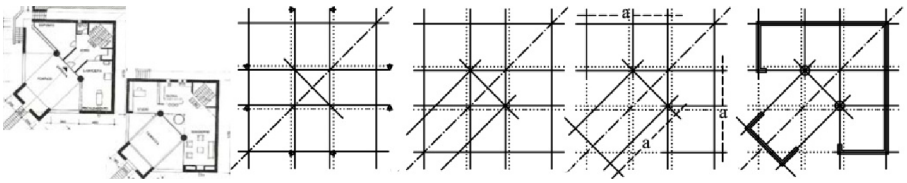

Figure 5. Formative operations: hypothetical reconstruction (Sept. 1984 stage).

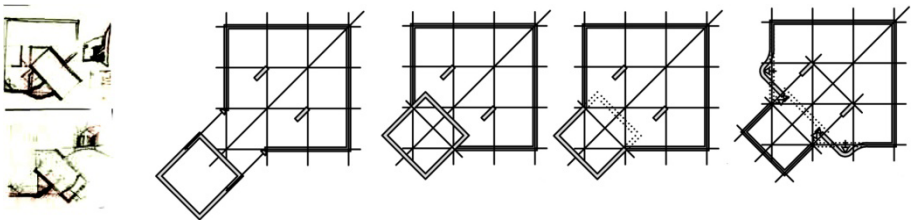

Figure 6. Formative operations: hypothetical reconstruction (July 1984 stage).

Endnotes

1. Schemata are one of the basic ideas of cognitive theory referring to "an internal representation of the world," which consists of "an organization of concepts and actions" that are used for perception, observation, thinking, judgment, learning, understanding, interpretation, problem solving and creation. Referring to cognitive theory, learning can be interpreted as building an intellectual organisation of such concepts and actions that is called a schema (Grider, 1993). A schema can be revised and expanded by new information. Within the context of architectural design, a schema is essential for conceptualising new designs as well as judgment and evaluation.
2. Proceedings of the workshop, "Research in design thinking," later published as a book under the title *Analysing design activity* (Cross et al., 1996).
3. Compared with the "protocol analysis" such an approach is rare. As far as I know, Alan Dubois (1987) employs a similar approach is his investigation of the materials produced throughout the design process of Le Corbusier's Villa Garches, although his main departure point and purpose is quite different from the departure point and purpose of the present paper.

4. The term roughly refers to expectations, but also problems, prejudices, previous knowledge, and all such, elements of schemata which affect understanding and judgment of things those are external to us.
5. The term roughly refers to expectations, but also problems, prejudices, previous knowledge, and all such, elements of schemata which affect understanding and judgment of things those are external to us.

References

Akın, Ö.: 2002, Case-based instruction strategies in architecture, *Design studies,* **23**, 407–431.
Akın, Ö.: 1986, *Psychology of architectural design,* Pion, London.
Botta, M.: 1989, *Mario Botta: una casa,* Electa, Milano.
Cross, N., Christiaans, H., and Dorst, K.: 1996, *Analysing design activity,* John Wiley and Sons, Chichester.
Dubois, M.: 1987, 2 into 1, *Architectural review,* 1079.
Eastman, C. M.: 1973, On the analysis of intuitive design processes, *in* G. T. Moore (ed.), *Emerging methods in environmental design and planning,* MIT Press, Cambridge, Mass., 21–37.
Eisenman, P.: 2003, *Guiseppe Terragni: transformations, decompositions, critiques,* Monacelli Press, New York.
Eisenman, P.: 2006, *The formal basis of modern architecture,* Lars Müller.
Grider, C.: 1993, *Foundations of cognitive theory: a concise review.*
Hillier, B., Musgrove, J. and O'Sullivan, P.: 1972, Knowledge and design, *in* W. Mitchell (ed.), *EDRA 3 Proceedings of the third annual conference,* Dowden, Hutchinson and Ross, Stroudsbourg, 69–83.
Lawson, B.: 2004, Schemata, gambits and precedent: some factors in design expertise, *Design studies,* **25**(5), 443–457.
Ledewitz, S.: 1985, Models of design studio teaching, *Journal of architectural education,* **38**(2), 2–8.
Mitchell, W., Liggett, R. S. and Tan, M.: 1988, The topdown system and its use in teaching: an exploration of structured, knowledge-based design, *in* P. J. Bancroft (ed.), *Computing in design education Acadia'88 workshop proceedings,* University of Michigan, Ann Arbor.
Newell, A. and Simon, H. A.: 1972, *Human problem solving,* Prentice-Hall, Englewood Cliffs, N. J.
Newell, A., Shaw, J. and Simon, H. A.: 1958, Elements of a theory of human problem solving, *Psychological review,* **65**(3), 151–166.
Oxman, R.: 1990, Prior knowledge in design: a dynamic knowledge-based model of design and creativity, *Design studies,* **11**(1), 17–28.
Oxman, R. and Oxman, R.: 1992, Refinement and adaptation in design cognition, *Design studies,* **13**(2), 117–134.
Oxman, R. and Oxman, R.: 1989, The computability of architectural knowledge, *CAAD Futures,* 171–185.
Popper, K. R.: 1965, *Conjectures and refutations,* Basic Books, New York.
Popper, K. R.: 1972, *Objective knowledge,* Clarendon Press, Oxford.
Rowe, C.; 1977, The mathematics of the ideal villa, *The mathematics of the ideal villa and other essays,* MIT Press, Cambridge, Mass.

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DISPLACING THE FRONTIERS OF RECONSTRUCTED CULTURAL HERITAGE

Representation of the non-existing within an urban context

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Abstract. Reconstruction work on more than twenty synagogues in Vienna has been ongoing for more than a decade. The fact that these sacred buildings no longer exist is a pivotal aspect in this undertaking. Research revealed archived material, however, which served as reliable basis for the reconstruction work. The paper focuses on the possibilities and limits of this exploration and discusses the long-term options for handling 3D models and the dissemination of results to a large audience. The appropriate illustration of spatial contexts is another aspect that has been explored. The publication of results in the form of a city guide is in line with the objective of conveying the reconstruction results to a large audience.

Keywords. Virtual reconstruction; 3D modelling; visual representation; urban context.

1. Introduction

For more than ten years, the virtual reconstruction of synagogues in the City of Vienna (Austria) has been dealt with as a research topic. Within this relatively long time, particularly the increasing use of 3D-modelling is a salient feature which required the introduction of conventions for layer structures to

ensure long-term transparency and comprehensibility of the data structures, even when the original members of the research team (which was partly interdisciplinary in composition) are no longer available for information purposes. Frequent software updates (approx. every 15–18 months) make data migration an eternally topical issue. Another major issue is data export, either for purposes of visualisation or for computer-aided model-making (by means of rapid prototyping), which requires a certain degree of detail. The reconstruction work itself can be compared to a virtual building site. The focus is on sacral buildings that were built around 1900, i.e., more than 100 years ago. Although historical records are usually available in the form of designs submitted for building permits, implementation records are often missing, since the planning firms involved have usually ceased to exist. Reference buildings offer a useful option for filling information gaps, as do historical photographs. The appropriate handling of information gaps is a vital aspect in this reconstruction effort.

This contribution presents the results of comprehensive modelling efforts and explains the specific use of rendering processes within the context of a project involving a *city guide* (Martens and Peter, 2009), which needs to address a broad circle of readers. For the purposes of this guide, it was important to clearly present the particularities of each location, a task which is helped considerably by the image of the computer-model. Three-dimensional imaging within the city fabric is of major importance since the synagogues were hardly ever free-standing buildings.

The novel contribution of this work lies in its longevity. Computer-assisted reconstruction projects hardly ever extend over such long periods, and further continuation is intended. Another essential aspect is the dissemination of results to a much larger audience than the narrow sector of specialists in the field at hand.

2. Framework conditions for virtual synagogue reconstruction

Computer-assisted imaging is usually forward-looking and oriented towards the future. Resounding slogans may well promise the user a virtual "heaven on earth". This future-orientation notwithstanding, the technique may just as well be used for throwing a "learning glance" back into the past (Grellert, 2007).

When buildings that no longer exist in reality are virtually reconstructed, the question arises as to whether this visualisation is a construction method based on abstract – i.e., fragmented – data. After all, the existing information includes a good number of uncertainties and gaps. The necessary information fillers and/or the resulting "distortion" of the original image need to be seen with a critical eye - a necessity well known to archaeologists. At any rate, the

reconstruction of historical structures puts at least a visual stop to decay or alterations.

Any reconstruction work is based on well-researched archived material, the quality of which is a determining factor for the validity of virtual reconstruction. It must be noted that the majority of reconstructions in this project involves synagogues that were erected in the second half of the 19th century. Due to the requirements imposed by the City of Vienna's building authority, the plan material submitted for approvals and any later implementation modifications (scale of 1:100) is reliable. As the plans do not, as a rule, include information about furnishings, this aspect requires more in-depth research. It is quite surprising that, despite some information gaps, a wealth of plan material has been preserved in the archives. When archived material has been lost, the three-dimensional visualisation has to work within stricter limits and the process is dominated by speculation, based for instance on comparable reference buildings. A great abundance of various section views of the structure will notably increase the realistic nature of the reconstruction. This is also the case whenever photographic material of interiors exists. The fact that there are very few interior photographs of Jewish prayer houses and synagogues is hardly surprising, since photographs are not made during religious services and celebrations, and the handling of cameras available at the time was hardly comparable with modern-day equipment. It would have been a great benefit to avail of some photographs in order to verify the details of structures and furnishings. Any photographic material would, of course, have been in black and white only, since colour photography was only just emerging in the first half of the 20th century. Monochrome pictures cannot convey more than an inkling of the original colour scheme. The fact that hardly any photographs exist seems to underline the need for the visualisation of interiors.

Sometimes, artist watercolours or paintings exist. While some caution is recommended in their use, they may well be useful as complementary information. Unfortunately, the plan material of the building firms involved has not been archived, which would have offered access to more detailed plans and design data. Sometimes, professional journals published at the time of the structures' completion offer pertinent descriptions of the buildings.

Although a century has passed and some information has been lost, the step back in time is still realistically possible. Unlike archaeological finds from classical antiquity, where sometimes only fragments exist that have to be assembled into a whole, the gaps encountered in this project are usually not as massive. Comparative studies of related buildings from the same era and typical effects of building materials and surfaces help to fill many gaps.

3. Design of appropriate information structures

The notion of "new frontiers", the title of this conference, can be interpreted in different ways (Affleck and Kvan, 2005). Are we continuously exhausting the performance limits of currently available hardware and software? What exactly does "new" refer to? What is meant is probably the continuous shifting of frontiers: CPU performance (hardware) is getting better as continuously as new software features emerge. We started out with kilobytes, went on to mega- and gigabytes, have arrived at terabytes and will certainly not have to wait another century for peta-, exa- and zettabytes to become common currency. "Unprecedented frontiers" are something like a higher level in the shifting of frontiers and refer to "that which has never been seen before". What could that be? The pace of development is still breathtaking, and access to affordable hardware and software tools plays a pivotal role in the process.

Even if frontiers are credited with major significance within the title of the conference, they are not really new if considered as such. Rather, it is the awareness that is new when we speak of a nearly unstoppable flood of development which users have to find a way of coping with, if they do not want to become "upgrade objectors". Mere orientation on growth and accumulation may lead to information structures becoming unusable or inaccessible if they are not subject to (constant) maintenance.

What about potential frontiers in the context of modelling environments? The first thing that comes to mind is the monopoly situation of individual software packages. Manufacturers probably would like to create lasting user commitment to an individual product and data exchanges are often linked to a certain degree of information loss. Interoperability efforts (cf. IFC) have mitigated this phenomenon to a certain extent. Some software developers lure users by integrating well-loved functions from competitor packages in their own CAD environments thus making it easier to switch products.

What impact did the above considerations have on the project of reconstructing more than 20 different synagogues? In principle, there is a clear preference for the ArchiCAD software environment (object-oriented modelling). At the project start, the product range had already reached a stable development status. Availability, including a range of useful interfaces (3ds, vrml, IFC, etc.), was secured for the long term, which is an important aspect, since more than half of the reconstructions were dealt with by students in diploma theses. Other useful aspects were the development of complex profiling tools or the handling of elements across several floors.

We have already reported about this project in previous publications (Martens and Peter, 2002a-b) and elaborated on the conventions developed for the layer structures and the handling of storey content (figure 1). These

structural conventions have turned out to be helpful for the people working with the data and with a view to long-term usability. It is quite remarkable that a CAD file first created a decade ago can still be read and processed almost in its entirety today. In the long run, a transparent modelling structure is therefore indispensable. The established conventions, which have been successfully translated into reality with ArchiCAD's "Virtual Building Concept", are now being investigated in other software applications with the help of the IFC and/or IFCXML data exchange formats. While the use of other CAD environments was not "prohibited", with the output being exported to ArchiCAD, it was found that the results suffered in terms of diminished data compactness (table 1).

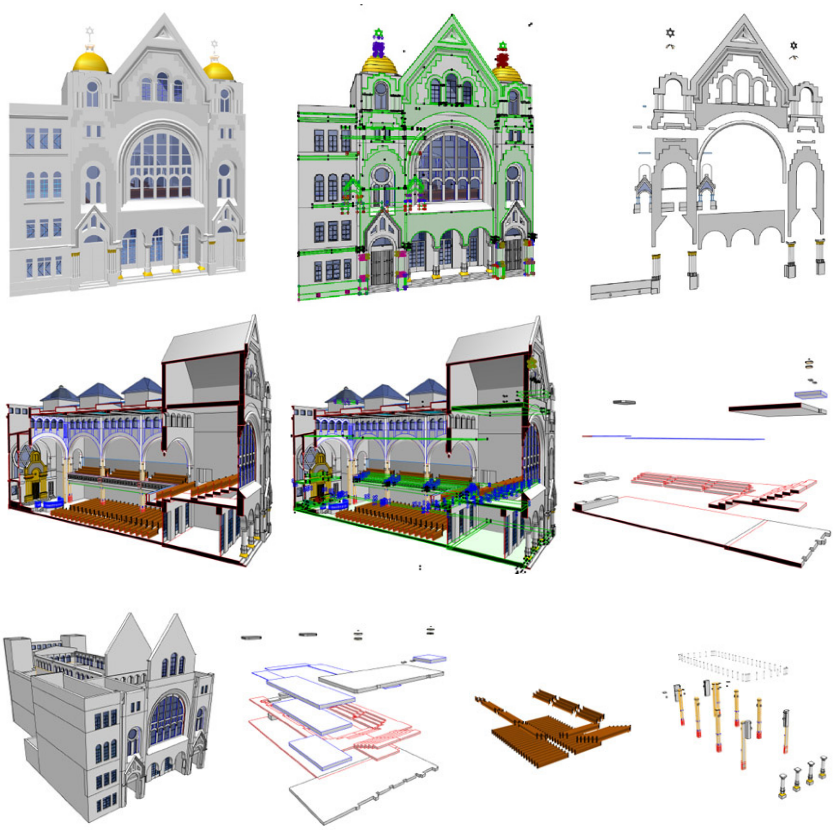

Figure 1. Grouping of building elements in a layer structure (example of Pazmanitengasse).

Although the process may look simple, it is time-consuming and does not generate immediate benefits. In the long term, it still harbours advantages, and it would make sense to archive earlier model versions (including earlier software releases) so that stepping back to earlier states is possible.

Table 1. Overview of accumulated data volume.

Location	Objects	Shape-polygons	AC File (PLA) Mb	GDL Model (bin) Mb	Artlantis Render Mb
Schiffschul	786	194.093	18,9	21,4	53
Humboldt-Tempel	1503	433.580	22,7	48,2	105,6
Kluckygasse	979	235.430	7,9	29,4	55,7
Polnische Schul	856	552.660	15,1	27,3	128,6
Pazmanitengasse	990	421.462	14,8	28,2	98,7
Tempelgasse	979	2.350.515	5,5	95,2	524,6
Turnergasse	611	431.524	7,6	47,8	88,9

4. Visualisation: communicating with larger audience

From the outset there was the intention of making the result of the reconstruction work accessible to the public at large (Tan and Rahaman 2009; Martens and Peter, 2008). Visualisation on the basis of detailed modelling seemed the obvious step to take in this context. It will hardly come as a surprise that developments have occurred in this area in the last ten years. While the internal ArchiCAD render engine has been helpful, a specific study of interior daylight conditions required the use of external rendering applications (3D-Studio; Artlantis Render Studio 2; etc.).

When the conceptual outline for the publication of a *city guide* was established, it turned out that some explanatory efforts were required for the illustration of built structures that are no longer physically available. If the site is a vacant lot, this may be relatively simple, but this was rarely the case. Free-standing synagogues were sacrosanct and were hardly ever found in Vienna. Several synagogues were built in a courtyard context, which made visual reconstruction harder. The disappeared structure was visualised as though it were still in its old place but with the current neighbouring buildings (Figure 2). Although on-site visits (with the city guide in hand) would be ideal, online solutions based on “street view-like applications” are a viable substitute today in an urban context (figure 3).

During the final editing of the city guide, most of the rendered illustrations were recomputed in order to provide maximum realism and consistency of the visualisations (figures 4–9). Visualisation of interiors was indispensable in cases where no photographs were available.

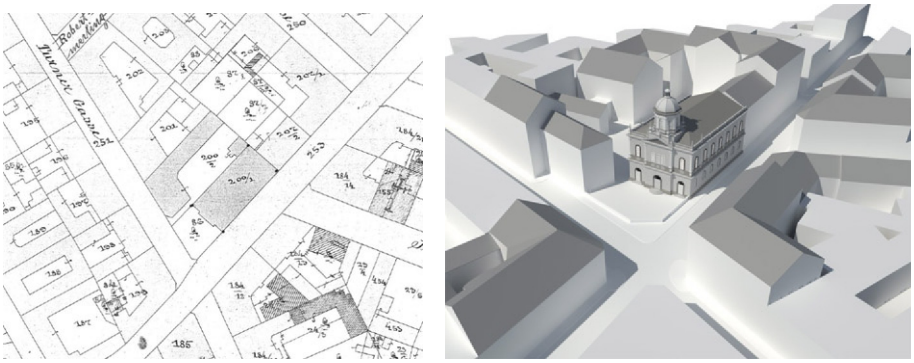

Figure 2a–b. Building in context (freestanding structure): Turnergasse 22.

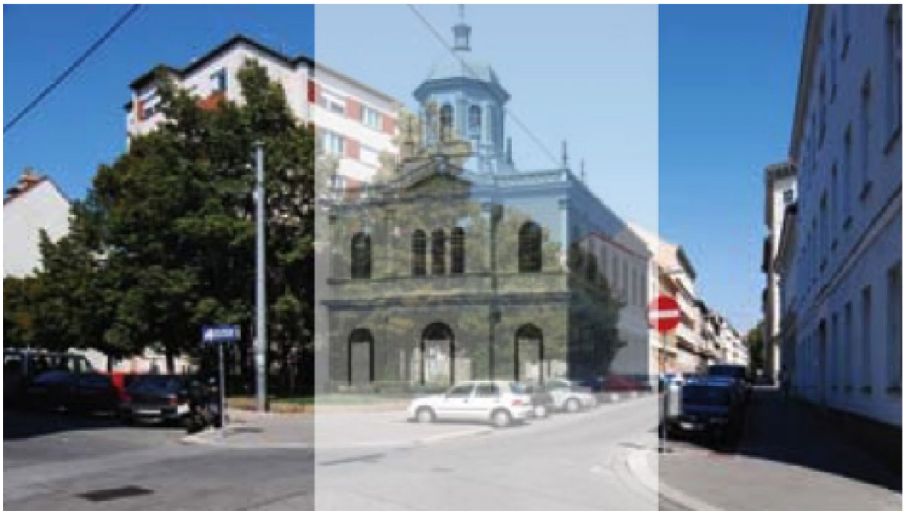

Figure 3. Street view: photomontage of situation at Turnergasse 22.

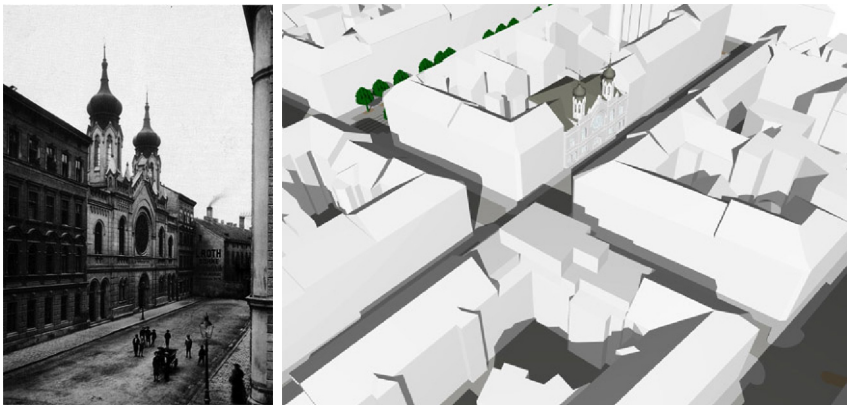

Figure 4a–b. Kluckygasse: historical photograph | illustration of urban context.

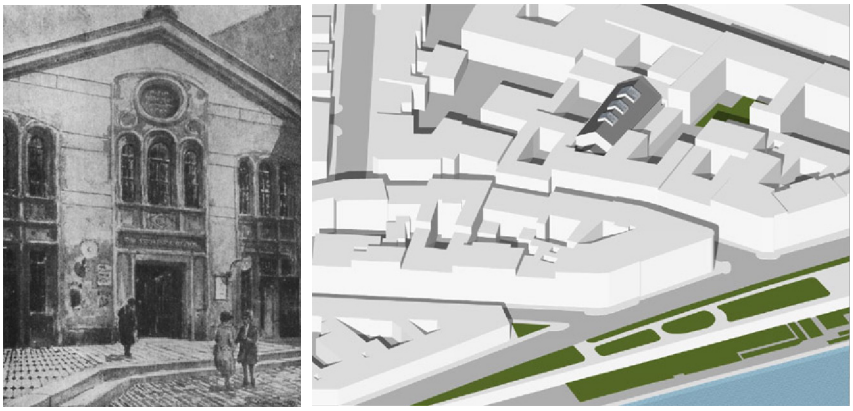

Figure 5a–b. Schiffschul: historical photograph | illustration of urban context.

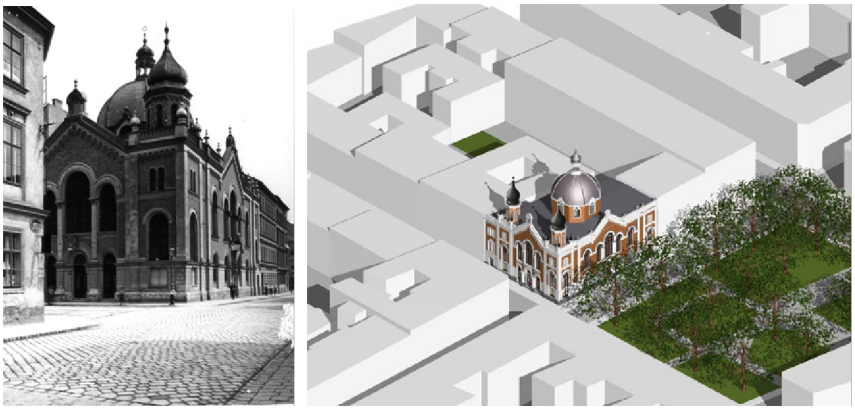

Figure 6a–b. Humboldt-Temple: historical photograph | illustration of urban context.

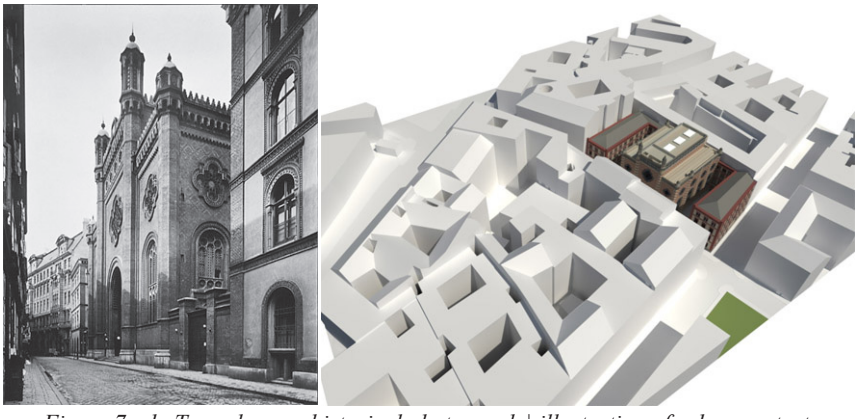

Figure 7a–b. Tempelgasse: historical photograph | illustration of urban context.

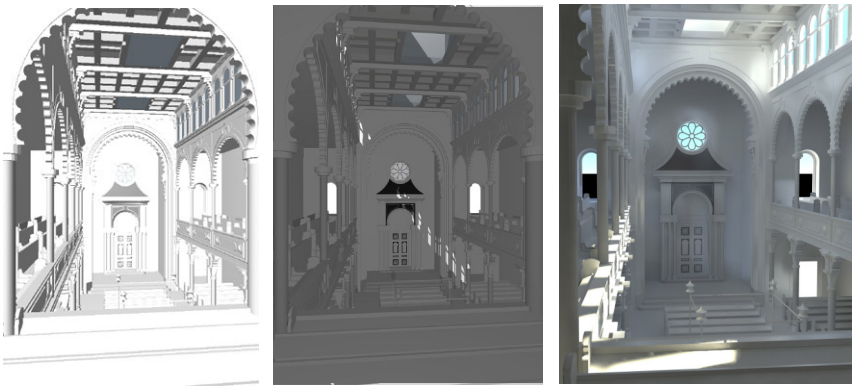

Figure 8a–c. Rendering results "Polnische Schul": shaded visualisation (ArchiCAD9 without shadow casting) | rendering with ArchiCAD9 | Artlantis Render.

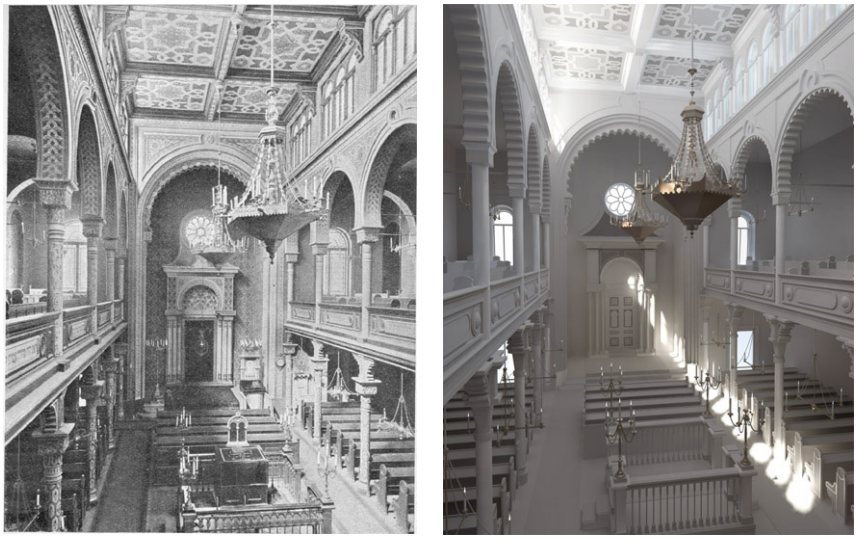

Figure 9a–b. "Polnische Schul": historical photograph | interior, visualisation using Artlantis Render Studio 2.

5. Conclusions and outlook

It is unlikely that the former synagogues of Vienna will be rebuilt in the foreseeable future. Apart from the fact that other structures have been erected on these sites, there is not currently the required volume of worshippers. These facts speak in favour of virtual reconstruction. Yet, there are a few exceptions: the courtyard at *Große Schiffgasse 8* has not been built up to date, and the basic structure at *Kaschlgasse 4* is available again after a supermarket has moved away.

This contribution has addressed the rarity of projects extending over a long period and the need to consider the future usability of data records. In terms of outlook we must mention the expansion of the knowledge base. In neighbouring countries (particularly Slovakia, Czech Republic, Hungary and Poland) eminent synagogue structures from the 19th and early 20th century are still preserved. Even if many of them are in need of restoration, they may at least be used for reference purposes. Another important aspect is the possibility for other disciplines (e.g., art history) to make use of the data structures established.

The dissemination of reconstruction results does not have to rely on rendered visualisations only, but may also use computer-assisted model-making on the basis of existing 3D modelling (Martens and Stellingwerff, 2005), since the investment involved can be estimated realistically. A travelling exhibition of model artefacts seems a conceivable goal.

The *city guide* concept has turned out to be very successful and has reached a large range of readers. Apart from the sales of the book, the guide received remarkable attention from German-language print media and radio channels and also resulted in local follow-up events related to the issue.

References

Affleck, J. and Kvan T.: 2005, Reinterpreting virtual heritage, *CAADRIA 2005 conference proceedings,* New Delhi, vol. 1, 169–178.

Grellert, M.: 2007, *Immaterielle Zeugnisse,* Synagogen in Deutschland [Intangible products. Synagogues in Germany], Bielefeld, Transcript Verlag.

Martens, B. and Peter, H.: 2002a, Virtual reconstruction of synagogues: systematic maintenance of modeling data, *eCAADe 2002 conference proceedings,* Warsaw (Poland), 512–517.

Martens, B and Peter, H.: 2002b, Developing systematics regarding virtual reconstruction of synagogues, *ACADIA 2002 conference proceedings,* Pomona (USA), 349–356.

Martens, B. and Stellingwerff, M.: 2005, Creating physical models using virtual reconstructions: mixed CAM-techniques for a Viennese synagogue scale-model, *SiGraDi 2005 conference proceedings,* Lima (Peru), 108–113.

Martens, B.: 2008, An update on the virtual reconstruction of synagogues in the City of Vienna, *SiGraDi 2008 conference proceedings,* Havana (Cuba) [CD-Rom].

Martens, B. and Peter, H.: 2009, *Die zerstörten Synagogen Wiens* [The destroyed synagogues in Vienna: city guide in German], Mandelbaum Verlag, Vienna.

Tan, B.-K. and Rahaman, H.: 2009, Virtual heritage: reality and criticism, *CAADFutures conference proceedings,* Montreal (Canada), 143–156.

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A FUTURE THROUGH AN ARCHITECTURAL PAST?

Designing an online information package for Al Jahili Fort

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Abstract. This paper details the process that students of UAE University's Department of Architectural Engineering have undergone in packaging architectural heritage data online. Facilitated by the Abu Dhabi Authority for Cultural Heritage, students were introduced to historical data. They digitally reconstructed a historical fort in Al Ain, UAE – Al Jahili Fort – and investigated methods of packaging the gathered information online. Some observations and assessments (strengths and weaknesses) pertaining to the unique historical information packaging are highlighted in this paper. In addition to acquiring skills in producing architectural abstractions and graphic composition, students assessed several online interactive techniques. A set of rules or patterns were prescribed to enhance the clarity of chosen data. While providing insights to the processes of and considerations in designing an online information package for an architectural heritage project, the underlying objective is to question the possibilities and role necessary in sculpting the future of CAAD education to propel the discipline forward through the medium. What would be the implications? It also asserts the notion that digital space may be architectural education's imminent next 'final' frontier.

Keywords. CAAD Education; Information Packaging; Architectural Heritage; Online Presentation.

1. Introduction

The amount of digital data has escalated exponentially in the past decade including those relating to architectural subjects – both historical and contemporary. In the digital world, 'presentation' [of data] has become an over-

used term, almost interchangeable for 'showing' or 'exhibiting'. To frame the topic more precisely, this paper adopts the concept of 'information packaging' instead.

Particularly in this past decade, we have been witnessing a phase in which we struggle to cope with the pace of production and the presentation of architectural data. Organising and collecting information into a single archive for ease of retrieval have been and still being attempted and developed – for example, Stouff et al. (2001), Ham (2002), Koutamanis (2007), Barci Castriota and da Silva Angelo (2007), Stefaner et al. (2008), Cheng et al. (2009). Meanwhile, in the midst of this struggle, in architectural education, we appear to have overlooked the most fundamental reason for having the information 'presented' – i.e., to facilitate an in-depth understanding about a particular subject. There is an urgent need to look beyond collecting, archiving, retrieving data or creating metadata. To say that architectural knowledge could be presented as a mere database of retrievable data is to suggest that architectural design itself could be reduced to a warehouse of catalogued building materials. Neither serves justice.

Historical architecture especially has largely been reduced to repositories of data. Besides databases of architectural information, the concepts of digital architectural information presentations we still often encounter today are what most are familiar with – ones that are intrinsically based on traditional slideshow or print format with additions of hyperlinks. The ability to 'hyperlink' information is one of the strengths of the digital media and usually the only feature that is extensively applied in most websites (eg. The Architecture Week Great Buildings Collection, 2009). Apart from being faster than printed materials in navigating from one group of data to another, they have not necessarily been utilised in manners that contribute sufficiently to the in-depth understanding of architectural subjects. Instead, we frequently experience that the reverse is true.

CAAD education has generally been successful in serving the industries by producing graduates who possess at least the fundamental skills to produce architectural abstractions – working drawings, 3D visualisations, etc. If we are able to push the envelope further by cultivating habits and skills necessary to present these abstractions online effectively, we could help propel the discipline to an unprecedented level of knowledge sharing as opposed to mere data sharing. Digital information package design should become an emerging area of attention in architectural education to escalate continued knowledge formation within the field.

2. Information package design

There are perhaps only two simple precursors to grasping the concept for an effective online packaging of architectural information:

- **Realisation of digital opportunities.** Many educators or academics still fail to perceive the digital platform beyond a mere exhibition space for hyperlinked architectural abstractions. We also seem to have underestimated the internet as a potential source of knowledge, generating graduates who are ill-prepared to communicate their architectural ideas online with utmost clarity. Most websites seen on the internet should not be considered appropriate as examples to present architectural information. Digital architectural abstractions come in various forms. Appreciating what each could offer and exploring how it could be fully applied also provide links necessary for maximising the opportunities.
- **Working with limitations.** There is a need to cultivate an awareness of the reality, not only of the opportunities they present but also the challenges and limitations. Designing an effective online information package requires a considerable time and effort. Choice of tool(s), technical know-how, screen real-estate size, the absence of a presenter, clarity of information, the choice of abstractions, their inter-relationships, human behaviour/psyche, etc, are just some of the issues.

As mentioned above, in order to augment understanding, due to the nature of the subject, architectural information should not be presented in similar manner as those in conventional web pages. However, there are some applicable 'standard' issues in web design that could be deemed common and need to be adhered to:

- **Navigability.** The ease of exploring a site and simplicity of navigation would help in transitioning an audience from one area of content to another. Navigation difficulty may adversely affect a viewer's cognitive thought processes.
- **Graphic composition and design.** The choice of graphics, layout, typography and their properties as well as placements could affect the perception and prejudgment of the content of a website. Too often, information is unnecessarily and/or inappropriately 'decorated'. To the extreme, some decorations have taken precedence over the content. Tufte (1990) drew parallels between them and 'Duck' or decorated shed in architectural design as highlighted by Venturi (1972).
- **File size.** Online materials are usually kept to the minimum possible size for optimum access speed.

Based on analyses of Tufte's proposed strategies of presenting information on printed medium (Tufte, 1990) and assessments of digital information packages (Kwee, 2007) in addition to analyses of student past projects (including the project detailed below), at present, the following are identifiable, strat-

egy patterns useful in augmenting the dimensions of digital architectural information:

- **Depth of information, validity and accuracy.** All of these require extensive research and tight collaborations with experts in the field to ensure that information that needs to be delivered is relevant, valid, accurate and of adequate details. Density or richness of information can rarely be provided by the information package designer alone unless he/she also serves an active role in the procurement and production or design of the architectural object and/or data.
- **Visual emphasis.** This is based on the argument that architecture is more effectively and immediately represented in visual forms than in written texts. The propensity of texts being a more culturally-biased form of representation seems to be another reason. However, this does not suggest diminishing the role of texts which are often integral supporting narratives.
- **Contextualisation of abstractions.** Since each architectural abstraction speaks its own narratives, its location in relation to another can usually also affect how it is perceived and understood. Ideally, all similar narratives [in abstractions] should cumulate into larger coherent structures.
- **Information layering.** As an extension to the above point, abstractions that are largely similar, but of differing information dimensions could be layered to highlight the congruity while adding extra relevant information depth. For example, a sectional perspective could be layered upon a sectional working drawing of the same view to visually and informatively complement one another (figure 1).
- **Visual continuity.** Due to the ease of hyperlinking of data, abrupt transitions between visual components are commonly observed in many online architectural presentations. Furthermore, an author's familiarity of the subject often renders a false assumption that viewers are also able to connect visual data or information readily. Viewers are usually coerced to provide their own mental translations to link.
- **Legibility.** Resolution of images or drawings and the screen that displays them naturally affect how well the information is read. Drafting and other graphic software applications have been successful in dealing with this by enabling

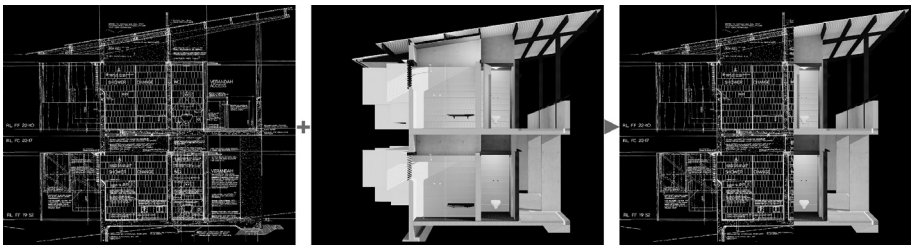

Figure 1: Layering a construction drawing and digital model in interactive manner to increase Depth of Information – the whole could be more than the sum of its parts.

users to zoom and pan to work with detailed drawings in vector or raster/ bitmap formats. However, architectural content providers or distributors have yet to adopt this to improve the legibility of their online data they present.

The above patterns are crucial in addressing the issue brought up by Scott Johnson (1997) – issue which reveals that forcing one to translate representations would inadvertently drain his or her cognitive resources affecting the individual's ability to use existing knowledge and problem solving strategies. The loose relationships between abstractions or representations in many architectural publications may be attributed by limitations of that printed media has imposed. The adverse effects to cognitive process has thus been long inadvertently overlooked and 'accepted' to the extent that digital opportunities have not been rigorously investigated. This 'acceptance' of the norm has become a deeply anchored culture that appears to override conscious, critical judgments.

3. Al Jahili Fort project: process and outcome

The Al Jahili Fort (reused as a museum) was located in the city of Al Ain within the emirate of Abu Dhabi, United Arab Emirates. This student project aimed to explain the historic fort online. It was with the assistance of and support from the Abu Dhabi Authority for Culture and Heritage (ADACH). While the project attempted to instill sensitivities towards the treatment of historical information and awareness of its online digital packaging considerations, it also served as a pilot study for a national grant application.

Similar classes have been conducted in the past with varying degrees of success (Kwee, 2009). The only difference in this particular was the subject matter, where additional data gathering would be required.

There were 14 female students involved in the project. They grouped themselves into four. Later, however, one team decided to split, resulting in five groups in the final. Due to cultural restrictions, female students would have limited access outside the university. This posed a minor challenge in arranging visits to the site.

The general process could be summarised as follows:

- **Data collections.** This comprised an information session by ADACH, interviews with the museum personnel, site measurements, procurement of survey drawings, photos of details and materials. Two site visits were arranged to facilitate the collection of onsite data – one at the beginning of the semester, and one near the completion of their 3D models to allow them to validate their collected data and gather additional materials – e.g., texture images for material mappings.
- **Digital reconstruction.** The digital reconstruction of the fort commenced

almost immediately after the initial site visit. Little time was set aside for familiarisation of the 3D software application in use – namely 3D Studio Max. Although all were senior students, most had no prior 3D modelling experience. Questions raised during the skill sessions were discussed with the entire class. Students who were able to solve the technical problems that others encountered were asked to demonstrate their solutions; in addition to encouraging peer-learning, it was deemed an effective way for students to retain their new-found knowledge. The 3D sessions were much tailored to deal with the fort digital reconstruction and manipulations. Students were also introduced to various other abstractions such as virtual reality in QuickTime format and VRML, Augmented Reality using ARToolKit as a means to viewing their 3D models as well as text-to-speech technology by AT&T Lab (2009). The idea of using Augmented Reality was quickly abandoned when it was realised that the file size exceeded the system's ability to display the digital model realtime.

- **Information packaging.** Lecture and discussion sessions were conducted to allow students to rethink the uniqueness of the subject, thus its information packaging. Students also critiqued existing online websites, discussing the graphics, clarity and effectiveness. Thereafter, students reviewed the materials that they had and proposed ways to deliver them based on these discussions and the patterns listed in Section 2. Lessons on web-authoring were conducted, specifically targeting on simulating these patterns to package their fort information. This proved challenging for none of the students had any previous experience in web-authoring. The basics of graphic file formats and treatment for web contents had to be learnt in addition to understanding computer coding in ActionScript (Flash CS3). Some ready-made templates were dispensed to assist students while others were sourced from the internet, but they needed to be modified to suit individual group project. Student presentations of the project development were done at regular intervals allowing feedback from their peers.

The final web pages were submitted and they were published online using the university server to host. These can be viewed from: http://faculty.uaeu.ac.ae/Verdy_Kwee/Spring2009/ST/index.swf.

4. Outcome discussions

It was encouraging to observe that some students have begun to explore presenting various abstractions in non-conventional manners. However, a few issues, assessments and caveats were also noted:

- **Team work.** The idea of working in team was entirely optional, but all students opted to work in groups. The planning was left entirely to them. It was interesting to observe that the students decided to subdivide the fort into parts, assigning each to every team member. Due to this arrangement, where members

work individually on their own segments, consistency in the final information packaging was an issue. This related not only to the general design or outlook of the 'pages' which was easily solved, but extended to the choice and quality of abstractions and navigation (figure 2). Although a higher number of team members helped in the collection of information at the initial stages, it was found difficult for team members to agree on the overall packaging standard. Team dynamics played an important role in the degree of successful integration.

- **Information accuracy.** Initial feedback from ADACH was encouraging. However, it was highlighted that some aspects of the published information were inaccurate. There was also inadequate depth of information. A closer working relationship could have been established early between students and the experts in ADACH. This was lacking due to the associated logistical problems in arranging direct dialogues with the relevant personnel during the design process. ADACH had intended to use some of the materials but by the end of the semester, students did not seem to respond actively to ADACH request for information changes and corrections.
- **Timeframe and student workload.** Understandably, to expect the project to adhere to all the principles of information packaging would have been unrealistic for a course which was of three credit hours in length. On average, students undertook around 17–20 credit hours of classes for that semester.
- **Availability of tools and user adeptness.** At present, available authoring tools

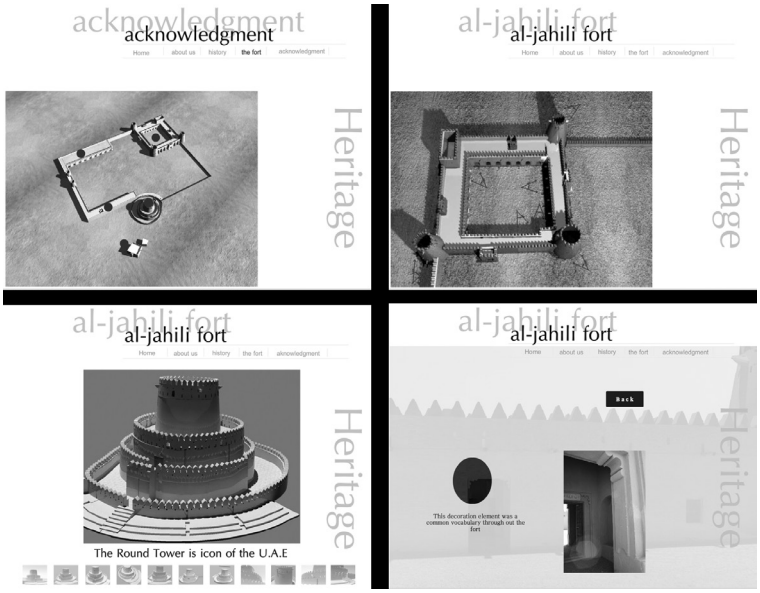

Figure 2. Differences in choice of navigation styles, 'buttons', abstractions and qualities amongst pages were markedly apparent in the team project.

lack user-friendliness and their learning curve is usually lengthy. For students to master the tools within a semester was extremely challenging. However, the main aim was to understand the concept of architectural information packaging.

- **Delineation and learning from the conventions.** Constant exposure to mostly-standard designs of web pages appeared to prevent some students from disengaging themselves easily from the conventions. On the other hand, while attempting to address some issues in the design of architectural information packaging, many students neglected other fundamental aspects such as navigability and file sizes.
- **Choice of abstractions and implementation.** It was also noted that students were much too preoccupied to show what they could do with the skills they acquired. In many instances they overlooked assessing what abstractions to use and failed to strategise the manners in which to use them with the tools they had (e.g., figure 3).
- **Inclusion of additional information.** Since the information packages were done in Flash CS3 authoring software, future inclusions of additional information will require the original files and understanding the structures of the written design logics. Reviewing these structures can be time consuming.

5. Conclusions and further studies

We are still very much at our infancy stage in digital architectural information packaging. Rethinking and implanting the concept of information packaging for the future of architectural education calls for investments not only in technologies but also in expertise. Effective online architectural information package designs can never entirely rely on experts outside the field – e.g.,

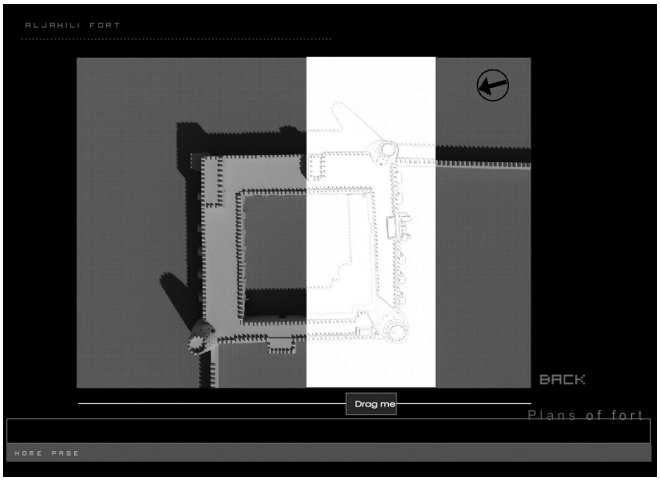

Figure 3: Layering of two congruous abstractions without adding to information depth.

web designers– much less on automation based on algorithms like that found in data mining, for example. They require an in-depth comprehension of the subject and the cognitive issues involved to be able to create and/or relate appropriate abstractions in the most coherent manners. Endless creations and publications of data fragments are prevalent on the internet and online database systems. Experts are required within the field to piece these into easily-absorbed knowledge.

The implications are potentially larger than it might first appear. Effective information packages should be able to reduce mistranslations of architectural ideas which are more often explained through various abstractions or representations than the physical object itself. This undertaking promises a heightened increase of knowledge formation speed, facilitating more profound and accurate academic analyses and syntheses.

From the angle of information treatments, by adopting similar patterns of information packaging, the direction of future architectural documentation formats could also be fashioned – formats which have largely remained the same throughout the past centuries. A reestablishing or development of current technologies necessitates this process.

Only equipped with an awareness of the theories and critical understanding of the opportunities and limitations, could the next generations help usher architectural education into a new knowledge frontier. It poses a challenge to schools to revamp their CAAD curricula to instill this awareness in order to strengthen the fundamentals of the discipline which will consequently and perhaps indirectly help better serve the industry as well.

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References

A Barci Castriota, L. and da Silva Angelo, C. V. :2007, Digital technology and accessibility: The Rede Latino-americana de Acervos de Arquitetura e Urbanismo (RELARQ) [Tecnologia digital e acessibilidade: A Rede Latino-americana de Acervos de Arquitetura e Urbanismo (RELARQ)] *SIGraDi 2007,* México, 200–204.

AT&T Lab.:2009, AT&T Labs Text-to-Speech: Demo, available from: <http://www2.research.att.com/~ttsweb/tts/demo.php> (accessed 4 November 2009).

Cheng, H. M., Yen. Y. N. and Yang W. B. :2009, Digital archiving in cultural heritage preservation, *CAADRIA 2009,* Yunlin (Taiwan), 93–102.

Johnson, S.: 1997, What's in a representation, why do we care, and what does it mean? Examin-

ing evidence from psychology design and representation, *ACADIA '97 conference proceedings,* Cincinnati, USA, 5–15.

Koutamanis, A., Halin, G. and Kvan, T.: 2007, Indexing and retrieval of visual design representations, *25th eCAADe conference proceedings,* Frankfurt am Main, Germany, 319–326.

Kwee, V: 2007, Architecture on digital flatland: a case-study on Murcutt, Lewin and Lark's The Arthur and Yvonne Boyd Education Centre, PhD diss,. The University of Adelaide.

Stefaner, M., Spigai, V., Vecchia, E. A., Condotta, M., Ternier, S., Wolpers, M., Apelt, S., Specht, M., Nagel, T and, Duval, E.:2008, MACE: connecting and enriching repositories for architectural learning, *EAAE transactions on architectural education,* **40**, Venice, 22–49.

Stouffs, R., Venne, R. F., Sariyildiz, S. and Tunçer, B,: 2001, Aspects and technologies of e-learning in an architectural context, *Architectural information management, 19th eCAADe conference proceedings,* Helsinki, Finland, 358–363.

The Architecture Week Great Building Collection: 2009, <http://www.greatbuildings.com/> (accessed 4 November 2009).

Tufte, E. R.: 1990, *Envisioning information,* Graphics Press, Cheshire, Connecticut.

Venturi, R., Scott Brown, D., and Izenour, S.: 1977, *Learning from Las Vegas: the forgotten symbolism of architectural form,* MIT Press, Cambridge, Mass.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010,* 83–92. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

PRESERVING MEMORIES WITH DIGITAL MEDIA

A methodology for the reconstruction of Castelnuovo Village

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Abstract. The historical centre of the village of Castelnuovo (located in Abruzzo, a region in central of Italy) was seriously damaged by the earthquake of the 6th of April 2009. Following the survey by the Civil Protection, all dwellings have been classified as unsuitable for habitation. The village should be either abandoned or totally rebuilt. But which is its value? Is there something worth of being preserved? If observed from a biodiversity point of view, or more precisely from a "cultural biodiversity" point of view, the historical centre possess interesting materials and immaterial characteristics. These qualities constitute real guidelines for a possible recovery project. Since there is not any possibility to make a survey of the inner village because of its destruction by the earthquake, in this research we have decided to use information technology, in order to rebuilt it and study it in a three-dimensional environment. In this paper we describe the theoretical basis, the method of elaboration and the instruments we have used to locate and evaluate the memories that should be preserved in a new project. Starting with a traditional documentation, such as photographs and drawings, we have used a variety of software (graphics editing program, CAD, 3D modeler, videogame 3D-engine), because of the several hypothesis considered.

Keywords. Digital heritage; digital design; design methods; digital reconstruction; memories conservation.

1. Introduction

The use of Information and Communication Technology (in particular CAAD, BIM and three-dimensional modelers) in the architectural field can be divided,

with some exceptions, in two large sets of applications: on one hand architectural design, and on the other hand the study/analysis of hand-made artifacts belonging to the old cultural traditions (constructions methods still in use or in protected archaeological locations). In the first case, the case studies and the documents developed in a virtual environment constitute the essential documentation to construct a building in the real world. Within the second set, the reconstruction of hand-made artifacts and objects of the real world in a virtual environment permit to deepen their knowledge (examples on Al-Qawasmi et al., 2008).

In our research, the interrelation between the real and virtual world is a mixture of the interrelations described above. The main object of study is real: it is the village of Castelnuovo, and particularly its fortified centre, destroyed by the earthquake. The passage to a virtual space has been useful to study more deeply and to increase the knowledge of a real world which was not only heavily compromised, but also dangerous to study on site. During the analysis and the creation of the various documents, these software applications has been useful to identify and evaluate those memories of the village that should be preserved, by including them in a recovery project. Therefore, the virtual environment is the link between a wounded present, which has strong roots in the past, and a future full of hope that wants to turn the page, by preserving the best qualities of the old village: the memories.

2. The case study: the fortified village of Castelnuovo

The disastrous earthquake that hit the Abruzzo region (located in central Italy, an area rich in medieval artistic heritage) on the 6th of April 2009, heavily damaged the regional capital itself, L'Aquila. Damages of various entity were registered in more than 50 small villages including Castelnuovo, a borough of the village of San Pio delle Camere, that counts less than two hundred inhabitants.

Castelnuovo is located within the "Piana di Navelli", a plateau surrounded by mountains, at about 700 meters above sea level. The village rises on the top of a hill where it dominates the entire landscape, today marked also by an important road. This privileged position inserted Castelnuovo, and in particular its fortified centre, inside the sighting and defence system of the valley of L'Aquila, during the Medieval period.

From the twelfth century to the present, the village has known for various phases of growth. In our research, we have dealt with the fortified centre, the most ancient and important part of the village, which is an a urban settlement inspired to the Roman "castrum". This peculiarity, that distinguishes Castelnuovo from the other nearby towns, derives probably from the closeness of the

ancient Roman settlement of Peltuinum.

2.1. CASTELNUOVO, THE EARTHQUAKE AND THE UNIVERSITY

The geological features, and the presence of spaces excavated in the rock, called “grottoni”, have amplified the effect of the earthquake, causing serious damage to the whole village. In fact most of the dwellings have been classified by the Civil Protection as uninhabitable (Class E damage).

The Faculty of Architecture of Pescara (University G. D’Annunzio, Chieti-Pescara) started immediately organising seminars, in order to discuss and reflect on the problems linked to the earthquake. After a first preparatory workshop, a group of PhD students (Building Technology and Environment programme, coordinated by Professor Forlani) continued working during the following months, in order to elaborate projects and research hypotheses useful to go through that difficult moment and to prepare a sustainable future (Forlani, 2009)

The research described in this paper is part of this study and it has a main object the fortified centre of Castelnuovo (figure 2). Since there are no buildings to be preserved, in a hypothesis of intervention the village should be totally rebuilt. But why should we rebuild it? And how?

Figure 2. Two views of the fortified centre of Castelnuovo after the earthquake.

3. A way to analyse the memories to be preserved

As anticipated in the introduction, other studies have as a main objective the preservation of memories only for educational and cultural purposes, such as virtual museums or virtual reconstructions of ancient archaeological sites. We wanted instead of analysing these memories in order to propose them in a real project but to create a continuity of the village with its own historic roots. The choice of rebuilding the heart of the town, its fortified historical centre has been symbolic and deeply meaningful.

But for what reasons should we be preserving these memories? And how should we work?

3.1. HOW AND WHY PRESERVING MEMORIES?

We have concluded that the phase of the reconstruction should be of a "perceptive-cultural" kind, in order to avoid the falsification of history, as a result of imaginative elaborations.

The fortified centre being the oldest part of the village, is the outcome of many transformations and stratifications occurred during the centuries. For this reason there are interesting material and immaterial features that should be preserved. Both these characteristics are the expression of "cultural biodiversities", a term which means: man's ability to influence natural processes and the way the environment appears in space; the issues related to culture and traditions of specific local realities, which are the expression of man's life in a specific local context and environment. The character of this biodiversity is thus resulting from the relationship between human and natural factors (Borrelli et al., 2007). A concept that has to be considered and protected in every intervention made on the territory, to face the alienation of the landscape, and hence the loss of the local identities.

A deeper knowledge of the fortified town is essential in order to propose its character, its "atmosphere", in a new project. In fact, a "location" is more than an abstract localisation; this word means "a set made by concrete things with its material substance, shape, and colour" (Norberg-Schulz, 1986). As a matter of fact, one should not consider only the functional aspects, because even the human functions are different, and are conditioned by different cultural traditions and by different environmental conditions.

4. The elaboration of a method

A working method was developed taking into account some important constraints: the impossibility of entering into the village and the desire to minimise the survey of the external areas because of the danger of moving through

the rubble and the crumbling buildings and the little information available documenting the village before the earthquake.

This situation has directed us towards the use of tools and methodologies of information technology allowing to reach a level of details greater than with methods using traditional tools.

The work was divided into several phases: collection of documentation, creative three-dimensional reconstruction to study the morphology of the original settlement and its criticality; realisation of three-dimensional models to develop a hypothesis of reconfiguration of the village, and the analysis of aspects relating to the perception of the place and its atmosphere. For the three-dimensional models different levels of synthesis were chosen in order to communicate various information.

4.1. TRADITIONAL AND DIGITAL DOCUMENTS

During the first phase we collected all the documentation available. The documentation on the village in its original condition before the earthquake is the result of previous studies and consists of floor plans, sketches and photos. Some pictures taken from above proved very useful because they allow to see almost all the building roofs, most of which have now collapsed.

These pictures have been scanned in high resolution and touched up in Photoshop, to analyse them better.

We have also included, together with the traditional documentation, a new photographic survey, made with a compact camera of 8Mp and some small avi videos, made with the same instrument. The longest video lasts 4′24″, and was made during a walk all around the fortified village. The videos have included important spatial information, and have completed the photographic documentation.

4.2. THE THREE-DIMENSIONAL MODELS

The three-dimensional models are useful to study more in depth the aspects linked to the localisation and evaluation: material memories of the village related to morphological-functional changes; the spontaneous transformations that have spoiled the original plan and that should not be preserved, a first design hypothesis that retains some traces of the original village. The physical models, in wood and in other materials, have always accompanied the work of the architects; the three-dimensional digital model can be considered as the natural evolution because it offers greater opportunities of elaboration.

A first synthetic model has been created in 3D Studio Max, starting from a plan prepared in AutoCAD, where only the perimeters of the single living

cells are shown. The photos from above were essential to understand the different heights and roofs of the buildings. In this case we can speak of an imaginative reconstruction because it was necessary to interpret and recreate the morphology of the village with the little information available.

Thus it was possible to make a more appropriate reading to comprehend the morphological-functional transformations of the town centre, which have also involved the buildings heights.

In fact, throughout the centuries, new necessities have modified the original uses and caused an increase of the number of floors, up to a maximum of five. The result of this first reading showed us an extremely complex urban centre, with constructions that had not only pitched roofs, but also terraces and loggias (figure 3).

In another three-dimensional model, based on the previous one and defined "Criticality model", we have identified the spontaneous transformations, such as the abandonment or the demolition of parts of the buildings, or the closure of important pathways. These modifications have compromised the original plan of the village.

The previous analysis has given us the possibility to understand that, in the plan of a new village, we should preserve some important peculiarities/characteristics that have been lost throughout the centuries. For instance all the pathways had exits towards the external part of the village and now there are only three paths left.

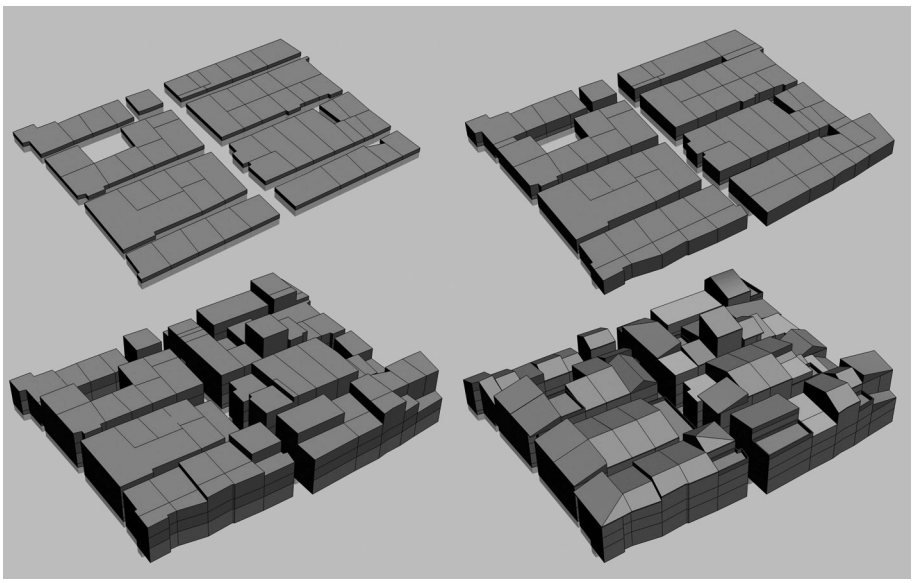

Figure 3. The three-dimensional models used to study the morphological transformations.

The third three-dimensional model was used to formulate a first design hypothesis. The new model was created using a base plan with a historical light structural grid shown by a slight extrusion.

On this model we positioned new bearing walls, in correspondence to the foundation plan of the old village, which is another trace of the past that we should preserve.

Through the study of this model, we tested some hypothesis trying to combine planning solutions in line with environmental sustainability principles, with signs belonging to the historical memory. In the new village, for instance, it would be possible to foresee some small heights variations among the buildings, both as reference-mark to the complex original morphology and as a way to avoid excessively monotonous solutions (figure 4).

5. A method to analyse the atmosphere: lights, shadows and spaces

Besides the characteristics of the materials such as building heights, the size of the living cells and other historical signs, we have also considered the immaterial memories linked to the image: the colours, spaces, lights and shadows all pertaining to create the atmosphere of the place.

Like all ancient settlements, Castelnuovo was built mainly with local materials, such as stone. There is a relationship between the settlement and the landscape, like between a figure and its background: if this relationship is missing, both of them loose their identity (Norberg-Schulz, 1986).

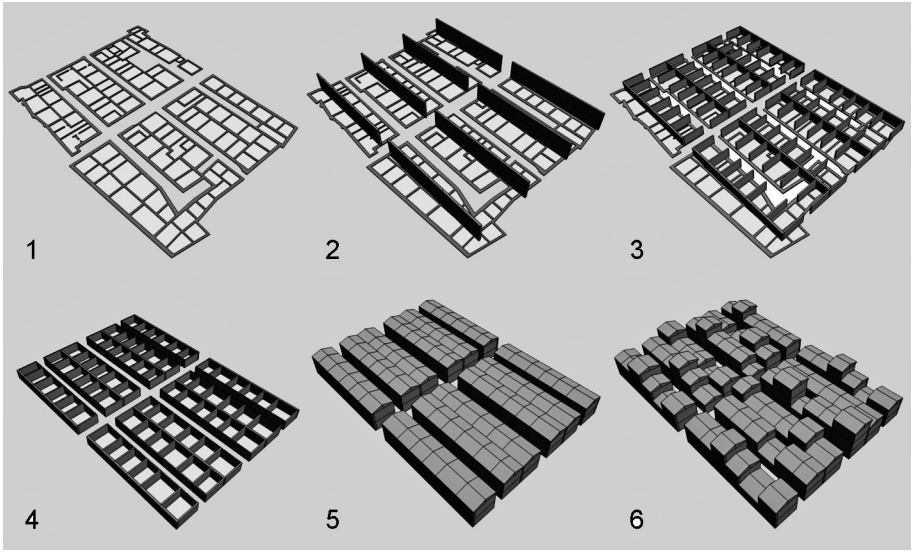

Figure 4. Models to study the first planning hypothesis (6) starting from the original plan (1).

Therefore, the old fortified village was chromatically inserted in its own natural contest. With Photoshop and Gimp, we analysed several pictures, using techniques that have permitted us to underline the predominant colours through a synthesis of pixel reducing image resolution, and therefore the number of pixels. By applying Photoshop's filter patchwork we splits the image into small squares filled with the predominant color in that area (figure 5). Most of these colours have been inserted in a diagram, together with the indications of RGB values of each one.

Starting from the synthetic three-dimensional model used previously, we have also studied the characteristics linked to the space and the perception of the lights and the shadows in the internal paths of the village.

With 3D Studio Max we rendered several images, both isometric views and eye-level perspective, placing the sun at three different time of the day: 9 am, 13 pm and 17 pm on the 1st and 15th day of each month. This analysis was used to understand whether and how the different paths were lit by the sun, and therefore where the darkest areas covered by the shadow cast by taller buildings would be (figure 6).

Together with the renderings, we also used another approach: the explorations in "real time", with the use of technologies for videogames. For these analyses we chose Unreal Engine 2 Runtime, a version of Unreal Engine 2 (used for videogames such as UT2003), which is free for educational purposes. This version is not the latest (Unreal Engine 3) but was chosen because it was sufficient for our analysis and it was faster to run on the computer used for the study, an Athlon 3800+, with 1MB of RAM and an NVIDIA GeForce 6600 256MB of RAM.

Figure 5. The analysis of the pictures used to underline the predominant colours through a synthesis of pixel.

The synthetic 3D model was reconstructed in the UnrealEd (The Game editor); in this way, thanks to the game engine, it was possible to do a few "virtual walks" inside the various paths of the village, using a eye-level perspective. Because it is impossible to walk on the real streets of the village, this experience is the only possible way to obtain a movement close to reality, using an inexpensive solution.

By using this technology it was possible to appreciate the usefulness of the "profferli", which are semicircular steps that permit the entrance to the houses from every direction. Unlike the standard steps, the "profferli" help to make the perception of the spaces more dynamic, reducing the sense of uniformity of the volumetry of the buildings.

6. Conclusions and future developments

The research presented in this paper had the following objectives: the development of a method, the choice and the application of the appropriate technologies to study an ancient medieval village (damaged by a tragic and exceptional event), in order to identify the most interesting memories that should be preserved in a new project.

In this paper, we propose an experimental working method that could be used in other places around the world. Moreover, this is an approach that uses affordable instruments, supported by a theoretical multidisciplinary basis. The opportunities offered by the concepts and the instruments of videogames, for

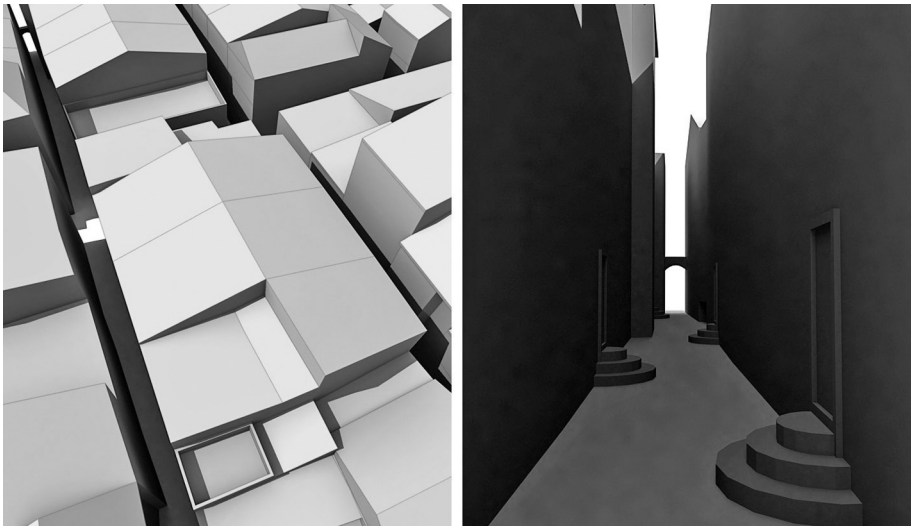

Figure 6. Study of the lights and shadows in the paths . Right: A virtual walk inside a secondary path characterised by the "profferli".

instance, offer new perspectives to the research field. A new planned research is centered on the use of these technologies, to deepen narrative and spatial aspects of architecture, which are impossible to be elaborated just with static representations that freeze an instant in time.

These analyses have permitted to gain a deeper understanding of the fortified village of Castelnuovo and to study the perceptive aspects linked to the atmosphere. The information gathered could be elaborated and enriched under the most appropriate aspects, in order to provide the basis for new research.

This study could also represent a starting point for the creation of a storytelling through a virtual and interactive exploration of the village, for educational-cultural aims.

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References

Al-Qawasmi, J., Chiuini, M., El Hakim, S. (eds.): 2008, DMACH 2008: digital media and its applications in cultural heritage, *International conference proceedings of the Center of the Study of Architecture in the Arab Region (CSAAR),* Amman, Jordan, 5–6 November 2008.

Borrelli, G., Carrabba, P., Di Giovanni, B., Padovani, L. M. , Palma, R.: 2007, Politica locale e biodiversità. <http://www.enea.it/produzione_scientifica/pdf_volumi /V07_01PoliticaLocaleBiodiversita.pdf> (accessed on 30 July, 2009).

Busby, J., Parrish, Z., Van Eenwick, J.: 2004, *Mastering unreal technology: the art of level design,* Sams Publishing, Indianapolis, Indiana, USA.

Di Mascio, D.: 2009, Digital reconstruction and analysis of Turchinio's Trabocco: a method of digital reconstruction of a complex structure as a way to improve our knowledge of a cultural heritage artifact, *Digitizing architecture: formalization and content, 4th international conference proceedings of the Arab society for computer-aided architectural design (ASCAAD 2009),* Manama, Kingdom of Bahrain, 11–12 May 2009, 177–189.

Forlani, M. C. (ed.).: 2009, *L'università per il terremoto,* Alinea editrice, Firenze, Italy.

Norberg-Schulz, C.:1986, *Genius loci: paesaggio ambiente architettura*, Electa, Milano, Italy.

Ricci, G.: 2006, *Itinerari narrativi tra realtà e simulazione,* Liguori Editore, Napoli, Italy.

Schmitt, G.: 1998, *Information architecture, basi e futuro del CAAD,* testo&immagine, Torino, Italy.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010*, 93–102. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

INTERPRETING DIGITAL HERITAGE

Considering the end user's perspective

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Abstract. Present virtual heritage projects are mostly focused either on 'process' or 'product' but rarely consider 'user' (end user's perception of the content) with project contents predominantly developed with an 'ocular-centric' tendency. There is no significant interpretation method or principles for interpreting digital heritage unlike other disciplines such as archaeology. This paper argues that, for better interpretation and experience of a digital heritage site, a comprehensive interpretation method is required, which should address multicultural background of end-users and overcome the linearity and subjectiveness in content creation. This paper also argues that instead of pre-determined instructional sequences or descriptive interpretation, the interaction setting can be participatory and contributive, where the visitor and environment may interplay mutually with each other. As a methodology, 'Interpretation' is first conceptualized by assimilating definitions from heritage scholars and organizations. Notions of interpretation-practice and level of interaction were identified from reviewing some online digital heritage projects. By identifying weaknesses, this paper finally proposes a few suggestions for overcoming and possibly developing a comprehensive interpretation method for future digital heritage projects.

Keywords. Heritage interpretation; end user; digital heritage.

1. Introduction

'Heritage' is a broad term that refers to the study of human activity not only through the recovery of remains (as in archaeology), but also through tradition, art and cultural evidences and narratives. It is a process of engagement

(Smith, 2006) rather than a condition; "it is a medium of communication, a means of transmission of ideas and values and a knowledge that includes the material, the intangible and the virtual" (Graham, 2002). On the other hand *'digital heritage'* UNESCO (2003) refers to unique resources of human knowledge and expression "created digitally or converted into digital-form from existing analogue resources". Whereas, 'Virtual heritage' (VH) is commonly used to describe works that deal with virtual-reality (VR) and cultural-heritage (Roussou, 2002). So far digital heritage has three major domains, i.e., *documentation*, *representation* and *dissemination* (Addison, 2000) and one of its major objectives is to disseminate knowledge of history and culture to general people (Tost and Champion, 2007).

2. End user's perception

Built heritage is not just about 'tangibility or materiality,' but comprises cultural and socio-spatial attributes related to built environment. To understand the inherent significance of a culture heritage site, mere watching or navigating through 3D virtual model is inadequate. As digital heritage deals with cultural artefacts, demographic differences always influence users' value judgment. What we see our concept-oriented brain tells us about it, not only through our eyes but also our previous experiences filter the perceived meaning (Preece et al., 1993). Therefore, experience and interpretation of prehistoric artefacts and landscapes largely depends on our own embodiment, subjectiveness and cultural positioning (Thomas, 2004). Hence, content without relating directly to how we perceive the world does not impart any meaning; rather it causes 'heritage dissonance' or 'disinheritance' (Tunbridge and Ashworth, 1996).

Yet in most cases, digital heritage projects are developed as an afterthought of some research or to demonstrate new technology (Gillings, 2000) and contents are often built in a 'descriptive' manner rather than 'interpretive' (Affleck and Kvan, 2008). Tan and Rahaman (2009) claimed that present digital heritage or VH projects are mostly focused either on *'process'* (authentication of data, site survey to epigraphy) or *'product'* (closer to reality and technical artistry) but do not necessarily consider *'user'* (end user's perception of the content). As a consequence, 'interpretation' has always been understood as a linear process, "a single and universal viewpoint about the past" (Thornton, 2007) supposing everyone should learn and understand similarly. But in reality everyone's thought and reaction to action and situation are unique and it is not possible to reproduce events exactly as 'actual' in any sense (Kaptelinin, 2006). So, digital heritage should address the 'cultural uniqueness' of end-users and overcome the linearity and allow multiplicity in interpretation.

3. Heritage interpretation in archaeology

In archaeology, *interpretation* has always been seen as an effective learning, communicating and management tool that increase visitors' awareness and empathy to the site and artefacts. Tilden (1977) defined *interpretation* as "an educational activity which aims to reveal meanings and relationship through the use of original objects by *firsthand experience* and by illustrative media, rather than simply to communicate factual information." Therefore "the chief aim of interpretation is not instruction but provocation." However, generally *interpretation* is often used to indicate the storylines, adopted to help visitors to engage with and understand the place or objects. According to ICOMOS's mission statement, *'Presentation'* denotes the carefully planned arrangement of information and physical access to a cultural heritage site. As such it is largely a one-way mode of communication. *'Interpretation'* on the other hand, refers to the full range of potential activities intended to heighten public awareness and enhance understanding of cultural heritage site (ICOMOS, 2007).

A compilation of definitions of 'heritage interpretation' from diverse authors and institutes have been presented in table 1. Notions presented in this table elucidate that archaeological '*interpretation*' has always been considered as a method or tool of presentation or communication with visitors for (i) *learning* (conveying symbolic meaning), (ii) *provocation* (facilitating attitudinal or behavioural change) and (iii) *satisfaction* (enhancing enjoyment of the place). Regarding archaeological interpretation, these considerations actually refer to a passive mindset of 'experts'; here archaeologists have always been considered as the interpreters of past and present, whereas visitors are treated as consumers with petty knowledge "to make sense of the information" (Moscardo, 1999). Heritage is not a concrete object; meaning evolves and is updated by subsequent generations, e.g., in relation to the interpretation of 'scriptures'. *The Oxford advanced learner's dictionary* (2009) defines interpretation as "the particular way in which it is understood or explained." This definition points to an inherent duality underlying the terms. 'Explained' indicates 'presentation' or 'communication' factor (Moscardo, 1999), i.e., more as an act of the interpreter or interactive interface; while by 'understood' indicates self-interpretation or self-learning, or rather as a reflexive phenomenon. In this, the understanding of interpretation may differ between archaeology and hermeneutics. Interpretation can also be seen as a reflexive process; instead of considering it as a medium of communication with passive audience. The process of interpretation should be dialectic and hermeneutic to empower social groups to tell their own stories (Hodder, 1991). In this way interpretation can allow more flexibility in the process and portrayal of

multiple viewpoints of the past, which is often absent in many digital heritage projects.

Table 1. Definition of heritage interpretation.

Affiliation		Definition of Interpretation
Heritage Scholars	Uzzell (1994)	Interpretation is that it opens a window on the past.
	Harrison (1994)	The art of presenting the story of a site to an identified audience in a stimulating, *informative* and *entertaining* way to highlight the importance and *provoke* a sense of place
	Beck and Cable (1998)	Interpretation is an educational activity that aims to *reveal meanings* about our cultural and natural resources.
	Moscardo (1999)	Interpretation is a special kind of communication
	Howard (2003)	Interpretation is deciding what to say about heritage and how and to whom.
	Goodchild (2007)	Interpretation is, in fact, only one aspect of the broader topics of '*Presentation*', 'Supplementary *Education*' and 'Visitor *Satisfaction*'.
Interpretation Associations/Authorities	Interpretation Association Australia	Interpretation is a means of communicating ideas and feelings which help people enrich their *understanding* and *appreciation* of their world, and their role within it. (source: http://www.interpretationaustralia.asn.au)
	The National Association for Interpretation, USA	Interpretation is a mission-based *communication process* that forges emotional and intellectual connections between the interests of the audience and the meanings inherent in the resource. (source: http://www.interpnet.com/)
	The Association for Heritage Interpretation, UK	Interpretation is the process of communicating messages and stories about our cultural and natural heritage, providing the audience with *inspiration* and a wider *understanding* of our environment. Or quite simply, interpretation is about telling stories. (source: http://www.ahi.org.uk/www/)
	ICOMOS Ename Charter (2007)	Interpretation refers to the full range of potential activities intended to heighten *public awareness* and enhance understanding of cultural heritage site.
	ICOMOS Charleston declaration (2005)	Interpretation denotes the totality of activity, reflection, research and creativity stimulated by a cultural heritage site.

4. Survey of some online digital heritage projects

Digital heritage (or especially virtual heritage) is an active area of research throughout the last decade. With the advancement of technology, digital heritage projects have enhanced their capability from linear limited interactivity to non-linear immersive environment. Due to cheaper computer hardware and the growth of World Wide Web, present trends in virtual reality applications are motivated towards the use of immersive technology for real-time interaction with high detail.

Table 2 presents a short list of projects regarding various technologies used as a media to interpret digital heritage. This study reveals that early projects

were typically focused on 'faithful' representation and visual realism; thus most of them were static, descriptive and inflexible for further interpretation. Even though the problem of large file size and free movement inside the virtual world were solved though VRML and gaming software, interaction as the core of embodiment largely remained limited in terms of exploration and manipulation. Descriptive nature of interpretation was dominant in most projects. Nevertheless, a few recent cases demonstrate the possibilities of heritage-interpretation through shared annotation-basis like 'wiki'; such as 'Memory Capsule' (Affleck, 2008) and 'Digital Storytelling' (BBC, 2009). These projects indicate new frontier in interpretation while opening up possibilities of creating multi-vocal, shared and heterogeneous perspective of past through active participation by end-users.

Table 2. Survey of online examples.

Adopted technology	**Examples**	**Interaction level**		
Multimedia based	- ArchiWAIS (Choi, 1992)	■		
HTML + Apples Hyper Card Data Base System or Quick Time	- Columbia University History of Architecture - The Chang'an project (2006)	■		
VRML	- The Glasgow Model (Ennis and Maver, 1999)	■		
Game Engine	- Palenque Project (2003) - Virtual Notre Dame Project (Moltenbrey, 2001)	■	▲	
Location-based Augmented Reality System	- Ename974 (2000)	■		
Portable augmented Reality System	- LifePlus (2005) - Archeoguide (2001)	■		
Immersive virtual reality system	- CREATE (2003)	■	▲	
Stereoscopic 3D projection	- Place-Hampi (2006)	■		
Multi user virtual environments (MUVEs)	- The Forbidden City: Beyond Space and Time (2008)	■	▲	
Web 2.0	- Memory capsules (Affleck and Kvan, 2008) - Moving Here (2005)	■	▲	●

Legend: ■ = Exploration, ▲= Manipulation, ● = Contribution

5. Points to ponder on present limitations

Present days digital heritage scholars and professionals are trying to enhance heritage interpretation through different approaches, such as (i) *Hermeneutic environment* though game-style interaction (Champion, 2003; Champion and Dave, 2002) (ii) *Embodied interaction* through somatic impulse (Flynn, 2008) or haptic devices (Roussou, 2008) (iii) *Multiple user virtual environment* (MUVEs) with dynamic content (e.g. 2nd life, virtual Forbidden City) (iv) *Greater immersion* through augmented stereographic panoramas (Kend-

erdine, 2008) or immersive displays (Tan, 2007). Still some limitations are quite evident and hindering the process of achieving a comprehensive interpretation method for digital heritage can be defined hereafter.

(i) Historic knowledge and subjectivity. The knowledge of 'past' is limited because it is always a selection of events and not 'complete.' To paraphrase Lowenthal (1985), every time we make a new statement about an artefact or an event, we make a new interpretation and then something new is born, different from the original. In that sense, the past is thus a cultural construction; it is more aesthetic, intuitive and subjective (Huizinga, 1998). Similarly digital heritage cannot also avoid the charges of subjectivity as heritage objects are mostly reconstructed out of long-lost ruins. Again, media experts (e.g., modellers, animators, programmers) who remain involved in reconstruction processes may not be aware of the intrinsic cultural values of particular artefact or environment although having a myriad of technical know-how. This way, the 'apparent' cultural preservationists and their implemented methods may well reflect their personal 'inappropriate' assumptions that Kalay (2008) referred as *'image of practice.'* A comprehensive understanding and reconstruction of past history is only possible when the interpretation framework will allow multiplicity. Perhaps a collective interpretation of the past may overcome this subjective and linear viewpoint.

(ii) Linear process of content development. According to Fitch (1982), interpretation constitutes two levels, 'Professional' and 'Popular'. The first is carried out from available evidences (excavations, ruins, artefacts, documents) as professionals (archaeologists, historians and architects) examine and verify for authenticity, and document them to feed interpretation for public. Public is only imparted information in second level, described as 'popular' level (figure 1); where limited or no scope remains for 'firsthand experience'. From case studies (table 2), it is evident that digital heritage projects followed the notion of archaeological interpretation (i.e., professionals interpret and visitors consume), even though digital media possess capability of developing

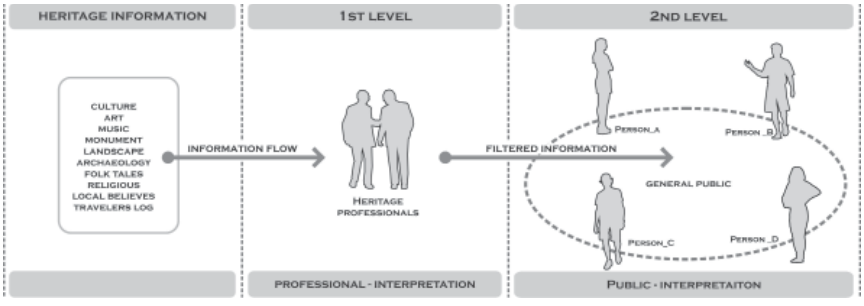

Figure 1. Fitch's model of interpretation

dynamic polysemic content by allowing active participation in content creation, development and dissemination.

(iii) Missing the potentials of collective cultural memory. The main objective of UNESCO's convention in Paris 2003 was to safeguard the intangible cultural heritage (UNESCO, 2003). Intangible cultural heritage such as oral traditions, knowledge and practice concerning nature and beliefs – transmits between generations and hence provide a sense of belonging, identity and community. Present digital heritage projects however, miss the potential of cultural transference and value placed on collective cultural memory; which could easily be supported by allowing a platform for dialogic interactivity and further capturing those to a knowledgebase. Undoubtedly the 'insiders' or the natives value their heritage (tangible or intangible) differently while showing more concerns, when compared with the reflections of outside experts.

6. Approaching the problem

Referring to section 3, 'interpretation' should ensure three aspects, i.e., (i) *learning,* (ii) *provocation* and (iii) *satisfaction*. As digital heritage has the potentials of 'dialogic interactivity' and multiplicity in content creation, we suggest the interpretation framework should also consider 'polysemic' viewpoint of past. *'Popular participation'* in the interpretation process as reflexive embodied interaction may overcome the linearity and subjectiveness of

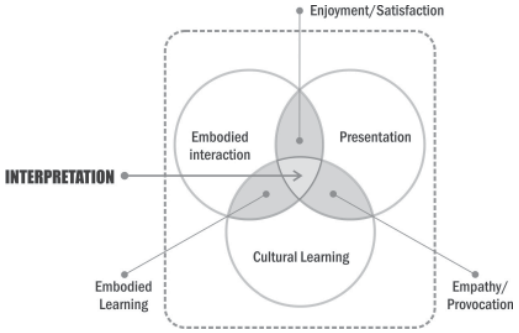

Figure 2. Proposed conceptual model for interpreting digital heritage

the past reconstruction, hence will enhance interpretation. For comprehensive interpretation of digital heritage, the process must consider three issues (figure 2), i.e., (i) embodied interaction, (ii) learning of culture and (iii) an effective presentation (Moscardo, 1999).

(i) Embodied interaction. According to Dourish (2001) *embodiment* is the property of our engagement with the world that allows us to make it meaningful and *embodied interaction* is the creation, manipulation and sharing

of meaning through engaged interaction with artefacts. Embodiment plays a key role of designing interaction as user's response to the environment; their engagement and understanding of the space and enjoyment depends on it. Allowing end-users to contribute or create content and share with others can enhance the interaction process. While through practical action, task accomplishment and getting feedback from the interface will allow greater embodiment.

(ii) Cultural learning. In most cases 3D environments are typically reproductions or reconstructions of archaeological sites or monuments. So it is important to know how a digital object can express cultural value and how that value is perceived by the viewer. From cognitive science perspective, our learning occurs through a reticular way rather than a linear pattern (Bateson, 2000). Referring to 'ecological approach,' Bonini (2008) explains 'learning' as a process that starts through perception and interpretation of the differences between the ecosystem and us. The feedback process simulates continuous and various levels of perceptive and cognitive interaction, as information transforms into knowledge. Hence, the interface should allow user to establish *'some relationship'* with the context and at the same time should have the *'feedback'* ability to satisfy viewers query. Champion and Dave's (2002) suggested cultural agency, personalisation of artefacts and role-play to ensure personal relationship with the context and having feedback from the environment or other participants.

(iii) Effective presentation. Tilden (1977) suggested a set of six principles for an 'effective or correctly directed' interpretation practice. Later different heritage professionals and scholars such as Richard Harrison (1994), Beck and Cable (1998), Moscardo (1999) and Copeland (2006) proposed their own principles which are actually an elaboration and clarification of Tilden's principles. These interpretation principles, developed initially for archaeology may also work as a good source for developing possible guidelines for presentation and communication for digital heritage.

7. Conclusion

This paper has set out to investigate the importance of end user's perception of digital heritage. It has argued that in order to minimise heritage dissonance and enhance understanding of inherent significance of cultural heritage, we need to consider 'end user' as a multicultural phenomenon. That is to identify how heritage interpretation can be considered as a continuous process and at the same time how to ensure multiplicity in understanding the past. This paper has pointed out some limitations of assuming a straightforward method for interpreting and transferring heritage knowledge in present practice. It argues

that meaning making is a dynamic process. Meaning emerges while being contextualised, from some kind of reflection of being involved and through action. This paper also suggests that past is culturally constructed, as well as should be reconstructed in a pluralistic manner, thus considering multicultural background of users and at the same time overcoming its present linearity and 'professional image'. Eventually, the paper proposes some suggestions for developing a framework for comprehensive interpretation of digital heritage. It outlines how the user as an active participant in content creation (i.e., in the process of knowledge formation) and how dialogic interactivity may leverage multiplicity in viewing the past cultural heritage. Overall, the paper raises a larger question rather than provide any specific answer. Developing a comprehensive interpretation method for digital heritage requires further theoretical development and attention through tailoring of methods of practice and prototype development.

References

Addison, A. C.:2000, Emerging trends in virtual heritage, *IEEE Multimedia,* **7,** 22–25.

Affleck, J. & Kvan, T.:2008, Memory capsules: discursive interpretation for cultural heritage through new media *in* Y. E. Kalay, T. Kvan, and J. Affleck (eds.), *New heritage: new media and cultural heritage,* Routledge, New York.

Archeoguide: 2009, available from: Open Source Repository <http://archeoguide.intranet.gr/project.htm> (accessed 10 April 2009).

Bateson, G.:2000, *Steps to an ecology of mind,* University of Chicago Press, Chicago.

BBC: 2009, Digital storytelling, available from: Open Source Repository <http://www.bbc.co.uk/ wales/audiovideo/sites/ galleries/pages/digitalstorytelling.shtml> (accessed 24 October 2009).

Beck, L. and Cable, T.: 1998, *Interpretation for the 21st century*, Sagamore Publishing, Champaign, Ill.

Tan, B. K.:2007, Virtual Bawa: unbuilt masterpieces of Geoffrey Bawa, CASA, National University of Singapore.

Beng-Kiang, T. and Rahaman, H.: 2009, Virtual heritage: reality and criticism, *CAADfutures 2009: joining languages, cultures and visions.* Montreal, Canada.

Bonini, E.: 2008, Building virtual cultural heritage environments: the embodied mind at the core of the learning processes. *International journal of digital culture and electronic tourism,* **1**, 113–125.

Champion, E.: 2003, Applying game design theory to virtual heritage environments, *Annual Conference, Graphite,* Melbourne, ACM, New York.

Champion, E. and Dave, B.: 2002, Where is this place? *22st annual conference ACADIA 2002: thresholds between physical and virtual.* 24–27 October 2002, Cal Poly Pomona.

Choi, J.: 1992, Archiwais: a multimedia-based architectural information system for teaching and learning architectural history and theory, *Reconnecting: ACADIA 94,* 161.

Copeland, T.: 2006, Constructing pasts: interpreting the historic environment, *in* A. Hems and M. R. Blockley (eds.), *Heritage interpretation,* Routledge, London.

Columbia University History of Architecture: 2009, available from: Open Source Repository <http://www.mcah.columbia.edu/ha/> (accessed date: 03 November 2009).

CREATE: 2009, available from: Open Source Repository <http://www.cs.ucl.ac.uk/research/vr/Projects/Create/> (accessed 10 April 2009).

Dourish, P.: 2001, *Where the action is: the foundations of embodied interaction,* MIT Press, Cambridge, Mass.

Ennis, G. and Maver, T.: 1999, Visit VR Glasgow, *ECAADE 1999: Education for Computer-Aided Architectural Design in Europe.*

Ename974: 2009, available from: Open Source Repository <http://www.ename974.org/Eng/ pagina/archeo_concept.html> (accessed 10 April 2009).

Fitch, J. M.: 1982, *Historic preservation: curatorial management of the built world,* McGraw-Hill, New York.

Flynn, B.: 2008, Augmented visualisation: designing experience for an interpretative cultural heritage, *12th international*

conference on information visualisation.
Gillings, M.: 2000, Plans, elevations and virtual worlds: the development of techniques for the routine construction of hyperreal simulations. *BAR international series,* 843, 59–70.
Goodchild, P.: 2007, Interpreting landscape heritage, International symposium 2007 on "Interpretation: from monument to Living Heritage" and 2nd ICOMOS Thailand General Assembly, Bangkok, Thailand.
Graham, B.: 2002, Heritage as knowledge: capital or culture? *Urban studies,* **39**, 1003–1017.
Harrison, R.: 1994, *Manual of heritage management,* Butterworth-Heinemann, Oxford.
Hodder, I.: 1991, Interpretive archaeology and its role, *American antiquity,* **56**, 7–18.
Howard, P.: 2006, Editorial: Valediction and reflection, *International journal of heritage studies,* **12**, 483–488.
Huizinga, J.: 1998, *Homo ludens: a study of the play-element in culture*, Routledge.
ICOMOS: 2007, The Icomos charter for the interpretation and presentation of cultural heritage sites, *Proposed final draft.*
Kalay, Y. E.: 2008, Preserving cultural heritage through digital media, *in* Y. E. Kalay, T. Kvan and J. Affleck (eds.), *New heritage: new media and cultural heritage,* Routledge, New York.
Kaptelinin, V. and Nardi, B. A.: 2006, Do we need theory in interaction design? *in* B. Nardi, V. Kaptelinin and K. Foot (eds.), *Acting with technology: activity theory and interaction design,* MIT Press, Cambridge, Mass.
Kenderdine, S., Shaw, J., Favero, D. D. and Brown, N.: 2008, Place-Hampi, *in* Y. E. Kalay, T. Kvan and J. Affleck (eds.), *New heritage: new media and cultural heritage,* Routledge-Taylor and Francis Group, London.
LifePlus: 2009, available from: Open Source Repository http://lifeplus.miralab.unige.ch/ (accessed 10 April 2009).
Lowenthal, D.: 1985, *The past is a foreign country,* Cambridge University Press, Cambridge.
Moltenbrey, K.: 2001, Preserving the past, *Computer graphics world.*
Mosaker, L.: 2001, Visualising historical knowledge using virtual reality technology, *Digital creativity,* **12**, 15–25.
Moscardo, G.: 1999, *Making visitors mindful: principles for creating quality sustainable visitor experiences through effective communication,* Sagamore Publishing, Champaign, Illinois.
Moving Here: 2005, available from: Open Source Repositor <http://www.movinghere.org.uk> (accessed 23 January 2010).
Palenque Project: 2003, available from: Open Source Repository <http://nzerik.googlepages.com/palenqueproject> (accessed 10 April 2009).
Place-Hampi: 2009, available from: Open Source Repository www.place-hampi.museum (accessed 10 April 2009).
Preece, J., Benyon, D., Davies, G., Keller, L. and Rogers, Y. (eds.): 1993, *A guide to usability: human factors in computing,* Addison-Wesley, Wokingham, England.
Press, O. U.: 2009, Advanced learner's dictionary online, available from:Open Source Repository <http://www.oup.com/oald-bin/web_getald7index1a.pl> (accessed 31.09.2009).
Roussou, M.: 2002, Virtual heritage: from the research lab to the broad public, *Virtual archaeology,* 93–100.
Roussou, M.: 2008, The components of engagement in virtual heritage environments, *in* Y. E. Kalay, T. Kvan and J. Affleck (eds.), *New heritage: new media and cultural heritage,* Routledge-Taylor and Francis Group, London.
Smith, L.: 2006, *Uses of heritage,* Routledge, London.
The Chang'an project: 2009, available from: Open Source Repository <http://www.arch.nus.edu.sg/casa/projects/hck_changan/pages/Content.htm> (accessed 03 November 2009).
The Forbidden City: beyond space and time: 2009, available from: Open Source Repository <www.beyondspaceandtime.org> (accessed 01 November 2009).
Thomas, J.: 2004, The great dark book: archaeology, experience, and interpretation, *in* T. Earle and C. S. Peebles (eds.), *A companion to archaeology,* Blackwell Publishing.
Thornton, M.: 2007, Think outside the square you live in: issues of difference and nation in virtual heritage, *Proceedings of 13th international conference on virtual system and multimedia (VSMM 2007), 23–26 Sept. 2007,* Brisbane.
Tilden, F.: 1977, *Interpreting our heritage,* University of North Carolina Press.
Tost, L. P. and Champion, E. M.: 2007, A critical examination of presence applied to cultural heritage, *The 10th annual international workshop on presence,* Barcelona, Spain, 25–27 October 2007.
Tunbridge, J. E. and Ashworth, G. J.: 1996, *Dissonant heritage: the management of the past as a resource in conflict,* John Wiley and Sons, Chichester.
UNESCO: 2003, Charter on the preservation of the digital heritage, *32nd session: the general conference of the United Nations Educational, Scientific and Cultural Organization,* UNESCO, Paris.
UNESCO: 2003, Convention for the safeguarding of the intangible cultural heritage, *32nd session: the general conference of the United Nations Educational, Scientific and Cultural Organization,* UNESCO, Paris.
Uzzell, D.: 1989, *Heritage interpretation,* Belhaven Press, London.

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PLACE AND PLACELESSNESS IN 3D ONLINE VIRTUAL WORLD

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Abstract. This paper examines the issue of place-making in 3D virtual world from the design point of view. It aims to find out what are the elements to create a sense of place. As Second Life currently has the largest users among 3D virtual worlds, it is selected as a study case. The methodology consists of theoretical studies and ethnographic observation. Firstly, literature review of theories regarding place-making in the physical world and the virtual world were done. From that a framework was formulated as a common basis for ethnographic observations and interviews at three real world public spaces and four locations in Second Life. This paper presents findings from the latter. The focus areas are physical settings, activities and experience of users. The observations are discussed and criteria for place-making in multiuser 3D online virtual environments are proposed. This paper will contribute to the understanding of how to design a place rather than space in 3D online virtual world.

Keywords. 3D virtual world; Second Life; place-making; multiuser online virtual environment.

1. Introduction

With Internet bandwidth becoming better and more affordable, coupled with rapid advancement in web technology, multiuser online 3D virtual environments have become a reality and are proliferating. Activeworlds (started in

1997), Second Life (launched in 2003), and more recently Twinity (launched in 2008) are some of them. These worlds are different from online sites such as World of Warcraft in that they are not for gaming. In Second Life users known as "residents" socialise, participate in individual and group activities, create and trade virtual property and services with one another, or travel together in a 3D virtual world. They socialise in public spaces just as in the real world. Successful public spaces are those that have a sense of place. A place is different from a space – a place is a space with experiences based on its physical setting and type of activities carried out (Relph, 1986). Much has been written about place-making in the physical world. However, little has been written about what makes a sense of place in virtual environment such as Second Life. Currently, many 3D virtual spaces do not offer a sense of belonging to its users. They are merely spaces stripped of any cultural context. As architects, we know how to design good public places in the real world but how do we do that in the virtual world? Are all the design principles for the real world applicable? What attracts frequent visitors to one virtual location than another?

To answer these questions, the method of study is as follows. We reviewed literature in place-making for real worlds and virtual worlds (Jacobs 1961; Canter, 1977; Relph, 1986, 2007; Kalay and Marx, 2001, 2003; Champion and Dave, 2002) and came up with an observation framework to be used at three locations in real-world public space and four locations of public space in Second Life. Much inspired by the seminal study of urban space by Whyte (1980), time-lapse photography was used to record activities in the real world spaces. During virtual world observations, screen shots were captured, notes were taken, and text log saved. In-world avatars were also interviewed. This paper presents only the virtual world studies due to space constraint. The four virtual locations were analysed using the cyber-placemaking criteria proposed by Kalay and Marx. The analysis highlights new criteria relevant to virtual worlds and presented in section 5.

2. Place-making

In their paper, "Re-place-ing space: the roles of place and space in collaborative systems," Harrison and Dourish (1996) stated that "Space is the opportunity; place is the understood reality." They explained how a space is a three-dimensional room that guides and moulds our actions and interactions while a place is understood as the concept behind the actions of the people in a space, guided by the cultural understanding of society, which altogether gives meaning to a space.

2.1. PLACE-MAKING IN PHYSICAL WORLD

The physical world such as a city, compared to the virtual world is better endowed in terms of structure and spatial organisation as urban planners have already laid down the basic guidelines for architects and developers to follow. Most of the studies linked to the issue of place-making, are centred on real life observations and as such do not provide incisive details on how to create place in the virtual world. Edward Relph (1986) and David Canter (1977) both worked on the concept of place-making in the physical world (figure 1). Though their methodologies differ slightly from each other, they have similar theories regarding three interrelated components in the physical world. They are physical settings, activities and experiences.

2.2. PLACE-MAKING IN VIRTUAL WORLD

Kalay and Marx (2001, 2003) discussed place-making in the virtual world by providing criteria necessary to create a place in cyberspace. In their paper "Designing places in cyberspace" (2001) they proposed eight criteria for cyber-placemaking. They are: (i) events, (ii) presence, (iii) relative locations, (iv) authenticity, (v) adaptability, (vi) variety of experiences, (vii) transitions, and (viii) memorable.

The eight criteria form a useful guideline in creating virtual places. However, they are adapted from physical place-making in urban planning and architecture and postulated to work in virtual environments. Champion and Dave (2002) commented that while helpful, they do not point to what features are most important, necessary or desired for virtual environments. Moreover, it was proposed before the birth of 3D multiuser virtual worlds such as SL and before features made possible by advanced game engines. In this paper, we want to verify if the criteria are relevant for SL environments.

3. Observation framework

Based on the literature reviews of place-making in physical world, table 1 was formulated to guide ethnographic observations in each case study. It is an expansion of the three components of physical settings, activities and cultural experience. *Theme* is similar to Relph's description of place settings where he mentioned that physical layout of the site is crucial when discussing physi-

David Canter (1977)	**Edward Relph (1986)**
Form	Physical settings
Function	Set of activities
Concept	Cultural values

Figure 1. The three components necessary for place-making defined by Relph and Canter.

cal settings, activities and cultural meanings. *Elements* describe any physical and visual activities or objects present. The items in the table vary depending on the location that is observed. A description of the avatars' *activities* is recorded, as it might have an influence on their behaviours and attitudes. It is broken into two parts: (i) *Fun and play* (promoting interaction through physical contacts with objects) and (ii) *interaction* (emergence of interaction through activities). *Adaptability* refers to the flexibility of the physical objects or of the activities to the site. Additional information such as time, scale, experience and social patterns were also recorded.

Table 1. An example of observational table for ethnographic studies.

Themes	**Element**	**Activities**	**Adapt-ability**	**Observation of activities by hour**		
				10–11am	11–12pm	Etc.
Physical Objects	Low walls Benches Fountain etc.	Interactive Interactive Fun and Play	No Yes No			
Etc…	…	…	…			

4. Second Life (SL) case studies

SL has 18 million accounts as of January 2010, and for the first quarter of 2009, there were 88,200 peak concurrent users (Second Life Economy). As it has the most users among similar 3D virtual worlds, it was selected for research. The criteria for the selection of case studies in SL were based on (i) the popularity of the places, (ii) the events and activities present and (iii) the spatial layout of the virtual locations. Since the real world public spaces studied were in Singapore, for consistency in terms of context and culture when comparing real world and virtual public space, three locations in SL used by Singapore residents were chosen. The final SL locations selected are: (i) Moonwater Isle, Kaki Island (77, 30, 35) (ii) Watersoul Lounge, Kaki Island (iii) Bear Dream Lodge Infohub (27, 128, 111) and (iv) Shiki Centre (100, 97, 38). The case studies are discussed below under the three components of (a) *physical settings,* (b) *activities,* (c) *experience.*

4.1. MOONWATER ISLE

Moonwater Isle provided an understanding of the relationship between space, objects and avatars. It is one of the popular destinations in SL for avatars who are Singapore residents. Its simple physical layout provided a minimal setting for small gatherings, with mainly seats and a few interactive objects. Moonwater constantly changes its design layout. The swift reconfiguration of

objects and spaces in the virtual world can arouse the curiosity and interest of avatars. These changes are important in maintaining a longer lifespan for the virtual places via a constant participation level. Through daily participation among the avatars, we observed how they responded and reacted with the objects and context. The outdoor space was designed to encourage interactions around two major spots:

- **The tree** is an interactive feature, which allows a maximum of eight avatars to sit on it.
- **Central sitting area** that accommodates 15 avatars. Its proximity to the tree makes it a focal point during discussions.

Most, if not all the discussions took place around and on the tree. The layout was revamped once during the period of observation (figure 2). The tree was relocated to the centre next to the central sitting area, and several interactive objects were introduced for the participants to interact with. The avatars now gathered at the centre but some avatars used the seats next to the water edge due to the introduction of a new feature in the pavilion, i.e., three interactive jellyfish. Interactive objects provide amusement and entertainment but also help to establish contact among avatars; they act as the catalyst for socializing in SL.

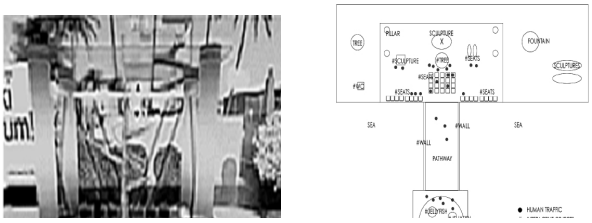

Figure 2. New layout of Moonwater Isle in August 2008 with tree in the centre. Plan on the right (source: Second Life).

Throughout the conversations and meetings with regular users of the space, we observed that some of their behaviour mirrored real life gestures. One significant event was the reaction of a female avatar to the sudden rain downpour on the island. Her first reaction was to remove her umbrella to protect herself and she complained about the weather soaking her clothes. This shows how avatars immerse themselves in the virtual environment and unconsciously react using real life gestures and behaviours. Another observation is the lack of direct "eye contact" between avatars. Avatars seldom "gaze" at each other during discussions as everything is done through typing text. Rapid texts can be frustrating at times and it becomes an obstacle to follow conversations without knowing who is talking to whom.

4.2. WATERSOUL LOUNGE

The indoor lounge was designed as a more formal meeting and entertainment area for businessmen willing to invest on advertising options on the island. The spatial layout is organised in a concentric geometry with numerous pose balls (blue and pink spherical objects embedded with scripts that make an avatar perform several movements) located at the centre, mainly on the dance stages with seats and sofas surrounding them. The pose balls generate Linden dollars, the currency used in Second Life.

The attractive space however does not attract as many avatars as it should. The middle portion of the space is reserved for dancers who are "camping," i.e., doing repetitive action at the same spot to earn money. The few avatars visiting the place are there solely to earn Linden dollars. Camping in SL is a new and strong culture. It provides a platform for avatars to interact but in this particular case study, little interaction is observed due to the lack of participants, which might be due to the location of the lounge, shallow and dark environment, enclosed area and poor promotions of the place. Moneymaking business is a major attraction for avatars in this case study thus it is not surprising to see avatars "working" in isolation rather than interacting, creating a sub-culture in SL.

4.3. BEAR DREAM LODGE

Bear Dream Lodge has a very specific function compared to the rest of the case studies. It creates opportunities for avatars to interact through the exchange of objects, mainly clothes and accessories. In comparison to Kaki Island, Bear Dream Lodge is a more open location, attracting many international avatars and not restricting itself to a specific context. The physical setting of the location is interesting in that very few features are provided – only two benches. Avatars tend to spend more time in the centre because it is spacious. Exchanging objects require a rather large area for them to deposit their 'boxes' and they need sufficient space to roam around. Interactive objects in the environment were hardly used by the visitors. This location is a favourite starting point among avatars once they logged on to SL. The main essence of this location is the sharing of ideas and objects and the success as a place is attributed to the people and activity rather than built form. The spatial layout constrains the activities of the avatars. Avatars are restricted to interact in the centre through simple discussions, which lowers the chance of creating new activities.

4.4. SHIKI CENTRE

The Shiki centre opened on 9 August 2008 at 9 pm SL time. For the occa-

sion, posters were placed in several SL locations, including Moonwater Isle, to create awareness among the SL community. The mall is owned by a group of avatars and it offers a wide range of objects, from clothes to simple tattoos. Just as in the real world, to mark the occasion, various activities including a treasure hunt, dating competitions and music concerts were organized to entertain and amuse the avatars before the official opening. The lounge design was relatively simple – a rectangular layout with a few sofas for the guests to relax and shelves that displayed numerous colourful boxes, accompanied by greeting texts and vocals from the host. Outside is a stage built for the upcoming events, including a SL rock band.

An interesting observation was the behaviour of the avatars during the opening ceremony at the lounge. Several avatars constantly clicked on colourful boxes that were meant for decorative purposes only, hoping to see something happen. This shows a high degree of interest for interactive objects in the virtual world and simultaneously the importance to familiarise with one's surroundings. Another interesting observation was that a group of avatars started discussing the possibility of a photo shoot for their online blog. The group then stood in position, with some changing their appearances (clothes and hairstyles) before the photo was taken. This shows that the avatars behave like in the real world. They care about the physical appearance of their virtual character when interacting with other avatars, just as they care about appearances in the real world.

5. Criteria for place-making in interactive virtual world

For the real world and SL case studies, we evaluated if each of the criteria proposed by Kalay and Marx's for "cyber-placemaking" is present or is relevant (table 2). 'o' indicates that it is absent from the case studies or not relevant. We have also expanded on Kalay and Marx's work and offer sub-criteria. Criteria 1 to 8 are from Kalay and Marx. From our observations of the SL case studies, we identified four additional criteria: context, gestures, improvisation and graphic representation.

5.1. EVENT AND MONETARY REWARDS

The most popular locations in SL are those that provide free stuff and free money through "camping." Camping in SL means an avatar doing an activity repeatedly such as sitting, dancing or standing at a location. They are paid Linden dollars by the owner of the location to create a buzz and "bodies" at the location in order to attract other visitors. This is a phenomenon unique to the virtual environment. In real world public space, it happens only occasion-

ally such as a product promotion with freebies given out at a public plaza. Boellstorff (2008) mentioned "Camping could serve as a social venue where participants can chat with each other, hence creating opportunities for interaction." Despite camping as a commercial and somewhat inappropriate activity, it plays a role in creating place in the virtual world.

TABLE 2. Criteria for evaluating real world and virtual world cases. Criteria 1 to 8 are from Kalay and Marx. Criteria 9 to 12 and sub-criteria are our additions.

No	Criteria	Sub-criteria*	Real world Case studies	Second Life Case Studies
1	Event	People	√	√
		Shopping	√	o
		Leisure	√	√
		Monetary rewards	o	√
2	Presence	Participatory level	√	√
		Human / avatar	√	√
3	Location		√	√
4	Authentic		√	√
5	Memorable		√	√
6	Experience	Social	√	√
		Cultural	√	√
7	Transition		√	o
8	Adaptability	Space	√	o
		Objects	√	o
9	*Context	Language	√	o
		Social	√	o
10	*Gestures	Human / avatar	√	√
11	*Improvisation		√	o
12	*Graphical representation	Visual delight	o	√
		Scale	√	√

5.2. TRANSITION

In the real world, e.g., in some Italian towns, there is a transition of spaces as one walks from a narrow alley before emerging into a public square. From our interviews in SL, 90% of interviewees do not explore places through walking even though they could do so in SL. They teleport or fly from location to location. There are no transition spaces designed between buildings / locations. We contend that the way to design transitions in virtual environments has to be different from in the real world. Designing forms in the sky and underwater in response to flying and swimming is a way to create a different experience from the real world that adds to sense of place.

5.3. ADAPTABILITY (SPACE AND OBJECTS)

Being able to shape and personalize a space is important in place-making. However, it is restrictive in the case studies seen. An avatar could not change her / his virtual space or modify a seat to make it longer or move it to a particular location in the public space. In the virtual world it is possible to allow personal modifications of worlds to improve sense of place. We also observed that 3D interactive objects are essential in the virtual environment to enrich the experience. It enhances interaction among the avatars (e.g. the jellyfish and tree described in 4.1). The 3D objects should change regularly to avoid loss of interest by visitors. However, a location with just an interactive object and one avatar is meaningless. It needs presence of other avatars (or people) to make it meaningful.

5.4. CONTEXT

By context we mean the cultural background of the group of users gathered at a location and the language of communication. The degree of participation as mentioned by Kalay and Marx is fundamental to create a sense of place. Participation is dependent on a common language and common interest in topics discussed. In Moonwater Isle, the group of users, mainly Singapore residents, gather there everyday to discuss local and SL issues. The fact that they understand "Singlish," a mixture of English and Chinese language makes it easier for them to interact with each other. In contrast, a location such as Bear Dream Lodge open to international visitors has few visitors and interactions happen only among avatars who "speak" the same language. In virtual world, it is possible to bridge language barriers if automatic language (voice or text) translations can be provided. A virtual place could be a place where there is no language barrier, e.g., a German-speaking avatar can be conversing seamlessly with a Chinese-speaking avatar.

5.5. GESTURES

Body language and appearances are associated with a person's identity. Ability to control body gestures and to change appearance of avatars is an important criterion in place-making. In the opening ceremony at Shiki Center (see section 4.4), several avatars congregated to take a group photo and were seen to change their physical appearance, clothes and take on some model-like poses before the photo shoot. It is interesting to note that the avatars still mirror real world behaviour when they have the freedom to do anything in the virtual world. There is a need to improve and provide a wide range of gestures and body language in the virtual environment.

5.6. IMPROVISATION

In real life, if someone needs a seat we are able to move a chair to let him / her sit. If we want to sit in a circle for discussion, we can move the chairs and form a ring. At one of the real world public spaces, we observed a group of teenagers practising their dance in front of a reflective granite wall using it as a mirror. They also use pillars as a prop to execute their stunts. Such improvisation boosts a sense of ownership of the place. In the virtual world, to build a sense of ownership of the space, designers can provide elements and scripting that will allow improvisation by the avatars.

6. Conclusion

Our expanded criteria build on the work by Kalay and Marx. They are not exhaustive or intended as a definitive formula to design virtual places. With advanced features offered by new technology, the sense of place can be enhanced through some of the items of the sub-criteria in future. This set of criteria is meant for multiuser online virtual environments (MUVEs) and may not be all relevant for massively multiplayer online games (MMOGs) environment. There is no doubt that more social, cultural and economic activities will happen in the 3D virtual world as advanced technology and faster bandwidth become affordable. This raises necessity to understand and design virtual worlds that are socially and culturally appropriate.

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References

Canter, D.: 1977, *The psychology of place,* St Martin Press, New York.

Champion, E., and Dave, B.: 2002, Where is this place? *in* G. Proctor (ed.), *ACADIA 2002, Association for computer-aided design in architecture 2002 annual conference,* Pomona, USA, 87–97.

Boellstorff, T.: 2008, *Coming of age in Second Life: an anthropologist explores the virtually human,* Princeton University Press, USA.

Harrison, S. and Dourish, P.: 1996, Re-place-ing space: the roles of place and space in collaborative systems, *Proceedings of the ACM conference on computer-supported cooperative work CSCW'96* (Boston, MA), ACM, New York, 67–76.

Jacobs, J.: 1961, *The death and life of great American cities,* Random House.

Kalay, Y. E. and Marx, J.: 2001, Architecture and the internet: designing places in cyberspace, *Reinventing the discourse, Proceedings of the 21st annual conference of the Association for computer-aided design in Architecture,* Buffalo, New York, 230–241.

Kalay, Y. E. and Marx, J.: 2003, Changing the metaphor: cyberspace as a place, *Digital design: research and practice, Proceedings of the 10th international conference on computer-aided architectural design futures,* Taiwan, 19–28.

Relph, E. C.: 1986, *Place and placelessness,* Pion Ltd, London.

Relph, E. C.: 2007, *Spirit of place and sense of place in virtual realities,* University of Toronto.

Second Life Economy First Quarter 2009: https://blogs.secondlife.com/community/features/blog/2009/04/16/the-second-life-economy--first-quarter-2009-in-detail.

Whyte, W. H.: 1980, *The social life of small urban spaces,* The Conservation Foundation, Washington, DC.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010*, 117–125. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

PROGRAMMING IN THE MODEL

Combining task and tool in computer-aided design

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Abstract. Programming takes designers away from typical domain- and task-based interfaces such as three-dimensional modellers. It thus imposes additional cognitive load on the already challenging design task. Programming in the model is a system design strategy that embeds the act of programming in a 3D CAD model. This paper presents the argument for programming in the model and two user interface constructs that support such programming.

Keywords. End-user programming; scripting; visual programming; direct manipulation.

1. Introduction

Most computer-aided design (CAD) systems for buildings provide designers with powerful graphical user interfaces that satisfy the requirements of conventional designs, but sometimes this is not enough for designers who want to explore unconventional design ideas or to work more efficiently. In such cases, designers need to use computer programming to have more capabilities and freedom to explore (Aish, 2003). However, the shift from a three-dimensional model to a programming environment presents cognitive challenges. Designers who program in CAD systems face the same difficulties that other end-user programmers face in other domains. In this ongoing project we address this issue and propose programming in the model as a way of using designers' spatial and visual abilities to bring programming and design tasks into closer proximity. In this paper we describe the problem of end-user programming in CAD and present some of the findings from the literature. Then

we introduce programming in the model as well as two example aspects of such programming.

2. The problem

Computer programming can improve designers' efficiency by allowing them to program iterative operations, making modules for future use, and helping others by sharing code. It also helps them with their design task by giving them freedom from the limitations of the interface and allowing them to explore unconventional and more complex forms, as well as accommodating change in the design process and enabling rapid exploration of variations and alternatives (Woodbury, 2010). In design, the word "scripting" often replaces "programming." The difference lies only in reception: "scripting" seems less foreboding than "programming." There is no meaningful technical difference between the two terms.

Users of computer-aided design systems have at least one special skill in common: they can understand and relate to a 2D or 3D model very easily. They are experienced and comfortable with the model and it makes sense to them. In working with CAD systems, their purpose usually is to create a model, for example a 2-dimensional drawing of a house or a 3-dimensional model of an engine or a skyscraper.

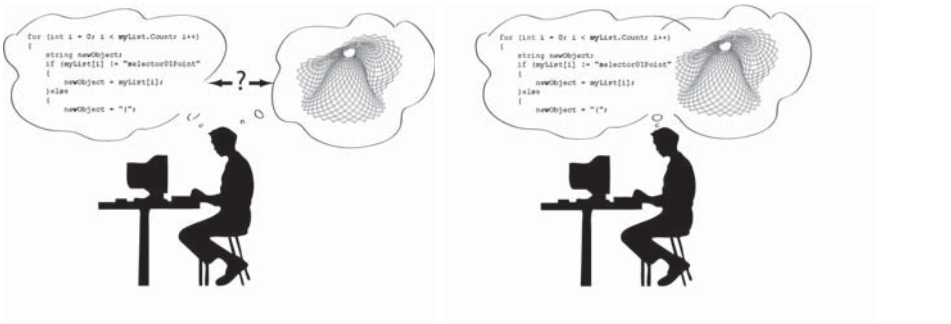
Designers may be capable with the model itself, but most are not as comfortable with programming. Some designers struggle to understand the underlying structure of a programming language and the structure of the model. Others have a hard time making sense of the syntax of the program.

Most such designers are amateur programmers acting as end-users, not system developers – they have relatively little formal education in computer science or programming. End-user programmers are people who are professional in domains other than programming who need to write programs in the context of their expertise and as part of their job in order to get a task done. End-user programmers may use any programming language independently or as part of a software depending on the nature of their job, such as spreadsheets for accountants, SolidWorks for mechanical engineers, and AutoCAD for architects.

For an end-user programmer, the focus is on the task in hand and not programming, and the goal is mostly to do the task, rather than to produce efficient, reusable code. Programming is only a tool for making algorithms to perform repetitive tasks quickly and more efficiently or to do things that are hard or impossible to do in the graphical user interface.

Literature shows that end-user programmers find difficulty when programming is separate or different from their main task (design, analysis, etc.). To

write or edit code in existing CAD systems (e.g., Generative Components, Grasshopper, Rhino script), the user has to open the scripting / visual programming window as a separate program with a completely different interface and functionality. During the process of writing the code, the user goes back and forth between the model and program in order to find the right objects and operations required for the task and also to test the code and see the result. The shift in mental activity from objects and forms to code and algorithm occurs repeatedly. Separation of design and program requires switching between tasks, with consequent loss of both focus and efficiency (see figure 1).



A: Programming task is usually separate from the design task.

B: Bringing programming closer to the design of the model.

Figure 1 . Computer programming and design in CAD.

3. Background

Kelleher and Pausch (2005) name *difficulty of code* as one of the challenges of programming languages for non-programmers that causes confusion and syntax errors. This issue can be addressed by simplifying entering the code or finding alternatives to typing code, e.g., constructing code by using graphical objects or interface buttons, and by demonstrating the action in the interface.

Green and Petre (1996) introduced the cognitive dimensions frameworks for evaluating visual programming languages. They consider *closeness of mapping* to be one of the important criteria in the efficacy of an end-user programming environment. They argue that the closer the programming world is to the problem world, the easier it is for users to mentally map between them. It's much harder to achieve this closeness in textual programming languages. Pane and Myers (1996) emphasise the importance of matching between the system and the real world by keeping the programming language consistent with user's external knowledge, in order to reduce novice's learning load and avoid confusion.

Spreadsheets are good examples of end-user programming environments that bring programming directly to the problem domain. In spreadsheets, the problem domain is the task being done, which is typically amenable to representation as a table or array. The representation is a table of cells filled with values and formulae. User can write programming statements directly into the cells and see immediate feedback in the form of numbers or other values. However, like most end-user programming systems, Excel's task mapping becomes much less clear when a user engages scripting (Visual Basic for Applications (VBA)).

There is a large body of research that addresses the issues of end-user programming and programming in general. Concepts such as *direct manipulation* and *visual programming* are particularly applicable to the issues of end-user programming in CAD. Two aspects of direct manipulation (Shneiderman, 1983) are reducing the distance between user's thoughts and the system and giving them the sense of directly manipulating the objects and not through the program and computer (Hutchins et al., 1985). Visual programming (the direct manipulation of programs) has appeared in CAD systems interfaces (e.g., Rhino's Grasshopper). In this technique, shapes and their connections represent programming constructs and the flow of data or control. Although visual programming may seem to be a good way of using designers' visual abilities, it still separates the task of programming from the task of designing the model and suffers scaling problems as models grow.

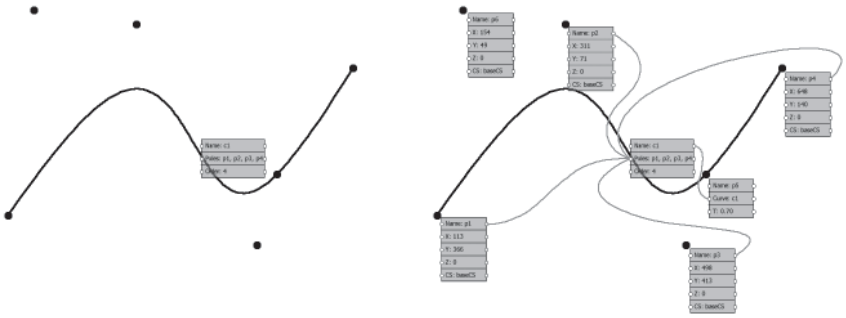
4. Programming in the model

In order to use designers' spatial and visual abilities in programming we suggest contextualising programming concepts and subtasks directly in the three-dimensional model. Relationship between objects are assigned and modified in the model view. Object properties are accessed directly in the model view by clicking on the objects. Programming constructs such as functions and loops are created in the model directly where they are needed and other objects in the model and their properties can be used as arguments.

Programming in the model also uses aspects of visual programming (e.g., Rhino's Grasshopper) but is different in that the goal is not just to make programming visual, but to bring it closer to the model. We use both text and visual elements in the model to program. In order to avoid scaling problems of visual programming for larger models, we give the user access to the underlying textual program at all time. Every programming task performed in the model is reflected in the textual language and vice versa. Small pieces of a program can be created in the model and larger pieces and modification can be done in the scripting window.

To make the concept of programming in the model clearer, we explain how it supports two types of tasks commonly performed in CAD: (1) accessing and modifying object properties and dependencies, and (2) making lists or series of objects.

Model objects (points, curves, solids) each have a collection of properties, the specifics of which depend on the creation method used. For instance, a point created by defining Cartesian coordinates may have a list of properties including coordinate system and X, Y, and Z translations, whereas a point that is located on a curve has no coordinate system but has additional properties such as the curve and the point's position on the curve given by a parameter *T*. In programming in the model, these properties are accessible and modifiable in the model. Short or extended lists of properties may be displayed based on the user's demand for one or some of the objects in the model. Figure 2 (A) shows a model with visible object properties. The level of visibility of property information boxes is adjustable by the user by changing their transparency.



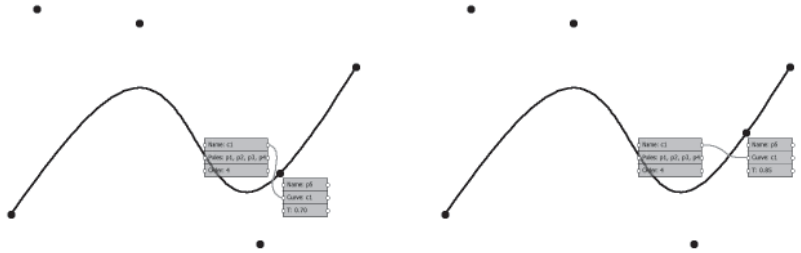
A: Object properties *B: Relationship between objects*

Figure 2 . Properties and dependencies represented in the model

In parametric modeling, an object may be dependent on other objects or variables if other objects or variables are used to determine the value of its properties. In programming in the model, these dependencies are shown by links connecting object properties to each other. For each object, inputs come from the left side and outputs exit from the right. This is similar to Generative Components' symbolic view and Grasshopper's graphic representation of the model. In fact, they represent the same information. The main difference is that the graph is embedded in the model. There is no need for a different window, therefore no need for the user to go back and forth between windows to get information about object relationships by trying to map the graph to the model. Figure 2 (B) shows dependencies between a curve and its poles by links connecting the poles to the left side (representing inputs) of the *Poles* field of the curve's properties. It also shows its relationship with a point on the

curve by a link connecting the right side (representing outputs) of the curve's property box to the point.

Object properties are editable in the model and the change immediately appears in the model. In figure 3 *point05* is located on the curve and its position is determined by a parameter *T* that has a range between zero and one. In this figure the user changes *T* from 0.70 to 0.85 by editing the field named *T* in the point's property list in the model. The change in *T* moves the point closer to the end of the curve immediately after she hits *Enter.*



A: T = 0.70 *B: T = 0.85*

Figure 3. Changing object properties in the model.

The user can change the dependencies in the model as well. By grabbing one end of a link, she can detach it from an object and attach it to another. Figure 4 demonstrates this action. In the figure on the left, *point02* is the second pole of the curve, so the curve is dependent on it. This dependency is shown by a link that connects *point02* to the *Poles* field of the curve properties. By grabbing the end of the link that is attached to *point02*, the user can move it to another point (in this case *point06*) to change the pole. The shape of the curve changes based on the new pole to reflect the change and the property list is updated accordingly.

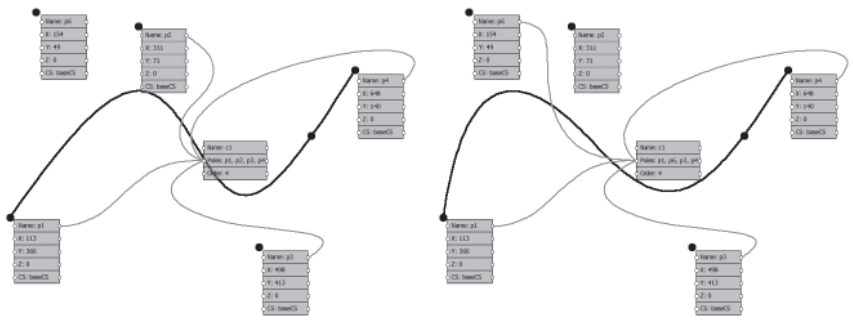
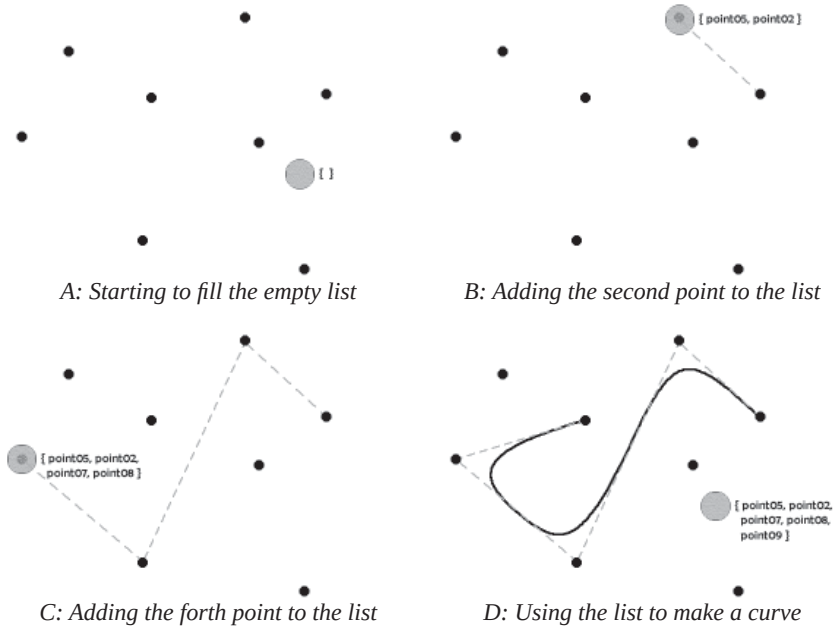


Figure 4 . Changing relationships in the model

The second example demonstrates how lists can be made in programming in the model. In parametric modeling, sometimes it is necessary to provide a list of objects as an input for other objects or a function. The syntax of a list is different in each programming language and can be confusing for users. For example in Generative Components, a list is defined by two curly brackets and object names are separated by comas, e.g., {*point01, point02, point03*}. Missing any of these characters results in syntax errors. Some systems provide the ability to select the objects in the model to be added to the list. But there is usually no feedback in the model on the current status of the list and the syntax needs to be checked for possible errors.

In programming in the model, lists are objects that can be placed in the model. The user can move a list around, select objects to be added to the list, see the textual representation of the list, and also keep track of the list in the model through the visual feedback in the model. In figure 5 a list of five points is made in the model and used for creating a curve. As points are being added to the list, the textual list is created with the correct syntax, without the need for the user to constantly check for syntax errors. At any time during this process and afterwards, the user can modify the list by typing the name of the points directly in the textual representation next to the list object. This ability



A: Starting to fill the empty list *B: Adding the second point to the list*

C: Adding the forth point to the list *D: Using the list to make a curve*

Figure 5 . The process of making a list of five points to create a curve by poles

gives the user the option to choose between multiple methods of making and editing lists.

5. Discussion and conclusion

As mentioned earlier in the paper, this is a work in progress. We have much more to find and explore. We are currently working on other programming concepts such as loops and conditionals and how to represent them in the model. Also, we are developing a prototype of the system that can be used by designers in future user testing of the project. It is important to mention that programming in the model is not a programming language on its own. Rather it is a way of presenting programming and scripting to designers that can be implemented in any CAD system and adapted to the programming language used in that system. This textual scripting language then works with programming in the model and provides additional editing capabilities when model grows in size and complexity or for designers who choose to write code.

Programming in the model will benefit designers by breaking the initial fear of code that prevents some of them from starting scripting in CAD. This is done by gradually introducing programming concepts in the 2D-3D model and allowing direct manipulation of the program in the model. Designers who choose to learn scripting along the way can follow the development of the textual program and familiarise themselves with the syntax. Although the program is represented visually in parts, there is a significant difference between programming in the model and visual programming in that the emphasis is on the closeness of program and model and not just visualising it.

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References

Aish, R.: 2003, Extensible computational design tools for exploratory architecture, *Architecture in the digital age: design and manufacturing,* Spon Press, New York.

Green, T. R. G. and Petre, M.: 1996, Usability analysis of visual programming environments: a cognitive dimensions' framework, *Journal of visual languages and computing,* **7**(2), 131–174.

Hutchins, E. L., Hollan, J. D. and Norman, D. A.: 1985, Direct manipulation interfaces, *Human–computer interaction,* **1**(4), 311.

Kelleher, C. and Pausch, R.: 2005, Lowering the barriers to programming: a taxonomy of programming environments and languages for novice programmers, *ACM comput. surv.,* **37**(2), 83–137.

Pane, J. F. and Myers, B. A.: 1996, *Usability issues in the design of novice programming systems,* Carnegie Mellon University, School of Computer Science, Pittsburgh, Penn.

Shneiderman, B.: 1983, Direct manipulation: a step beyond programming languages, *Computer*, **16**(8), 57–69.
Woodbury, R. F.: 2010, *Elements of parametric design*, Taylor and Francis, forthcoming.

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A FRAMEWORK TO INTEGRATE GENERATIVE DESIGN TECHNIQUES FOR ENHANCING DESIGN AUTOMATION

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Abstract. This paper presents and demonstrates a computational framework that facilitates the integration of different generative design techniques to enhance design automation. The framework is based on the evaluation and comparison of four main generative design algorithms. Effectiveness of the framework is demonstrated through an example scenario. Compared to most existing generative design systems that are based on one of the techniques, which often bias the generative design process in a certain direction, new generative design systems by applying the proposed framework will provide the trigger at each stage as demonstrated in the example scenario for the designer to perceive the emergent designs from different viewpoints. This advantage will enhance design generation and automation by assisting the designer in making more informed decisions in understanding and selecting the suitable generative techniques for different design needs.

Keywords. Generative design systems; shape grammars; L-systems; cellular automata; genetic algorithms.

1. Introduction

Design automation is an important research area in the architecture, engineering and construction (AEC) domain, having the potential in significantly cutting time, cost, as well as other design and human resources involved in a project life cycle. Generative design systems are essential computational approaches for achieving design automation. This paper presents and demonstrates a computational framework for enhancing design automation by facilitating the use of different generative design techniques for different needs. Most existing generative design systems are developed based on one of the generative design techniques. This limitation often compromises the performance of the system in certain aspects for although there are overlaps and similarities across these generative techniques, each of them appears to be more suitable than others for specific design tasks.

This paper aims to bridge this gap through the development of a computational framework that facilitates the integration of different generative design techniques to enhance design automation. The framework is based on the evaluation and comparison of four main generative design algorithms: shape grammars (Stiny and Gips, 1972), L-systems (Lindenmayer, 1968), cellular automata (Wolfram, 2002), and genetic algorithms (Holland, 1975). Effectiveness of the framework is demonstrated through an example scenario. The framework enables designers to produce different design languages rather than hand crafting individual designs. The actual design tasks are carried out and (semi-)automated by the system according to the design knowledge or constraints set by the designers, during real-time interactions with the system. Compared to most existing generative design systems that are based on one of the techniques, which often bias the generative design process in a certain direction, new generative design systems by applying the proposed framework will provide the trigger at each stage as demonstrated in the example scenario for the designer to perceive the emergent designs from different viewpoints. This advantage will enhance design generation and automation by assisting the designer in making more informed decisions to select the “right” techniques for the “right” tasks.

2. Literature review of generative design techniques

Various computational approaches have been developed to support design automation. These generative design systems range from simple rule based systems that produce random outcomes to more advanced AI based systems that try to reproduce aspects of human design processes. Design is a co-evolutionary process where part of the knowledge and understanding of the

goals and solutions is generated as the design progresses (Schön, 1992). Gero (1998) describes design as a situated activity. A situated stance emphasises the designers' interaction with the design representation and how the designers' past experience and the environment influence the emergent design solutions. A situated view suggests that the same designers may generate different solutions in different situations. Based on this implicit assumption various creative design techniques such as brainstorming, TRIZ and morphological charts have been developed to modify the designer's situatedness and facilitate greater design exploration. Thus, generative design techniques that are applied to produce emergent forms also provide new ways for designers to see the design problem and the solution space, enriching the design process and the design outcome.

2.1. OVERVIEWS OF THE FOUR GENERATIVE DESIGN TECHNIQUES

The four commonly used generative design techniques are reviewed below.

Shape grammars (SG). SG is a set of shape rules that can be applied to generate a set or language of designs (Knight, 2000). SG is both descriptive and generative. The rules themselves are the descriptions of the forms of the generated designs. SG can be used as (1) design tools to generate vast varieties of design languages, (2) analysis tools for existing designs in order to better understand these designs and to generate shape rules that produce the designs and other similar designs. Stiny (1980) defines four basic components of SG: (1) S: a finite set of shapes, (2) L: a finite set of symbols, (3) R: a finite set of shape rules, and (4) I: initial shape. SG is typically used for generating patterns or 2D compositions, spatial layouts, and 3D compositions (Duarte, 2005; Stiny and Mitchell, 1978; Halatsch et al., 2008).

L-systems (LS). LS (Lindenmayer Systems) are mathematical algorithms first developed by biologist Lindenmayer (1968). Essentially, LS is a set of production rules that can be applied recursively through string rewriting. In design, LS is in principle a design grammar. LS has been distinguished from SG as being operated on strings (the symbolic representation of the shape) rather than directly on the shape itself (Parish and Muller, 2001). LS is typically used to generate repetitive patterns, fractals and natural organic forms like plants (Lindenmayer and Rozenberg, 1972), textures, etc. In design, LS has been used to generate road networks (Parish and Muller, 2001), city planning (Kelly and McCabe, 2007) and building forms (Mueller et al., 2006).

Cellular automata (CA). CA is a collection of cells on a grid of a specified shape that evolved over time according to a set of rules driven by the state of neighbouring cells (Wolfram, 2002). The complexity of the system is partly determined by the type of grid, which can range from one-dimensional

lines, two-dimensional grids to Cartesian grids in arbitrary dimensions. CA is always context-sensitive and defined in terms of cell states and states of the neighbouring cells. CA tends to follow the approach of "form follows function" because the emergent form is the result of the desired functionality (cell states). CA is useful for study of social effects that can be simulated using the neighbouring conditions, e.g., urban design (Herr and Kvan, 2005), zoning and building massing (Krawczyk, 2002).

Genetic algorithms (GA). GA is inspired from natural evolutionary processes. GA uses the analogs of evolutionary operators on a population of states in a search space to find those states that optimised by a fitness function. The search space consists of character strings of fixed or variable length (genotype) composed of the elements of a given alphabet (allele). The genotype space is mapped onto another (phenotype) search space. The fitness function is defined as a function of a state in the phenotype space. Various modifications of GA have been reported in literature. In design they have been used for design optimisation (Caldas, 2001), spatial layout (Gero and Kazakov, 1998), architectural forms (Caldas, 2001) and so on.

2.2. COMPARISON OF THE FOUR GENERATIVE DESIGN TECHNIQUES

Technical aspects. In general, each of these techniques defines a finite set of elements and/or symbols that can be operated upon using a finite set of production rules and/or operators. CA, LS and SG are generally represented in graphical forms that result from transformations and operations (i.e., addition, rotation, subtraction, etc.) on the initial elements, Further, there have been instances where some of these techniques are shown to be equivalent, for example, CA and LS (Alfonseca and Ortega, 2000). There are also examples where some of these techniques are used in conjunction with other techniques to manipulate the terminal elements (Jacob, 1996) or derive rules (Speller et al., 2007).

Table 1 highlights each of these techniques in terms of their (1) components and rules to define and implement the system, (2) advantages in design generation, (3) limitations, and (4) design accuracy (predictability), which can relate to the level of designer intervention. It is important to note there are always exceptions, for example, even for SG and LS it is possible to have systems that are constrained enough to generate valid designs that may not require validations by the designer. However, greater the number of constraints, fewer is the opportunity for exploration and emergence.

Design aspects. Each technique is useful for design exploration in their own way. GA is mainly used for optimisation. The design quality in GA tends to increase in each generation. Unlike CA, which is always constrained and

context-sensitive, SG and LS can be designed with(out) constraints depending on the level of intervention desired by the designer. SG and LS typically follow "function follows form", i.e., once the form is generated, it is evaluated for functionalities. Table 2 compares the techniques in terms of (1) suitability to design phases and approaches for application, (2) type and complexity of the design problem, (3) characteristics of the design outcome.

Table 1: Technical aspects of the four generative design techniques.

	SG	LS	CA	GA
Comp'ts	Set of terminal shapes (SG) or symbols (LS), operators, and rules Initial shape.		Grid and cells Set of state rules Initial cell states	Genotypes Phenotypes Population Operations Fitness function.
Rules	Usually, one of the rules fires if conditions match LHS.	Usually, as many rules are applied at the same time as defined.	Very few rules relating to current states, relevant rules fire to change states.	Usually, one operation is applied at a time on a population sub-set.
Advt.	Geometric.	Symbolic.	Context sensitive Constrained Bottom-up.	Multiple solution alternatives Optimisation.
Lims	Trade off between usefulness v.s. emergence exploration.		Constrained by cell geometry and definition.	Near optimal solutions but rarely optimal.
Acurc.	In general, often requires post-generation analysis by user.		Depends on problem representation and solution interpretation.	Depends on choice of genotypes and the fitness function.

System development. GA can be implemented as a pure bottom-up design approach as once the genotypes, phenotypes and fitness function are identified the mechanism is fixed. However, GA's efficiency lies in their selections and representations. CA also tends to be easier to model because CA is generally defined in terms of states, e.g., the rules corresponding to the state changes in CA can be easily identified because the relationships between the neighbouring cells and potential configurations are easy to visualise exhaustively (the emergent configurations are not necessarily easy to visualise). Developing CA is straightforward because often it is used to simulate and explore social behaviours. Hence, a pure bottom-up approach works and emergent behaviours are generally considered to be valuable.

LS and SG are not clearly defined as much in terms of the states as often the emergent and unexpected qualities of the design outcome are desirable. Thus, in many cases, a re-engineering or backward tracking approach is adopted to generate terminal and non-terminal elements, and a set of production rules

that may generate the desired outcomes. In many cases, not all results are promised to be functional, and, hence, developing such systems may take a greater number of iterations. Thus, the development of LS and SG is rarely a purely bottom-up approach (Tapia, 1999).

Table 2. Design aspects of the four generative design techniques.

	SG	LS	CA	GA
Phase	Design exploration: space layout (SG), patterns and compositions.		Grid-based design and planning.	Design exploration, optimisation.
Approach	Emergent Function follows form Iterative and re-engineering based approaches.		Study of neighbouring effects, growing patterns, social phenomenon etc. Form follows function.	Design optimisation Combined and morphological designs.
Charact's D' Problem	Patterns Architectural forms and styles Usually 2D, 3D applicable.	Natural and organic forms, road networks, terrains, textures Usually 2D.	Urban planning, zoning, block design and massing Usually 2D, 3D applicable.	Component based designs Optimisation.
	Geometric Emergent and exploratory Solutions usually require validation.		Emergent and normative Context-sensitive Usually predictable solutions.	Optimised.

Table 3. Development issues of the four generative design techniques.

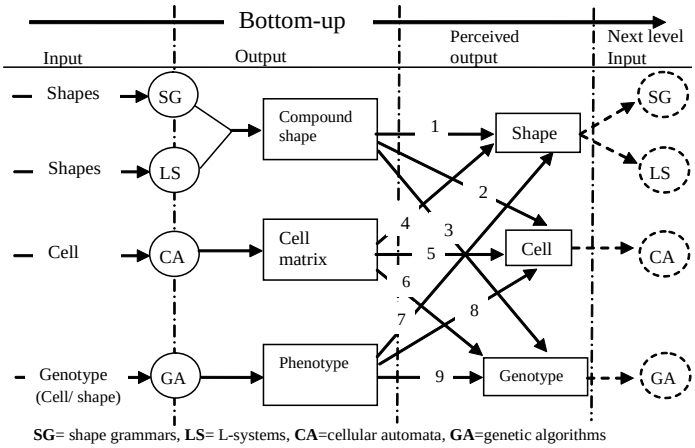
	SG	LS	CA	GA
User intervention	High level of user intervention to validate outcomes Iterative process.		Low level of user intervention once cell dimension, state rules and initial states are defined.	Low level of user intervention once fitness functions, genotypes and termination conditions are defined.
Challenges	Difficult to foresee expected outcomes. Hence, often requires re-engineering and backtracking.		Pure bottom-up Easy to identify possible cell states and neighborhood conditions.	Choice of representation can be challenging.

From the above summaries and comparisons, there are noticeable differences and similarities across the four generative design techniques. They are each unique in terms of design generation. Therefore they can be applied to solve different design problems and to suit different design preferences. Based on a situated view, the remainder of the paper presents and demonstrates a computational framework that facilitate the integration of the four different generative techniques for designers to explore the diverse solution spaces,

guiding them in selecting and applying the suitable generative design techniques for different design needs.

3. A framework to integrate generative design techniques

Fig. 1 shows a computational framework to assist designers in facilitating the integration of different generative design techniques. The framework is based on a bottom-up approach, where the designer starts with the smaller design components and tasks. However, following a similar approach, the framework can also facilitate the top-down approach, for example, given the site (e.g., a city), the designer may start with the initial zoning tasks. Once the first level zoning is completed, the sub-zones (e.g., a residential zone) can be further designed using the generative techniques. Thus, the designer is able to step back and select the alternative top-down and bottom-up approach as needed, in an iterative way.



1: A compound shape generated at the lower level is used as a terminal shape for generation of further complex shapes at the next level.
2: A compound shape generated at the lower level suitable for repetition over a grid, where neighbouring relationships can be defined. In that case a cell envelope that encloses the shape can be used in CA at the next level.
3: Multiple compound shapes generated at the lower level can be used to generate further complex shapes using GA. In that case each compound shape is a genotype for GA for the next level.
4: Output of CA from the lower levels can be perceived as a shape. This shape can be used for complex shape generations at the next level.
5: Cell matrix at the lower level is part of a larger cell matrix.
6: Multiple cell matrices at the lower level can be combined together to generate new designs using GA at the higher level with each cell matrix as a genotype.
7: Outcome of GA at the lower level creates a compound shape, which is used as terminal shape for further shape generation at higher level.
8: Outcome of GA at lower level is suitable for repetition over a grid, where neighbouring relationships can be defined in CA at the next level.
9: Phenotypes at the lower levels are perceived as genotypes for GA at the higher

Figure 1. A framework to facilitate the integration of generative design techniques.

4. An example scenario for framework demonstration

The scenario is to demonstrate the use of the computational framework. The design brief is to generate a layout plan for an exhibition space of a given dimension and the design needs to meet the constraints of providing (1) four exhibitions zones with similar capacities and (2) adequate display panels.

The scenario adopts a bottom-up design approach. The designer starts by composing the panel and uses SG to generate a compound shape that satisfies the requirements. Next the designer may intend to use this as a modular unit. At this stage, the designer may adopt different techniques. As described in "1" in fig. 1, the designer adopts this compound shape as the terminal shape for generating further complex shapes using SG. Thus, in this case the designer uses SG for local module as well as for the overall panel layout. Alternatively, as shown in "2" in fig. 1, the designer may choose to repeat the same module by dividing the exhibition space into four similar zones. However, the designer may require defining neighbouring conditions such as how the panels in different cells/zones are related, e.g., the modules in each cell are arranged such that in each of the neighbouring cells the red panels face different directions. Thus, in the second case, the compound shape generated from SG in the lower level can be used to define cell characteristics at the higher level, where CA is used to generate the higher level space layout. These are illustrated in the top half of fig. 2. Similarly, in another case, the designer may start with CA by considering an envelope around each panel as the basic cell dimension. Using the neighbouring relationships a space layout in the local cell matrix is obtained. At the next higher level, the designer has the option to choose SG ("4" in fig. 1) or CA ("5" in fig. 1) as the technique to develop space layouts at the next higher level, as shown in the bottom half of fig. 2. Beyond what was illustrated in fig. 2, the designer may generate different modular alternatives from the basic panel using SG. Once alternatives are obtained the designer may create further space layouts using GA by combining modules and applying genetic operations. Further, the designer may also be able to configure these modules to optimise the desired function such as maximising the circulation space or maximising the number of available panels, and so on.

As fig. 2 demonstrates, the different generative techniques can be used in conjunction to generate different design alternatives to suit different design needs and preferences. The proposed framework facilitates the use of multiple generative techniques during the iterative design process by providing the trigger to change the designer's situated state. At each stage, once the designer has taken an action and looks at the outcomes, one has the opportunity to perceive the design task differently, which will assist one in making more

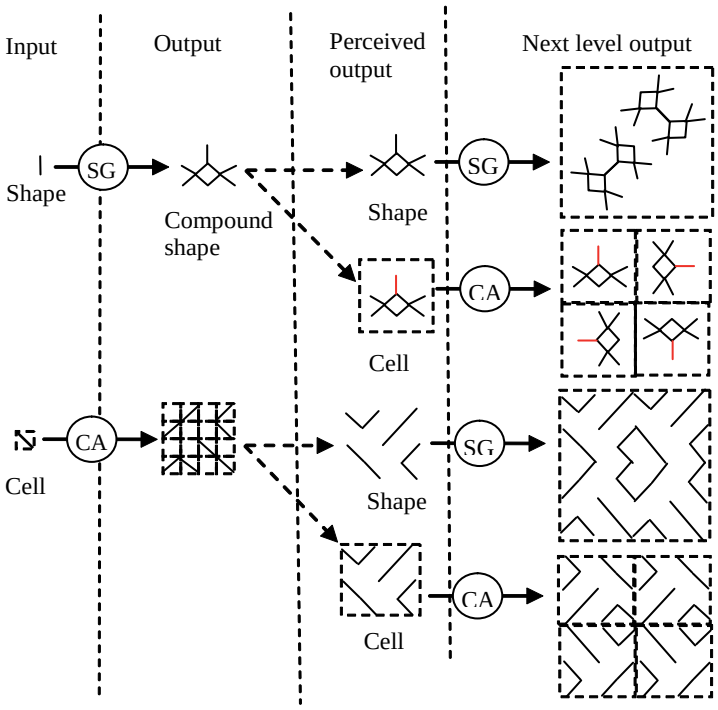


Figure 2: Design generation using multiple generative techniques.

informed decision in selecting the suitable generative design techniques to continue the design process.

5. Summary

The paper presents and demonstrates a computational framework to facilitate the integration of different generative design techniques. A review of the four main techniques namely shape grammars, L-systems, cellular automata and genetic algorithms is presented. The review shows that although there are overlaps and similarities across different techniques, each of them appears to be more suitable than others for specific design tasks. Hence, given the different strength of each technique, a computational framework that facilitates the integration of these techniques is developed. The framework enhances design automation by assisting the designer in marking more informed decision in understanding and selecting suitable generative techniques to suit their needs and preferences. Currently, existing generative design systems are based on one of the techniques, which often bias the generative design process in certain directions, i.e., designers working on a system based on SG tend to interact with and perceive the design artefacts as shapes. Generative design systems

by applying the proposed framework on the other hand provide the trigger at each stage for the designer to perceive the emergent designs from different viewpoints. The future project extension includes (1) the development of an example scenario that examines the framework in a top-down approach; (2) the development of an example scenario that examines the framework in a mix of bottom-up and top-down approaches; (3) prototype development of a trial system in Second Life.

References

Alfonseca, M. and Ortega, A.: 2000, Representation of some cellular automata by means of equivalent L-systems, *Complexity international*, **7**.

Caldas, L. G.: 2001, An evolution-based generative design system: using adaptation to shape architectural form, PhD thesis, MIT, Boston.

Duarte, J. P.: 2005, A discursive grammar for customizing mass housing: the case of Siza's houses at Malagueira, *Automation in construction*, **14**(2), 265–275.

Gero, J. S.: 1998, Conceptual designing as a sequence of situated acts, *in* I. F. Smith (ed.), *Artificial intelligence in structural engineering*, Springer, Berlin, 165–177.

Gero, J. S. and Kazakov, V.: 1998, Evolving design genes in space layout problems, *Artificial intelligence in engineering*, **12**(3), 163–176.

Halatsch, J., Kunze, A. and Schmitt, G.: 2008, Using shape grammars for master planning, *Proceedings of design computing and cognition 2008*, 655–673.

Herr, C. and Kvan, T.: 2005, Using cellular automata to generate high-density building form, *Proceedings of CAAD Futures 2005*, 249–258.

Holland, J.H.: 1975, *Adaptation in natural and artificial systems*, Michigan University Press.

Jacob, C.: 1996, Evolving evolution programs: genetic programming and L-systems, *Proceedings of genetic programming 1996*, Stanford, 107–115.

Kelly, G. and McCabe, H.: 2007, Citygen: an interactive system for procedural city generation, *Proceedings of game design and technology 2007*, 8–16.

Krawczyk, R.: 2002, Experiments in architectural form generation using cellular automata, *Proceedings of eCAADe 2002*.

Lindenmayer, A.: 1968, Mathematical models for cellular interaction in development, I. Filaments with one-sided inputs, *Journal of theoretical biology*, **18**, 280–289.

Lindenmayer, A. and Rozenberg, G.: 1972, Developmental systems and languages, *Proceedings of ACM symposium 1972*, Denver, Colorado, ACM, 214–221.

Mueller, P., Wonka, P., Haegler, S., Ulmer, A. and Gool, L.V.: 2006, Procedural modeling of buildings, *ACM transactions on graphics*, **25**(3), 614–623.

Parish, Y. I. H. and Muller, P.: 2001, Procedural modeling of cities, *Proceedings of SIGGRAPH 2001*, 301–308.

Schön, D.: 1992, Designing as a reflective conversation with the materials of a design situation, *Knowledge-Based Systems*, **5**(1), 3–14.

Speller, T. H., Whitney, D. and Crawley, E.: 2007, Using shape grammar to derive cellular automata rule patterns, *Complex systems*, **17**, 79–102.

Stiny, G.: 1980, Introduction to shape grammars, *Environment and planning B*, **7**, 343–351.

Stiny, G. and Gips, J.: 1972, Shape grammars and the generative specification of painting and sculpture, *Proceedings of information processing 1972*, Amsterdam, North Holland.

Stiny, G. and Mitchell, W.J.: 1978, Palladian grammar, *Environment and planning B*, **5**, 5–18.

Tapia, M.: 1999, A visual implementation of a shape grammar system, *Environment and planning B*, **26**, 59–73.

Wolfram, S.: 2002, *A new kind of science*, Wolfram Media.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010,* 137–146. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

OPEN TOWER

Developing design research practice

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Abstract. This paper critically reflects on computational methods of design in relation to social and environmental sustainability design research within contemporary and future tall building typology. It develops the author's experience in large-scale building design practice into academic design research. The analysis of tall building typology is presented initially in the context of practice, followed by its development in an architectural master's studio. The authors discuss their design research within a practice context that determined the question: what opportunities do computational processes offer to the conception of the tall building typology? Its transference to an educational research context allowed for the deeper exploration and development of a position on algorithmic and parametric methods, their relevance to the typology of the contemporary tall building and complex architectural scenarios.

Keywords. Computational; tower; practice; research; typology; teaching.

1. AIM

> Most, if not all, explorations into algorithmic process- and form-generation generally neglect the structural and material integrity of architecture (Rocker, 2006).

There is a particular opportunity at this moment in architectural thinking in linking the opportunities of computational generative processes and the complexity of the contemporary urban condition into which architecture is required to operate. The intent with the larger project as described by this

paper is to examine contemporary computational techniques through the register of a relevant architectural typology capable of dealing with the complexity of contemporary urban, cultural, social and environmental issues; namely tall buildings.

> The skyscraper offers one of the best case studies for analysing whether architecture can still be practiced in a way that revives its reflective and critical dimension – a dimension vital to the very survival of the architect, and of architecture in its social and cultural roles (Abalos and Herreros, 2005).

The focus of the tall building typology to be discussed developed out of exploratory design work undertaken in a design research practice, of which both authors are directors. Speculative design proposals exploring social and environmental sustainability, urban conditions, structural types, infrastructure modes and organisational logics were prepared for multiple scenarios and audiences. Through critical reflection of this work we determined our interest in and obvious need for exploration of multiple systems and sets of logic. Concurrent research in computational processes indicated a clear opportunity for the use of relational logics and rule-based generative approaches and promoted an interest in developing a non-totalising or dis-integrated systems design environment.

> Now that technology lets us treat abstract schemas as objects for manipulation, it makes no more sense to design by drawing each line and modeling every surface than it does to drive an aeroplane down a highway (McCullough, 2006).

2. Background

Initially work began that sought to explore large-scale issues of environmental sustainability strategies, primarily energy harvesting, as a register for experimental design of tall buildings. This work resulted in a project titled *the Open Tower.*

The premise for the tower is based on the notion that the past and current tall building typology as single program is unsustainable on multiple levels. Large amounts of energy are invested in the construction and infrastructure of tall buildings. Tall buildings use to be limited to single programmatic cycles results in needless energy inefficiencies and consumption.

As discussed in such texts as *Delirious New York* (Koolhaas, 1978) and *Tower and office* (Abalos and Herreros, 2005) multiple programs in tall buildings develop concepts that not only advance architectural form and space, but develop the high-rise as a sustainable typology for the contemporary city. The

opportunity for the future of the typology is to conceive of tall buildings as valid urban strategies via infrastructural logics, rather than limiting them to discrete objects servicing singular purposes.

> In the new skyscraper three overlaid structures – public, private, and mechanical – define a self-sufficient vertical organizational system that tends to break down centrality into dispersed components and subsequently multiplies it (Abalos and Herreros, 2005).

Through the open tower project a variety of overlapping concepts relevant to super-tall buildings have been explored for their design potential. 24-hour use of building fabric and infrastructure offers a means of offsetting the large costs and energy use associated with tall buildings. Integrated public space enables multiple and connected programs throughout the height of tall towers. The base concept of optimum social group size and resultant interaction is examined for its generative potential within the programmatic organisation of the tower.

3. The open tower

The open tower project is a speculative un-built exploration of very tall building typology in an era of resource management, fluid programmatic and financial dynamics. It is also an important reconsideration of the future of public space within the realities of high-density urbanism. We set about to design an exploratory model for very tall buildings, explicitly to challenge several seemingly inviolate assumptions within this type. These are explained below.

3.1. PRIVATE OWNERSHIP IS NOT THE ONLY MODEL

Tall buildings considered as public infrastructure could work on novel models of public and private ownership considering the building part of the city fabric rather than an island in the grid. Our proposal is to treat primary circulation and super structure as public domain, and accumulate property deeds for vertical location and orientation to private interests, from shops to commercial scale floor plates. Continuous and accessible central public spaces, link the tower to larger urban concerns for public amenity.

3.2. A TOWER IS NOT A MONOLITH

Towers do not have to be mono-climatic, or monolithically programmed or serviced. We propose the open tower, an internally highly distributed or discontinuous tower, consisting of multiple micro-climates and highly atomised and fluid programmatic mixes, in overlapping *vertical* spatial parcels based

on a concept of scalable communities rather than horizontal floor plates. The volumetric clustering (hexagonal grid pods and gasket spaces, see figure 1) works bi-directionally across levels of communities and neighborhoods to commercial office workforces. The interconnections between these nodes allow for multiple means of entering and traversing the sections of the tower, either formally from the core or informally from the perimeter.

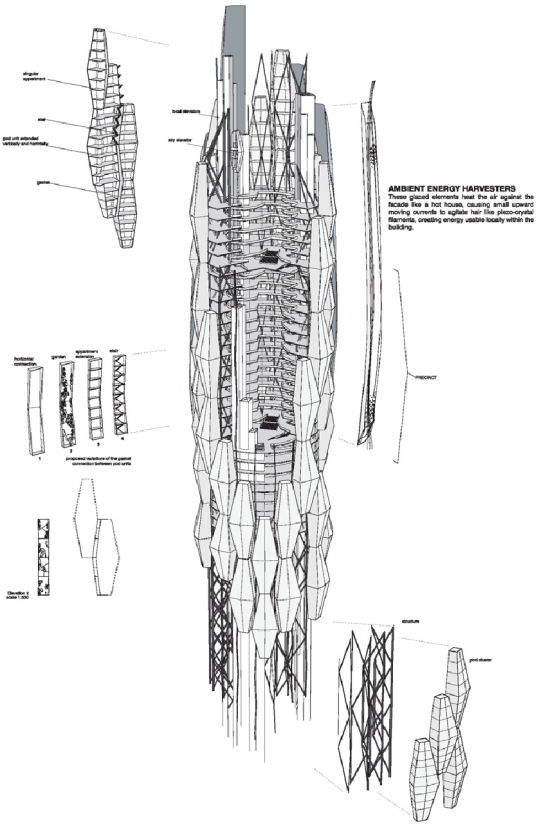

Figure 1. Open tower organisational logic (offshore studio).

3.3. OPPORTUNITIES

The role of the tall building in the future will be to generate, not just consume. Conceiving of the tower beyond the iconic single program object can fulfill the necessity for responsible and sustainable urban density. As a profession we need to develop strategies to enable these opportunities, and to advance the tall building typology as a critical contribution to the future urban condition.

4. Research question

So it can be understood that the investigation of the tall building typology follows a contemporary 'mixed-use' approach that seeks a layering of functions as a way of obtaining the density and richness characteristic of urban life. However, in developing our proposal, programmatic mix and circulation systems are not compartmentalized or seen as absolutely efficient connections as might be found in the typical mixed-use tower. Multiple paths of travel and speeds of connection between a layering of program mixes have been designed in order to encourage movement closer to that within the urban condition of a city with its network of streets, public spaces and blurred distinctions.

It is this moment in the project that opportunities offered by algorithmic processes were recognised, and the research question posed for investigation within a teaching environment. Of prime interest to the authors was speculation regarding the implications of this research project on computational methods for the design of super-tall towers and specifically complex systems. We asked how might computational processes be created to further develop these re-imagined assumptions of the tall building typology?

The goal of promoting and combining multiple agent based and rule-based systems while accessing some form of rudimentary "real time" performance analysis became our fundamental interest.

5. Studio

Over the course of the process outlined above, it became clear that we were less interested in the design of the tower as an object through compositional methods (e.g., tower as icon, understanding form in relationship to city via silhouette, etc.) but rather how one might design the organisation of the systems that produce the infrastructure and logic for the object as an environment.

In doing so, the multi-program tower with infrastructural organisational logic and urban scale sustainability objectives became a worthy testing ground for novel computational methods. Our objective then was conceived as a parametric 'rig,' consisting of *multiple* overlapping or weakly connected parametric systems, with a focus on structure as one of the primary logics required in tall building morphology. The other important reading of structure is in terms of organisational logic enabling control of spatial and programmatic configurations that would enable unexpected or novel spatial relationships and qualities to emerge.

The studio specifically sought to develop a process to quickly sketch and test structural performance through a code environment that encompassed structural analysis, while promoting an environment of 'fail fast' generative

methods for tall building design. This master's level studio was broken into three phases. The first consisted of an introduction to procedural logics and "relational" architectures through the Java Based software *Processing,* an open software platform developed at MIT by Casey Reas and Ben Fry in 2002. The second phase explored tall building morphology around types related to structure and program to develop a parametric "structural rig." The final stage brought these two parts together through a short group thesis project developed by student teams in collaboration with the instructors. The thesis focused on how non-uniform structural and organisational systems for tall buildings can be generated and developed. This master of architecture studio was run as a small research workshop of 10 students.

The first two parts have been explored in some detail in a paper 'Contingent geometries,' also co-written by the authors, presented at the AASA conference in 2008 and will only be briefly summarised as background to the computational techniques employed. The third part form the material discussed in this paper, as it involved the application of the relational logics and parametric rigs to an architectural brief for a complex mixed-use tall building on a site in Sydney's CBD, where this enabled a specific architectural context to be tested against.

In the first part students were required to explore basic structural *phenotypes* relevant to tall building morphology using *processing* as a generative code based environment and multi-frame for preliminary structural feedback, with an ambition to demonstrate and develop the possibilities of a performatively based generative design environment. These structural tests included scripting *stacking, network, lattice* and *branching* structural logics using associative and contextual (environmentally contingent) design environments. Investigation was limited to structural performance and the potentials of the structural morphology selected.

In the second phase Bentley's Generative Components (GC) was used to develop a parametric scaffold or rig of the structural system of a large tower based on the accumulated systems expertise of the first exercise. Moving beyond structural concerns only, a more complex set of ambitions was introduced, aimed specifically at avoiding the smoothly differentiated totalising geometry typical of parametric design to date. The focus was to develop multiple systems that produced and capitalised on localised structural effects rather than a globalised structural solution meeting minimum design standards. Students were challenged to investigate how GC might balance efficiency and effect within a non-standard structural praxis. Students were subsequently required to assess their parametric structural rig for its spatial consequences – that is, to consider structure and organisational logics relevant

to program. It was precisely those moments of apparent failure of a parametric system to smoothly encapsulate competing demands that were sought after and interrogated.

In the third part of the studio students teamed up in pairs and responded to the scenario of system(s) meeting the more defined architectural constraint outlined above. Students were required to respond to controls on height, envelope, floor area, solar access (to city parks), adjacent infrastructure and neighboring buildings. A novel programmatic mix was set as the brief – the combination of Museum of Contemporary Art and commercial hotel (replacing the existing site's hotel accommodation requirements). In addition, an equivalent area of commercial program was required as a means of simulating a possible financial model to provide further complexity to the organisational and infrastructural requirements for the tower.

Programmatic (and resultant circulatory requirements) were required as specific areas to address, with the understanding from the initial work produced that this would not only allow engagement with relevant and important social and cultural values / parameters, but they would also serve to qualify emergent structural formal and spatial results. This requirement is a deliberate move away from the contemporary form-finding processes most computational processes create whereby use was fitted into a form already created from any number of positions.

As a start to this work the students were required to integrate their relational logics developed as individuals in the previous task, together into an integrated proposal for the project, thereby immediately adding a significant level of complexity to their parametric rig. In doing so, this additional complexity would further enable their ability to deal with multiple local contingencies.

A clear focus to the studio was the specific requirement to avoid creation of a system in which singular global control as one might see in a parametric rig for the façade of a building or exhibition object. The position taken was that global control was insufficient to deal with contingent parameters and local requirements of complex architectural propositions. A 'global control' of form evidenced in some proposals was quickly encouraged to become one of the systems, not the prime control for the form of the tall building.

Interpretation and interrogation of iterative results, based on initial parameters selected was essential for the development of a feedback loop. That is, to allow for the examination of the structural, formal or spatial logic (depending on the particular students' focus) to re-inform the parametric rig, and be folded back into the parameters for the rig, increasing its complexity and scope for contingent responses.

The design of multiple and concurrent complex systems for a future tall

building, as well as the more speculative potential suggested by the project, exceeded the capabilities for parametric design control via a single model (of building or system). As a result multiple parametric systems were employed in combination. Within this process the overlap and juncture of systems created a new opportunity for generating spatial condition, integration and organisation of building program, structure and systems.

6. Examples

Project one developed from consideration of a highly redundant structural logic akin to the fibrous make-up of felt. Initially an environment of structural form finding was created that used layers of proximity queries to connect fibres in upper and lower levels of an initial point field. Once fibres had been drawn, their thickness, geometry through their length (changing section), their profile and extension were developed as control parameters. From a fibre-based logic to a logic of adhesion, the elements were then formed around basic connecting volumes, mapping their minimal surface to connection, while distributing fibres within a range of randomised orientation and distribution algorithms.

Figure 2. Project one, "Structuring felt" (Erik Escalante Mendoza and Albert Quizon).

The resulting test case developed a highly controlled yet free forming structural solution that queried typical boundary relationships through identifying a possibility for the role of highly controlled structure as boundary.

Project two developed a consideration of multiple circulation types into the proposal for a tower that challenged the elevator as the major structural and programmatic organizing element in tall buildings. Using a range of circulation types, in combination with a number of programmatic opportunities

they identify, this proposal completely broke with circulation to perimeter and program relationships creating a highly novel programmatic logic for the tower, intertwining the commercial, gallery and hotel components together through a series of circulation helix-like entanglements.

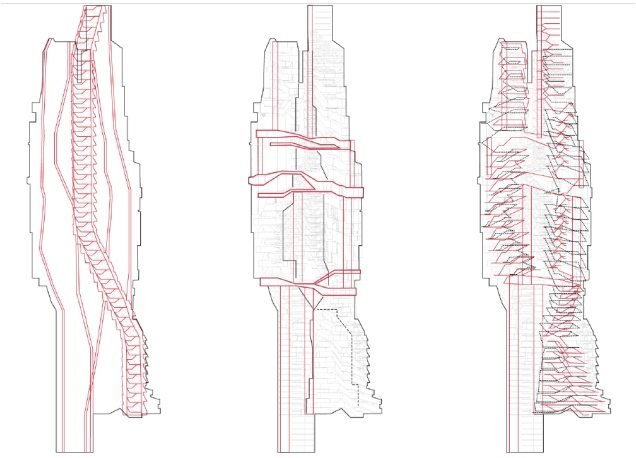

Figure 3. Project two: "Pervasive circulation" (Amanda Clarke and Alina McConnochie).

The result developed systems that promoted the dynamism and complexity possible in the inhabitation and interaction of mixed populations inhabiting a multi-programmed tower.

The ambitions for the tower typology the authors developed within the open tower project have been taken up methodologically in the studio through the testing of multiple software packages in combination with multiple systems of logic. The subversion of the typical tower logics via the dispersion and multiplication of program meeting regularised structural requirements promotes new spatial conditions, circulatory systems and modes of inhabitation.

7. Conclusion

I have always been committed to the proposition that the production of architecture is one of emergence. It is not about a pre-ordained image, icon or aesthetic that is imposed on the world, but rather an opportunity to devise and experiment with a conceptually rigorous methodological system offering a broad range of adaptations in relation to an ever-increasing body of interests. This approach is obviously tainted with risk and unpredictability for those who aspire to instant gratification, but most importantly its unique contribution for our current generation of architects is one of utilizing controlled chance as a means to managing complexity and taming the unfamiliar (Douglis, 2006).

Through the process of translating the parametric structural rig to the formal, spatial and infrastructural requirements of the tall building typology, two key issues emerged. The first is that we can conclude projects of significant architectural complexity require more than a single parametric system for their design control and relevance to larger social, environmental and political contexts. As such the design space lies in what Evan Douglis refers to as a "complex of complex systems." Our framework to meet the complexity of the contemporary and future architectural project is conceived as 'ecology of systems' (whereby ecology refers to relations between systems and to their context).

Secondly, that in the design of this ecology of systems and the relationships amongst them, unexpected spatial and organisational opportunities emerge in the overlap of systems, in the glitches that occur when computational processing power is insufficient or when errors arise in the application of otherwise sensible parametric constraints.

Currently parametric systems tend to homogenise structure and programmatic opportunities, opting for unity of expression over a robust complexity. However, the authors believe the typological reinvention of tall buildings will occur as a result of promoting ecologies of systems. As such, the tall building typology will continue to offer experimental and tangible visions for the complexities and requirements of future urban conditions.

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References

Abalos, I. and Herreros, J.: 2005, *Tower and office: from modernist theory to contemporary practice,* MIT Press, Massachusetts.

Douglis, E. and Silver, M.: 2006, Codes, eros and craft: an interview with Evan Douglis, *in* M. Silver (ed.), Programming cultures: art and architecture in the age of software, *Architectural design,* July / August 2006, Wiley-Academy, London, 12–15.

Koolhaas, R.: 1978, *Delirious New York: a retroactive manifesto for Manhattan,* Monacelli, New York.

McCullough, M.: 2006, 20 years of scripted space, *in* M. Silver (ed.), Programming cultures: art and architecture in the age of software, *Architectural design,* July / August 2006, Wiley-Academy, London, 12–15.

Rocker, I.M.: 2006, When code matters, *in* M. Silver (ed.), Programming cultures: art and architecture in the age of software, *Architectural Design,* July / August 2006, Wiley-Academy, London, 16–25.

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SPATIAL TOPOLOGY RETRIEVAL

A visual approach for representing and retrieving spatial topology in a case library

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Abstract. This paper aims to develop a visual tool named Spatial Topology Retrieval (STR) for integrating a physical-based spatial allocation tool, which offers a visual interactive interface for architectural space layout in early design stage, into an online case library, which is based on rational database technology with ontology-based authoring tools of metadata of case features. STR services the case library as a tool for representing and retrieving the plane views of a design case.

Keywords. Case-based design; case library; knowledge representation; implicit knowledge; spatial topology.

1. Introduction

Design precedents are considered the containers of the required knowledge for past design problems, experience and solutions (Kolodner and Leake, 1996). By collecting and analysing the design precedents, architects and students will be able to recognise the design problems, and acquire the relevant knowledge and the solution experience. One purpose for developing a design case library is to accumulate the design knowledge and experience obtained from case

studies. However, the means for abstracting, encoding, and indexing the case information determine the way for how to retrieve, represent, and reuse the knowledge in the design cases.

Currently, a case library is usually constructed by rational database technology, which requires selecting the most specific common features of a case then converts those features into metadata of the case information. The selected explicit features serve as the index mechanism and knowledge representation of the design cases in the library. However, the index mechanism using the explicit features often overlooks the acquisition, re-index and generalisation of the implicit knowledge of a given case.

Eastman proposed the building product models, which categorised a building's information into three types – geometric, semantic, and topological information – and initiated the researches of building information model (BIM) (Eastman, 1999). Nowadays, BIM is applied in commercial CAAD tools, and is widely adopted by the AEC field, thus assuring easy coordination, management, and indexing of the geometric and semantic information of the physical components of a complex building project. Every popular commercial CAAD software, such as Autodesk Revit, Bentley MicroStation and Graphisoft ArchiCAD, has its own BIM implementations. However, those implementations seem to be more aligned to documentation production and final construction application rather than to early architectural design and performance analysis (Howell and Batchele, 2005). Consequently, those implementations all lack the topological information of the indoor and outdoor spaces, which is required for the early architectural design and performance analysis.

The purpose of this paper aims to combine two previous investigation results: (1) Space Layout Game (SLG): a physical-based interactive allocation tool for the architectural space layout in the early design stage (Lin, 2005); (2) Open Case Study (OCS): an online case library with the rational database technology as an ontology-based authoring tool of the metadata of case features (Lin and Chiu, 2009). A visual tool named Spatial Topology Retrieval (STR) is developed to integrate SLG into OCS case library. Via Internet-ready visual interface and database connecting capabilities, STR thereby services OSC as a tool for modelling, representing, and retrieving the plane views of a design case.

2. Approach for modelling, representation and retrieval of spatial topology

Modelling, representing and retrieving the spatial topology are critical to the investigation of the geographic information system (GIS), but are often overlooked by the recent CAAD researches. Early investigations involving case-based systems such as CADRE, FABEL, and SEED attempted to directly

include spatial topology in their systems; however, due to the IT limitations in earlier times, those systems were either difficult to use or limited in terms of the function scope. Furthermore, earlier systems failed to link other existing case libraries to expand the indexing and retrieving capabilities of the case library.

Many design theories, principles, and rules of the architectural design and performance analysis are expressed in terms of the topology relationship. Common examples are space coordination, viewing sights, or circulation relationship. There are at least three approaches for modelling, representing and retrieving the spatial topology: (1) automatic, (2) BIM, and (3) content-based.

2.1. AUTOMATIC APPROACH

Design automation was one of the initial motivations to develop CAD and AI, and automated spatial layout was one of the first desired tasks. Many different methods and almost every AI algorithm for solving this problem have been proposed. Since the spatial topology is actually determined by the geometric information of spaces – such as the relevant positions and dimensions of spaces or components within the architectural layouts, it is possible to establish a tool for automatically recognising, then indexing and retrieving the spatial topology from the spatial layouts. For example, algorithms were proposed for recognising, then indexing and retrieving indoor furniture's topological relation and their layouts from the existing architectural plans in FABEL (Coulon, 1995).

The automatic approach is based on three criteria: (1) geometric information of the relevant spaces or physical components, (2) semantic attributes of the spaces or physical components for recognition, and (3) algorithms that can convert the geometric information and the topological relations to each other. Nevertheless, even modern BIM implementations usually fall short of the necessary geometric information of architectural spaces and the feasible algorithm for spatial topology. Let alone those old design cases without useful digital geometric and semantic information. Hence, even the automatic approach is practical, but how to extract the useful geometric information from the old cases and to integrate algorithms into a case library remains a critical problem.

2.2. BIM APPROACH

The geometric and semantic information is the key to the spatial topology, and many BIM implementations have modeled the essential information of building design objects. Therefore, one feasible approach is to extend the informa-

tion models and necessary algorithms into the existing BIMs. To replenish BIM with spatial information, which obviously distinguishes the current BIM implementations from Eastman's original intention, should be one reasonable means. For example, a space syntax-based model is proposed to enhance the BIM capabilities for the early architectural design (Li et al., 2009).

However, the relations between the physical components and the vacant spaces are dialectical, and four walls or two floors cannot define all spaces of a spatial layout. To name one example, Azuma House in Sumiyoshi, an early masterpiece of architect Tadao Ando. Azuma House is characterised by an atrium within the middle of this small row house, which has a stair without a handrail attaching to the wall of the atrium, and a bridge with two concrete parapets connecting two rooms over both sides of the atrium. The physical components are too simple to clearly define spaces of the atrium, so there is more than one single way to model this case in BIM. The second floor of the atrium in the house can be modeled as: (1) a bridge in the middle of an atrium without floor; (2) two excavations on both sides of a bridge; or (3) an excavation, a bridge, and a staircase. The definition of a space not only depends on the geometric information of physical components that enclose the space, but also depends on the semantic contents of the space and the building type. However, present BIM cannot accommodate multi-interpretations of the space in one single model.

2.3. CONTENT-BASED APPROACH

The definition of a space varies with the semantic contents of architectural design. In other words, the next feasible approach traces back to the contents of a building. The building type, the functions of the space, and the physical components collectively define the spatial topology. For example, an information model named "SpaceScope" was proposed to improve the retrieval of a house floor plan in a case library by a graphic interface (Hwang and Choi, 2003). Another model was also proposed for representing a special building type. This second model classified the school building in Netherlands into three types of spaces: the corridor, the hall, and the pavillion (Steijns and Koutamanis, 2005). The content-based approach creates a building-type-specific information model based on the domain knowledge of the case contents. These contents include domain-specific semantic metadata and spatial topology, such as representing a hall of a school as a multi-nodes space in the topology.

The content-based approach must depend on the case contents such as a special building type, and it is inevitably restricted by the domain knowledge about the case contents. As a result, the multi-types of a design case usually

become a problem in the approach itself. At the same time, a structured plan of the spatial layouts, such as CAD drawing or BIM model, still is necessary for this approach to analyse spatial topology of a case.

3. The STR approach

All the approaches elaborated in this paper require a structured floor plan for analysing, modelling, or indexing spatial topology. However, due to the data source problems, copyright issues and many other reasons, we cannot always obtain a well-structured floor plan or a complete BIM file of a design case for storing into a case library. For the purpose of teaching or early case study in practices, image files of a floor plan are easier to be collected from the historical documents, the architect's portfolios and Internet. Although possible, it is usually strenuous and unnecessary to rebuild a detailed structured floor plan from those image files simply for analysing spatial topology. On the other hand, technological difficulties imply more investigations to understand how to integrate the semantic and geometric information of a structured floor plan, regardless of CAD drawings or BIM files, into the indexing machine of an existing case library. To sum up, STR proposes a visual and intuitional approach to improve the capabilities of a case library in modelling, representing, and retrieving spatial topology from the unstructured floor plans.

3.1. TOPOLOGICAL LAYOUT AS VISUAL ANNOTATIONS

Although the image files of a floor plan are easier to be collected and then to be stored in a case library, they fall short of the structured data for indexing. Except for some special patterns such as human faces, machines cannot automatically recognise most of the useful design information in an image file for now. Since a space usually cannot be easily defined by physical components of BIM, an alternative of automatic recognition by machines is to attach textual or other annotations with human efforts, such as the textual "tags" of image files on Flickr. However, simple textual annotations obviously cannot represent most of the implicit information in a floor plan, such as spatial topology. A visual interface for annotating graphic information such as spatial geometry and topology of the floor plan then becomes necessary in this situation.

Another problem with extracting geometric space information from the image files is scale precision and correctness. Some basic image processing tools, such as scaling, rotating, and measuring, and manipulative skills, become necessary for a visual approach to improve the precision of geometric information. For example, an image file of a house floor plan may not be in appropriate scales. Assuming that the normal dimension of an interior door

is 90 cm wide, we can reproduce this image in the new scale. After simple adjustments, most of the image files of a floor plan can be used to annotate their spatial topology in STR. However, on account of API's limited abilities in image processing, not all necessary pre-processing of a floor plan image can be implemented in STR as of today.

3.2. PHYSICAL-BASED VALIDATION FOR SPATIAL TOPOLOGY

Annotations attached by human efforts cannot be free of mistakes and inconsistency. Therefore, a validating machine helps users to check up the inputs to determine whether or not these inputs are acceptable. STR is based on SLG. SLG has a physical-based algorithm to check every space whether it is overlapped, separate, adjacent, or connected by accesses or not, and to automatically modify the relative positions of the relevant spaces to satisfy assigned topologies. When a user wants to validate the inputted topology, STR will then (1) check every space whether it complies with the topology assigned by the user or not, and (2) try to modify the relative positions of the relevant spaces, and/or (3) prompt the conflicts if any problem goes beyond the algorithm of SLG.

Since the SLG-based algorithm is very simple for now, STR cannot automatically correct all conflicts caused by the inconsistent topologies. However, by comparing the previous layout inputted by the user to the new layout modified by STR, and by the visual cues of conflicts provided by STR, the user should be able to detect any inconsistency in the topological layout and to correct the inputted topological relations by interactions of relevant spaces in STR.

3.3. TOPOLOGICAL LAYOUT AS VISUAL RETRIEVAL

When a user finishes the topological layout of a floor plan, the layout will be stored in OCS database and, there, the user can retrieve it and its relevant image files of the floor plan. STR provides the same interface for annotating and retrieving topological layouts in the case library. By drawing spaces and assigning topological relations to those spaces, the user can enter a partial topological layout as a query in order to retrieve a similar layout in the case library.

Based on the features of a queried layout, STR can rank the similarities of the query and the stored layouts in OCS database by comparing the semantic attributes – the name of a space, dimensions, relative positions, assigned topological relation, etc. Then, STR can retrieve cases with the similar topology and sort the similarities by the ranking results. Via STR's visual and instinct

manipulations, OCS can be a visual and interactive encoding and indexing tool for spatial topology. STR can then assist the designers in coding the existing design cases, indexing, and retrieving spatial topology of the design cases by searching and mapping functions of the OCS database, and further derive the similarities and differences among the retrieved cases.

3.4. THE IMPLEMENTATION OF STR

OCS is an online case library of house design cases, which is developed in MySQL rational database, PHP script language for server-side data accessing, and JavaScript for client-side interface. The semantic information of the case features and their semantic relations can be modified and extended in OCS by an ontology-based metadata-authoring tool. STR is developed to extend the representing and retrieving capabilities of OCS in the implicit topological knowledge.

Just like SLG, STR is developed in Processing, a simplified software IDE developed by MIT based on JAVA programming language for teaching fundamentals of the computer programming in the visual art and design education (Reas and Fry, 2007). Via a visual, interactive, Internet-ready interface and the MySQL database connective capabilities of Processing, STR thereby serves as a visual and interactive tool for encoding, representing, and retrieving the plane views of a design case within the OCS case library. A user can interpret a floor plan by drawing space objects, modifying dimensions and positions of spaces, assigning topological relations to spaces, and validating those relations (figure 1).

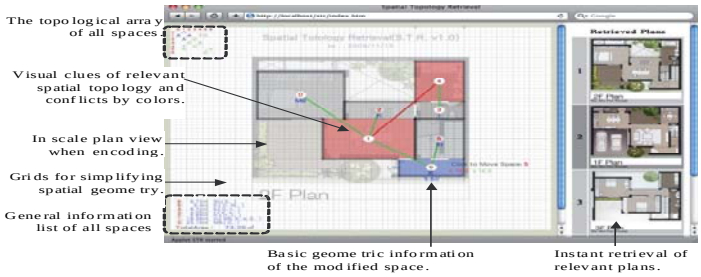

Figure 1. The interface of STR.

4. Conclusions

Case libraries developed by the database technology usually fail to help the users to be aware, then to acquire the implicit design knowledge such as spatial topological information of a design case. For students and beginners, a visual

and graphic tool is more satisfying than the complex textual and numeric indexing tables. Although the present BIM implementations may be very useful to digitalise the geometric and topological information of a building's physical components, most BIM implementations are still found deficient in the necessary spatial information model and effective algorithms for converting physical geometric information into spatial topology. As a result, a visual and graphic tool like STR emerges and should be able to assist a teacher or an expert in coding the existing design cases, indexing, and retrieving spatial topology of the relevant cases. Then, by applying searching and mapping functions of database technology, OCS can further derive the similarities and differences among the retrieved cases and help students and beginners to learn the implicit knowledge of spatial topology. Finally, assisted by STR, OCS is able to (1) derive the design patterns in the spatial topology of building types, such as the different types of local dwellings based on the entered cases, and thereby (2) assist the user in teaching or learning the design knowledge of the spatial layouts in relevant cases.

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References

Coulon, C. H.: 1995, Automatic indexing, retrieval and reuse of topologies in architectural layouts, *CAADFutures 1995*, Singapore, 557–586.

Eastman, C. M.: 1999, *Building product models: computer environments supporting design and construction*, CRC Press, Boca Raton.

Howell, I., and Batcheler, B.: 2005, Building information modelling two years later – huge potential, some success and several limitations retrieved, available from: LaiserinLetter <http://www.laiserin.com/features/bim/newforma_bim.pdf> (accessed 1 November 2009).

Hwang, J. E. and Choi, J. W.: 2003, SpaceScope: spatial content-based retrieval of architectural floor plans, *CAAD Futures 2003*, Tainan, Taiwan, 53–62.

Kolodner, J. L. and Leake, D. B.: 1996, A tutorial introduction to case-based reasoning, *in* D. B. Leake (ed.), *Case-based reasoning: experiences, lessons, and future directions*, MIT Press, Cambridge, 31–65.

Li, Y., Lertlakkhanakul, J., Lee, S. and Choi, J.: 2009, Design with space syntax analysis based on building information model: towards an interactive application of building information model in early design process, *CAAD Futures 2009*, Montreal, 501–514.

Lin, C. J.: 2005, Space layout game: an interactive game of space layout for teaching and representing design knowledge, *CAADRIA 2005*, New Delhi, 130–141.

Lin, C. J. and Chiu, M. L.: 2009, Open case study: an ontology-based case encoding tool for architecture design case study, *CAADRIA 2009*, Douliou, Taiwan, 393–440.

Reas, C. and Fry, B.: 2007, *Processing: a programming handbook for visual designers and artists*, MIT Press, Cambridge.

Steijns, Y. and A. Koutamanis: 2005, Representation and typological refinement in a case-base, *eCAADe 2005*, Lisbon, Portugal, 837–844.

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SCALABILITY

Parametric studies from exoskeletons to the city

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Abstract. This research will explore and provide an initial study into the diversity of contemporary computational design methodologies emerging in the field of architecture. It will rely on modern philosophical and mathematical ideas as a resource to integrate a seemingly disparate set of design techniques into a unified framework for architectural design. The explorations in this paper will demonstrate a preliminary study into various methods of operating across this framework through a series of parametric design experiments that span across multiple scales. The result indicates new techniques and skills that are becoming increasingly important for architectural design.

Keywords. Parametric; generative; systems; interface; design.

1. Background

This research is rooted in the domains of philosophy, mathematics and computation as they relate to new frontiers in architectural design. The research will draw on the philosophies of Deleuze (1987) and De Landa (2006, 2002), specifically the concepts of multiplicities and their relation to manifolds and dynamic theories. It will demonstrate an alternate way of understanding design, avoiding essentialism and objective qualities in exchange for design through morphogenetic processes and systems thinking. This will be linked to emerging computational techniques to create a process of design that embraces the virtual and the actual, in an attempt to understand design trajectories emerging in this field of design.

1.1. PHILOSOPHY, MATHEMATICS AND SCIENCE

Multiplicities are at the core of the philosophies of Deleuze. This research will both explain and explore the idea of a multiplicity, and its potential applications in an architectural context. The idea of a multiplicity contains traits evident in the closely related mathematical concept of manifolds. Manifolds belong to the discipline of differential geometry; an alternate geometric language to the traditional three-dimensional Cartesian space architecture typically operates in. The importance of this shift in language is the possibility of now studying geometry without any reference to a global space. Friedrich Gauss studied the two-dimensional manifold proving that a surface becomes a space in itself and can be studied entirely through local information without the need for a Cartesian description. His successor Bernhard Riemann successfully developed the more general notion of abstract n-dimensional surfaces or spaces.

To understand these abstract spaces relating to material objects or physical systems, we refer to theories of dynamical systems, where the manifold dimensions are used to represent various properties of a physical process. The dimensions map degrees of freedom, which are the relevant ways an object can change. Using differential calculus, we can capture the state of an object at any given single point in this n-dimensional manifold which can now be defined as a state space of possibilities for that object. The exciting potential of such representation is the ability of an object's state to change, describing trajectories of behaviour over time. Hence, the state space not only captures an object's instantaneous state, but how its properties can change over time; it captures processes. The processes, or trajectories, can be studied directly with the mathematical resources developed in the field of topology. In particular, we can study topological features called singularities which exist in manifolds that determine recurrent or typical behaviour common to many dynamic models and hence many physical systems. Depending on the initial conditions and the deterministic laws of the manifold, there will be a multitude of trajectories, each specifying a possible history of the physical system.

Critical to this research is the notion of progressive differentiation. To understand this theory, we need to rely on a separate field of mathematics; the theory of groups. Geometry can be transformed in various ways, and if this transformation leaves the object visually unchanged to an observer, we can state that it is invariant for this transformation. An object's degree of symmetry relates directly to its invariance, a sphere being more symmetrical than a cube under the rotational transformation. Describing an object by its degree of symmetry classifies an object relative to a transformation and not by its intrinsic properties. It is possible to imagine a process where the cube could become the sphere by losing invariance through a symmetry breaking transi-

tion. This form of transition is called a bifurcation and can apply directly to the topological singularities discussed previously.

An important revelation comes from Felix Klein who realized that all geometries known to him could be seen in a hierarchy, each level possessing more symmetry than the level below it. Hence the hierarchy of geometry (topological – differential – projective – affine – Euclidean), indicates that metric geometry emerges out of the topological and differential geometries of manifolds into real space. The undifferentiated intensive space of manifolds hence forms a real dimension of the world, a non-metric continuum that can progressively specify the discontinuous real spatial structures familiar to us in metric space through a series of symmetry breaking bifurcations.

1.2. PARAMETRIC DESIGN

The introduction of parametric associative modelling software into the field of architecture has instigated the opportunity to embed these theories into a new understanding of design. Parametric software empowers an ability to describe objects by parameters and relationships to each other. The designer has to consider design not as a static object, rather a flexible system that has varying degrees of freedom and the capacity to produce divergent possibilities. To construct an architectural system computationally, there needs to be consideration of the data structure (which will influence the search methodology); the degrees of freedom and parameters; the relationships between the parameters; methods of searching the solution space and criteria to evaluate the appropriateness of the solution.

A critical piece of the puzzle revolves around methods to search these complex solution spaces. Search algorithms are commonly studied in the field of computational science seemingly with a focus on search efficiency. The most basic search methods are uninformed and face difficulties when dealing with large search spaces. Terzidis (2006) describes a stochastic search procedure that randomly places objects within a site so there is no overlap. The process is inefficient and relies on chance; for a simple search space an uninformed solution will be less likely to produce an acceptable solution in comparison with more advanced techniques. To improve the search process, algorithms can incorporate heuristics and data structures that are easily traversed. For example, graphs are data structures that have a variety of search algorithms that have been explored extensively and appear commonly in most computer science literature. Frazer (1995) and Bentley (1999, 2002) describe an evolutionary approach to search algorithms, uniting the neo-Darwinian model of evolution with computer technology in an attempt to solve complex ill-defined problems. These algorithms differ from traditional search algo

rithms by considering populations of solutions at once. This methodology implements various types of genetic algorithms, all with an underlying architecture that allows the evolution of solution populations through the processes of reproduction, evaluation and selection.

Janssen (2004) makes a distinction between two modes of evolutionary design; parametric and generative. The parametric approach takes a predefined design and searches for optimal solutions by adjusting smaller parts which have been parameterised, hence systems that have strong relationships and minimal degrees of freedom. The generative approach is useful for complex ill-defined problems, relaxing the constraints and allowing a much larger search space with differing criteria in an attempt to produce novel or unpredictable results.

Janssen refers to the paradox that emerges from the two alternate approaches as the variability problem. As the criteria are relaxed, designs evolve that are unpredictable and creative but often unintelligible or difficult to evaluate. The parametric approach is useful for optimizing solutions; however it is unlikely to provide novel unpredictable solutions. I would argue that there is no formal difference between the two methods, simply a difference in the initial construction factors of the system; that is the degrees of freedom and strength of relationships between parameters. Focusing our attention to the logic of multiplicities, topology and dynamical systems may reveal more similarities between design methods. Hopefully this research will demonstrate that the divergent modes of design that are currently being explored are intrinsically linked via a virtual continuum. Understanding the relationship of existing designs and my own work to this virtual space could describe trajectories to provide clarity and an origin to a seemingly diverse and divergent set of working methods. This will provide an opportunity to see the field from a unique perspective and perhaps highlight potential future trends that will only be evident from this new viewpoint.

This paper describes three distinct parametric explorations conducted during the Masters of Digital Architecture at the University of Technology Sydney. The work is unique in the sense that it attempts to understand some very diverse design systems implemented across multiple scales through an all-encompassing framework, identifying a proposal for a unique understanding of architectural design. The key drivers for architectural design can be replaced by the degrees of freedom a particular system may have, the number of dimensions for the state space of possibilities, and the methods of designing and parsing through this virtual environment. It must be understood that the metric result or output of the system is intrinsically linked to the virtual realm of possibilities. This research will demonstrate various strategies for explor-

ing design across multiple scales and material systems. Each system will be discussed by describing both the logic of the virtual system and the associated metric forms. There will also be a dialogue about the various experimental techniques to search the complex design spaces that are now being presented to emerging designers.

2. System design

Following is a series of parametric explorations spanning multiple scales; from material systems to the city. These will demonstrate an initial attempt at understanding a logic and framework for design using virtual systems intertwined with various geometries as a methodology for architectural design. The key elements of this framework (figure 1) involve data storage capabilities, relationships (geometrical and data), user interface and methods to search the possible solution space. As these are a work in progress, the various case studies explore individual parts of this framework. With further progress, it is foreseeable that each of these case studies could implement the full framework.

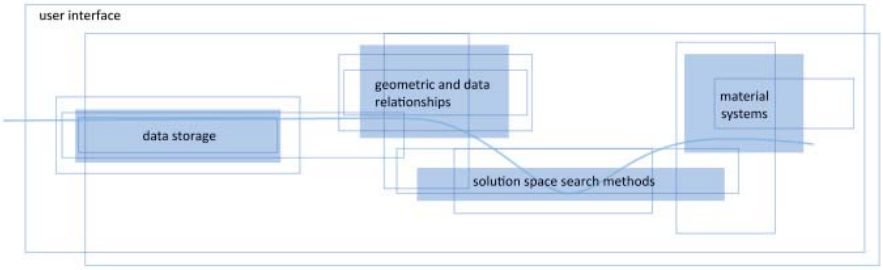

Figure 1. Design framework

2.1. EXOSKELETONS

The first system is constructed at the material scale; the metric reality becomes various facade exoskeletons primarily concerned with the control of environmental conditions through the manipulation and distribution of material across a building skin. A primary rig was constructed by modelling a series of deformable ribs with a network of fibres spanning between (figure 2). Each rib could be manipulated in multiple ways, including a change to the rib shape, rotation, number and density of fibre connection points and finally the scale of the rib. A typical system was constructed with multiple nested skins, each consisting of 15 ribs with six degrees of freedom, creating a large, complex state space of possibilities.

In order to intersect with the vast set of possibilities, a parameter control panel was setup which allowed the designer to manipulate the relevant param

eters for each rib. The methods of operating the system were to manually tweak the parameters to achieve a solution. This worked because there was a capacity to map the transformations to physical effects. For example, a rotation of one rib would enhance an exoskeleton's structural capacity by developing a diagrid formation. Increasing the radius of a rib would spread the fibers out, allowing more ventilation through the skin. Decreasing the density at various points would allow more visibility and daylight into the space. The result was a highly controllable exoskeleton that could be manipulated and adapted into a divergent set of environments (figure 3).

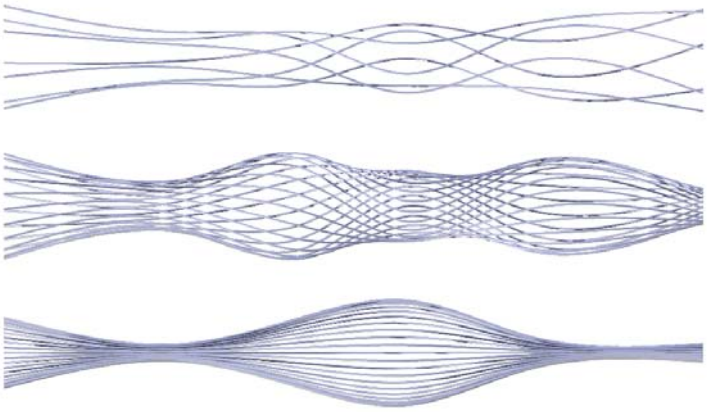

Figure 2. Parametric rig control.

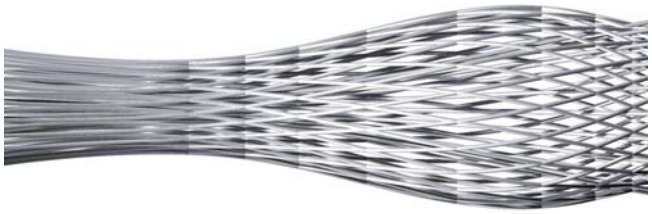

Figure 3. Exoskeleton design.

2.2. GENERATIVE MASSING MODELS

The second exploration is at the building scale, exploring the potential for parametric systems to assist in the planning stages of design. This exploration demonstrates that a more advanced yet similar logic to the first exploration can be used for building massing analysis and the generation of novel building designs. This exploration begins to also formalize this methodology for

design. The design is broken down computationally into the following functions: storage of data, generation of solutions, optimization of solutions and geometric design. The separation of these functions allows for a division of workflow and focus for division of skills when designing this way.

This exploration used Microsoft Excel for data storage. This also provided a user interface that would allow the user to determine the amount of rooms, dimensions, location constraints and various relationships between the elements of the building. This was intrinsically linked into the generation module, where the building design data was interpreted and encoded into Generative Components massing features (figure 4). Using the constraints, multiple solutions can be generated and checked against the initial requirements.

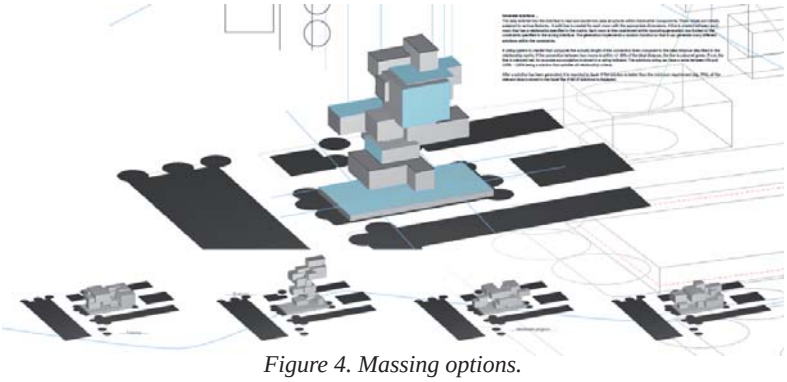

Figure 4. Massing options.

Preliminary optimization techniques were coded to increase the suitability of solutions. A locking mechanism was programmed to increasingly lock the positions of rooms that start to satisfy their requirements. The best solutions were then able to be saved into Excel spreadsheet for later viewing. The final stage was to embed an architectural language to the system. This is perhaps the most flexible stage, and is equivalent to the metric bifurcation of the virtual possibilities (figure 5).

Figure 5. Design options.

The system becomes more than the virtual manifestation of relationships; it becomes the metric object. Hence, the same initial system could be used to produce a divergent set of architectural designs. The metric emerges out of the virtual system.

2.3. URBAN PROXIMITIES

The final project explores the use of employing a similar framework for analysis purposes in the urban context. The task was to create an analysis tool that would produce a rated diagram of building sites based on multiple criteria. The initial driver for the project was to locate a site in Sydney that embodies a conflation of the surrounding city. The approach was to identify the important nodes of the city and develop a system to compare each building to the proximity of these nodes (figure 6).

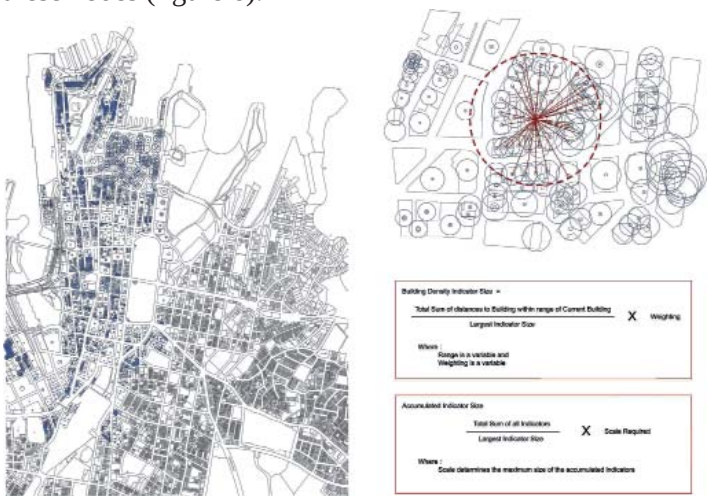

Figure 6. Node proximities.

The initial node data included train stations, bus stops, green space and building density. An advantage of using Generative Components was the ability to convert an entire map of the city into workable objects which could embed relationships. A custom function was designed to calculate a weighted response of each building to the distance from the various nodes. Once multiple criteria are integrated, the result is a unique diagram of the city tailored to the search requirements for your site.

This exploration implemented parts of the emerging design framework. Data storage and generation of solutions were critical in this work. The tool did not require a metric output, so the output was purely a representation of the virtual relationships and connections between components of the city.

3. Conclusion

The three projects outlined in this paper attempt to piece together a series of case studies with a priority of positioning them within a unified understanding of parametric design methods. The explorations demonstrate that a consist-

ency in logic has been applied to a variety of scales and design requirements. Parametric design tools have proven to be an ideal tool for the construction of both metric and virtual spaces. This methodology of design allows the virtual and metric components to be developed separately yet be intrinsically related. More importantly, this paper has identified new skills and techniques that are becoming increasingly relevant in the design profession, including the need to understand data storage, search algorithms and system design.

References

Bentley, P. (ed.).: 1999, *Evolutionary design by computers,* Morgan Kaufmann, San Francisco.

Bentley, P., and Corne, D. W. (eds.): 2002, *Creative evolutionary systems,* Morgan Kaufmann, San Francisco.

Deleuze, G. and Guattari, F.: 1987, *A thousand plateaus – capitalism and schizophrenia*, University of Minnesota Press, Minneapolis.

De Landa, M.: 2006, *A new philosophy of society: assemblage theory and social complexity,* Continuum, London.

De Landa, M.: 2002, *Intensive science and virtual philosophy,* Continuum, London.

Frazer, J. H.: 1995, *An evolutionary architecture,* AA Publications, London.

Janssen, P. H. T.: 2004, A design method and computational architecture for generating and evolving building designs, PhD thesis, School of Design, Hong Kong Polytechnic University.

Terzidis, K.: 2006, *Algorithmic architecture,* Architectural Press, Oxford.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010*, 165–174. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

AUTOMATIC PLANNING OF RESIDENTIAL QUARTER UNDER INSOLATION CONDITION BASED ON MULTI-AGENT SIMULATION

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Abstract. Based on multi-agent simulation principle, this study establishes an automatic layout model for planning residential buildings under the constraint of insolation condition, programmed with NetLogo. According to the residential planning regulations, our model respectively deals with two kinds of constraint: sunshine spacing and sunshine duration.

Keywords. Residential planning; multi-agent simulation; NetLogo; sunshine spacing; sunshine duration.

1. Introduction

Residential quarter planning usually confronts many interrelated problems such as apartment type, floor area ratio, green space, sunlight, as well as form and other design targets, in which insolation standard is a basic and usually a critical constraint. In conventional planning process, the designer usually makes one or several preliminary layouts first based on his understanding of the planning requirements and his premeditated targets, then checks whether the requirements are satisfied. If not, the layout(s) will be adjusted through changing the state of planned objects and checked again, until solutions meet all the requirements and targets. Otherwise, the designer should conceive new preliminary layout(s) and run the process again. Such repeated trial-and-error process is suitable for computational program to do, which can evolve at least the preliminary layouts that meet the requirements or produce satisfactory solutions for the designer to refer.

The trial-and-error process of design can be alternatively regarded as a self adaption process by design elements through the rules of behavior of the indi-

vidual elements as well as the interactions between them. Although the objects in residential quarter planning, such as housing buildings, road system, green spaces, and public buildings, are not active subjects, in planning process the designer's operations such as changing dimensions, rotating, and moving can be transferred to behaviors of the planning objects, so that the process of planning can be seen as the process in which planning objects change their attributes to search the solutions of planning targets. In this way we can apply the principle of multi-agent simulation to develop a computational device to automatically generate residential quarter plans.

The application of multi-agent systems in architecture and urban planning area is quite new, mainly in two directions: (1) simulation of human behavior in built environment, and (2) simulation of the evolution of cities or habitats. The typical examples include the study on the phenomena of pedestrians by Center for Advanced Spatial Analysis at University College, London (Castle and Crooks, 1994; Batty, 2003), the simulated city model developed by Northwestern University and Illinois Institute of Technology (Lechner et al., 2004; Lechner et al., 2006), and so on. Recently a number of studies applying agent simulation in computational architectural and urban design have been published (Krause, 1997; Testa et al., 2000; Canepara et al., 2005), which discuss various problems of building agent simulations for design.

Li Biao's work (2007, 2008) demonstrated the use of multi-agent simulation in dealing with special concrete problems in design and planning. His model of "HighFar" (Li et al., 2008) developed an automatic mechanism for searching high density residential quarter layouts. But the model was still rough: the buildings were abstracted to circles and various situations of sun shadow were not fully considered.

Our study is a sort of amelioration of the model. This paper introduces our efforts in using the principle of multi-agent simulation to develop a system of automatic planning for residential quarter. We take the problem of sunshine as case study, currently using NetLogo as experimental platform.

2. Definition of housing plan and site plan

NetLogo is a multi-agent programming language and integrated modeling environment developed by Northwestern University's Center for Connected Learning and Computer-Based Modeling. In NetLogo, there are three types of agents: turtles, patches, and the observer. Turtles are agents that move around in the "world". The "world" is two dimensional and is divided up into a grid of patches. Each patch is a square piece of "ground" over which turtles can move. The observer can control turtles and patches through codes.

Because geometrical objects are not well supported in the "world" of NetLogo, we have to find alternative ways to describe them. We abstract the housing building plan to a rectangle, setting 5 synchronous turtles respectively located on the central point and the four corner points to define the plan. The central turtle is the positioning base, and the position of the corner turtles are calculated with the width and the depth of the building plan. The lines connecting corner points are figured by links, which are special turtles in line shape, to indicate the outline of the building (figure 1).

The housing buildings must be planned in a certain confine of a site. We define the site in NetLogo using the attributes of patches. In the planning process, a housing plan defined as agents can distinguish whether it is inside the site through the attribute of the patches underneath.

3. Automatic planning under the constraint of sunshine spacing

3.1. THE CONTROLLING METHOD FOR THE CONSTRAINT OF SUNSHINE SPACING

The minimum row distance between housing buildings can be calculated through the coefficient of sunshine spacing, and the minimum fireproofing spacing between buildings which is basically a constant. In this case, we can assume that there is a forbidden area around each housing building that other buildings should not intersect. As Figure 2 shows, this area is defined by the width of the building, the height of the building and the coefficient of sunshine spacing, as well as the fireproofing spacing.

When the shapes of the buildings are the same and the buildings are facing same direction, the relationship between two buildings has four situations shown in Figure 3. The distances between two buildings' east-west walls and south-north walls can be calculated through the coordinates of the central turtles with the width and the depth of the buildings as well as the orientation angle. Based on the distances, the system judges whether there are other buildings in the forbidden area of a building. If yes, the building will move toenlarge the distance to the other buildings. This process is programmed in the procedure Position-Searching, based on the rules of OPEN-MIN, OPEN-

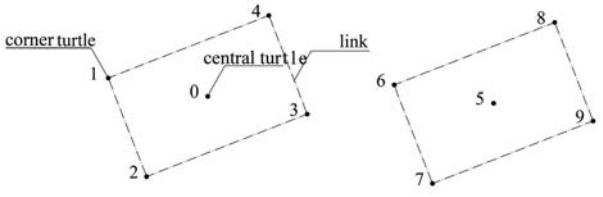

Figure 1. The abstract plan defined through turtles.

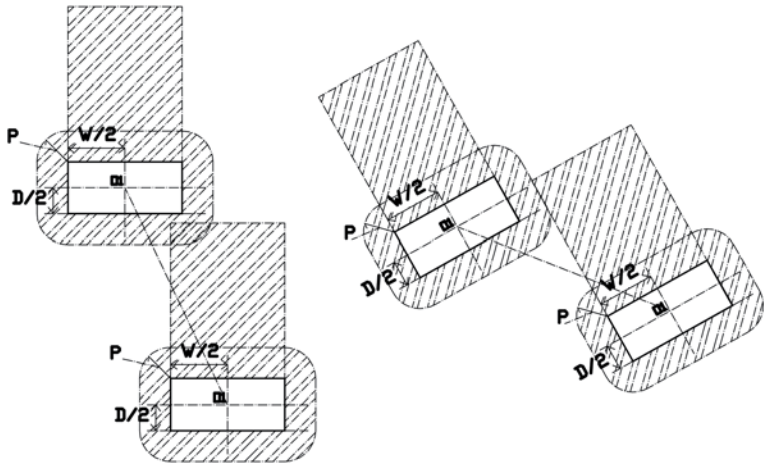

Figure 2. The forbidden area of a building.

MIN-MAX, and RANDOM-AWAY of the Scattering Model published on NetLogo home page (Wilensky, 1998). Two searching methods have been tested: (1) finding out the nearest building and moving in reverse to the direction connecting the central turtles of the two buildings, and (2) calculating the average coordinates of all the buildings in the forbidden area and moving in reverse to the direction connecting the central turtle to the point of the average coordinates of those buildings' central turtles. The former is faster in each step calculation, while the latter is better in mastering overall situation and its total

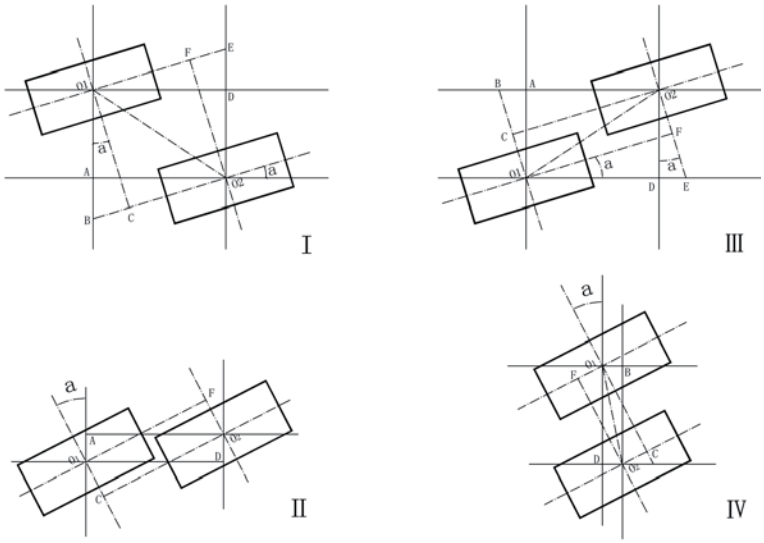

Figure 3. The relations between two buildings.

times of calculation is less. If the building moves out of the site, a procedure will be called to put it randomly inside.

3.2. PLANNING OF DIFFERENT-SHAPED BUILDINGS

A housing quarter normally has more than one type of housing buildings. In the case of the planning of multi-floor housing buildings, the forbidden area of each type of building varies according to its plan size and height. Our system has considered the mixture of two types of buildings, dividing the sunshine obstruction into four situations: Type A building(s) shading a Type A building, Type A building(s) shading a Type B building, Type B building(s) shading a Type A building, and Type B building(s) shading a Type B building. Accordingly we store the Type A building(s) in the forbidden area of a Type A building in the set A-A, and use the sets A-B, B-A and B-B for the other situations respectively. Figure 4 shows the flow of position-searching.

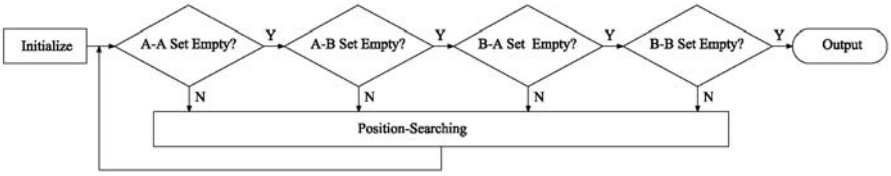

Figure 4. Flow of position-searching for the mixture of two types of buildings.

3.3. PARAMETERS, INTERFACE AND RESULTS

The parameters of the system of automatic planning under the constraint of sunshine spacing include the number of housing buildings, the width, depth, number of floors, and height between floors of the buildings, as well as the minimum fireproofing spacing, the coefficient of sunshine spacing, the orientation angle, the pace that the buildings move, and the initial distributing range of the buildings. Figure 5 shows the interface of the system. The user firstly clicks the "Edit" button to input the coordinates of site border, uses the sliders to adjust the parameters, clicks "Setup" to initialise, and then clicks the "planning" button to start the process to find out the layout that satisfy the constraint of sunshine spacing. The user can activate the "click nodes" button and then drag housing buildings to new positions to intervene in the process, or click the "planning" button to pause the process at any time. Figure 6 shows two results of the same parameters shown in figure 5: the site is 200 by 100 meters, in which there are 20 housing buildings of 55 by 9 meters and 25 buildings of 38 by 13 meters; and the buildings are facing 10 degrees east of south.

4. Automatic planning under the constraint of sunshine duration

The above system can be only applied in the planning of multi-floor housing buildings, while the automatic planning system based on sunshine duration is more universal because the Code for Planning and Design on Urban Residential Areas of P.R. China expressly stipulates the sunshine duration of housing on the day of Mid Winter (approx. Dec 22) or the day of Great Cold (approx. Jan 20), and the coefficient of sunshine spacing is a substitute of sunshine duration specially for the planning of multi-floor housing buildings.

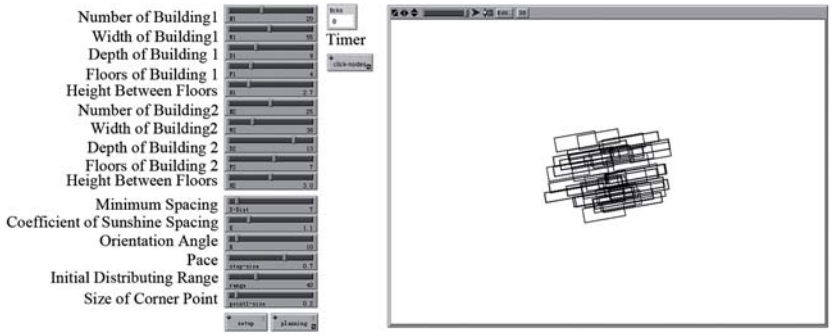

Figure 5. The interface of the system of automatic planning under the constraint of sunshine spacing.

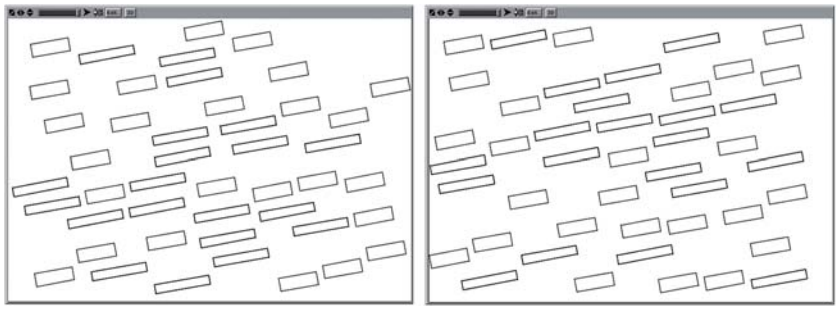

Figure 6. Two results of the same parameters shown in figure 5.

4.1. ACCUMULATIVE SHADOW DURATION

The sunshine duration of a building is actually the sunshine duration of the ground where the building is located. The sunshine duration of a piece of ground of a certain day is the sunshine duration of the day minus the duration that building(s) cast shadow on it. To calculate the shadow duration of the ground, we divide it into grid and divide the valid sunshine time into short periods, then calculate the accumulative shadow duration of each grid unit.

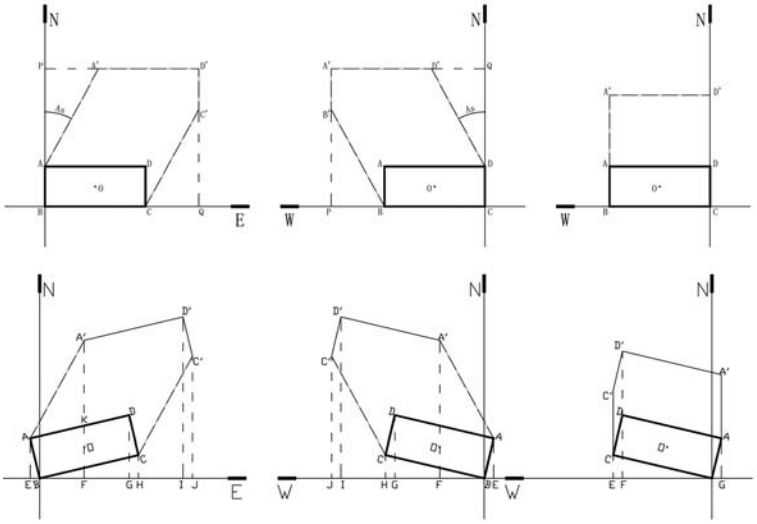

Figure 7. The shadow area casted by a building

The shadow area cast by a building at a certain time can be calculated through sun's azimuth and altitude, as well as the dimensions of the building. The question then becomes one of judging whether a point (patch) is inside a polygon (shadow) at a certain time.

As figure 7 shows, the shadow area is the concave Polygon AA′D′C′CD or ABB′A′D′D. In order to reduce the difficulty, we subdivided the concave polygon into two convex polygons, for example, dividing AA′D′C′CD into AA′D′D and DD′C′C. To determine a point inside or outside a convex polygon, first calculate the vector distances of the point to each edge, then compare the signs of the vector distances: only if all are positive or all are negative, the point is inside the polygon.

We use the patches' attribute Color to record the calculation result of each time period. Firstly we initialise the Color with a certain value. After each calculation, the value of Color of every patch that is inside shadow will be added 0.1, if the time period division is 10 minutes. At last the Color of the patches represents the accumulative shadow duration of the ground.

4.2. ACCUMULATIVE SHADOW DURATION CAUSED BY MORE THAN ONE BUILDING

When the shadow areas caused by more than one building overlap, the shadow duration of a patch cannot be simply accumulated. If the two buildings cast shadows on the same patches at the same time, the shadow duration of the patches should be added once rather than twice, otherwise it will cause error.

To solve the problem, we add the variant Shadow-Time for each patch to record the time list of shadow. When calculating the shadow caused by a building of a certain time, if the time list of a patch already contains the time, whether the patch is in shadow will not be calculated so that the total duration of the patch will not be added incorrectly.

4.3. POSITION-SEARCHING PROCESS

After the overall calculation, the housing buildings will check the total sunshine duration of the patches underneath to decide whether to enter the Position-Searching process, which is similar to that introduced in Section 2.

Because the calculation of the accumulative shadow duration of each patch is relatively slow, position-searching process will take a long time if it starts from a randomised distribution of housing buildings, which is the situation when the system starts. Hence after the initialisation, we start a procedure that the buildings move to make the distance between them bigger than the minimum fireproofing space, followed by the Position-Searching process for satisfying the constraint of sunshine duration.

4.4. PARAMETERS, INTERFACE AND RESULTS

The system of automatic planning under the constraint of sunshine duration has similar parameters to those under the constraint of sunshine spacing. The constraint of sunshine duration in current version was set as constants in the programming according to the condition of Nanjing, China.

Figure 8 shows the interface, and the usage is similar to the previous system. At anytime the user can click the “SUN-Calculate” button to calculate the sunshine situation of the time. Clicking the “MARK-SUM_TIME” button will shade the patches in color according to their sunshine duration. Figure 9 shows two results of the same parameters shown in figure 8.

5. Further work

The numerous and complicated results presented by the model based on the idea of multi-agent simulation are the outcomes of actions and interactions of agents. Such system reflects the complex phenomena of the real objects, whereas the model does not need to be complex. This idea related to complex systems is able to jump out of the increasingly complex analytical framework, indicating a new way of thinking. Similarly, the automatic problem-solving for residential planning is difficult to achieve using the conventional idea of analytical calculation, while in multi-agent simulation framework; the model can be established with relatively simple mathematical approaches.

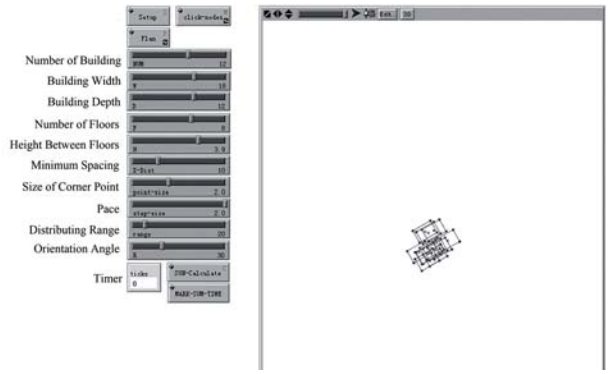

Figure 8. The interface of the system of automatic planning under the constraint of sunshine duration.

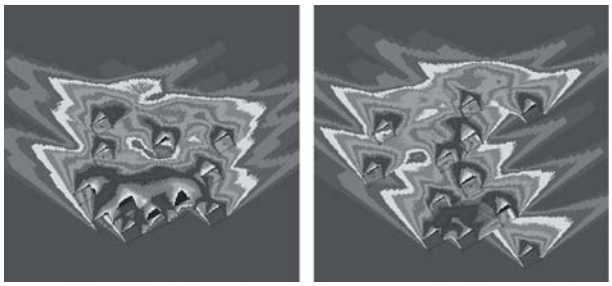

Figure 9. Two results of the same parameters shown in Figure 8, with colour shading indicating the time duration.

What we have shown is merely a test of computer-generated design, which applied the multi-agent simulation platform NetLogo to make automatic planning of residential quarter under insolation conditions. The establishment of data structure, the optimisation of algorithm, and the realisation of program in transforming architectural problems to computational models has been our key concern. It represents just a basic framework, in which a number of problems, such as the non-parallel layout of buildings, the shape of site, the interplay of the constraints of sunshine spacing and duration, the mixture of various planning objects, and so forth, have yet to be considered. Additionally, the algorithm to calculate shadows, which is very crucial for the system speed, will be our next focus in the research. Moreover, the buildings as agents in our system now only have the behavior of position-searching. Their orientations, height and other attributes are still parameters to be set by the user. Our further work will add behaviors of the agents so that they can change those attributes in the problem-solving process. Finally we hope the system will be developed as application software that can be used in the practice of residential planning.

References

Batty, M.: 2003, Agent-based pedestrian modelling, available from: Open Source Repository < http://www.casa.ucl.ac.uk/publications/workingpapers.asp> (accessed April 2007).

Caneparo L., Masala E. and Robiglio M.: 2005, Dynamic generative modelling system for urban and regional design, *The 11th International Conference on Computer Aided Architectural Design Futures*, Vienna, 259–268.

Castle,C. J. E. and Crooks, A. T.: 2006, Principles and concepts of agent-based modelling for developing geospatial simulations, available from: Open Source Repository <http://www.casa.ucl.ac.uk/publications/workingpapers.asp> (accessed April 2007).

Krause, J.: 1997, Agent generated architecture: design and representation, *ACADIA '97*, Cincinnati, 63–70.

Lechner, T., Watson, B., Wilensky, U., and Felsen, M.: 2004, Procedural city modelling, available from: Open Source Repository <http://ccl.northwestern.edu/papers/> (accessed April 2007).

Lechner, T., Watson, B., Ren, P., Wilensky, U., Tisue, S. and Felsen, M.: 2006, Procedural modeling of urban land use, available from: Open Source Repository <http://ccl.northwestern.edu/papers/> (accessed November 2009).

Li, B.: 2007, A generic house design system: expertise of architectural plan generating, *CAADRIA 2007,* Nanjing, 191–198.

Li, B., Li, R., Xue, K., Liu, C., and Gao, Q.: 2008, A generative tool base on multi-agent system: algorithm of "HighFAR" and its computer programming, *CAADRIA 2008,* Chiang Mai, 335–342.

Testa, P., O'Reilly, U.-M. and Greenwold, S.: 2000, AGENCY GP: genetic programming for architectural design, eternity, infinity and virtuality in architecture, *The 22nd Annual Conference of the Association for Computer-Aided Design in Architecture*, Washington, D. C., 227–231.

Wilensky, U.: 1998, NetLogo scattering model, available from: <http://ccl.northwestern.edu/netlogo/models/Scattering> (accessed April 2007).

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010*, 175–183. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

FLOATING BUBBLES

An agent-based system for layout planning

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Abstract. This program converts bubble diagram into an agent-based system for architectural design. The program suggests a model for layout planning based on bubble diagram which explicitly describes the adjacency requirements in architecture. Generally there is a basic set of rules for every agent dealing with adjacency topology and also an alternative set for other objectives. Then this basic program is developed into several generative tools for different design tasks. They imply that the agent-based system is efficient for elementary spatial arrangement and it could generate a wide range of complex solutions.

Keywords. Agent-based modeling; layout planning; bubble diagram.

1. Introduction

"Floating bubble" program comes from the bubble diagram, however, its mechanism differs from the conventional ways in which architects use the diagram in design. The main feature of bubble diagram is that it extracts adjacency requirements out of numerous objectives and constraints in architectures and it illustrates the specifications by 2D graphs which could be easily understood. The floating bubble program does follow the two features of the bubble diagram, while the primary purpose of the program is to produce complex forms with restrictions.

The program actually converts the bubble diagram into an agent-based system through programming. It is not only a research on methods but also oriented to architectural design practices which demand efficiency and flexibility. The program reproduced master plans for a research on Chinese tra-

ditional courtyards and also yielded a series of solutions with corresponding 3D-models in *Clouds Collective* project (figure 1). These projects imply the agent-based system can evolve into a basic model for layout planning and it offers unpredictable diversity in solutions.

Figure 1. Clouds Collective project.

2. Backgrounds

By means of computation there are a wide range of methods to generate layouts according to the adjacent relationships between rooms. One method is optimisation on the basis of state space search, for instance, the approach to "optimum layout of single-storey building" by Peter Manning and the programs by Whitehead and Eldars. They usually work on a data structure representing a range of solutions on regular grids and search for a best state employing special strategies. William Mitchell termed these methods with "automated spatial synthesis" in his *Computer-aided architectural design* (1977) which offers a list of strategies: generate and test, heuristic search procedures, analytical procedures, etc. Actually many of them were not always competent except for using advanced algorithms such as genetic algorithm. While the IMAGE system (Weinzapfel and Handel, 1975) discussed in the book (figure 2) may connect to many contemporary concepts such as agent-based modeling, evolution strategy and being self-adaptive.

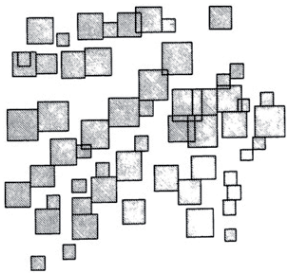

Figure 2. IMAGE system by Weinzapfel and Handel, 1975.

In fact this alternative method is similar to an active bubble diagram. Significantly, bubble diagram has indicated that layout planning task can be divided into the arrangements of relationships between one bubble (room) and another, a "divide and conquer" strategy. Thus a direct method for layout

planning is to construct a dynamic system in which every bubble floats for its own adjacency configurations. Here comes the method of agent-based modeling. It's a little surprising that the primary advantage of the method is not the efficiency on solving the adjacency problem but is the potential of producing complex forms since it extracts order from chaotic initialisation.

3. Basic model of floating bubble

As an agent-based concept the system is made up of autonomous agents, each of them (in a bubble shape) presents a room (or a space extent). Furthermore, every bubble carries its own adjacency configurations as well as its specified area. A square matrix is employed to hold all adjacency information. Every element a_{ij} in the matrix can hold a Boolean value which denotes "whether bubble i needs to be adjacent to bubble j." Whereas a_{ij} can also hold a real number indicating different levels of adjacency.

The system exposes adjacency relationships explicitly just as bubble diagram: a line connecting a pair of bubbles means the two bubbles should be next to each other; otherwise the system doesn't concern the relationship between them. These connections could also be weighted then the bubble diagram becomes a weighted graph.

Boolean values are used to describe the connections with bubbles (value of "true" denotes "two bubbles need to be adjacent" and there will be a line connecting them, figure 3) in the basic floating bubble program. This data structure helps connection lines to examine the current adjacent situation (see figure 3, wide black connection lines suggest two bubbles have not been adjacent, gray ones already adjacent) and to witness the history of adjacent situations. (The history is essential for adding perturbation to the system when it's stuck).

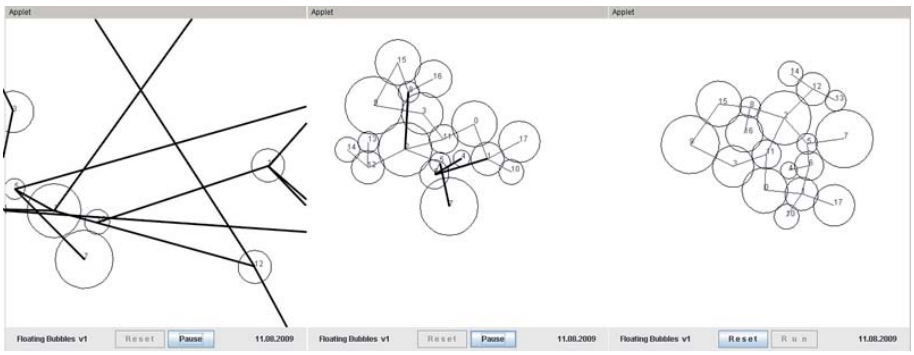

Figure 3. Three stages in the basic floating bubble system.

In the dynamic system showed above, every bubble behaves based on its own rules in a changing environment composed by other bubbles. The system is initialised randomly (first picture in figure 3) and will not stop evolving until all connection lines turn to gray (which means all of the adjacency requirements are satisfied, see the third picture in figure 3). This programming approach makes the bubble diagram live and subsequently make the program be easier to be understood compared with many other complicated spatial synthesis solutions. While it's must be emphasised that this program doesn't only aims to solve spatial problem but also to exploit the diversity of the forms resulting from the adjacent configurations.

Most generally, all the rules for agents lie in two main categories: a basic set of rules dealing with adjacency topology and an alternative set for other specified objectives.

The basic set is the essence of the system. The principle is to generate a structure emerging from "unfixed but stable" balance between several forces. Thus there must be at least two types of "forces": one drives a bubble moving towards other bubbles that it must be adjacent to; the other keeps an agent not overlapped with all other ones. The two forces are against each other, however, they are the very source building a system contributing to an unpredictable structure (layout) when it reaches equilibrium.

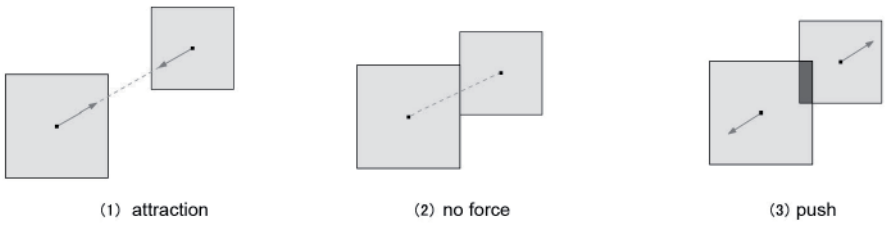

Figure 4. Forces betweens agents.

Two types of forces (attraction and push) are illustrated in Figure 4 (instead of circles, rectangles are used to present the extents of the agents). As is shown in the figure, attraction force drives two agents to be closer, more rigorously, a vector corresponding to an agent moves in this way:

$$\partial V_i / \partial t = k a_{ij}[(s-1)V_i + (1-s)V_j] \quad (1)$$

V_i and V_j are the vectors describing the positions of agent i and agent j respectively, a_{ij} denotes the weight of the connection between the two agent ($a_{ij} = 0$ means that the two agents needn't to be adjacent then there will be no attraction between them), k is a positive constant. Notice that if $s = 0$ then equation (1) becomes:

$$\partial V_i / \partial t = ka_{ij}(V_j - V_i) \quad (2)$$

In this case the attraction force will not vanish until the two vectors of a pair of agents are equal. We can also make the forces disappear once the two agents touch each other, just assign a special value to s:

$$s = (r_i + r_j) / ||V_i - V_j|| \quad (3)$$

r_i and r_j denote the corresponding radiuses of the two agents.

The equations above just take account of one of the adjacency requirements of agent i, the overall effect on the vector is:

$$\partial V_i / \partial t = \sum^n_{j=1} ka_{ij}[(s_{ij} - 1)V_i + (1 - s_{ij})V_j] \quad (4)$$

s_{ij} is the same item as the s in (1), while it is unique to every pair of agents.

On the other hand the push effect on the agent i can be described as:

$$\partial V_i / \partial t = lS\,(V_i - V_j) / ||V_j - V_i|| \quad (5)$$

S equals to the area in which a pair of agents overlap and l is a positive constant. We can see that there are both attraction and push forces for the bubbles in the same time; this is a key characteristic making the agent system evolve towards balance.

4. Improved model

Unfortunately the original system seldom works for it always gets "stuck": all the bubbles stop moving but some adjacency requirements are still not satisfied. In other words, the system always becomes "mature" before it develops its form adequately. Figure 5 shows this situation according to eight independent executions of the system: horizontal axis is the time axis and vertical value denotes the current number of unsatisfied adjacency requirements in the system.

This disadvantage can be considered as an innate consequence of the mechanisms of the agent system. Notice that all agents are moving for themselves (local optima) then it's reasonable that global target is difficult to be hit. It is a fatal problem since the system never satisfies all the requirements during dozens of executions.

One method to solve this problem is to introduce mutation, or perturbation into the system, which is guided by the "memory" of wide black lines (presents unsatisfied adjacency requirements, see figure 3). If one adjacency requirement stays unsatisfied for a long time then it drives one connected agent jumping towards another connected agent. This action breaks the current balance and usually brings chaos to the system, however, it creates

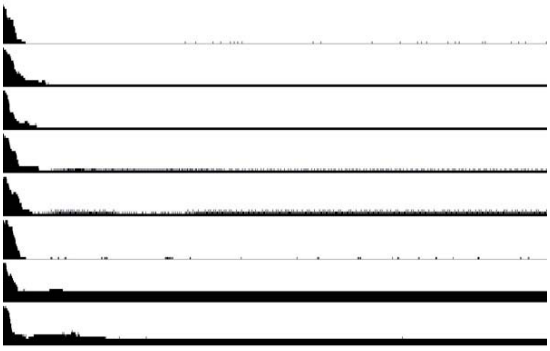

Figure 5. Records of eight executions of the original program. Horizontal axis is the time axis and vertical value denotes the current number of unsatisfied adjacency requirements in the system.

vital opportunities for the whole system to get out of stuck situation. This mechanism also contributes to the complex forms of the final solutions.

As is shown in figure 6 there are many disturbances in the number of unsatisfied requirements compared with the flat patterns in figure 5. The new pattern indicates that the system is struggling between local and global objectives, is breaking balances and making gradual achievements. The result is that the improved system is always able to reach equilibrium though the processes take more time.

5. Alternative systems

The system demands an alternative set of rules dealing with a wide range of particular requirements besides adjacency issue, for instance, some principles in plans of Chinese traditional courtyards.

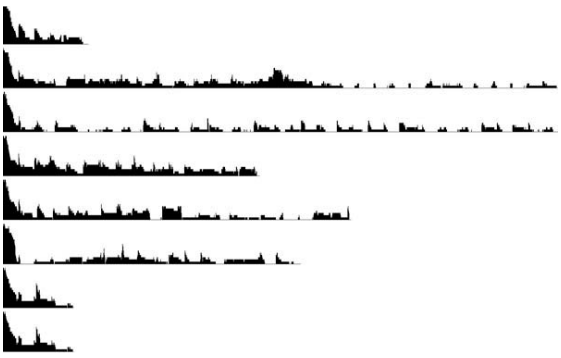

Figure 6. Records of the improved program.

Figure 7. Courtyards in Dali, China (http://blog.sina.com.cn/s/reader_4c8dfded01000e9b.html, 2008-09-18).

In spite of a great number of different types of courtyards in China, there are several common rules in planning, for example, primary courtyards are usually located around the center of a cluster of courtyards, which is consistent with traditional ethic culture. So new rules are added to the alternative set to make "important" courtyards much easier to get a central location than other ones. Usually the new rules are not opposite to basic rules, while it's necessary to negotiate between the two sets of rules to improve the performance of the system.

In another project, Clouds Collective, the system arranges spatial structure in a two-storey museum design. The rules in the alternative set deal with relationships between the rooms in different layers. For example, the two main exhibition halls in two layers are supposed to be overlapped (in top view) to get a vast space.

In addition, a BIM solution (Autodesk Revit) is connected to this system via Revit API for an integrated design flow: First, models of elements are created and modified in Revit manually (figure 10), then these models are imported into the bubble system; after the system gets a solution, the plan and 3D model of the solution are produced automatically (figures 11, 12).

Employing this method every agent in the system holds full 3D information. This project suggests a design mode that designers can both work with

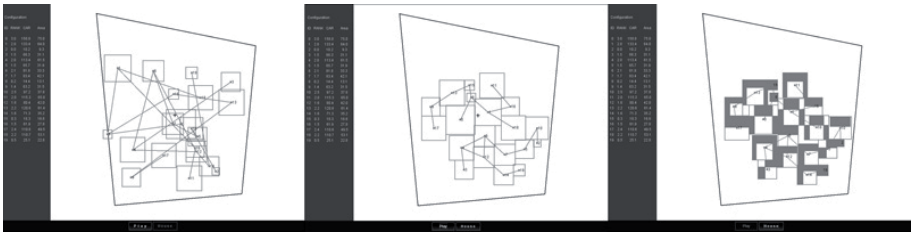

Figure 8. Three stages of the generative process.

their modeling software and benefit from automated spatial arrangement of generative system.

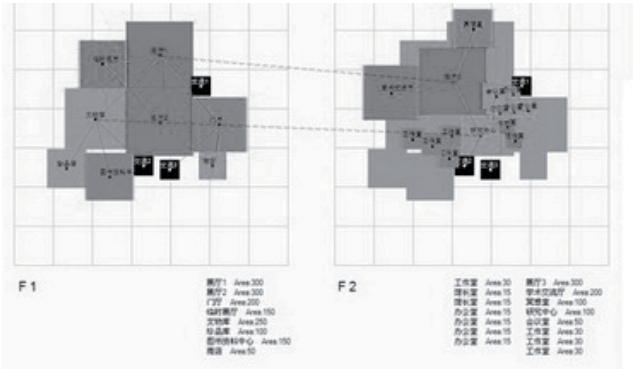

Figure 9. Two-storey layout arrangement, Clouds Collective project.

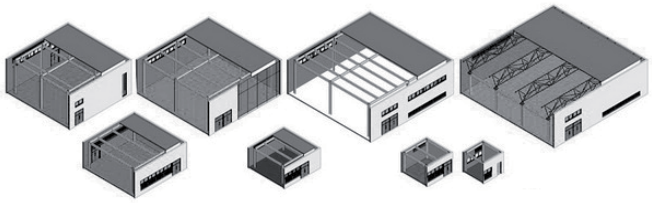

Figure 10. Modes of elements by Revit.

6. Conclusion

These applications stemming from the basic floating bubble system indicate that efficient is agent-based system for layout planning in terms of adjacency topology. Moreover, these systems don't lose the compatibility to combine other objectives such as transportation, shape constraints, space order and so on. As a result, more generative tools can be developed from the basic float-

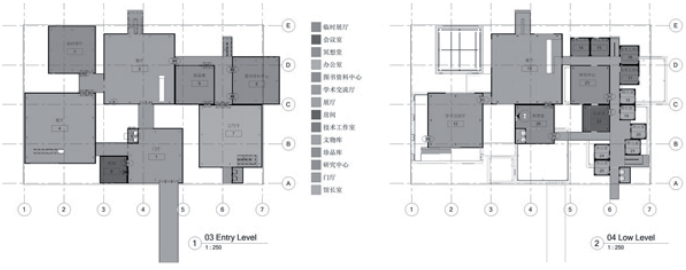

Figure 11. Plans of a solution.

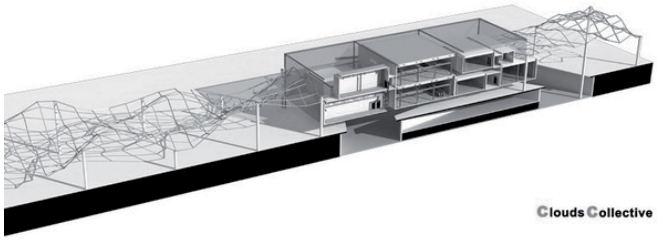

Figure 12. 3-D model of the solution.

ing bubble system. It is also reasonable that other agent-based programs could take the rules from bubble system as an attachment to their own systems, for it is sometimes true that adjacency issue is not the concentration of architects but a basic consideration in designs.

After all, in contrast to classic methods of searching a good state base on grids, floating bubble system leads to diversity rather than deterministic solutions, and towards complexity rather than finite forms.

References

Hensel M. and Menges A.: 2008, *Versatility and vicissitude: performance in morpho-ecological design,* Wiley-Academy, London.

Li, B.: 2007, A generic house design system based on multiagents: expertise of generating architectural plan, in G. Yu, Q. Zhou and W. Dong (edss), *CAADRIA 2007,* Nanjing, 191–198.

Manning, P.: 1964, An approach to the optimum layout of single-storey buildings, *The architect's journal information library,* **17**, 1373–1380.

Mitchell, William John.: 1977, *Computer-aided architectural design,* Van Nostrand Reinhold, New York, 425–474.

Ruch, J.: 1978, Interactive space layout: a graph theoretical approach, *Design automation conference proceedings 15,* IEEE/ACM, SIGDA, 152–157.

Weinzapfel, G. and Handel, S.: 1975, IMAGE: computer assistant for architectural design, *in* C. Eastman (ed.), *Spatial synthesis in computer-aided building design,* Wiley, New York, 61–68.

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SHAPING BUILDING VOLUMES THROUGH LIFE CYCLE COSTS

A constraint programming approach for building volume optimisation

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Abstract. Due to a general freedom in the architectural design process, a wide range of possible alternatives exist; although building-volume designs must also continue to meet numerous, possibly conflicting design requirements originating from various related disciplines. This research addresses problems associated with missing quantitative design aids during the early design stages. It aims to provide designers with solutions that provide optimal cost-effectiveness. The demonstrated building-volume optimisation model minimises life cycle costs by determining optimal-volume dimensions, floor number, building orientation and 'window / wall' opening ratios while satisfying site and building code regulations and design constraints. Results indicate an optimal solution can be found within a practical timeframe. The proposed, novel approach to introduce cost objectives into building-volume design provides designers with a valuable decision support tool in a design domain that is known to be complex owing to multiple design criteria and constraint influences.

Keywords: Decision support; design optimisation; building volume design; life cycle costs and constraint-based design.

1. Introduction

The presented research focuses on the development of a decision support tool for a building-volume optimisation (BVO) model by considering life cycle costs (LCC) as a design objective. The model embeds exterior constraints for building volume design such as site criteria, building code regulations and suggested floor-area boundaries. These are associated with relevant cost declarations over a given study period. Thus, the BVO model not only guarantees constraint fulfillment that determines building volume validity, but also allows an insight into the relationship between building volume design and its relevant costs.

Using a constraint programming technique, BVO through life cycle costs has been established and investigated. The visual, three-dimensional display of optimal or feasible test-result solutions allows for the establishment of a more effective understanding of the BVO model results.

2. Literature review

Scientifically, the design process is understood to be a procedure involving problem definition and solution finding (Rittel et al., 1973). Hence, a common methodology during the architectural programming phase is to develop a design by describing the objectives of what it is expected to be accomplished and by establishing constraints marking possible solution limitations (Gross, 1985). When considering design as a computer-based process, design objectives are often excluded from an automated approach. Instead, processed design solution alternatives remain for later consideration and evaluation by the designer.

Donath and Gonzales (2006) introduced a “building-bulk” design support using a constraint-based, design-declaration method. Likewise, by introducing a “massing-study support,” used with a commercial software package, Donath and Lobos (2008) attempted to find feasible solutions by implementing criteria-satisfaction in their approach to solving building design problems. Both methods guarantee a possible design remains within a feasible, theoretical building volume; however, they do not define objectives of how a generated solution could be improved.

An exception to this lack in implementing design objectives was presented by Sowa and Hovestadt (2008). In their research, a “digital support for strategic planning” was proposed, during which the design process for building volume-generation and evaluation could be automated. This proposed method, based on employing existing, reliable data through case-based reasoning helped to define design objectives and allowed design solutions to be gener-

ated and improved through evolutionary algorithms.

The intended evaluation and reduction of LCC during the early design stage can be seen as a major economic improvement since design decisions made in the early phases of architectural design are significant, irreversible, and can only be changed later at very high cost (Cherry, 1990). One important aspect when considering LCC is the increasing significance of continuous operation costs over a project's running time, as the percentage of total expenditure steadily increases compared to initial investment at project commencement. However, a major difficulty can be seen in cost establishment during this stage, as it requires either extensive evaluator experience and / or a sufficient database of existing, comparable building information (Leifer et al., 2004).

The implementation of constraint programming (CP) techniques into design-criteria definition and evaluation has recently been introduced to architectural design (Lömker, 2007). One CP advantage is the wide variety of possible constraints including disjunctive, relational, explicit, unary and logical (Hillier et al., 2005). The much greater flexibility in expressing problem constraints greatly increases the ability to more accurately formulate valid models for complex problems such as architectural design. Although, CP is ideally suited for highly constrained problems without an objective function, procedures for finding optimal solutions can be implemented as well when incorporating integer-programming techniques.

Thus, this proposed BVO model has the advantage of implementing design improvement based on financial objectives associated with initial constraint satisfaction of building-volume design. The demonstrated method to optimise building volumes using LCC objectives therefore represents a novel and significant contribution to this effort.

3. Methodology

3.1. BUILDINGVOLUME OPTIMISATION (BVO) MODEL

Unlike common representations of rectangular volumes using width, length and height definitions, building volume in the proposed optimisation model is defined through a rectangular floor-area unit per floor and its perimeter length indicating its exterior surfaces per floor. Though the current setup of the BVO model is based on singular rectangular floor areas, it generally allows setups using combinatorial floor areas per floor as well. The three-dimensional building-volume characteristic is implemented by stacking floor areas on top of each other. The model's advantage can be seen in that it not only satisfies building volume dimensional constraints itself, but also constraints that

relate to usable floor-area limitations. Additionally, the separation of building volume into floor areas and exterior surfaces provides significant model data for LCC diversification of individual cost members within the optimisation objectives. This setup, using a floor-area unit per floor, also allows later implementation of optimisation solutions such as floor-area zoning and multi-level floor space layouts.

The BVO model development as a computer-aided design tool is based on optimisation techniques used in operation research. An optimisation model describes a mathematical model that attempts to optimise an objective function without violating resource constraints (Bazaraa et al., 2004). Consequently, the BVO model can be described through its objective function, decision variables and constraints. The complexity of the BVO model can be seen in the computational effort to search for optimal solution based on non-linear objective function and constraint definitions.

3.2. OBJECTIVE FUNCTION

The objective in finding an optimal building-volume design is based on finding the lowest LCC over a study period. For the proposed BVO model, the following cost members have been integrated based on their direct influence on building-volume properties: Construction Costs (CC), Energy Costs (EC), Operation and Maintenance Costs (OMC), and Repair and Renovation Costs (RRC). Thus, the objective function can be stated as:

$$\textit{Minimize}: LCC_{PV} = CC_{PV} + EC_{PV} + OMC_{PV} + RRC_{PV} \quad (1)$$

The subscript “PV” declares that each cost is understood as a present value (Ruegg et al., 1990). Since all members represent real costs appearing during the life-cycle period, all cost members are treated equally. Therefore, the objective function represents the summarised building cost expenditure to be minimised.

3.2.1. Cost specification

In addition, a separation into individual cost constituents per area unit, categorised into horizontal and vertical building elements is proposed.

The construction costs (CC) during early architectural design stages are based on cost estimation. While different cost estimation models are in practice, the most common approach is to calculate construction costs via a predefined cost per floor-area unit. To allow for more accurate feedback, cost estimates can be more rigorously established by separating specific building elements. In this BVO model, a separation into individual construction costs

per area unit for the following building elements is proposed: foundations, floor areas for lower, medium and high floor levels, roof areas and exterior surface areas (façade).

For simplification and comparison purposes, actual annual energy costs (EC) can be determined via local electricity cost per KWh and the electric use of HVAC system, lighting and appliances. The activation of building elements is achieved through separation into floor areas and exterior surfaces, including individual window to wall opening ratios per orientation.

The operation and maintenance costs (OMC) can be defined through annual cost estimation. Similarly, to be effective, OMC needs to be established by consequently breaking occurring costs into respective building elements. For example, for higher floor levels, OMC are expected to increase due to increasing vertical infrastructure demands.

Repair and replacement costs (RRC) gradually increase over time due to aging. Typically, these are not indicated annually, but instead over a predefined time. Further, RRC estimation is defined as repair or replacement of individual building system parts. Therefore, RRC calculation depends on earlier assumptions as to when certain building elements will require repair or replacement. While building parts are not directly represented in the BVO, RRC reference is limited to horizontal and vertical cost constituents at a predefined time.

3.3. DECISION VARIABLES

Decision variables in the BVO model are building-volume determinants and are the dimensional representatives of a rectangular floor-area unit per floor. Each unit is defined through its two dimensional position in a Cartesian coordinate system, width and length, along with floor level reference.

Floor-area unit location and expansion on the ground floor level is limited through property constraints. Floor-area units on the following upper levels are primarily restricted in location and dimension by the floor level below. The geometrical model in figure 1 demonstrates an adaptation of an existing space layout problem (Medjodoub et al., 2000), where topological and dimensional constraints have been developed to limit space units.

An additional set of decision variables is required to determine building-façade. The opening ratio is measured between window and solid wall openings on exterior surfaces, separated by their orientation. The ratio determines the amount of openings allowing solar gains through interior spaces. However, while individual openings in the exterior wall need to relate to interior spaces, the opening ratio is theoretical in nature. Therefore, results of an optimisation run are not made visible in later visualisations of the processed BVO solution.

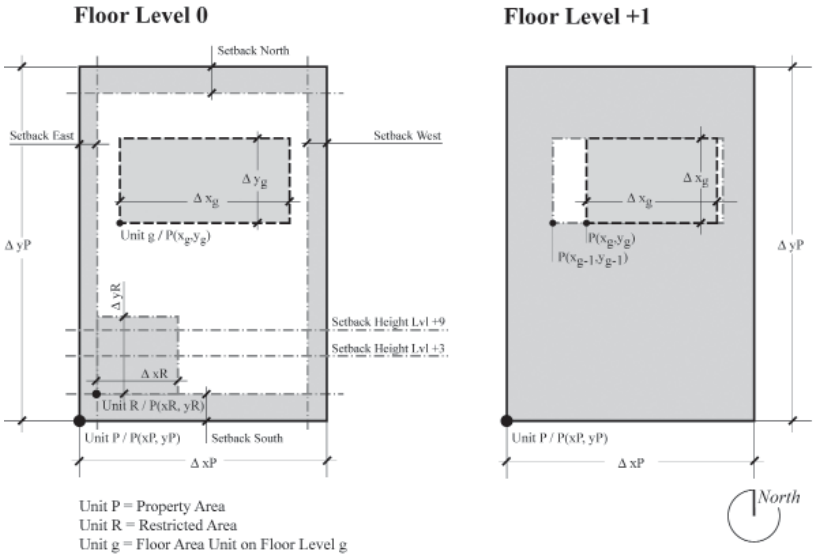

Figure 1. Area units per floor, their location on the ground floor and the following upper floor level.

3.4. CONSTRAINTS

Constraints on the proposed BVO model, guaranteed volume design remains within the theoretical volume. These constraints are defined through regulations originating from building codes, local ordinance and site-specific declarations (Donath et al., 2008), as well individual design intentions. These regulations constitute the search space of the optimisation problem in which the optimal building-shape configuration is to be found. The constraints have been organised into three categories: Property, Topology and Design Constraints.

The following property constraints: “Force to Inside Constraint, Force to Outside Constraint” and “Force to Border Constraint” have been adapted from earlier research concerning space layout problems (Medjodoub et al., 2000; Michalek et al., 2002). In reference to the building volume optimisation model, these constraints are used to define allowable floor-area unit on the ground floor. Additional property constraints are:

- **Setback Regulation Constraint,** limiting the property area according to distance regulations on ground and/or at different height levels,
- **Building Line Constraint,** forcing a building orientation to a specified building line, mostly for building attachment purposes,
- **Site Coverage Ratio,** guaranteeing that only an allowable percentage of the property is to be covered by the planned building volume,
- **Buildable Floor-area Ratio,** limiting total building floor area volume below

an allowable percentage for the specified property, and
- **Building Height Constraint,** ensuring the building height remains under a specified height limitation.

Regarding topological constraints, consecutive floor levels are primarily regulated by the Force to Inside Constraint, guaranteeing that increasing floor level units remain within the boundary of the floor unit below.

Finally, design constraints mostly limit dimensional expansion of rectangular floor-area units. Existing constraints are width, length, width to length ratio and perimeter. Additional design constraints are:

- **Total Floor-Area Constraint,** guaranteeing building volume remains within an earlier defined, allowable range,
- **Building Depth Constraint,** guaranteeing floor-areas receive sufficient natural lighting, the constraint is used on the ground floor level only, and
- **Opening Ratio Constraint,** preventing the search space from increasing unnecessarily, a boundary range, based on designer experience and/or expectation is foreseen.

4. Implementation

To solve this optimisation problem, the software application 'ILOG OPL Development Studio 6.1.1,' an optimisation package, was used in combination with 'Processing.' an open-source programming environment for data presentation and visualisation. For the experiments, specifications regarding construction and electricity costs, as well as climatic and solar radiation data were employed in reference to Bangkok, Thailand. Further, a medium sized, quadratic shaped property was defined, allowing medium to high-rise building volume up to a given building height. Additional property regulations, including setback definitions at increasing height levels and prohibited building area were included. A two-year construction period and a 30-year operation were assumed.

The results in figure 2 demonstrated that an optimal solution could be found with an average running time of less than three minutes, when the range for the allowable building-volume opening ratio was limited beforehand to 40–60%.

All generated solutions remained within theoretical building-volume boundaries, satisfied all constraints and demonstrated continuous improvement in the objective value. Each test run resulted in 15 to 35 feasible solutions.

The resulting visualised solutions illustrate how dimensional changes in building volume led to a continuous LCC improvement. In the demonstrated example, the following building volume improvements during the optimisation process have been documented in figure 3. From the first feasible solution

until solution 13, the objective value improved through the optimal distribution of floor areas and exterior surface area reduction. Solution 14 improved due to the reduction of one floor level. Then, similar to the earlier process, the amount of floor areas and exterior surfaces were consolidated. Solution 25 represents another significant change in the optimisation process in which building orientation changed from north–south to east–west. Finally, the

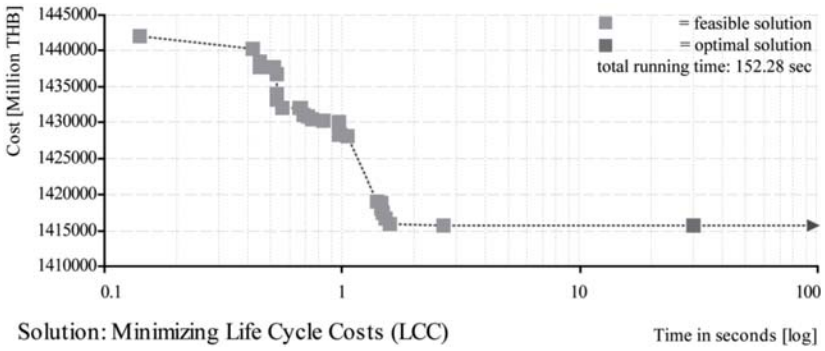

Figure 2. Objective-value solution time for all feasible and optimal solutions found when minimising life cycle costs.

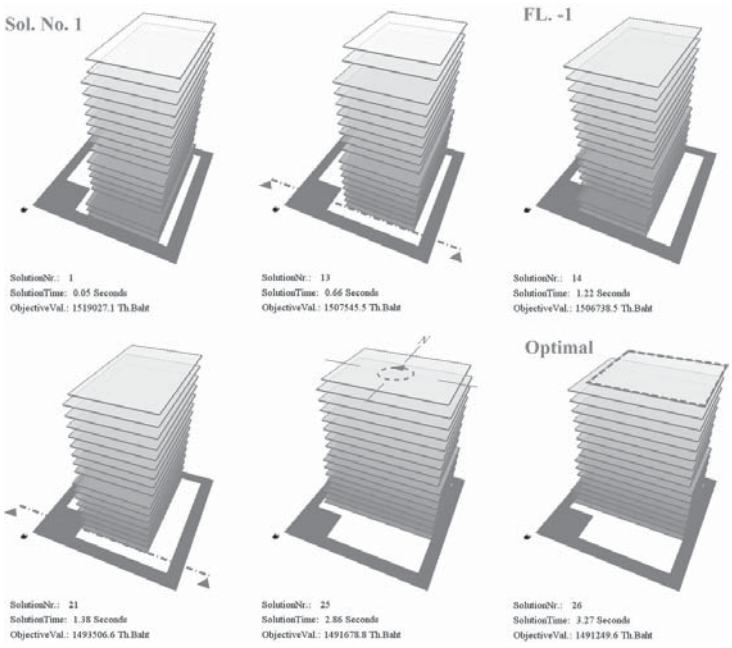

Figure 3: Feasible and optimal solution selection (26) found when minimising life cycle costs.

optimal solution (#26) slightly improved over its successor by decreasing the top floor perimeter, reducing its exterior surface area.

5. Analysis

The proposed BVO model allows designers to investigate building volume dependencies regarding building costs and volume shape. Studies of feasible building volumes indicate a general tendency to generate compact building shapes affiliated to volume design primary cost factors. In construction cost terms, this mainly derives from cost diversification into building floor-areas and exterior surface areas. While floor areas are constrained by lower and upper boundaries, cost minimisation can be primarily achieved through optimal floor-area distribution over available floor levels and exterior-surface area reduction.

The BVO model therefore endeavours to calculate a compact quadratic building volume. A similar tendency can be seen when inspecting energy costs individually, where heat conduction and radiation play an important role. In a tropical climate such as Bangkok, a primary building volume design goal can be seen in reducing exterior surfaces due to continuous exposure to a hot and humid outdoor environment. By considering solar gain only, a reduction in exterior surfaces oriented towards east and west was prioritised in the optimisation process due to solar radiation on these exposed plains. Similarly, the opening ratio, indicating the opening amount and thus influencing solar gain tends towards the need to decrease openings on surfaces exposed in east and west orientations. The results proved that optimal building volume shapes not only depend on a combination of individual cost members, but on individual property constraints and their requirements as well.

Besides LCC, a multi-objective approach achieved through goal programming technique was implemented and tested. The strategy to increase building floor areas could be seen as a more realistic approach, where not only cost minimisation dictates building design but also usable floor area maximisation. Its implementation led to design solution findings that combined cost minimisation with interior floor-area maximisation.

One critical aspect of the demonstrated BVO model can be seen in the quality of the feasible and optimal solutions found. The search algorithms strategy is to find an optimal solution, if it exists. However, the feasible solution findings that were uncovered do not represent a complete set of solutions, nor do they guarantee a possible variety and quality of alternative solutions. With this in mind, and to allow designers a more investigative decision support, a population of solutions that are near to optimal should be made available.

6. Conclusion

The BVO model demonstrates an applicable approach for designers to not only attain a deeper understanding of quantitative design options through constraint definition, but also the ability to strive for meaningful design solutions with respect to optimised building information such as LCC assessments. Its results can provide designers with insight into dependencies between building volume and building costs. The visual display of optimal and feasible solutions employing the demonstrated method allows designers to successfully understand design-optimisation impact and to integrate it into an effective decision support mechanism.

Although the rendered BVO model guarantees the generation of building-volume based on single, rectangular footprints, to allow for a more realistic investigation, ongoing research is concentrating on investigating combinatorial formations of rectangular geometries. Similar to allocation problems, such as space layout design, running time for an optimisation problem is expected to increase significantly.

References

Bazaraa, M. S., Jarvis, J. J., and Sherali, H. D.: 2004, *Linear programming and network flows*, 3rd ed., Wiley Press.

Cherry, E.: 1999, *Programming for design: from theory to practice*, John Wiley & Son, New York.

Donath, D. and Gonzalez, L. F.: 2006, A constraint based bulk design support, *Proceedings SIGraDi*, 278–282.

Donath, D. and Lobos, D.: 2008, Massing study support, *Proceedings eCAADe25*.

Gross, M. D.: 1985, *Design as exploring constraints*, Ph.D. thesis, Massachusetts Institute of Technology.

Hillier, F. S., and Liebermann, G. J.: 2005, *Introduction to operation research*, 8th ed., McGraw-Hill, New York.

Leifer, D. and Leifer J. M.: 2004, Towards computer aided life cycle costing, *Proceedings ASCAAD*, 361–372.

Lömker, T. M.: 2007, Designing with machines: solving architectural layout planning problems by the use of a constraint programming language and scheduling algorithms, *Proceedings ASCAAD*.

Medjodoub, B. and Yannon, B.: 2000, Separating topology and geometry in space planning, *Computer-aided design*, **32**, 39–61.

Michalek, J. J., Choudhary, R. and Papalambros, P. Y.: 2002, Architectural layout design optimization, *Engineering Optimization*, **34**(5), 461–484.

Rittel, H. W. and Webber M. M.: 1973, Dilemmas in a general theory of planning, *Policy sciences*, **4**, 155–169.

Ruegg, R. T. and Marshall, H. E.: 1990, *Building economics: theory and practice*, Van Nostrand Reinhold, New York.

Simon, H. A.: 1973, The structure of ill structured problems, *Artificial intelligence*, **4**, 181–201.

Sowa, A. and Hovestadt, L.: 2008, Decision support in architectural strategic planning, *Proceedings eCAADe25*.

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STAGE-BASED DESIGN BRIEFING BEYOND THE WATERFALL MODEL

Tracing students' design processes in relation to prescribed design stages throughout an architectural design studio

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Abstract. Based on visualisations of data obtained from field observations, this paper describes and discusses how a group of ten undergraduate students of architecture negotiated their ways through the tutorials of a design studio lasting 17 weeks. The main question guiding this empirical study is how the initially prescribed linear, stage-based framework of the design studio relates to design processes as experienced by participating students and as observed by myself as tutor and participant observer. Visualisations of tutorial observations show that instead of proceeding from one stage to the next sequentially, students tend to engage in continuous and parallel re-consideration of almost all aspects of their work. This results in a process that can be described as a cumulative and layered process, and illustrated as 'fan'-shaped diagrams. The role of the design stages initially scheduled in the detailed studio brief seems to be to gradually introduce students to increasingly advanced and challenging project scopes rather than to enforce sequential design steps.

Keywords. Design stages; design process; design education; data visualisation; tutorials.

1. Design process models

As recent research work in the field of design cognition takes a critical attitude towards previous stage-based models of the design process, design education finds itself in a dilemma: While experienced architectural practitioners

lean towards scepticism of stage-based models of the design process, those involved in structuring, coordinating and monitoring design processes – be it in design education or in design management – still tend to appreciate such frameworks. Stage-based, linear models of design processes enable teachers to prescribe, direct and control the flow of design processes and to provide guidance to inexperienced learners, and for these reasons often find their way into the design curriculum. Furthermore, increasing pressures on universities to adopt explicit and outcome-based accounts of teaching are likely to encourage prescriptive tendencies in brief writing as well as studio scheduling.

In observations of applied design processes, however, designers appear to follow such predefined linear processes only to a limited extent. Based on a detailed empirical study of applied design processes, Guindon (1990) suggests that prestructured top-down decomposition of design tasks is a problematic approach, and that experienced designers will typically embrace individual and opportunistic choice-making. Conklin and Weil (1990) illustrate this difference in line diagrams where a line plotted to illustrate designers' progress indicates sudden and unpredictable jumps between predefined design stages rather than an orderly and linear waterfall model. In a comprehensive review of previously proposed design process models, Gedenryd (1998) rejects the separation of design processes into stages entirely and argues that design processes may best be described as processes of interactive inquiry. During design processes, understanding of design challenges typically proceeds in parallel to, and in relation to, the development of design proposals. Maher et al. (1996) have described this pattern as co-evolution of problem and solution. This requires designers to maintain awareness of the possibility of reconsideration of many aspects of an ongoing project even when focusing on one particular aspect.

Guindon (1990), Conklin and Weil (1990) and Maher et al. (1996) all employ diagrammatic visualisations to illustrate and discuss the characteristics of design processes, which are difficult to describe in their entirety. Conklin and Weil (1990) present an abstracted and simplified explanatory model that illustrates the discrepancies between prescribed stage-based models of design processes and applied design processes in the context of design in practice. But does this discrepancy between prescribed design stages and applied design processes suggest inadequacy as Conklin and Weil suggest? Alternatives to stage-based models such as inquiry (Gedenryd, 1998) or evolution (Maher et al., 1996) do not seem to offer educators similarly practical frameworks in writing studio briefs. In this context, this paper examines how prescribed design stages and applied design processes are related within the educational setting of an architectural design studio. Can the discrepancy

between the need to prescribe on the part of the teachers and the need to divert from prescribed schedules on the part of the students even be understood as a productive context for design processes? To this end, this paper presents digital data visualisations of field observations as a way of reflecting on design studio experiences. The aim of this study is primarily to describe, analyse and make explicit the authors' observations to inform future design teaching and to explore alternatives in organising design studios.

2. Tracing prestructured design processes in tutorial conversations throughout an architectural design studio

The architectural design studio discussed in this paper was a particularly well-planned second-year studio, set at a Chinese university in 2009. It was taught by 8 tutors, each supervising a group of 8-12 students, who worked individually. As is often the case for architectural design studios, the schedule and brief of this studio set out a linear sequence of several design stages, which students are required to follow in order to achieve good design outcomes. A detailed schedule handed out in the beginning of the semester (which I as a tutor followed but did not write) prescribed students' design activities for each of the twice-weekly tutorial meetings and lectures in the following stages: 1. site analysis, 2. concept development, 3. spatial design, 4. structural design, 5. elevation and façade design, 6. staircase design, 7. finalising and drafting. This overall plan was consistently enforced through the requirements that students had to comply with in seven interim presentations and submissions. During studio tutorials, however, students' design processes and progress seemed to differ not only from the initially given plan, but individual students also differed from each other.

Based on the understanding of designing as a circular, conversational process, where new ideas arise from differences in understandings or viewpoints between those engaged in the conversation (Glanville, 1995), tutorials and the opportunities for exchange they provide can be seen as central to design development. While students can emulate such conversations by and with themselves (ibid.), tutorial conversations with tutors are essential sources of ideas as they are usually not entirely controlled by either student or tutor, and support both variety generation as well as variety reduction. In tutorial conversations, new ideas may thus hatch between the perceptions and intentions of tutors and students (Herr and Karakiewicz, 2008). In this primarily qualitative case study, tutorials are seen as pivot points of the design process, where students' thoughts and decisions are developed and made explicit. For this reason, observational data collected during these occasions is taken to be representative of students' current design stage. Tutorials during which stu-

dents were absent as well as meetings consisting of lectures without tutorials are not considered in the data coding and subsequent visualisations and left blank. The following sections examine these field observations of the design processes of 10 individual students, how these can be expressed visually and how they relate to the initially given schedule.

3. Coding and visual expression of field observations

As a studio tutor and participant observer, I collected an extensive amount of field observation data during tutorials and intermittent design reviews throughout the design studio, consisting of both written notes and photographs that mainly served as memory aids to allow comprehensive subsequent write-ups of observations. These written notes served as basis for the analysis presented in this paper. The roughly 14,000 words of notes were coded and archived in an Excel spreadsheet, and then analysed and visualised using the three-dimensional modelling software Rhinoceros 3D in conjunction with VBA scripting in Excel (figure 1). The coding of field observation data took as its basis the initially determined ‘stages’ of the design studio as defined in the studio brief. These seven categories, as outlined in Section 2, represent a stage-based model of the design processes that proceeds from research and analysis to partial solutions to overall design proposals. While this choice of only a few simple coding categories ignores many of the qualitative and individual aspects of designing, it also provides a basis for clearly illustrating the differences between prescribed design processes as laid out in the brief and students’ experiences in tutorials with the author.

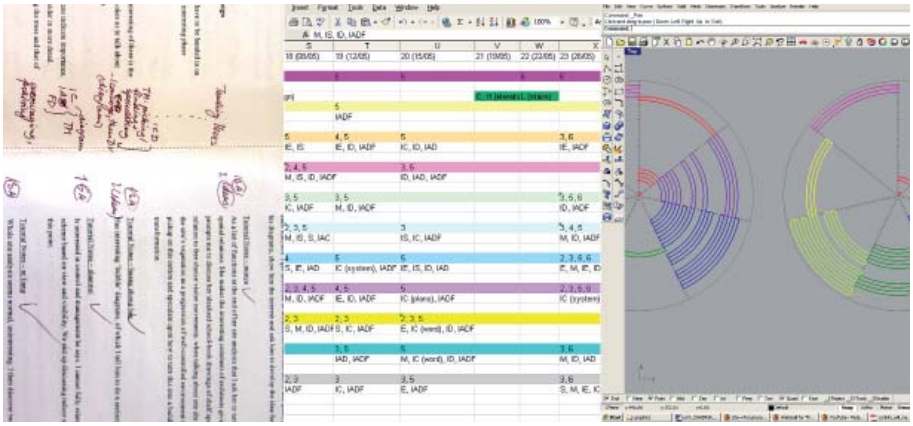

Figure 1. Coding of field notes and translation into visualisations.

For producing visualisations from the field observation data stored in the Excel spreadsheet, a combination of VBA scripting in Excel and three-dimensional modelling in Rhinoceros 3D presented a straightforward procedure. Rhinoceros 3D allows for the production of both line drawings as well as three-dimensional models and provides a wide range of import and export options for subsequent editing of graphics. While digitally aided presentation may seem merely a simple step in this project, it has afforded insights that may be difficult to gain, illustrate and show otherwise. The following questions underlie the data visualisations presented in the following sections: How can individual students' design processes be described in relation to the predefined framework of design stages? How do individual students differ from each other? How do answers to these questions relate to perceptions of the role of the design tutor? Furthermore, how could these answers inform the prestructuring of future design studios and how could design progress be managed more appropriately?

4. From spirals to fans

The diagram format developed to express the field observation data in terms of the seven design stages prescribed in the studio schedule consists of concentric circles, each divided into seven segments corresponding to the seven prescribed design stages. The concentric circles indicate the progression in time from the centre of the diagram outwards, such that each ring describes one of an overall total of 30 tutorial meetings. Within each ring, any combination of seven stage segments is possible to indicate the design concerns observed during tutorials and coded to conform to the seven design stages outlined in section 3. In the following, this diagram format provides the basis for illustrating tutorial observations by the author. In figures 3, 5 and 6, the basic diagram format is changed slightly to allow for more emphasis and clarity or to facilitate quantitative comparison.

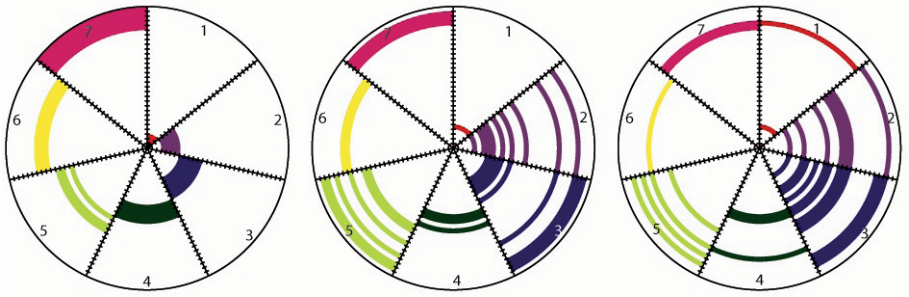

Figure 2. Design stages as prescribed in the studio brief (left) and as observed in the design processes of two students during design tutorials (middle and right).

Figure 2 illustrates the predetermined sequence of design stages as found in the studio brief (left-hand side) and the design processes of two students (middle and right-hand side) as observed during studio tutorials. When comparing visualisations of students' design processes to the prestructured sequence, students' design processes differ in two main aspects: the sequence of progressing through the predetermined design stages, and the amount of attention and overall time dedicated to each of these stages. Where the prescribed design stages are aligned neatly along a spiral, students' design processes are much more spread out, in particularly in the 'earlier' sections of the diagrams. None of the ten students followed the prescribed sequence of stages exactly as set out in the studio brief.

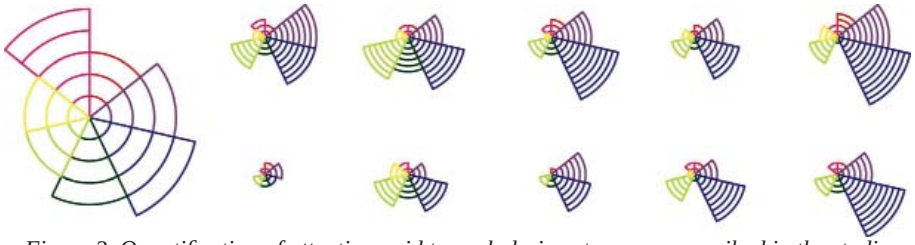

Figure 3. Quantification of attention paid to each design stage, as prescribed in the studio brief (large) and as observed from individual students during tutorials (small).

Figure 3 presents a visual comparison of the overall attention students paid to each of the design stages, as expressed in the overall number of tutorial meetings during which topics pertaining to each design stage were discussed. The comparison of field observation data shows that students tend to distribute their energy unevenly and not necessarily according to the prescribed design schedule. Students instead seem to emphasise individually chosen aspects of their design processes while trying to simultaneously comply with the prescribed design stages in order to fulfil basic requirements. These individually determined foci can further be described as 'clusters' along the timeline (figure 2). The design process visualised in the middle diagram of figure 2, for example, indicates the students' preoccupation with plan development and refinement (stage3) in two distinct bouts early and late in the design process.

With students' design processes diverging not just from each other, but often also from the prescribed studio schedule, studio tutors experience discussions across a broad range of topics during each tutorial. Figure 4 illustrates how each tutorial meeting (consisting of individual discussions with all ten students) covered a much broader range of design stages than the prescribed stages for that meeting (as suggested by the spiral-shaped visualisation in figure 2, left).

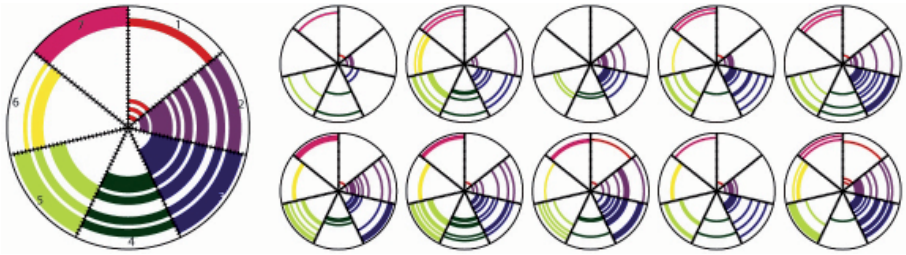

Figure 4. Design tutor's covering of design 'stages' in discussions with students throughout the design studio (left) and individual design processes of all observed students (right).

As illustrated in figure 2, students' design processes seem to negotiate and compromise between adhering to prescribed design stages roughly while still maintaining individual ways of working and thinking. To emphasise individual ways of addressing the initially prescribed design stages, the previously introduced diagrams are rendered three-dimensionally, with the circular segments indicating tutorial meetings placed with increasing distance along the z axis according to the studio timeline. Figure 5 compares three-dimensional visualisations of two students' design processes (left-hand side and middle) with the initially prescribed 'spiral' of progressing through design stages (right-hand side). In the diagrammatic visualisations presented in this paper, all students' design processes present as cumulative, fan-like shapes. In many instances, new design stages introduced or suggested by the studio schedule do not only incite students to consider new aspects of their developing design proposals, but also seem to trigger the re-thinking of previously addressed aspects, adding new layers to a cumulative process of thinking, which produces the 'fans'. The role of prescribed design stages in the observed design processes seems to be to 'unfold' these fans.

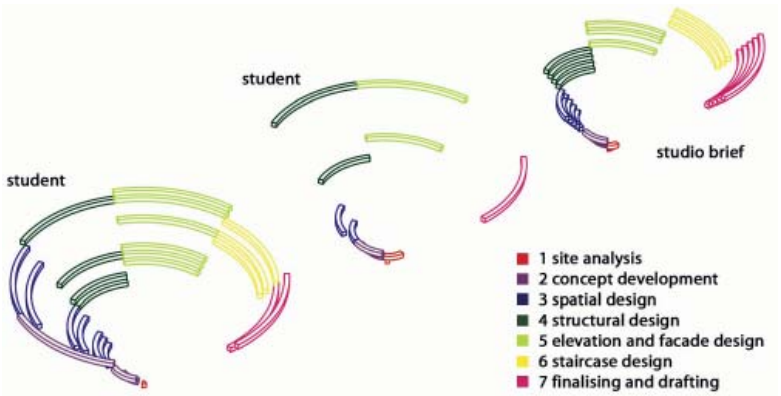

Figure 5. Three-dimensional visualization further emphasises the differences between prescribed design stages and observations of students' design processes.

5. Relating process visualisations, studio performance and final grades

Students' final grades were determined at the end of the studio based on a weighted calculation of previous submissions and reviews of drawings and models handed in at the end of each design stage. When comparing visualisations of students' design processes to their grades, it seems that those students who engaged more actively in rethinking and refining their projects beyond the currently prescribed design stage received good grades (average and above). None of the ten observed students followed the schedule literally in terms of exclusive sequential design stages. Figure 6 shows the design processes of a student performing very well in terms of final grades (left-hand side), an average student (middle) and a student performing not very well in terms of final grades (right-hand side). When comparing the process visualisations, it may be concluded that willingness to reconsider and revise previous decisions is a designer's strength rather than a weakness. Based on my observations during tutorial meetings, the best-performing students characteristically developed very intense engagements with their design projects, often reconsidering many previous thoughts in the light of new ideas to 'get it right'.

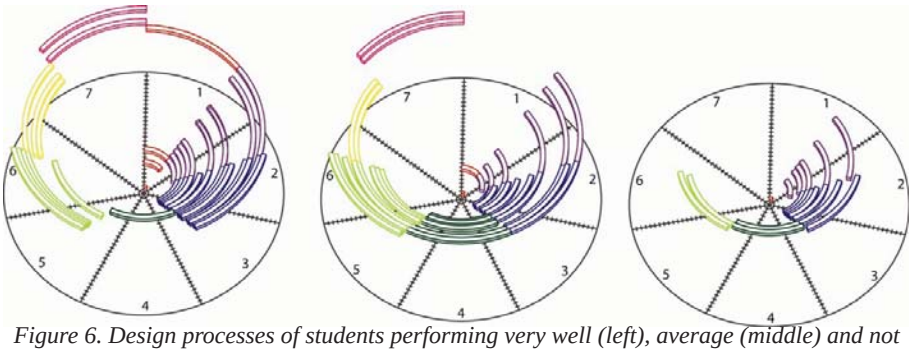

Figure 6. Design processes of students performing very well (left), average (middle) and not very well (right) in terms of final grades.

Students were assessed independently of whether they followed the prescribed design stages during each meeting, which suggests that adherence to the linear stage model was not necessarily expected by studio tutors. There seems to be an implicit understanding that prescribed design stages coordinate the design process and assure completeness of student work but that they are not meant to be taken literally nor actually followed. Rather than prescribing sequential stages, they seem to introduce new layers to a cumulative and holistic thinking process. To experienced architects, this may be a self-evident statement – to others, including students learning to master architectural design processes, this understanding may not be as obvious.

6. Navigating design processes

This study is limited to the detailed examination of one particular design studio and the design processes of ten students as I observed them as their tutor throughout the design tutorials of one semester. While the scope of this case study is limited, it has provided a basis for developing an understanding of the design studio process and its underlying expectations as well as visual material to share this understanding. The process of coding and visualising field observation also required choosing a particular viewpoint. This is expressed in the formats of the diagrams presented in the previous sections, where emphasis is placed on the description of students' design processes in terms of design stages, their expression as visual patterns, their quantification and their unfolding in time.

Assuming design processes as cyclical in nature, how can the linearly structured studio accommodate cyclical re-entry? The 'fan' shapes expressed in particular in figures 2, 3 and 5 may provide one possible answer. Design processes are described as cyclical as they are experienced as generating new ideas in a process of recurring playing with, re-considering and modifying of previous ideas. The fan-shapes in the visualizations suggest recurrent and parallel consideration of individually chosen foci, where new ideas trigger the rethinking of previously made decisions. The fan shapes can thus be read as design cycles that increasingly widen their scope with the introduction of every new design stage, which leads to interconnections, increasing coherence and stability amongst all elements of the projects. If the prescribed design stages were to be followed exactly and exclusively, students would have to set all other considerations aside to focus on only one aspect of their projects at a time. Most students observed in this study instead seemed to maintain a holistic view of their design projects by remaining open to discard previous and partial solutions in favour of more fitting or more consistent ideas. While working on particular tasks, students seemed to keep previous decisions in mind for possible changes, thus consistently keeping options for improvement open.

7. Inquiry between cycles and stages

Based on the outcomes of this study, I understand the relationship of prescribed design stages and applied design processes in the architectural design studio both as a dynamic and interdependent relationship. This may be described in analogy to the relationship between design tutors and students: Studio tutors usually have empathy with their students and will attempt to 'steer' them into a direction deemed desirable, but will also take into account their individual

or collective tendencies in design processes, possibly even over-compensating for such tendencies. Students' design processes will neither follow teachers' advice literally nor may this be intended by the tutors. Tutor advice can inspire and initiate new aspects and layers of thought, which lead students to develop their own responses (that may be quite different from the ideas of the tutors). While students' design processes may be unpredictable and highly individual, design studios need to be planned and structured to fit into allocated times and budgets similar to design processes in practice. The traditional studio structure which emphasises intense individual tutorial conversations between tutors and students once or twice per week already provides a middle ground between rigid overall frameworks and the opportunistic and unpredictable design processes experienced by individual students. Based on the outcomes of this study, it seems that the studio structure provided support to unfolding accumulative processes rather than determining a linear roadmap. In future design studio instances, I am thus interested in exploring this understanding further, such as by suggesting a layered structure that acknowledges explicitly the need to simultaneously (re-)consider any aspect of the design project that may be necessary. Another possibility may be to avoid a literal prescription of design stages and taking into greater account the dynamic navigation process characteristic of designing which Gedenryd (1998) has characterized as "interactive inquiry".

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References

Conklin, E. J. and Weil, W.: 1990, Wicked problems: naming the pain in organizations, *Human–computer interaction*, **5**, 305-344.

Gedenryd, H.: 1998, *How designers work*, PhD thesis, Lund University.

Glanville, R.: 1995, Communication without coding, *Modern language notes*, **111**(3), 441–462.

Guindon, R.: 1990, Designing the design process: exploiting opportunistic thoughts, *Human-computer interaction*, **5**, 305–344.

Herr, C. M. and Karakiewicz, J.: 2008, Towards an understanding of design tutoring: a grounded study of presentation materials used in tutorial conversations, *Proceedings of CAADRIA 2008*, 321–327.

Maher, M. L., Poon, J. and Boulanger, S.: 1996, Formalising design exploration as co-evolution: a combined gene approach, *in* J.S. Gero and F. Sudweeks (eds.), *Advances in formal design methods for CAD*, Chapman and Hall, London, UK.

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WORKING OUTSIDE OF THE SYSTEM

Engaging in Web 2.0 to enhance learning and teaching in the design studio

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Abstract. The Deakin Studies Online (DSO) Learning Management System (LMS) forms the fundamental basis for tertiary education at Deakin University. This LMS is founded on Web 1.0 principles, however significant potential exists for engagement in Web 2.0 technologies to support learning and teaching in the design studio. A digitally enhanced design curriculum is discussed starting with html-based reflective folios in 2001, the use of blogs for reflection and resource creation and culminating in a Web 2.0 design studio based on social networking.

Keywords. Learning management systems, blogs, Web 2.0, learning and teaching, design education

1. The university LMS and Web 2.0

Deakin University has been recognised since its inception for its engagement in off-campus education. Throughout its five campuses in three different cities in metropolitan and regional Victoria, 'the use of distance education methodologies and materials for both on-campus and off-campus cohorts 'gathered momentum in the early to mid 1990's under the strategic umbrella of flexible teaching and learning' (Palmer and Holt, 1997). Since 2004, Deakin University has sought to further the 'technological imperative' (Holt and Thompson, 1995) through the initiative of Deakin Studies Online (DSO). DSO was introduced to the university in 2004 using Web CT learning management system (LMS) software, which was upgraded to the Blackboard Vista platform. This university-wide initiative represents a multi-million dollar investment in IT-enhanced education for both on-campus and off-campus tertiary education.

University operational policy dictates that all units throughout the university must have ‘an online site’ in DSO, which includes a minimum of unit guide, discussion ‘chat’ forum, faculty notice board and student–staff communication expectations. Basic engagement can be extended to the level of ‘wholly online’ units, with university policy dictating that all students in all courses must complete a wholly online course before graduation.

A wide array of online learning and teaching initiatives exist across the university. DSO forms the core LMS for these activities, however educators often work outside the system in order to achieve educational innovations. Deakin educators have engaged in Web 2.0 technologies across a wide variety of educational situations, including the use of Wiki’s (Augur, Raitman and Zhou, 2004), social software (Goold, Augar and Goodman, 2008) and Second Life (Warren et al., 2008). Many educators working outside of the core system of DSO have been recognised for their contribution to learning and teaching through university-based and national awards.

DSO is an example of a LMS based on pre-Web 2.0 philosophies, which limit ‘interactive information sharing, interoperability (and) user_centred design’ (http://en.wikipedia.org/wiki/Web_2.0). The university must balance the needs of controlling large amounts of course materials, managing digital resources and tracking assignment submissions with enhancing courses through user interaction. A blended learning approach must balance the potentials of Web 2.0 with control of information required in the university LMS environment.

2. Pre-Web 2.0 digital design initiatives

The www.ab.deakin.edu.au/online site (known as a+b/online), set up in 2001, acts as the host for digital design initiatives at the School of Architecture and Building at Deakin University. This website operates independently of DSO and is used for peer learning, retention, online folios and benchmarking of work from year to year. It contains exemplars of many digital design initiatives, including reflective ‘Games’ (Woodbury et al., 2001) an online virtual gallery (Ham and Dawson, 2004; Ham, 2008) and online case studies (Ham, 2002).

Web 1.0 digital design education often placed a serious overhead on staff and student workloads. Students enrolled in digitally-enhanced units in design and technology were required to learn Dreamweaver to create web pages for digital project submissions, or to rely on the limited html publishing capabilities PowerPoint. This placed a time overhead above the required learning outcomes for each project – a critical issue for time-poor students.

Independent evaluation commissioned by the Institute of Teaching and Learning of a second year unit in building construction in 2003 highlighted this issue. A number of students were resentful at the additional burden placed on them and, at the time, could not see the benefits of learning web design and the extra work required just in order to achieve some form of digital output (Challis, 2003). At this time, even learning PowerPoint was perceived as a burden on some digitally challenged students.

'Digital reflective folios' worth 10% of unit marks were introduced in 2001 to engage students in digital media and facilitate the retention of student work online. Digital reflective folios differ from a simple digital translation of traditional physical folios through the inclusion of a requirement for students to engage in reflective activity. Folios were posted on the school's online virtual gallery as a lasting record of student involvement in the unit. Although the outcome of the digital reflective folios provided valuable insights for educators and may have contributed to students learning cycle, there were evident limitations of this method. Principal of these was the submission of folios at the end of semester, which may have limited the quality of reflective comments due to the time delay between the design activity and the reflection.

The subsequent engagement in Web 2.0 technologies changed the very nature of the digital design education approach by reducing these overheads, enabling greater functionality and interaction capabilities between students and staff. Online weblogs, YouTube-based design projects posted to virtual galleries that enable international feedback and social networking have been used together or alone since 2005 in various units in design and technology. The unique attributes of these technologies enable different opportunities to enhance design education.

3. Web 2.0 digital design education initiatives

3.1. REFLECTIVE BLOGGING IN DESIGN EDUCATION

Online blogs have been employed since 2006 in second, third and fourth year design studios with enrolments of 90–120 students. Blogs have also been used in a core unit in construction technology for the development of shared learning resources. Blogs are hosted at www.blogger.com and included in the a+b/ online virtual gallery (www.ab.deakin.edu.au /abGallery/blogs.php). From the university's database-procured spreadsheet of student information, students were assigned a unique blog address, linked to an online gallery created from exporting the spreadsheet to .html. Formatting of the blog link was strictly templated to unitcode_studentid.blogspot.com to enable immediate linkage to the blog virtual gallery.

Integral to engagement in reflective blogging is the delivery of a lecture on Donald Schön's research on reflective practice (see Schön, 1983), outlining the various modes of reflective activity and their importance to the development of mature designers. The intention was to involving students in learning theory, as a part of learning how to become a mature practitioner.

Students uploaded formative images of their designs and provided reflective comments on at least a weekly basis (see figure 1, below). They were asked to become actively involved in the blogging community by providing quality reflections and participating in peer-to-peer feedback and discussion in addition to meeting the minimum requirements for assessment.

The level of engagement and quality of blogging varied widely according to students' learning modes and strategies. Deep learners would be expected to conceptualise approaches, seek interconnections between concepts and data, and engage in reflective activity (Saljo, 1979). Shallow learners however, would be expected to treat the task as an external imposition, focus on discrete elements without integration and be unreflective about purpose or strategies (Norton, 1999), whilst adopting lower-order cognitive skills and completing

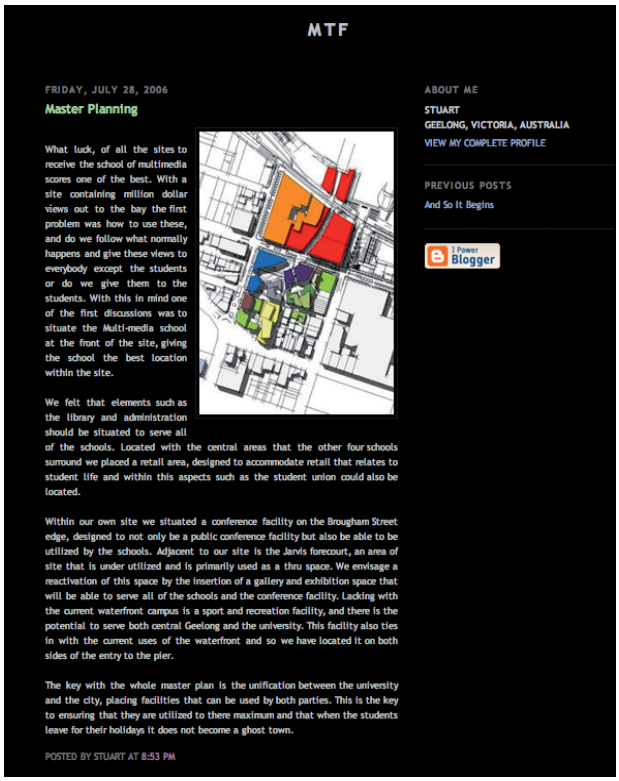

Figure 1. Example of student blog post.

of tasks with minimum effort (Biggs, 1999, p. 1318).

Reflection in blogs varied from a case of a single post that simply paraphrased the unit guide. This student obviously strategically adopted a strategy of losing 10% of unit marks to concentrate on the design projects worth 90% of unit marks. In contrast, some students made daily commentary outlining the full details of their feelings and emotions during design activity, responses from reviews, self and peer critique. Comments on the blogs also reflected unease in engagement in blogging, and an awareness of the time the blog may take away from what they may perceive as core design activity. Students were mindful that the blog constituted 10% of unit marks, and that the lecturer was reading their comments:

> this is my first time setting up a weblog … need to explore more as it would be 10% for my design unit.

Comparisons between first posts and last posts provide some interesting insights. One student started the semester with trepidation:

> Welcome all, a forum for our thoughts is a challenging concept, putting into concise words what is rattling around in ones head can be quite unnerving… So generating these 'high-quality' thoughts and 'reflections' to accompany our striking architecture should be an interesting journey for all involved.

And by the semester's end, the same student must have realised the benefits of reflective blogging as a learning tool:

> So this will be the last post for the unit requirements, but possibly not the last post on the blog. The blog has been a lot of fun and I like it as a tool expression and putting my ideas and work out there so I think that I might continue blogging away for the rest of my life as an architecture student.

Most engaged in the blogs in a non-reflective manner, effectively using the blogs as a weekly report of progress. Students appear to have great difficulty engaging in reflective activity, particularly when reflections are published online. A typical factual, non-reflective post is as follows:

> I have integrated a small piazza to the rooftop. This level of the building already has medium sized lecture theatre, to large student studios, male and female toilets, access to first level cafeteria and student lounge.

Reflective blogs differ from the traditional folio and digital reflective folios in that they enable students to form 'reflective communities' by engaging in conversation, commentary, debate, collegial assistance and team building through the blogs. Amid the 'noise' of conversation in student-to-student blog

comments, some valuable insights were gained into the depth of thought being put into the project. In some cases, students engaged in extended debates over several weeks on issues of architectural theory and philosophy. Several groups of students also took the initiative to set up their own blog sites to facilitate their own group interaction, resource sharing and knowledge transfer during group design projects.

Another key element of reflective blogging in the design studio is the role of the lecturer in extending engagement with students into online space. Reflective blogging allows, at the lecturer's discretion and time availability, an interface with the students outside of the physical studio. Unit budgets currently limit students to only around 6 minutes of direct tutor contact per week. Considerable value can be added to design studio teaching through the lecturer's own blog and regular online engagement with students through blogs.

Blogs have been used to further the programme of resource creation on the online virtual gallery site in units in construction technology. By using blogs as an information repository for posting the outcome of student job site visits and research on building construction, a vast potential exists for the creation of shared resources for peer learning. This approach references the Construction Primer (Burry and Smithers, 1997) as an excellent example of Web 1.0 student authored construction technology resources, wherein student work is given value beyond just for assessment.

The blog, as a user-controlled interface between the construction site and the academy, is ideally suited to capturing information related to 'real world' construction technology. Construction research blogs contain images of projects under construction, written descriptions and student-authored simulations of construction processes using CAD models, drawings and images. Linkage to product supplier websites and databases are included in blogs as a reference.

In 2009, the use of blogs in construction technology units was enhanced through the introduction of student-created videos uploaded to a university server. This added considerable value to the construction technology resources created by students by adding the ability to video interview builders and architects and record construction processes. Copyright policies preclude the posting of these videos to YouTube, however remain on the school server for 'in-house' reference.

A number of challenges exist with this method of blogging as resource-creation. Access to commercial building sites is restricted in Australia to 'red card' holder – those who have completed safety and induction programmes. Builders are traditionally open to assisting students, but wary of releasing information to students that will become available to competitors online.

Assessment presents further challenges for educators using blogs in design education. Assessment criteria need to be clearly stated in the unit guide to reflect the need for both regularity of blog posts and quality of reflections. Although blogs allow the creation of web content without web-authoring skills, the basic principles of web design still apply. Unit evaluation has revealed some cases where student felt that parts of their blogs were left unassessed. Issues of poor blog structures are compounded by limited time allocations to explore blog sites to their full depth. A formative assessment model appears the best way to overcome the issue of dealing with the large amount of information and reflections on blogs. Summative assessment results in a large amount of marking at the end of semester, which increases the potential for missing relevant information for assessment.

Copyright remains an issue of concern. Many students posted images of architectural works from around the world in their reflections on inspirations for their designs. Quite often, these images were downloaded from an online source and included in blogs without any plagiaristic intentions, but simply to illustrate an idea. A strict reading of the university copyright policy would disallow this activity. Re-mixing of information, the 'mashing up the media landscape of the 20th century and shattering the wall between users and producers' (http://films.nfb.ca/rip-a-remix-manifesto/) however seems the norm in the Web 2.0 community.

3.2. A WEB 2.0 DESIGN STUDIO

In 2009 the use of Web 2.0 in the design studio was expanded for a third year design studio using the social networking site Ning.com (see http://deakin2009.ning.com/). This site enabled the development of a social network dedicated to the design studio, allowing high quality student to student, and student to staff interactions.

The Web 2.0 design studio comprised two projects: a four week project designing a Future House for 2050 and a seven-week design project based on the design of a pencil tower in Hong Kong. Each project utilised different attributes of Web 2.0 technologies within a blended learning environment.

The Future House 2050 project required students to design a contemporary house that is "loose fit", adaptable to the needs of the "typical" family of the 2050's and sustainable in energy usage, and low-impact material. Students were required to present their design in the form of an eight to ten minute video, posted to YouTube.com.

Formal submission for the project was in the form of an email to the unit chair containing the direct link and embed code for the video. The embed code was pasted into a html-based online virtual gallery with links to these videos

alongside a “mail to” link to enable students to receive emailed feedback (see figure 2). Links to the virtual gallery were emailed out to networks of academics and practitioners around the world, who viewed videos and provide feedback via email, with a copy sent to the unit chair for consideration in assessment.

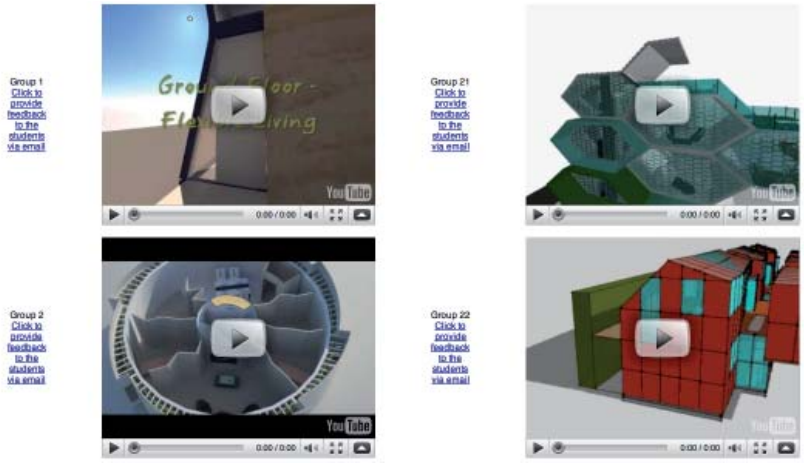

Figure 2. Future House 2050 virtual gallery.

The design of this project intended to provide students with an alternative to the traditional paper-based poster and review format of assessment. YouTube based submission challenged students to express their design in video format, allowing their designs to be viewed worldwide whilst receiving the benefit of emailed feedback from America, Hong Kong and Europe.

The second design project in the studio sought to further the engagement in Web 2.0 to enhance learning and teaching in the design studio. The location of the design project in Hong Kong was ideal for a social networked design studio and posed multiple challenges to Australian students. Ning.com served as an information repository for student-authored research on the site, Hong Kong culture, climate and building regulations.

Peer-to-peer feedback was enabled through students posting images of drawings, CAD models and physical models in development. Additional feedback outside of studio class time was enabled through the site with students posting images and messaging unit staff with specific questions. As the project was partly undertaken in groups of three, some students set up their own social network to facilitate teamwork. This served to facilitate teamwork interaction within a context where some students live 60 kilometers from their team members.

A key to the outcome of the project was the participation of Hong Kong-based colleagues Marc Aurel Schnabel and Christiane Herr, who volunteered their time for the project. Both acted as virtual studio staff for the project, providing valuable assistance to students through ning.com and participating in a series of Skype-based lectures. Although the project was presented in the form of traditional posters and models, international input was facilitated by the presence of Skype-based reviewers in Hong Kong.

This web 2.0 design studio resulted in several thousand online interactions. In the last month of semester, the www.deakin2009.ning.com website reported 3,928 visits, with between 74 and 229 site visits per day by members culminating in 36,945 page views. Unit evaluation revealed 76.6% agreement with the statement that 'the on-line teaching and resources in this unit enhanced my learning experience', a 13.2% increase for the same studio in 2008 using DSO and blogs. Agreement with the statement that 'the technologies used to deliver the online content in this unit performed satisfactorily' increased from 68.2% in 2008 to 76.0% in 2009.

The Ning.com site took over the role of DSO as the LMS for this studio, serving as the location for unit materials, forum for online chat, resource exchange, and linkage to digital assessment. The interface, ease of operation and similarity with FaceBook provide significant potential for this to be explored further in the digital design studio setting. One may question the need for an expensive university-based learning management system when free alternatives are available.

4. Conclusions

The DSO LMS provides a platform to meet the basic needs of the university, however its effectiveness is limited by a Web 1.0 approach to learning and teaching. The educators have achieved significant learning outcomes by working outside of the system through engagement in Web 2.0 technologies. The design studio is particularly suitable for further exploration of Web 2.0 technologies, including social networking through ning.com and student-authored videos in YouTube, to enhance the LMS.

A hybrid or blended approach to digitally enhanced design education should engage in the positive attributes of each technology with the aim of balancing learning outcomes with staff and student time overheads. The universities' need to control information needs to be balanced by an informed response to educational opportunities offered by Web 2.0 technologies. Significant potential exists for working within an online social network setting, where educators can create a learning environment that relates to, and responds to the needs of the Web 2.0 generation.

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References

Augar, N., Raitman, R. and Zhou, W.: 2004, Teaching and learning online with wikis, *Proceedings of beyond the comfort zone: 21st ASCILITE Conference*, Perth, Australia.

Biggs, J.: 1999, *Teaching for quality learning at university: what the student does*, SRHE and the Open University Press, Buckingham, UK.

Burry, M. and Smithers, M.: 1997, Networked based decision support for building design, *Proceedings of the 6th international EuropIA conference*, Europia Productions, Edinburgh, 181–193.

Goold, A., Augar, N. and Goodman, A.: 2008, Using social software to support the teaching of IT professional practice, *Proceedings of world conference on educational multimedia, hypermedia and telecommunications* (ED-MEDIA 2008), Association for the Advancement of Computing in Education (AACE), USA, 5223–5228.

Ham, J.: 2008, Developing the A+B / online virtual gallery, *Beyond computer-aided design: proceedings of the 13th conference on computer-aided architectural design research in asia (CAADRIA 2008)*, Pimniyom Press. Co. Ltd., Thailand, 357–363.

Ham, J. and Dawson, A.: 2004, Managing digital resources for design education, *Architecture in the network society: proceedings of the 22th conference on education and research in computer-aided architectural design in Europe (eCAADe)*, The Royal Danish Academy of Fine Arts, Denmark, 444–450.

Ham, J., Anson, S., Datta, S. and Skates, H.: 2002, The construction primer in case-based E-education: the Deakin Woolstores case study, *Proceedings of the 20th conference on education in computer aided architectural design in Europe*, eCAADe and Faculty of Architecture, Warsaw University of Technology, Poland, 130–133.

Holt, D. M. and Thompson, D. J.: 1995, Responding to the technological imperative: the experience of one open and distance education institution, *Distance education: an international journal*, **16**(1): 43–64.

Norton, L.: 1999, Encouraging students to take a deep approach to learning, Liverpool Hope University, <http://ltsnpsy.york.ac.uk/LTSNPsych/Specialist/Norton/Introduction.htm> (accessed 22 April 2008).

Saljo, R.: 1979, Learning about learning, *Higher education*, vol. 8.

Schön, D.: 1983, *The reflective practitioner*, Basic Books, New York.

Warren, I., Palmer, D., King, T. and Segrave, S.: 2008, Second Life and the role of educators as regulators, *Hello! Where are you in the landscape of educational technology? ascilite 2008 Melbourne*, ASCILITE, Australia.

Web page without author information: available from Wikipedia: http://en.wikipedia.org/wiki/Web_2.0, (accessed 29 September 2009).

Web page without author information: http://conferences.oreillynet.com/web2con/ (accessed 2 November 2009).

Web page without author information: http://films.nfb.ca/rip-a-remix-manifesto/ (accessed 1 February 2010).

Woodbury, R., Wyeld, T., Shannon, S., Roberts, I., R., A., Burry, M., Skates, H., Ham, J. and Datta, S.: 2001, The summer games, *Architectural information management. proceedings of the 19th conference on education in computer-aided architectural design in Europe (eCAADe)*, Helsinki.

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THE INTERPROFESSIONAL VIRTUAL DESIGN STUDIO

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Abstract. With the advent of Web 2.0 technologies, the Virtual Design Studio (VDS) has been revived in many schools of architecture around the globe. The recently evolving online Social Networks (SN) Platforms, as instruments for learning, have provided a potentially fruitful operative base for VDS. Yet these platforms have not enabled the VDS to explore new frontiers. All participants come from the same professional field and learn elements directly related to their existing design curriculum. The development of the VDS for interprofessional learning moves design education beyond conventional boundaries. The Interprofessional VDS (IPVDS) is an innovative method of teaching students from two different professional faculties the skills required for successful consultancy and promotional communication in the public realm. The IPVDS enabled students to develop consultancy skills and evidence-based communication strategies appropriate for disparate target audiences. It employed a digital SN learning platform to engage remotely-located students in acquiring new skills, transferring knowledge and achieving learning outcomes that enrich their professional experience. The paper presents details of the IPVDS, its methodology, outcomes, and evaluation of the studio, and discusses how the IPVDS is effective in enabling architectural students to understand and use communication and consultancy skills for collaboration across professional disciplines for the purpose of community engagement.

Keywords. Virtual Design Studio; interprofessional; collaboration; consultancy; design skills.

1. Introduction

The early nineties saw the emergence of one particular form of design studio, which investigated various possibilities that digital media and Virtual Environments (VE) can offer to the learning and the exploring of architectural design (Kvan, 2001). These Virtual Design Studios (VDS) established virtuality as acting while physically distant or as acting by employing digital tools (Maher et al., 2000). VE were established by the choice of design (Achten, 2001), way of communication (Schmitt, 1997) or digital tools (Kurmann, 1995). Later the VDS developed into real immersion within a VE, the medium for design interaction being the VE Design Studio (VeDS) (Schnabel, 2002). With the advent of Web 2.0 technologies, it became apparent that the next logical step to develop the VDS was collaboration within a social learning environment. Ease of communication, leadership opportunity, democratic interaction, teamwork, and the sense of community are some of the improved aspects that are offered by Social Networks (SN) (Owen et al., 2006). Mitchell (1995) also refers to the need for an ongoing evolution of the VDS towards a fully integrated studio where the borderlines between realms, professions, tools and mode of communications are dismantled. Subsequently the advancement of VDS moves design education beyond conventional boundaries and curricula, and engages participants socially from diverse professional fields. This leads to novel frontiers that enhance the deep learning within an interprofessional realm.

2. Consultancy and interprofessional collaboration

Historically, with little exposure to communication and consultancy skills during training, architects have been expected on graduation to be able to promote design using professional communication and consultancy skills. Usually consultancy experience within the architecture curriculum comprises communication with colleagues who have a sophisticated understanding of the design process and ability to envisage design outcomes. However, in practice, architects are required to explain their designs to people who often have little or no architectural design sense or background, an experience very different from explaining a project to someone who is cognizant of the field (Nicol and Pilling, 2000). The opportunities for consultation with clients about design in an authentic context are limited (Woo et al., 2007); although a few schools provide opportunities to undertake design in live projects or other simulations of collaboration with clients, engineers or general public. Learning how to consult professionally with clients who undertake design for themselves but who have only limited understanding of it remains a major gap in professional

education, especially since, in architectural business practice, the satisfaction of the client is of prime concern (Adam et al., 2008).

3. Design communication

Architects need to realise an aim to provide service to the broad community supporting their education. The service ideal has to be achieved without limiting the market for services because of inadequate attention to the necessity for good business practice (Freidson, 1986). The increasing marginalisation of architects in the workplace (Bennetts, 2008) suggests that professional ideals and professional work are poorly aligned. Unlike the health professions, architects are trained in design excellence, a key tenet in the espoused theory of architecture, without development of a concomitant understanding that design excellence must take into account the economic and social context of clients and project teams. Architecture students thus have a huge amount to learn following graduation about managing and sustaining relationships with diverse community and professional groups.

3.1. REQUIRED ABILITIES

This raises the question of what architects in professional practice require of new graduates entering employment with them. A qualitative analysis of person and job specifications for Australian architects, derived from a qualitative analysis of job advertisements (Schnabel and Howe, 2009) revealed that the majority of job advertisements specified communication skills as a key performance criterion in the job specification. Communication skills were cited more frequently than managerial, business or presentation skills. However, client communication skills are not formally taught within most architecture schools. Design communication and public presentation skills are taught well and practiced in the social context of peers and colleagues, but this does not address the need for community engagement required in professional practice. Most architectural schools teach a component of practice management in their courses and the Board of Architects requires competency in knowledge about practice management before registration is granted but, from an educational point of view, these courses do not comprise vertically integrated training throughout the degree to facilitate student acquisition of these skills.

Architecture is also influenced by pressures from external forces. The final decision about design can be subject to input from corporations, builders and town planners, regulatory bodies and councils (Cuff, 1996). To be successful, the professional requires the participation of the client and the acceptance of professional expertise by the client. However, clients have pre-existing

concepts and beliefs about what products or services are acceptable. Architects feel the constraints of participatory communication because this must be cost effective to be acceptable to them. Additionally, the architect also must communicate with other members of the team whose position it is to actually construct the building (e.g., project managers, construction contractors, engineers). The opportunity to practice interpersonal skills with members of other professional communities offers architecture students a means of developing confidence and competence in professional engagement and teamwork.

3.2. PROFESSIONAL COMMUNITY ENGAGEMENT

Not only do architects have to develop interpersonal skills, they also need competence in community education. A significant factor informing professional relationships with clients in the health sector is the growing awareness of the importance of literacy in determining client understanding of health information (Neilsen-Bohlman et al., 2004). The prime reason for failure of the community to understand, accept or act upon health information is its low level of literacy, to understand health concepts (health literacy). Similarly, the community has a low level of *design literacy*, which impedes acceptance and pursuit of aesthetics and elegance of function in all forms of design, including architecture. This has been described by many authors, like Boyd (1963) and more recently Hollier (2008). In the same way that health professionals must take responsibility for the education of the community in hygiene and disease prevention, design professionals must take responsibility for education of the community in the basic elements and principles of good design. This means that teaching communication skills in undergraduate architecture programs must include action-based projects in consultancy and community engagement.

3.3. DESIGN LITERACY

Design literacy is critical for the production of functional and aesthetic environments. It is a crucial part of communication skills training for other professions wishing to avoid rejection in communication with their client communities. The situation where architecture students create designs from briefs manufactured by non-existent clients which are evaluated by like minded people, peers or colleagues, means that architects are trained to respond to challenges from peers but not from those of lay people who may be misguided, prejudiced or uninformed (Cuff, 1996). Similarly, in dentistry, patients arriving in an under-resourced, overcrowded public health system, have little power to accept or reject treatment, since most treatment is provided in emergency conditions.

Thus the student has only to satisfy the instructor with the quality of the work. Rejection is only experienced when the client has more pressing reasons to reject it. In architecture, students may also experience rejection by their colleagues. However, rejection of a good design is rare in this context. In the practice context, rejection of good designs by uneducated clients for inexplicable reasons comes as a surprise for which their education mostly has usually left them unprepared. It was for these reasons that we developed an authentic interprofessional design studio that utilised real clients, who were not asking for buildings, but instead, for design in community service promotion, one which required a clear understanding of principles in visual communication and engagement with the vagaries of disparate community groups.

4. The interprofessional virtual design studio

Based on the methodology of a conventional VDS and following Aristotle's concept of phronesis or practical wisdom (learning to judge when and where to put skill or knowledge into action) and drawing upon the arts to facilitate acquisition of knowledge (Dahlman, 2007), the 'Interprofessional Virtual Design Studio' (IPVDS) was set up to teach students the skills required for successful consultancy and interprofessional collaboration.

The students' learning and interactions were conducted in a blended (real and virtual) learning environment that was aided by a freely available Web 2.0 Social Network platform provided by 'Ning' (http://ning.com). This virtual Learning Management System (LMS) allows participants to interact in multichannels, varied media forms, with rich text or media content, which enable their peers, experts, facilitators and invited guests to share social communication and generate knowledge (Owen et al., 2006). Our findings are similar to those of Harrison and Donn (2006), who explain how online SN allow the students to preserve and share their own thoughts and conversation about design, decisions and related issues to create a network of intelligence as the designs evolve.

Proceeding to their log-in to the LMS all students completed the *VIA Signature Strengths Questionnaire* (Peterson and Seligman, 2002) to identify key strengths to be featured in their online presence of the SN. This allowed members, who did not know each other prior to the IPVDS, to learn about strengths of their peers and group-members. Then one student of the School of Architecture at the Chinese University of Hong Kong (N=11) was assigned as the consultant to a group of four students of the Faculty of Dentistry, the University of Sydney (N=55). Within the IPVDS they collaborated in developing a dental health promotion project for a community audience.

In order to develop skill in health promotion, the dentistry students require an understanding of communication in visual media and how design can alter the efficacy of message transmission (Evans, et al., 2008; Katz et al., 2006). The quality of materials produced for use in public health education clearly shows failure to grasp basic graphic design skills. Dental students require assistance from genuine design consultants to develop an understanding of how to communicate these vital messages to the public, applying trained standards of design aesthetics and elegance to facilitate professional engagement with the community. Architecture students require genuine clients, who can consult with them, bring preconceived ideas to the table, question and challenge them as real clients do. To provide an exposure to an authentic client–expert relationship for each architecture student was a dilemma that was resolved by collaboration with dentistry students. Hence all students learned together about the challenges of persuasive communication and community engagement.

The objective was to develop an oral health promotion program for caries prevention around the message: *"Tooth decay can be stopped, reversed and prevented"*. The students were provided with in-class and live video-lectures as well as electronic resources before being assigned to their work-group, each group working with a different target audience (e.g., infants, school children, teenagers, older adults, ethnic or indigenous communities). They reviewed literature about caries prevention, target audience characteristics and design concepts, then collaborated via the LMS to develop a booklet for health educators working with the target group containing the evidence base, a promotional product (poster, brochure, web-site, DVD, T-shirt, etc.), and a audio-visual presentation for peers. The products were assessed for research quality by the Faculty of Dentistry and quality of design communication by the School of Architecture and presented at the *National Australian Oral Health Week.*

The student groups presented their work with each target audience in peer-teaching virtual (design) crits that were broadcast to the other university's location via a live video-stream using *Skype* software. Students at both faculties evaluated the IPVDS as a learning experience using the Web Attributes Flow and Performance Questionnaire (Huang, 2003) and provided qualitative feedback in focus group interviews. They finally provided evaluative feedback to each other about consultancy and teamwork skills using a protocol derived from Lurie et al. (2007).

5. Results

All student teams developed products meeting the requirements for each project program. Student groups successfully developed within the IPVDS framework eleven research-based, well designed oral health promotion pro-

grams of a quality suitable for publication or use in public campaigns as evaluated by the two teaching faculties and presented at oral healthcare campaigns as well as at their online SN platform (http://dentarch.ning.com).

5.1. STUDENT EVALUATION OF THE LEARNING EXPERIENCE

Overall evaluation of the project was positive. The issue most impacting student satisfaction was the delivery of information and resources in the virtual studio format. They enjoyed its multidimensionality and scope for interaction, reporting that the LMS allowed them to participate naturally and collaborate within their accustomed pace and style. Their experience with other social networking sites enabled them to use the project site easily, although the architecture students were more impressed with the utilitarian performance of the site than were the dentistry students. The multiple channels for communication were enjoyed by most students, although a small number found them distracting from the main academic task.

All students were unanimous in their appreciation of the virtual design crit as a rich learning experience. This was reported to be the highlight of the program, enabling students to describe their experiences to their professional peers and to discover how differently the project brief was interpreted for each new target audience. The IPVDS succeeded in providing the students an environment that allowed them to bridge interprofessional boundaries, social and cultural differences and international time zones.

5.2. ORGANISATION

Because flexible time in the curricula of two professional faculties is limited, students had to develop efficient ways of communicating with each other, holding team meetings and delegating individual responsibilities. The setup of the IPVDS with its SN platform allowed students to work synchronously, asynchronously and remotely. Resources had been provided to assist understanding of meeting procedures and students documented their application of strategies for team organisation, role delegation, meeting minutes and individual research contributions.

All students reported that, despite their recognition of the requirement for self-directed learning, they had experienced some difficulty in negotiating the time difference between their two countries and needed more allocated time within the curriculum for their online interactions. Discussion involved the usefulness of a Ning application that would permit the group members to video-conference on the site during the design phase of the project.

In order to meet the perceived expectations of their peers in the other faculty, students reported working very hard in research of the evidence base and mastery of core skills. Dentistry students completed extensive research into the project topic whilst architecture students, recognising the requirement to educate their dental clients in design principles and publishing software, ensured their own proficiency in these things. The dentistry students reported that they valued the gain in design knowledge that would assist them in their practice promotion tasks in the future. The architecture students found the experience of working with clients with poor design skills but clear ideas about project outcomes to be interesting but challenging at times.

5.3. TEAMWORK AND SOCIAL ENGAGEMENT

The publication of personal strengths was found to be useful in facilitating development of communication between the dentistry group members and their architecture consultants. An analysis of the personal strengths of each group found that while both dentistry (36%) and architecture students (80%) identified curiosity as signature strength, in the architecture group this appeared to be a defining characteristic. The other signature strengths of architecture students were fairness and spirituality (each 50%), social intelligence, integrity and appreciation of beauty (all 40%). Somewhat in contradistinction to prevalent stereotypes but not surprising in a health profession, dentistry students cited their other strengths as loving and being loved (48%), gratitude (48%), kindness (43%) and fairness and citizenship (each 41%).

A common shortcoming of student group-projects is the inequitable division of labour, where some students coast as ‘passengers’ on the effort of other team members. All aspects of communication and social engagement of the IPVDS, with the exception of ‘instant chat,’ were visible to supervisory staff on the SN site, generating an incentive for every student to take part in the whole studio at all times. At any point of the IPVDS the contribution of each team member was openly commented upon by all other participants of the studio. This open evaluation was rigorous, honest, diplomatic, constructive, and informed, this last quality being one often not open to academic staff assessing students’ work.

In all but one group, working relationships were found to enhance productivity and enjoyment, although some groups reported difficulty in managing the large amount of background material generated by diligent research of the topic area. They suggested that the opportunity for a supervised group discussion during the early part of the project would assist them with this problem.

5.4 COMMUNICATION WITH OTHER PROFESSIONS

The requirement that students understand each other's professional background needs and skills resulted in their high appreciation and recognition of the value of interprofessional collaboration. Dental students developed a better grasp of why they needed to understand principles of design in order to develop effective health promotion materials. Architecture students were surprised by the difficulties encountered in dealing with clients, often with limited experience of design but strong opinions about what they wanted. The IPVDS also allowed participants to reflect on their own professional understanding, jargon, dealings, assumptions and shortcomings.

6. Conclusion

The IPVDS moved both faculties from sequestered autonomy into an enriching, deep learning experience in communication for both cohorts of students. Subsequently the IPVDS has enabled development of a strong link, not only between two professional disciplines, but also between two faculties usually perceived as having little in common. The project engages both students and academic staff in learning about professionalism, communication, collaboration, consultation, blended environments and community engagement.

Acknowledgement

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References

Achten, H. H.: 2001, Normative positions in architectural design: deriving and applying design methods, *in* H. Penttilä (ed.), *Architectural information management: 19th conference on education in computer-aided architectural design in Europe (eCAADe)*, eCAADe, Helsinki, Finland, 263–268.

Bennetts, R.: 2008, Reasserting the architect's position in pursuit of sustainability, *in* S. Roaf and A. Bairstow (eds.), *The Oxford conference: a re-evaluation of education in architecture*, WIT Press, Southampton, 11–16.

Boyd, R.: 1963, *The Australian ugliness*, Penguin, Ringwood.

Cuff, D.: 1996, *Architecture: the story of practice*, MIT Press, London.

Dahlman, Y.: 2007, Towards a theory that links experience in the arts with the acquisition of knowledge, *International journal of art and design education*, **26**(3), 274–284.

Evans, R. W., Pakdamen, A., Dennison P. J. and Howe, E. L. C.: 2008, The caries management system: an evidence-based preventive strategy for dental practitioners: application for

adults, *Australian dental journal*, **53**, 83–92.
Freidson, E.: 1986, *Professional powers: a study of the institutionalization of formal knowledge*, University of Chicago Press, Chicago, London.
Harrison, D. and Donn, M.: 2006, Using web 2.0 technologies to preserve design history and improve collaboration, *CAADRIA 2006*, Kumamoto, 111–117.
Hollier, N.: 2008, *The new Australian ugliness*, Overland, available from: <http://www.overlandexpress.org/183%20editorial.html> (accessed 1 February 2010).
Huang, M. H.: 2003, Designing website attributes to induce experiential encounters, *Computers in human behaviour*, 19, 425–442.
Katz M. G., Kripalani, S and Weiss, B. D.: 2006, Use of pictorial aids in medication instructions: a review of the literature, *American journal of health-system pharmacy*, **63**(23), 2391–7.
Kurmann, D.: 1995, Sculptor: a tool for intuitive architectural design, *in* M. Tan and R. Teh (eds.), *The global design studio: sixth international conference on computer aided architectural design futures (CAADFutures)*, Centre for Advanced Studies in Architecture, National University of Singapore, Singapore, 323–330.
Lurie, S. J., Lambert, D. R., Nofziger, A. C., Epstein, R. M. and Grady-Weliky, T. A.: 2007, Relationship between peer assessment during medical school, dean's letter rankings, and ratings by internship directors, *Journal of general internal medicine*, **22**(1), 13–6.
Kvan, T.: 2001, The pedagogy of virtual design studios, *Automation in construction*, **10**(3), 2001, 345–354.
Maher, M. L., Simoff, S. J. and Cicognani, A.: 2000, *Understanding virtual design studios*, Springer-Verlag, London.
Mitchell, W. J.: 1995, The future of the virtual design studio, *in* J. Wojtowicz (ed.), *Virtual design studio*, Hong Kong University Press, Hong Kong, 51–60.
Neilsen-Bohlman, L., Panzer, A. M. and Kindig, D. A.: 2004, *Health literacy: a prescription to end confusion*, National Academic Press, Washington, DC.
Nicol, D. and Pilling, S. (eds.): 2000, *Changing architectural education: towards a new professionalism*, E and FN Spon, London.
Owen, M., Grant, L., Sayers, S. and Facer, K.: 2006, Social software and learning, available from: Futurelab, **1**(71) <http://www.futurelab.org.uk/resources/documents/opening_education/Social_Software_report.pdf> (accessed 1 February 2010).
Peterson, C. and Seligman, M.: 2002, Via signature strengths, available from: Positive Psychology Center, University of Pennsylvania, <http://www.authentichappiness.sas.upenn.edu/tests> (accessed 1 February 2010).
Schmitt, G.: 1997, Design medium–design object, *in* R. Junge (ed.), *CAADfutures 1997: 7th international conference on computer aided architectural design futures (CAAD Futures)*, Kluwer Academic, Munchen, 3–13.
Schnabel, M. A.: 2002, Collaborative studio in a virtual environment, *in* Kinshuk, Lewis, Akahori, Kemp, Okamoto, Henderson and Lee (eds.), *Learning communities on the internet: pedagogy in implementation, proceedings of the international conference on computers in education (ICCE)*, Auckland, New Zealand, 337–341.
Schnabel, M. A. and Howe, E. L.C.: 2009, Client design literacy and consultancy skills in architectural education, *in* Ning Gu, Michael Ostwald, and Anthony Williams (eds.), *Computing, cognition and education: recent research in the architectural sciences*, Australian and New Zealand Architectural Science Association (ANZAScA) and University of Newcastle, Australia, 205–218.
Woo, Y., Herrington, J., Agostinho, S. and Reeves, T.: 2007, Implementing authentic tasks in web-based learning environments, available from: EDUCAUSE Quarterly, **30**(3), 36–43: <http://www.educause.edu/ir/library/pdf/eqm0735.pdf> (accessed 1 February 2010).

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REPRESENTATION IN A TIME OF RE-PRESENTATION

Design media processes in architectural education

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Abstract. This paper examines what is appropriate and valuable to include in architectural education in light of changing representational conventions and techniques. Architecture finds itself at a unique moment in time where the means of production for the profession, and indeed the entire discipline, are transforming and fundamentally undermine the existing models of education, production and understanding. The threat to architecture education is that architecture becomes learned techniques rather than a way of operating within a body of knowledge that grows and responds to its context. These digital media processes offer contemporary education new and challenging ways to communicate ideas, sometimes subverting the imperative for "drawing" as the representation does not refer to information in the abstract, but IS the information quite literally.

Keywords. Design education; design theory; digital design representation.

1. Introduction

Abstraction and its role in architectural representation have traditionally been about fragmentation and isolation of the parts from the whole. Contemporary educational models presume this relationship of the parts to the whole.

Digital design media re-presents design information as a context driven, anti-fragmentation design process that is dependent on contextual relationships in increasingly simulation based modelling environments and fundamentally reconceives the relationship of the whole through the parts. Speculation about this shift provokes a critical debate about the possibilities and pitfalls of a new trajectory suggested by digital education and practice.

Traditional representational conventions of communication like plan, section and elevation are fundamental to the way architects are educated. When avant-guard practitioners such as Thom Mayne proclaim "I haven't drawn a plan in five years" (Mayne, 2006), they expose a significant issue of digital practice's effect on education. Digital modeling fundamentally subverts plan thinking by prioritising a three-dimensional view of the world. While seasoned practitioners may not need to work in plan, does an education in that form of abstract thinking still serve them well? To find way forward academics might be well served to expose debate or hybridised transition in the design studio projects themselves. Figure 1 is an example of this hybridised transition where the rules of elevation (a projected orthographic isolated instance) are still at play, but spatial and contextual information are also revealed. This simultaneity is achieved through a conflated "side-view" of the 3-d model and selected use of transparency.

Does architectural education still require representational abstraction in this age of digital design techniques, methods and processes that privilege simulation as the model of architectural production? What are the issues and knowledge that academia should now address to enable the novel transformation of methods of communication emergent in the digital design proc-

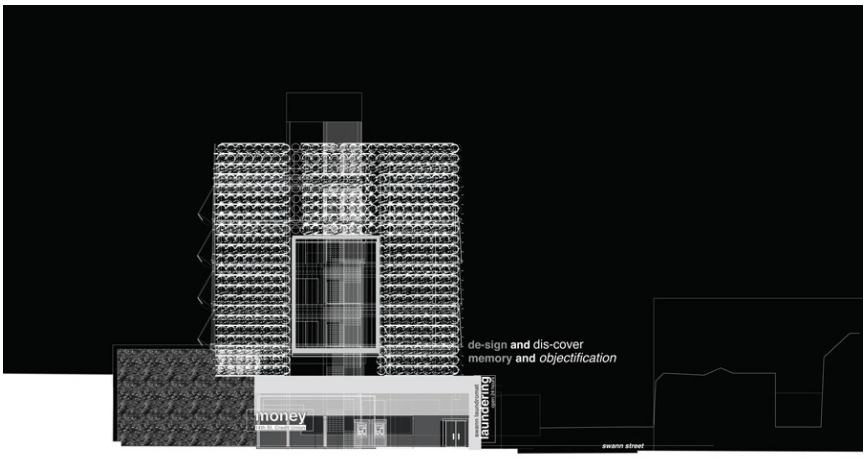

Figure 1. Hybridised transition of spatialised elevation – Lisa LaCharité-Lostritto, 2009.

esses of contemporary practice and education? Many academics and scholars favor a reductionist approach (Guidera, 2006) that mediates the complexities and simultaneities that digital media brings to bear. Perhaps academia might hybridise existing educational models with the goals of integrated practice and reprioritise the value of technologies and processes and the presumptive connection of architectural design and representation.

2. Representation and re-presentation

Architecture is a way of seeing and thinking that privileges visual communication that oscillates between abstract and literal systems. Here abstract systems are understood as representational conditions whereby the very media of design exploration translates ideas. Conversely, literal media are understood as systems that re-present information without representational translation. By using media as more than just a representational system or communicative necessity, media is capable of directing process. Cyclical observation of media processes informs one's design and it is in this reprioritisation of outcomes and expectations that one can be informed by media to direct design process. This leverages media as a way to evaluate and inform the architectural design process.

This division of abstract and literal methods of communication provides the opportunity to construct a design process working non-linearly in explicit systemic, conditional and metaphorical operations. Speculative design methods develop across a series of disparate media processes that are structured, rather than dictated, by the particular architectural issues of visual communication. Accommodating and embracing a diverse and complex range of issues of input and testing the variable levels of output lead to novel outcomes in the form of new discrete ideas and compositions.

Contemporary architecture continues to value the Modern position that multiplicitous phenomenon are symptomatic of valuable and interesting complexities (Venturi, 1966). The analog design processes of mid-century Modernism persist in the instruction of architectural design. The challenge to effectively introduce contemporary digital media towards new and speculative types of architectural communication remains to be explored.

3. Design media processes

The conventional practice of architecture today assumes a traditional set of orthographic projections (plan, section, elevation, etc.) at varied scales and levels of detail, that when taken in concert signifies a whole, complete idea of a building. Contemporary architectural practice assumes a simple one-to-one

correspondence between design intent and interpretation, between the representation of ideas and the interpretation of the design of buildings. Contemporary models in architecture education reveal this assumption, these abstract, fragmented representations of the building and its components rely on reductive syntactic connections (Lonna, 1997) where each abstraction is part of a dissected whole. Taken as a summation these fragments exceed their individual abstraction and constitute a representational description of the complete building. Digital and computational media conversely begin with the virtual construction (simulation) of the whole, which is then viewed as a series of isolated assemblies of constituent components. Is there an inherent value in the translation of ideas into abstract representation or is there a greater value in transcription of ideas in to a simulated construction?

Students in a graduate design studio were asked to model the shapes, forms and gestures from assigned paintings and in so doing, create spatial interpretations/analyses of the painting. Students were asked to consider a temporal interpretation of the painting to interpret the motion implied by the painting and the elements of motion contained within the compositions. The speculative digital model generated should reveal a specific formal/spatial aesthetic analysis of the original painting. The fundamental components of the paintings- line, tone, shape, color, texture and depth were the parts of the compositional whole, and were often related to the artist's interest in point, line, surface and depth. The visual language of each painting should be expressed in the digital models, the new artefacts of discovery.

In the case of Taureau III by Le Corbusier, there are layers that divide the painting into three parts vertically. The color masses give the painting depth,

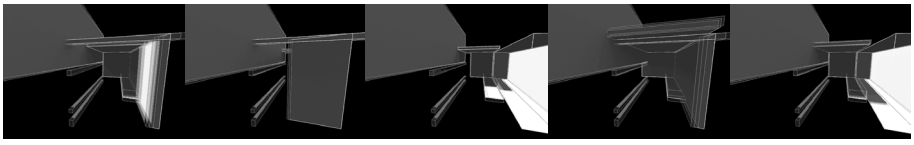

Figure 2. Frames from animate translation of original painting – Lisa LaCharité-Lostritto, 2008.

as some colors read at the forefront while others recede to the back. Within this compositional reading lie many sub-readings, including ideas about time through the morphology of the composition's color regions while presenting all morphological versions simultaneously. The animations illustrated in figure 2 translate the set of morphological regions from the painting into a set of digital volumes, lines, planes, and spaces. In the animation shown in figure 2, faces and points animate based on a repeat behavior temporarily extending, shortening, or inverting the masses. In between each frame are four sub-

frames. These sub-frames trace the paths of the moving faces. Eight animations are made, each with a different composition. The animations are then arrayed into an image sequence. From this, a collection of frames is selected to create a composite animation, as seen in figure 3. The animation shown in figure 3 uses digital video tracking software to produce many new combinations of overlapping frames while incorporating compositional ideas from the original painting. The production controls the time between the frames and emphasises the transition from one frame to another.

The frames chosen from the constructed montage are put together in an action script movie allowing the viewer to choose the composition (figure 4).

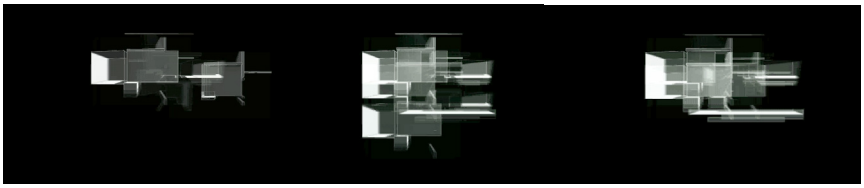

Figure 3. Frames from animate montage of frames from animate translation through analytic processes of rhythm and transition – Lisa LaCharité-Lostritto, 2008.

There are three sets of the same set of compositions. Each set can be changed, scaled, and moved within the virtual frame. This movie provides a way to generate a vast collection of virtual montages. The interaction results in a hybrid experience that is perceived as more physical because it provides a parallel connection between body and other sensory experiences, via the action script interface, similar to interaction with physical space.

The value of these processes of animate dimensional translations lies in their ability to accommodate analyses of non-spatial information. The potential lies in the opportunity to provide a digital path to an authored, developed, and editable system of representation that could produce new representational artefacts to describe spatial speculations rooted in cross-disciplinary ideals. Collage is typically defined as a drawing that is made of an assemblage of different forms in a composition. In architecture, an idea is communicated through the method of assemblage. This can be translated to the idea of animation as a temporal collage. There are co-present layers of line and surface as in a collage, but the connections that the lines make and the characteristics of a surface can change over time in a temporal collage. The method becomes a polymorphism, a combination of ideas and/or operands that create at least two or more related results that may or may not be immediately recognised as related. Many static compositions can hint at the idea of change in time, but cannot create a series of seemingly autonomous compositions linked by time. Montage is typically defined as a drawing that is made of an assemblage of

different forms in a composition. An architectural idea is typically communicated through a method of assemblage, as seen in a typical set of plan, section, and elevation drawings.

There are non-animate applications of collage and assemblage processes that include graphic conditions that conflate modeling, drawing, and typography. These digital media processes have allowed architectural design and graphic design to merge (figure 5) removing the separation between type setting and architectural graphics. The incorporation of text into conceptual architectural drawing was influenced heavily by cultural changes in the twentieth century. Russian constructivist, Kazimir Malevich, a painter and art theoretician, incorporated text by typography and language that indirectly relate to the content of the media, simultaneously sending a message and using the text as structure for the composition and the implication of new spatial interpretations within the image.

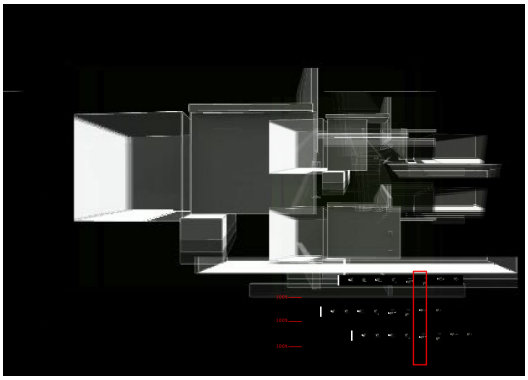

Figure 4. Interactive animate representation of scale, position, and transparency – Lisa LaCharité-Lostritto, 2008.

Often digital media and computational design shifts focus away from representational development (drawings) and towards formal and spatial development (ideas) through the development of the three-dimensional model. It is this gap between design theory and digital practice that exposes a possible path for engaging digital design media in education that explores how fundamentally new digital conventions of communication might reshape the design process, digital practice and educational priorities. These novel digital conventions of architectural communication will conceptually shift production of architectural ideas and objects like nothing has since orthographic and perspective projection in the 15th and 16th centuries.

4. Process is the product

In the move beyond drawing-centric practice into a dynamic process oriented

digital practice, a new conceptual foundation for architectural thought and production is emerging. A foundation based not on drawn conventions of a representational nature but instead re-presentation of design information based on computation and simulation of architectural assemblages. These digital processes are of a non-representational nature, and focus on fluid relationships between design, documentation, conceptual representation and descriptive representation in which digital information (computation), not graphic information (drawing), are the primary medium.

This movement of digital computation and simulation has continued to affect the culture of architecture in many ways. The means of production,

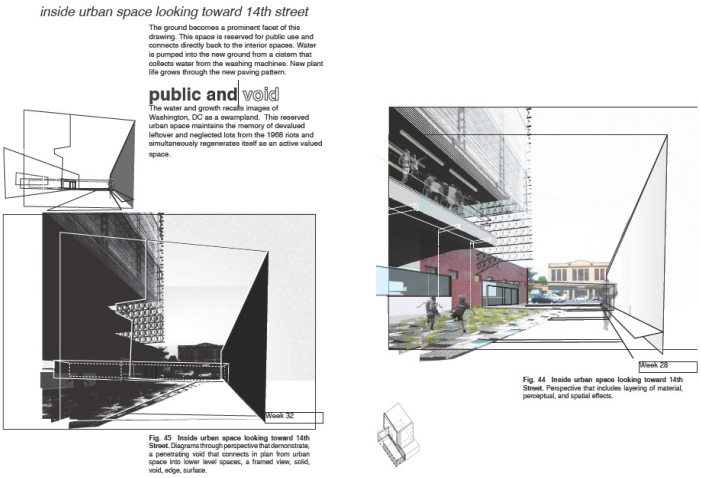

Figure 5. Hybrid representation – re-presentation – Lisa LaCharité-Lostritto, 2009 http://0095b6.com/lacharite/index.php?/project/thesis/.

fabrication, simulation, and 4D project simulations are again expanding the conventional thinking about modes of construction and visual conventions of communication as well. There is simultaneity in exploration of scales, tectonics, and aesthetics. This has changed the meaning of curricula in architectural education. The curriculum has become more of a framework to set up an experience where bodies of knowledge overlap and indirect connections can be made rather than a way to control a body of knowledge.

New conventions of architectural communication that evolve out of digital fabrication information (SHoP, 2004) re-present the computational processes used in the design process. This visual communication or re-presentation (figure 4) of design intent demonstrates the fluidity between design process and design product in contemporary digital processes. The novel conventions of digital fabrication are not trying to represent the intention, it IS the

intention. Re-presenting information in its unadulterated truth speaks more accurately to the design process and architectural product liberated from any representational obligation or agenda.

Formal, tectonic, and experiential performative requirements are often the driving force in digital projects and are communicated in each drawing or form of architectural communication simultaneously. The initial stages of their projects are based on the coalescence of the computational study of parameters and restrictions derived from the site, program and requirements of the space that is being designed (SHoP, 2003). This digital modeling analysis generates architecture that informs the spatial, formal, and temporal properties throughout the entire design process. (Rahim, 2002) From this digital model, physical dimensions are extrapolated and recorded on a spreadsheet and software is used to separate the pieces of the digital model and organise them on cut sheets in a way that minimises the amount of materials used. The cut sheets are sent directly to a machine to be cut or produced (SHoP, 2004). There is no need for symbolism or traditional convention to communicate what the piece does or how it looks. The drawing becomes the actual information for the thing itself. These construction drawings can be tied to design as they are rooted in generative geometric processes (McCullough, 2004). The drawings represent the process of designing, the process of making and the process of fabricating.

As evident in the drawings of Dunescape, the temporary installation in the P.S.1 courtyard, the parameters are the dimensional requirements for

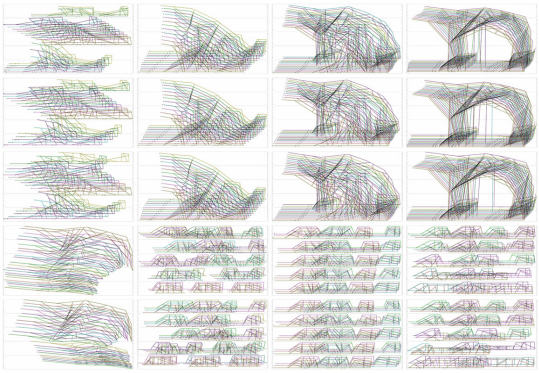

Figure 6. P.S.1. Dunescape 1:1 Conceptual Process/Construction Document information drawings – image courtesy of SHoP Architects, PC.

certain actions (figure 6) or contours drawn as sections, directly resulting in the architectural form. The process is the product; the image at 1:1 is the representation of every component and is literally the construction document for

architectural assembly. These drawings represent the process, fabrication, and form, directly exposing all instances simultaneously.

5. Why does this matter?

The threat to architecture education is that architecture becomes a collection of learned techniques rather than a way of operating within a body of knowledge that grows and responds to context. The application of digital technologies such as BIM, parametric design, and digital fabrication are fundamentally altering the how and what of architectural design.

The possibilities afforded by digital design media and robust computational technologies are increasingly affecting what we make and simultaneously how we make as architects. Increasingly intelligent (or semi-intelligent) digital modeling is replacing (or displacing) digital drawing or representational (un-intelligent) modeling. We see diminishing returns of the value of transforming three-dimensional spatial/formal ideas into two-dimensional conventional abstractions (drawings) of those complex ideas. The basic conventions of architectural visual communication are all based on the predisposition for abstract, two-dimensional communication that has long been a part of architectural education, understanding and practice.

Figure 7 began as a conceptual investigation of ideas and definitions from readings that influenced ideas about the design. Simultaneously, this concep-

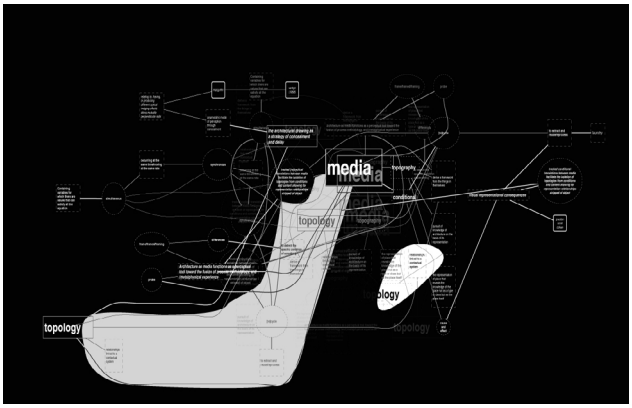

Figure 7. Novel convention of diagram|palimpsest – Lisa LaCharité-Lostritto, 2009
http://0095b6.com/lacharite/index.php?/project/thesisdiagrams/

tual mapping condition creates an evocative image, and also creates its own conventions and cultures. If, then, each drawing has its own conventions and culture through exploitation of established traditional convention, each individual drawing has an opportunity embed in it a closer connection that iden-

tifies a connection between design processes and products or specific conventional conditions. The media here directs the process of analysis through the process of connection developed in the re-presentation of representational connections in the information presented.

The issues and knowledge that academia addresses to enable novel transformation of methods of communication emergent in the digital design processes of contemporary practice and education challenges existing definitions of representation and re-presentation. There is no longer a set body of knowledge or abstract conventional norms but instead it is a process driven fluctuating body of knowledge that prioritises ways of thinking through media processes that embody design process of any given project in the media used to design. Academia must revisit current curricular approaches and imagine a system that acknowledges the obsolescence of the how and what of that which is taught in today's schools of architecture.

Acknowledgements

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References

Cheng, R.: 2006, Suggestions for an integrative education, *in* M. Broshar, N. Strong, and D. S. Friedman, *AIA: report on integrated practice,* The American Institute of Architects, Washington. D. C., Section 5, 1–10.

Guidera, S.G.: 2006, BIM applications in design studio, *in* G. A. Luhan, P. Anzalone et al., *Synthetic landscapes: ACADIA 2006 conference proceedings,* Mansfield: The Association for Computer-Aided Design in Architecture, 213–227.

Kolarevic, B.: 2003, *Architecture in the digital age: design and manufacturing,* Spoon Press, New York, 3–10.

Lonna, F. C.: 1997, Prelude. Mapping the question: the perspective hinge, *in* A. Pérez-Gómez and L. Pelletier, *Architectural representation and the perspective hinge,* MIT Press, Cambridge, 2–87.

Mayne, T.: 2006, Change or perish, *in* M. Broshar, N. Strong, and D. S. Friedman, *AIA: report on integrated practice,* The American Institute of Architects, Washington, D. C., Section 1, 3–5.

McCullough, M.: 2004, *Digital ground,* The MIT Press.

Perez-Gomez, A. and Pelletier, L.: 1997, *Architectural representation and the perspective hinge,* MIT Press, Cambridge.

Rahim, A.: 2002, Potential performative effects, *Contemporary techniques in architecture,* Wiley Academy, London, 52–63.

SHoP: 2004, Complexity and customization: the Porter House Condominium, *Praxis,* **6**, Garrity Printing, United States, 46–53.

SHoP: 2003, *Versioning: evolutionary techniques in architecture,* Wiley Academy, London.

Venturi, S.: 1966, *Complexity and contradiction,* The Museum of Modern Art, New York.

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FABRICATING TWISTED TOWERS

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Abstract. The miniature replicas of multi-billion dollar property development projects provide every year a spectacle of the vast imagination of architects and master developers at Cityscape Dubai exhibition. The technical aspect of the model-making industry component is a complex one in that it often engages the modelling of very subtle structures such as twisted towers. One illustration of these is the Infinity Tower in Dubai Marina (designed by SOM). To be completed in 2011, this 330-metre high-rise is composed of 80 floors and is intended to be the world's tallest high-rise featuring a 90˚ twist. Each floor rotates by 1.2 degrees to attain the full 90˚ spiral, creating the shape of a helix. The paper discusses the physical modelling of this tower, with a description of both the digital and the constructive parts.

Keywords: Fabrication; models; Rhinoceros; twisted towers; Dubai.

1. Introduction

The Arabian Gulf's oil-fuelled property sector is promoting many businesses, including the model-making industry. The miniature replicas of multi-billion dollar property development projects provide every year a spectacle of the vast imagination of architects and master developers at Cityscape Dubai fair. The technical side of this model-making industry category is a complex one, though, as it involves the modelling of very subtle structures such as twisted towers. The fabrication of these miniatures implies new domains of expertise that do not fall within the bounds of traditional modelling-making techniques. Issues of flexibility, precise contouring and unrolling/smashing manipulations are at work to achieve the construction of the desired non-uniform polysurfaces. It also involves operations such as the folding of several webs, which implies the introduction of material processes that are as new as

they are complex. We recall, for example, how the design and construction of the Yokohama Terminal required a basic development operation whereby the folds of the web were woven with each other every half fold, so that the curvature at a larger scale could be secured (Moussawi and Zeara Polo, 2002).

Beyond their attractive presentations at fairs, twisted structures imply meticulous and detailed planning and unquestionable degrees of sophistication. One specific example is the SOM-designed Infinity Tower in Dubai Marina (figure 1). To be completed in 2011, this 330-metre-high structure is composed of 80 floors and is supposed to be the world's tallest tower featuring a 90˚ twist. Each floor rotates by 1.2 degrees to achieve the full 90˚ spiral, creating the shape of a helix. The shape of the tower is a variation on HSB Turning Torso in Malmö, Sweden, designed by Spanish architect Santiago Calatrava, which also twists exactly 90 degrees.

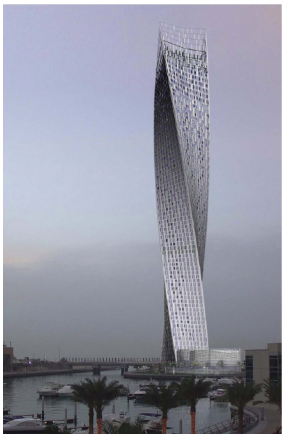

Figure 1. Dubai Infinity Tower.

Dubai Infinity Tower is located in the Dubai Marina, a city-within-a city and possibly the world's most exclusive waterfront development, where a stylish, sophisticated lifestyle has been created to delight its residents. The building's unique spiral design means that every apartment will have a view of the sea and marina in a truly unique setting. The Marina is ideally located for easy access to the Jebel Ali Free Zone, Dubai International Airport, Dubai Internet City and Dubai Media City, and some of Dubai's finest five-star hotels.

To design the Infinity Tower, the architects have used open-space architectural concepts to ensure that there are no pillars anywhere in the building, thus creating a true sense of space and light. Pre-finished titanium metal panels on cast-in-place concrete perimeter columns along with repetitive staggered

screen panels filter the direct sunlight to the units. The tower's slender elegance conceals great strength; secured by a reinforced concrete column superstructure that rotates with the twisting shape to create a helix. The shape and size of these columns has been determined by wind tunnel testing and innovative engineering using 3D computer modelling analysis. At all times, in creating such a unique and radical architectural project, safety and stability have been the architects' primary concern, both in design and in the quality of materials and construction. Every stage of the Infinity project has harnessed the skills and experience of world-class professionals in every field. The building itself is still under construction (figure 2).

Figure 2. Dubai Infinity Tower under construction (May 2009).

2. Modelling

Back in the days before computers, architects, engineers, and artists would draw their designs for buildings, roads, machine parts, and the like by using pencil, paper, and various drafting tools (Schneider, 1996). These tools included rulers and T-squares for drawing straight lines, compasses for drawing circles and circular arcs, and triangles and protractors for making precise angles. Of course, a lot of interestingly-shaped objects couldn't be drawn with just these simple tools, since they had curved parts that weren't just circles or ellipses, and which needed to run smoothly through a number of predetermined points. This problem was particularly acute in shipbuilding. Although a skilled artist or draftsman could reliably hand-draw such curves on a drafting table, shipbuilders often needed to make life-size (or nearly life-size) drawings, where

the sheer size of the required curves made hand drawing impossible. Because of their great size, such drawings were often done in the loft area of a large building, by a specialist known as a loftsman. To aid in the task, the loftsman would employ long, thin, flexible strips of wood, plastic, or metal, called splines, which were held in place with lead weights, called ducks because of their resemblance to the feathered creature of the same name. The resulting curves were smooth, and varied in curvature depending on the position of the ducks. As computers were introduced into the design process, the physical properties of such splines were investigated so that they could be easily modelled. Specialized software have thus been developed (e.g. Rhinoceros, Maya, Catia, 3-d Max) to address, among other things, these issues.

Now, a twisted tower is an instance of a NURB (Non-Uniform, Rational, B-spline). A NURB could be a complex architectural object (building), a ship, an automobile, an airplane, a sailboat, etc. The underlying modelling of a NURB involves a mathematical technique using polynomials to describe smooth curves or surfaces. This technique was developed in the early 1970's as a method for creating smooth curves and surfaces interactively on the computer screen. A NURB is defined using vertex points, a knot vector, a polynomial degree, and one weight value per vertex point. The most identifying feature of a NURB is that the curve (or surface) does not pass through the defining vertex points. This means that a program that uses NURBs allows to edit the shape of a curve or surface by moving or dragging these vertex points. Since these vertex points do not lie on the curve or surface, the program usually connects the vertex (edit) points with straight lines. These lines are sometimes called the vertex mesh for NURB surfaces (Kolarevic, 2003).

In the present research, Rhino 4.0 has been used to undertake the modelling operation. Besides providing the tools to accurately model and document designs ready for rendering, animation, drafting, engineering and analysis, the software in question can translate NURB curves, surfaces and solids into forms that could be easily cut on laser machines, then later manufactured and constructed. The affordability, precision, short learning curve, speed and compatibility are attributes to be stressed alongside some specific modelling functions such "Contour" and "Unroll Surface." Since no existing software could meet the demands of every complex project, the interfaces between programs should therefore be highlighted (Franken, 2003). Files migrated back and forth between several platforms until the last stage of the modelling process.

The fabrication operation proper, conducted at our Advanced Digital Fabrication Lab, involves several steps. A 3-d digital model is first generated. The model is then twisted, "contoured" (sliced) and "smashed" (unrolled). The resulting layers, sections and unrolled elevations are then sent as 2-d files

to a laser cutter to be cut, followed by an assembly operation that negotiates its success with the careful placement of all the components around a central core, at specific levels and with the right angular twist. The whole set of pieces is then assembled together.

The paper will present and debate the difficulties and challenges encountered in this process. Because the bulk of the present research deals with a precise technical exercise in fabrication, stress will be made solely on the technical steps involved, starting from the digital design to the final stage of the fabrication process. To start with, the 32 × 40m plan was imported as a dwg file. A central core was drawn in the middle, to be later used as a shaft supporting the several floors plates and elevations. The plan was next extruded to a height of 330m, using the "extrude surface" command. The tower is now a polysurface that is ready to be twisted (figure 3).

Figure 3. Digital model (wireframe), after being twisted.

The use of the "Persistent Osnap Dialogue" is also crucial, for it assists in making the precise selection of both the starting and the end of the axis of twisting. After correctly entering the start and end of the twisting axis, the system prompts the user to enter the angle of twisting, or to pick two reference points to define the rotation angle, which is 90 degrees in our case. Once the tower as polysurface has been twisted, the next step is to model the central core, which has to be extruded after the polysurface has been twisted, and not simultaneously. The rectangular/square shape will force the different plates to be locked in one specific position, corresponding to a precise angular coordinate, and thus inhibit their lose rotation around the axis.

Next, the contour curves and points are created from the intersections of a series of invisible parallel planes cutting through the selected object (figure 4). The contour command creates a spaced series of planar curves and points resulting from the intersection of defined cutting planes through curves, surfaces, polysurfaces or meshes. The first step here is the selection of the poly-

surface and core to be contoured. The second step is the picking of the base point; one of the contour planes will go through this point. Third, the system prompts the use to pick a direction perpendicular to the contour planes, which will be generated in both directions from the base point and will be perpendicular to the picked direction. Fourth, the system prompts the user to type the distance between contours (which is 3m in our case), then press enter. This will create contour curves where the contour planes intersect the selected surfaces and polysurfaces. One has to also make sure that the "GroupObjectsByContourPlane" is set to "Yes." This will force all the segments forming a given floor to be joined to each other.

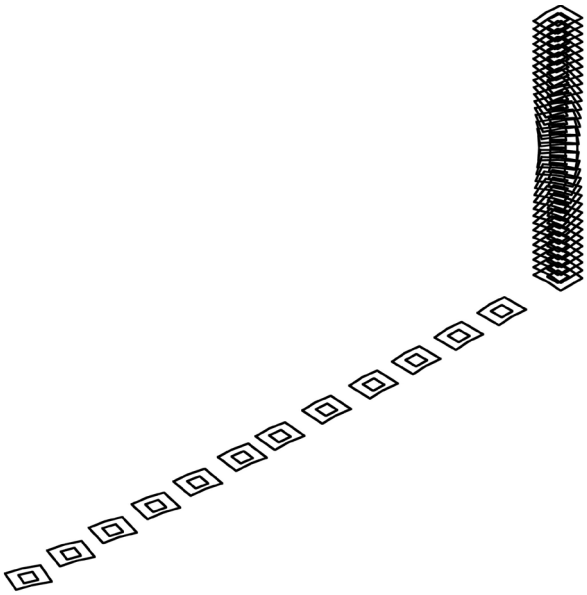

Figure 4. Some of extracted contour curves.

The still-highlighted contours have to be dragged away from the original polysurface for further manipulations. In the Front View, the lowest contour (corresponding to the ground floor) has to be dragged to the left, then the second contour, etc, until all the contours are distributed evenly in all the views. The use of Align command in the Top View is helpful. Unfortunately, the software used does not have a "distribute" command available on its menus (there are a couple of scripts online though); and so one has to try to do this manually.

The very useful command UnrollSrf flattens (develops) a surface or polysurface to a planar surface. When the Explode option is on, the resulting surfaces are not joined, which is convenient for later manipulations and laser cutting operations (figure 5).

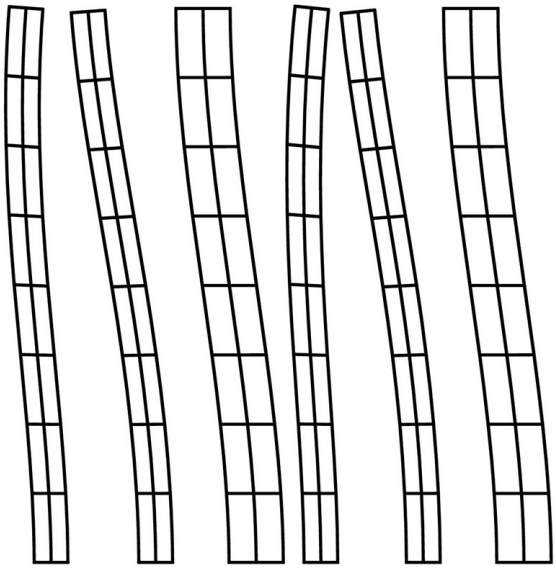

Figure 5. External surfaces unrolled.

The selected plans and elevations are next exported to AutoCAD, to be plotted at the desired scale. A mock up model should be next built to make sure that there are no mistakes in the conception of the floors and elevations. This crucial step is also justified by the fact it is easier and cheaper to test a model made from cardboard than from Perspex. Once the mock-up model is built, and that no mistakes are detected, the original plans and sections are sent to the laser machine to be cut. Depending on the model's scale, the thickness of the Perspex plates is determined. In general, the plates' thickness varies between 3mm and 6mm. The cladding material is cut from thin and malleable polycarbonate sheets, upon which vertical and horizontal lines are engraved so as to simulate fenestration patterns. The core around which the horizontal plates are to be placed is constructed from thick Perspex sheets. Because it also contains within it a miniaturized lighting fixture, special attention and care have to be paid to the detailing of this component. Also, because the stability and solidity of the whole model depends on it, the core should be firmly fastened attached to a wooden base with special bolts and screws. A thread maker is used to make the female thread in the model's core. Once the core is firmly fastened to its base, the floor plates are mounted, each at the right vertical level (figure 6).

Since we are here limited by space, only one final model is presented (figure 7). Out of the twelve models built so far, at different scales and using

different cladding techniques, the model presented here is 165 cm high. The final presentation of the paper will exhibit other versions.

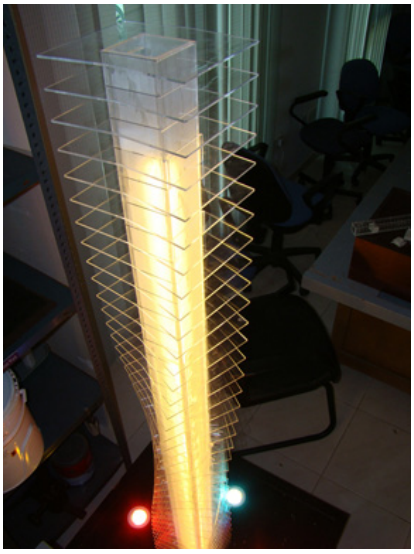

Figure 6 (left). Mounting of floor plates. Figure 7 (right). Final model (165 cm high).

3. Conclusion

It is finally pertinent to stress that the purpose underlying the writing of this paper is not to foster any design innovative intention, but to present a practical way to model one of the many architectural unusual forms that increasingly populate Dubai skyline, and which the architectural student, using traditional modelling techniques, often finds difficult to model and build at reduced scales. The process that is here described falls, therefore, within the pragmatic and not the theoretical or creative field of the architectural process. As such, it could easily be applied to the fabrication of any structure, no matter how complex and twisted it may be, as tested during the few last years in our digital fabrication lab. Based on this careful CNC/Laser-Cutting-Rapid-Prototyping orientation, other non-standard architectural objects have been modelled and built at various scales including planes, ships and motorcycles. Innovation here should rather be seen from a practical, and not a speculative, angle.

This orientation also means that the status of the architectural model is to be defined in terms of a convergence of particular technological possibilities, a fact tested through the making of a wide variety of prototypes, of which only

one example has been particularly debated in the present article. This stress on fabrication allows a smooth and fluid dialogue between digital design and digital making at a reduced scale (Kenzari, 2006). One specific entailment of this is the fact that model-making is getting closer to the real act of building. For if we assume that the building industry will soon take advantage of the extensive capabilities of modelling-cutting techniques that have been, for example, exploited in the aeronautics/aerospace, automotive and shipbuilding industries, then it will be easy to see the closeness between the current making of an architectural model and the construction of a twisted building, for example. This closeness could be witnessed in terms of the technologies, the process of making itself, and the nature and application of the materials used. Alongside these similarities, there is also a convergence of the manual and the digital aspects of the making process. The meeting of cutting technologies and miniature tooling at the model-making level may not be exactly mirrored on the real construction site (for the problem of size and the typical nature of modelling and building, with all the empirical requirements embodied, stipulate different modes of constructing 3-D). And yet, the one level points clearly points at another, and one could easily tackle construction issues at a very reduced scale in this fashion, with all the empirical entailments involved.

Acknowledgements

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References

Franken, B.: 2003, Real as data, *in* B. Kolarevic (ed.), *Architecture in the digital age: design and manufacturing,* Taylor and Francis, New York, 123–138.

Kenzari, B.: 2006, Physical modeling: the convergence of cutting-edge technologies and miniature tooling, *International journal of architectural computing,* **3**(4), 119–134.

Kolarevic, B.: 2003, Digital morphogenesis, *in* B. Kolarevic (ed.), *Architecture in the digital age: design and manufacturing,* Taylor and Francis, New York, 13–27.

Marrian, N.: 2008, Model makers benefit from growing real estate, *Gulf news,* 10 October 2008.

Moussawi, F., and Zeara Polo, A.: 2002, Roller-coaster construction, *in* N. Leach (ed.), *Designing for a digital world,* Wiley-Academy, West Sussex, 80–87.

Schneider, P.: 1996, NURB curves: a guide for the uninitiated, available from: Open Source Repository <http://www.mactech.com/articles/develop/issue_25/schneider.html> (accessed 4 November 2009).

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010,* 249–258. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

UTILISING DIGITAL DESIGN AND RAPID PROTOTYPING TOOLS IN DESIGN EDUCATION

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Abstract. This paper presents a formal framework for utilising different digital design and rapid prototyping technologies in design education. The framework has been applied in a studio created for a mixed cohort of tertiary students from architecture and industrial design. A comprehensive survey was conducted at the end of the course as a means for evaluation, and for student self-reflection. This paper reports the experiences in conducting the studio and the student perceptions of their design processes and outcomes whilst confronting these tools. The paper provides insight into the application of digital design and rapid prototyping tools in design education, supported by a qualitative analysis of the survey result.

Keywords. Student perceptions; digital design; rapid prototyping.

1. Introduction

The increasing adoption of computational design technologies and methods has been significantly changing the way design is perceived, conducted and constructed. The use of leading-edge digital design and rapid prototyping tools has presented opportunities for supporting creative processes across the whole design life cycle (Sass and Oxman, 2005; Kolarevic, 2003). As witnessed in the latest development, they have radically changed design and design education, resulting in innovative design with new forms and processes as well as design theory and pedagogy that support such practices (Oxman, 2007). A wide range of digital design and rapid prototyping tools have been applied in design education over the past decade, and we have witnessed a diverse range of creative outcomes resultant from the processes. Although

the accumulated experiences of applying such technologies has been reported by many design researchers and educators alike, there is a general lack of formal studies that systematically address the application and evaluation of such technologies, As pointed out by Oxman (2007), most educational cases of such, for example, Stavric et al. (2007) were inspiring, yet they were often motivated and influenced by "individuals", without adequate considerations for a theoretical and pedagogical basis. This paper presents and evaluates a formal framework for utilising different digital design and rapid prototyping tools in design education. The framework has been applied to a design studio for a multi-disciplinary class of tertiary students. The paper will contribute to a greater understanding of digital design and rapid prototyping technologies in design education.

Firstly the paper presents the developed framework: a project roadmap that utilises three main categories of tools involved in a typical digital design and rapid prototyping project life cycle. The framework is applied and demonstrated through the design and implementation of a design studio conducted in 2009 for a mixed cohort of 3rd year architecture and industrial design students. The paper then discusses the evaluation of the tools through a qualitative study that investigates students' perceptions of applying the tools. A comprehensive questionnaire was designed and distributed at the end of the studio to document and reflect students' design experiences using the tools. The study specially focuses on two sets of questions: (1) Has the use of the technologies changed the processes and outcomes of their designs, and how? (2) What design and technological factors have the students considered in choosing tools and processes from the project roadmap for design development? Supported by a qualitative analysis of the survey result, the paper aims to provide insight into the application of digital design and rapid prototyping tools in design education, from students' perspective.

2. The digital design and rapid prototyping project roadmap

The digital design and rapid prototyping project roadmap has been applied as a course framework for the design and implementation of a 13-week design studio, in the School of Architecture and Built Environment at the University of Newcastle, Australia. The inaugural studio was attended by 14 3rd year students from the architecture and industrial design programs. All students had an expected intermediate skill level of applying conventional Computer-Aided Design (CAD) systems such as ArchiCAD and SolidWorks. The aim of the studio is to introduce senior-year design students to the creative and exploratory practice of digital design and rapid prototyping, and to equip the students with the start-of-the-art design knowledge and technical skills that

reflect the contemporary digital design culture. In order to achieve the aim, the syllabus was divided into two main parts. The first half of the studio comprised of dedicated lectures of digital design theories and group discussions on key literature and case studies. The second half of the studio emphasised on the introduction and technical skill development of different digital design and rapid prototyping tools. The weekly studio includes a one-hour lecture / instruction and a two-hour design development / discussion. The assessment items include a design project, and a report that reflect on students' digital design and rapid prototyping processes.

The roadmap utilises three main categories of tools involved in a typical digital design and rapid prototyping project life cycle. The roadmap also provides a base for students to identify the suitable tools and techniques to form their own "path" for project development, according to their needs. The roadmap as illustrated in figure 1 comprises of three main components: *input tools,* tools that support the development and digitisation of design representations; *design interaction tools,* tools that support digital design interactions for conceptual and detailed design; and *output tools,* tools that support rapid prototyping design representations. Depending on the complexity and the timeframe of the project, the roadmap is recursive enabling further design development, evaluation and refinement.

Common physical *input tools* such as sketching devices and clay models were mirrored with virtual options by utilising digitising devices such as 3D scanners and haptic pen devices to generate the creative forms students desire, without being compromised by their (lack of) abilities in applying particular digital tools. The acquisition of the scanner and haptic pen provides the students with alternative means of generating their digital representations, with an emphasis to support their freeform designs. Sculpted physical models from clay or foam can be scanned into a 3D virtual model. The similar practice can also be conducted solely in the virtual domain by using a haptic pen device that offers clay-like form creation through a digital tactile interaction. 3D freeform design representations generated with conventional CAD software can be challenging and time-consuming in comparison to more geometrically based models, often resulting in restricted creativity and unfulfilled representations of the designers' intentions. The integration of the scanner and the haptic pen device would, in theory, increase creativity and realisation of intent. However studies into design with haptic devices, and their applications in design education, are particularly limited. Research such as Garcia (1999) centres on sensory evaluation rather than using the functionality in form creation. The outcomes of the design project and students' perceptions on the particular matter will provide valuable evidence in this respect.

Output tools such as rapid prototyping (RP) devices have long been used in industrial design circles and are growing to be a major force within the architectural design process. Prototyping processes such as Computer Numeric Controlled (CNC) machinery and Stereolithographic techniques are enabling designers to accurately realise their concepts developed during their *design interactions*. Adbullah et al. (2006) comments from an industrial viewpoint that a physical model can help people understand a complex design instantly, which supports the use of RP as a fast, cost-effective solution for representing and evaluating more complex and intricate designs. Successful RP outcomes require suitable CAD strategies as a pre-requisite, which suggests that within the roadmap a process skill graduation must occur for the next design phase to begin.

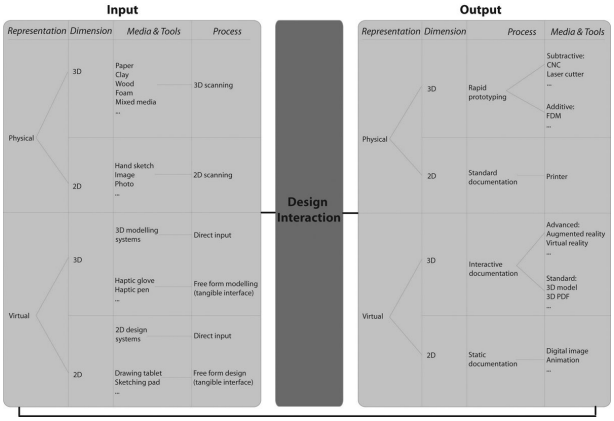

Figure 1. The digital design and rapid prototyping project roadmap.

The roadmap is inclusive, which enables students to explore and alternate between the physical and the virtual domains, following the suitable path and finding the appropriate tools for their design needs. It is essential to balance and blend the tools from both domains to ensure that the design process was to operate efficiently but not to be biased to any particular elements or pathways. The roadmap is provided for the students to understand different alternatives and to choose their individualised path through the roadmap in order to suit their needs and preferences. Schnabel (2004) comments that virtuality can become its own reality to compliment the physical realms. This supports the objective of design exploration and creation using varying realities, whereas the roadmap can be served as a structured framework for creating proven pathways that support such practices. Through tutorials, students are guided to master the tools. Through design exploration, they further understand the advantages and limitations of the tools, gradually refine the design

concepts, and make informed decisions about their own individualised path on the project roadmap.

Introducing advanced technologies in a short timeframe has been identified as a challenge, consequently specific training and support were provided as intensive tutorials. As a result, some high-end digital design tools such as those for parametric and generative design were reserved for the future agenda. Among the technologies listed in the roadmap, focus was given to advanced tools including the 3D scanner, the haptic pen device, the CNC RP machine, the laser cutter and the Fused Deposition Modeller (FDM) RP machine. The tutorials adopt the "learning by doing" principle to familiarise the students with the new hardware and software. In our case, to aid a student's understanding, learning, selection and application of suitable tools for project development without feeling overwhelmed by the new tools is the key to a successful outcome, within the short given timeframe.

3. The design project and selected outcomes

The studio is exploratory in nature. The design project enables students to explore creativity in design form marking through the introduction and application of leading-edge digital design and rapid prototyping technologies and techniques. Students were asked to design and decorate a dinning space as an installation piece to be exhibited at the Watt Space gallery in Newcastle, Australia, creating discussions on cotemporary design culture among the design community and the general public. Each student were asked to design and present a prototype of a functional object within the dining space, with a new form that challenges our common perceptions about the object. The rationale of the project topic selection is based on the following: For all designers including architects and industrial designers, form making is an inseparable part of the integrated design process. Forms as an important part of the design vocabulary and the necessity of having designers mastering the arts of form making has always been emphasised in practice and echoed by scholars such as Ching (2007). Therefore an important part of design education is the process of enabling students to explore and exercise form making. This given brief is general and yet provocative, with which we aim to encourage the students to push the boundaries with the newly gained theories and techniques.

In-class competition. The detailed requirements of the design brief were developed through an in-class competition during a gallery visit. The winning design, voted by all participate students, provides a conceptual framework that combines both the eastern and western traditions of dinning and identifies 14 functional areas within the dinning space for individual project development. The setup of the competition increases students' sense of "ownerships"

of the project and has greatly motivated them.

Project process. The students, developed their own selected areas, and collectively formed the dinning space in the gallery. Each area is filled with a list of familiar objects. Each student then selected a particular object from the list, and applied suitable digital design and rapid prototyping tools and techniques from the roadmap to transform the selected object, and produce a prototype with a new form that challenges the common perceptions. The generated new form was to critically reflect the digital design theories they have researched; and demonstrate their understanding and technical skills in digital design and rapid prototyping. Post-project, the students collectively constructed the dining space for the exhibition with both the original objects and the new designs presented to show the transformation. Their project progress was managed and evaluated through two minor assessment items: an initial project proposal and a mid-term design review.

Selected project outcomes. The 14 designs emerged from the studio have been very refreshing, ranging from forms translated from sound waves, to forms influenced by 4D space, to forms that transforms traditional patterns. The stimulus of the new theories and technologies and the opportunities of the gallery exhibition have been proven effective. Students' "usual" ways of conceptual development and project implementation have been largely challenged. Although further studies are needed in order to understand the impact of the roadmap on students' creative development, nevertheless they were able to create a new from for a functional object in a dinning space that challenges our common perceptions as required by the brief. The selected projects below showcase some of the works developed in the studio and demonstrate three different approaches to supporting the creative process: (1) by physical design interactions; (2) between physical and digital interactions; and (3) by digital design interactions. Each of which adopt a different path on the project roadmap. Students were able to explore the opportunities presented in different approaches and alternated between the physical and the virtual according to their design needs.

Figure 2. Physical working model of an origami influenced plate by Henrike Parkhouse.

The first example is a dinner plate design created with the influence of the origami folding techniques. The student was fascinated by the arts of origami and applied for form creation to reflect the eastern theme. Figure 2 shows

three working models for her project development. Here the creative process is largely supported through her physical interactions with the papers and her interpretations of the origami folding techniques. The student then digitised a final version using the 3D scanner to create a digital model, the 3D model was optimised and refined with additional details, and finally a prototype was produced using the FDM RP machine for submission.

The second example is the design of a central display piece for the dinning space, with a reflection on deconstructivism. The student selected a Buddha sculpture as a base for form creation. Firstly she digitised a physical sculpture

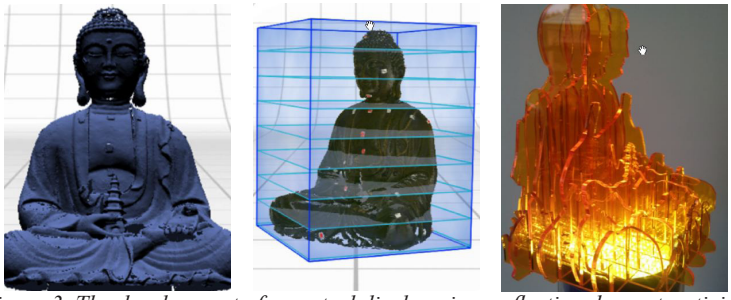

Figure 3. The development of a central display piece reflecting deconstructivism by Rebecca Sengers.

to develop a digital model (fig. 3 left). The student then explored various techniques in order to deconstruct the digital model. The slicing technique (fig. 3 middle) was selected as the mean to deconstruct the model into horizontal and vertical profiles. The developed profiles were then rapid prototyped in the laser cutter to develop the final outcome (fig. 3 right). In this case, the creative process was supported between physical and digital interactions, through the digital profiling and the physical assembling.

The third example presents a form for a bowl design that was transformed from sound waves of a music piece. The student's conceptual develop-

Figure 4. The transformation of audio waveforms by Michael Thorogood.

ment started with the reflection on cultural significance through music. He highlighted the standout frequencies in a visual sense, namely their individual waveforms, and blended them in a 3D space for form creation. The three main stages identified are audio sampling to create sound waves (fig. 4 left);

algorithmic interpretation to create the desired 3D form (fig. 4 middle); and the final rapid prototyping to develop the output (fig. 4 right). The creative process is largely supported in the digital process of algorithmic interpretation from the sound waves to the functional 3D form. The student explored different theories and applications in order to develop a set of constraints for controlling the form transformation.

4. Survey result and discussion

As evident in the designs emerged from the studio, the application of the roadmap as a course framework has enable the students to critically evaluate, explore and select the suitable digital design and rapid prototyping tools to suit their projects and design preferences. Three approaches for supporting the creative process as by physical design interactions, between physical and digital interactions, and by digital design interactions, have been discussed above. To further our understandings of the effectiveness of the tools and the application of the roadmap, a comprehensive survey was conducted at the end of the studio as a means for evaluation of the framework, and for student self-reflection of their experiences. The paper concludes with a general discussion of the survey result, and issues identified for future works.

The questionnaire has three parts including 15 questions. The first part aims to reveal students' perceptions on the effectiveness of the tools and their experiences in applying the roadmap for selecting *input tools*. The second part aims to study the same issues for selecting output tools. The third part is general open questions that aim to invite more detailed discussions on the issues. Although the survey result is limited due to the small size (14 students) of the studio, nevertheless students' responses and commentaries provide very valuable evidences for evaluating the roadmap and the tools. We synthesised the result in the following two categories with a focus on two specific issues: (1) Has the use of the technologies changed the processes and outcomes of their designs? (2) What design and technological factors have the students considered in choosing tools and processes from the roadmap for developing the design?

Students' perceptions on the input tools. Among the six types of input tools as listed in figure 1, most of the students have adopted more than one type in their project. The selected tools were evenly distributed among *physical 3D; physical 2D; virtual 3D – direct;* and *virtual 3D – free-form modelling*. The other two categories of *virtual 2D* tools have a significantly low preference. It was interesting to note that many students indicated hand sketching (physical 2D) as an important means for conceptual design, yet the majority of students have not used any 2D digital tools.

The main rationales for the tool and process selection were identified as the ability of the tools *to support the conceptual development of the project; to support complex or unique form marking, to complete the project more efficiently; and to learn about the new technologies.* Students' previous experiences, and existing knowledge and technical skills were identified as less important in influencing their selections. A small group of students indicated that the complexity and technical difficulties of certain tools have influenced their decisions in not selecting those tools.

Among all the input tools, the haptic pen device has been identified as most effective. All 10 students who have adopted the tool in their project commented that the haptic pen device has enabled them *to explore different design options, to develop design in a different way from their normal process and practice;* and *to develop a more interesting / creative design.* Students commented positively regarding the capability and flexibility of the tool especially in modelling and form making. The 3D scanner has been identified as least effective as students commented that the scanning process was long and the outcome was not ideal, for which they would have preferred direct 3D modeling with other CAD applications.

Students' perceptions on the output tools. Among the five types of output tools as listed in figure 1, over half of the students have chosen the FDM RP machine *(physical 3D – rapid prototyping – additive).* The rest of the selections were evenly distributed among *physical 3D – rapid prototyping – subtractive; physical 2D – standard documentation;* and *virtual 3D – static documentation.* Students who have adopted the FDM RP machine all agreed that the device has enabled them *to explore different design options.* However, the opinions were largely divided in terms of the abilities of tools to enable them *to develop design in a different way from their normal practice;* and *to develop a more interesting / creative design.* The reason can well be that due to the constrains of time and cost, most students considered the prototype produced from the FDM RP machine as their final outcome, and therefore did not experience the full potentials of the rapid prototyping process for evaluating, refining and improving their designs.

The main rationales for the tool and process selection were identified as the tool ability *to support complex or unique form marking;* and *to complete the project more efficiently.* A small group of students also indicated that *to support the conceptual development of the project and to learn about the new technologies* also contributed to their selection processes.

Based on the survey result and reflecting on our own experience in applying the project roadmap for planning and conducting the studio, we conclude the paper with a list of issues for future improvement.

To further explore design interaction. This part of the roadmap was largely unexplored in the current studio. In the survey, students commented positively regarding the introduction and exploration of new digital design theories in the studio, yet there were inadequate conceptual design tools available. Therefore the future plan will include the introduction and tutorial of conceptual design technologies such as those for parametric and generative design. Due to the complexity of the tools, a supporting unit may be required outside the studio to serve as a pre-requisite for the studio.

The cycle of the roadmap is not recursive. Due to the constrains of time and cost, most students considered the prototype produced as their final outcome, and therefore did not fully explore the potentials of rapid prototyping in design. This is an open question for further works in the field.

To explore deeper and more complex architectural issues. The inaugural studio has successfully adopted the digital design and rapid prototyping tools to challenge students in design form making. We aim to further challenge the students with deeper and more complex architectural issues. The future integration of more advanced conceptual design tools will contribute greatly in this regard.

Challenges for large classes. The design outcomes and the exhibition resultant from the studio have attracted greater attention from the student body. We expect a significant increase of student number next semester. While all is positive, the challenges for offering the studio to a large number of students are very great, imposing many pressures on the academics especially in accommodating technical tutorials; on the institutions in providing adequate high-end technologies; and on the laboratory technicians who must ensure and assist the delivery of the prototypes in a timely fashion.

References

Abdullah, S., Ramesh, M. and Munir, A: 2006, An analysis of the applications of rapid prototyping, *Proceedings of ASCAAD 2006,* Sharjah, United Arab Emirates.

Ching, F.D.K. (2007). *Architecture: form, space and order,* John Wiley & Sons, Hoboken, NJ.

Garcia, R.: 1999, PUSH: generating structural form with haptic feedback, media and design process, *Proceedings of ACADIA 1999,* Salt Lake City, USA.

Kolarevic, B.: 2003, *Architecture in the digital age: design and manufacturing,* Spon Press, New York, NY.

Oxman, R.: 2007, Digital architecture as a challenge for design pedagogy: theory, knowledge, models and medium, *Design studies,* **29**, 99–120.

Sass, L. and Oxman, R.: 2005, Materializing design: the implications of rapid prototyping in digital design, *Design studies,* **27**, 325–355.

Schnabel, M., Kuan, S. and Li, W.: 2004, 3D transformations: 3D scanning, digital modelling, rapid prototyping and physical depiction, *Proceedings of CAADRIA 2004,* Seoul, Korea.

Stavric, M., Schimek, H. and Wiltsche, A.: 2007, Didactical integration of analog and digital tools into architectural education, *Proceedings CAAD Futures 2007,* Sydney, Australia.

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ROBO STUDIO: TOWARDS ARCHITECTRONICS?

Kinetic architecture on control systems: a responsive environment

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Abstract. Contemporary architecture can be seen as a dynamic system that causes change to its environment, or even as system that can modify itself. Interactive or responsive environments are not totally new to architecture however the possibilities in architecture have only been lightly referred to. This interdisciplinary design studio, with mechatronics engineers and architects collaborating, explored possible applications with real world equipment, sensors and knowledge. Development of responsive architecture requires architects to have a fluency in sensors, actuators and their control system programming. New potential application of technologies requires a re-framing of what that technology could do in a different social application. Together these issues challenged architecture and engineering students in a collaborative design environment. The resulting projects – kinetic architecture on control systems – challenge our understanding of what our built environment could be.

Keywords. Architecture; mechatronics; robotics; kinematics; design.

1. Introduction

The impact of the digital environment on design practice and its education is now massive due to the proliferation of computer aided design in problem modeling and simulation, numerically controlled design fabrication, algorithmic design and now the emergence of responsive, performative architecture informed by mechatronics and robotics. This paper, recognising the importance and interdependence of these trends in contemporary design, focuses

on investigating the application of mechatronics[1] and robotics[2] in architecture. The word *architectronics* in the title is coined from the combination of architecture and mechatronics as it defines the emerging field of research, practice and design education.

Today, through the use of mechatronics, design can be seen as verb or action: a system that causes change to its environment, or even that can modify itself via information feedback. Clearly architecture need not be static, as it can adapt to changing conditions with the performative feedback loop relationship being its essential aspect. The argument for an architecture on a control system is strengthened when we consider the ubiquitous nature of control systems in our environment: from a thermostat to traffic lights to anti-lock brakes to driver-less public transit. The question of why it is not yet in widespread use in architecture comes to mind. And since it is not in widespread use, there is no concept yet developed as to what mechatronics could bring to architecture and, further, what might or might not be beneficial applications of this technology in architecture. A mechatronic system affords the opportunity for a responsive form of design: one that interacts with environmental conditions, occupancy, input from other systems and even input from prior use.

Interactive, or responsive, environments are not totally new to architecture. Le Corbusier's Phillips Pavilion for the 1958 Expo was integrated with the first electronically controlled multimedia exhibition. Its performative nature was amplified decades later in Archigram and Archizoom projects. In 1967 Peter Cook described architecture as "intermittently intermeshed series of happenings". The Open Form Aesthetic introduced by TeamX recognised the importance of framework open to user and context input. The sustainability agenda present in the contemporary discourse brings a new dimension and importance to responsive, interactive and networked architecture.

However, design of a responsive environment demands that architects understand basic electronics, control systems, sensors and actuators. Trying to understand and develop detailed knowledge of this type of technology can be accomplished by an interactive relationship with mechatronics engineers, who are experts in mechatronics but perhaps not in creating new applications for their expertise. In order to seriously engage the discussion of the technical requirements for interactivity, engineering students with expertise in mechatronics were included in ROBO studio. Both engineering and architecture students worked collaboratively on research and projects; in this way there was a detailed working knowledge of the requirements, possibilities and limitations at every step in the project.

Design studios in architecture are project based learning environments guided by critical feedback of instructors and peers. The goal of the ROBO studio was to develop a culturally relevant and socially accountable design which includes new technical, creative and environmental aspects and incorporated them into a comprehensive design. This design studio methodology is common in architecture, but less common although equally valuable in engineering education. By exposure to this methodology, engineering students become able to make judgements on a more global level about their technical decisions and the application of technologies. By working in a collaborative studio environment, both disciplines are challenged to explain clearly their perspective on the design project but are also required to learn and consider the other discipline's perspective and expertise. This enriches the learning of the students as they see what they understand from a different perspective. The term Robot, originally coined by Czech writer Karl Capek in 1920's, stood for android-like mindless servant/workers, was quickly adopted by the architecture students as a humorous label for studio whose participants worked hard on integration of mechatronics into design.

2. Interdisciplinary design studio

ROBO studio was a project-based course offered by School of Architecture in collaboration with the Departments of Mechanical Engineering, Electrical Engineering and Engineering Physics. The initial goal was to bring together students of architecture and engineering to explore the possible application of robotics, mechatronics and kinematic structures in architectural projects. In order to introduce students to the new environment, a period of research began the studio. This stage introduced the architecture students to the technology of mechatronics and introduced the engineering students to the culture of design. Case studies involving kinetic art, kinetic architecture, mechatronic applications in design and industrial applications of mechatronics were researched. In addition, basic theories of control systems were introduced and a database of sensors and actuators was compiled.

This short period of research was followed by the two problem sets: the first was framed very tightly in order to limit the design considerations and allow a fluency to develop with the new technology. The second was framed more loosely so that students could apply their newly found knowledge to a range of architecture applications. Further, the projects were framed architecturally such that investigations with the first problem set addressed the issue of essential need, and the second one of electronically assisted transfigurations and the revisitation of collective memory. The project studies ranged from concrete problem-solving to investigations highly speculative in nature; the

students could pursue any combination of digital, wired and/or kinetic models and videos to illustrate their explorations. It became evident early in the studio that the prevailing methodology of illustration would be videos: even in the research, very few case studies were illustrated without use of video technology. This is made necessary by the fact that movement must be illustrated and the most effective way of illustrating movement in today's digital environment is video.

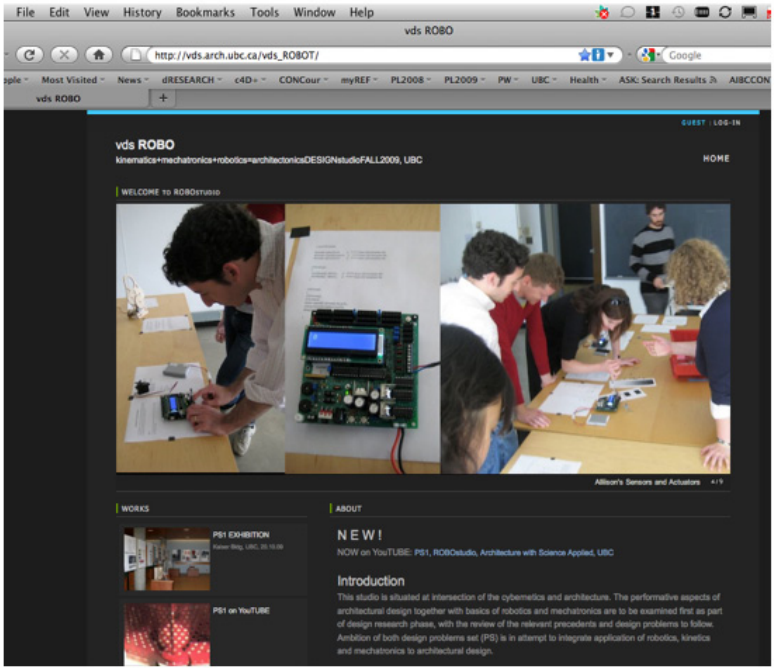

Figure 1. ROBO studio explores sensors and actuators on the front page of VDS portal.

Collaborative work across disciplines in today's context involves exchange of information and drawings virtually. By use of a virtual design studio (VDS) website through which information can be exchanged in a very visual way, a discussion can occur without as much scheduling difficulty. Engineering students' schedules are tight and often require that a collaborative project take place as much virtually as sitting together in studio. This is facilitated by a virtual tool, allowing shorter and more concise discussions when the students meet together in studio. The VDS website is a specialised tool which was developed at UBC for the digital architecture studios. It is formatted to allow images to be immediately seen and synthesised. The website allows publication of research and presentations at each stage of the studio. Research thus

can be easily shared among groups and easily accessed as the studio moves into the problem sets. Although the VDS website was not developed as an application for an interdisciplinary studio, it worked well to facilitate the communication between disciplines and eased the cultural and schedule difficulties which inevitably occurred.

The introduction to micro-controllers was initially given to architecture students, who learned that micro-controllers are like small computers that perform programmed and logical operations. The key realisation that most micro-controllers have only two kinds of input – analog and digital – was important to formulation of future designs. Architecture students realised that the familiar notion of digital means, in effect, that there are only two possible states, whereas analog means there is a scale of infinite levels between on and off. Extending this as a metaphor for two educational systems, engineering students were rather comfortable with binary design thinking, but attitude of architects was amazingly fuzzy and accommodated all shades of grey. It made process of collaboration difficult initially, but quickly the cultural difference was found to be creative and productive.

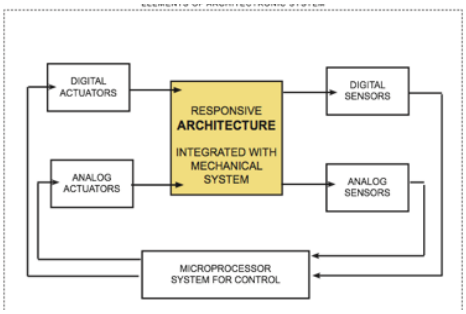

Figure 2. Architectronic control system diagram, 2009.

The engineering and architecture students worked in collaboration to produce drawings, computer simulations, animations, and working scale models of all or part of their designs. Decisions as to what software and what types and scales of wired models would be presented were made on a case by case basis by the students involved in each project. Just as an architecture student must decide which software best represents their project or which material they should model in, similarly judgements must be made on what should be wired and at what scale: sensors and actuators, as with many elements in architecture, do not always scale well. As such, decisions must be made as to what actuators would be used for the models versus what would be used at full scale. Similarly, what sensors would be used for presentation of an idea and how would these compare to the installed, full scale sensors.

Control systems were similarly discussed. A whole new set of judgements were brought to the table for discussion amongst the group.

Organisation of the studio and companion engineering course was undertaken by three faculty members from the school of architecture, two of whom are engineers as well as architects. The students' progress was monitored through formal and informal review sessions. Specific technical assistance with regard to mechatronics issues was provided by a teaching assistant from the engineering field of mechatronics.

The intent of the integrated studio was to bring engineers and architects to work together in a collaborative studio environment, using the expertise of the engineers, but placed within a new cultural and social context with the end goal being a comprehensive design project which addresses cultural and technical issues for a specifically framed project.

Figure 3. P1: Swarm skin by Patrick Danielson, Brady Del Rosario, and Dylan Gilmore

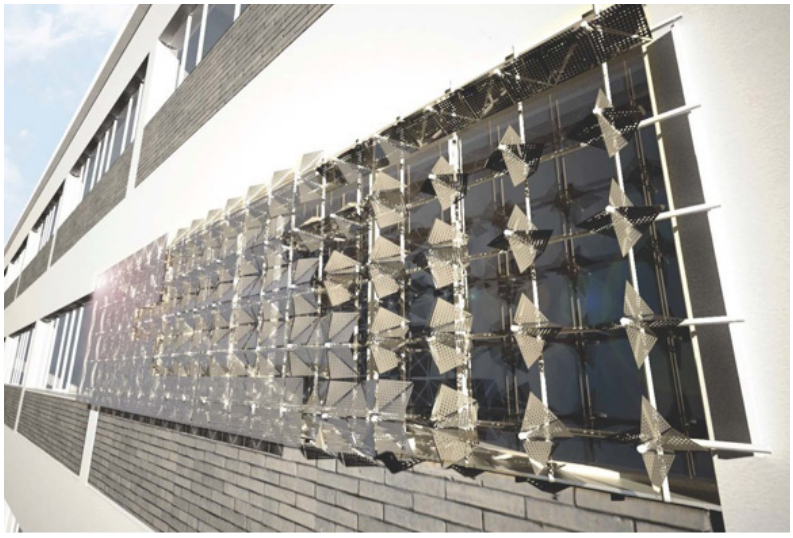

Figure 4. PS1: Parasol by Stephanie Au, Lori McGillivray and Adrian Straka.

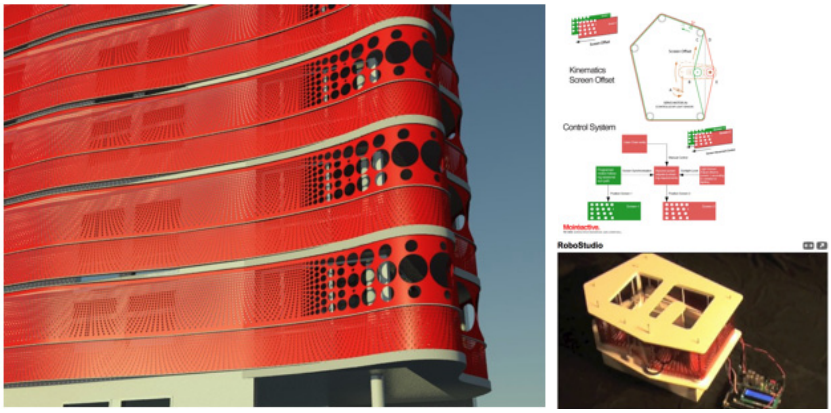

Figure 5. PS1: Moire by Peter Loebel, Esteban Matheus and Sina Sajadian-Mousavi.

3. PS1 skin

The initial design project (PS1 Skin) was a retrofit for buildings on campus whose envelopes had problems with their environmental performance. These problems resulted in poor conditions for the building occupants (i.e., inadequate solar control, uncomfortable interior temperatures or lighting conditions, etc.). The buildings chosen were representative of typical building types on and off campus from the time periods in which they were built. The speculative projects completed by the students proposed mechatronic facade

systems which responded both to occupation and environment. The students were asked to speak to occupants and determine what was problematic about the envelope, and respond with a solution which incorporated technical performance as well as design quality. The responsive building envelope involved design and modeling of a fragment of a building enclosure, sensored to perform. The situated building skin would formatively adjust itself to the dynamic criteria derived from human or environment interactions.

Although the project was situated as a skin retrofit, each building had a specific circumstance that was to be remedied which related to building exposures and orientations as well as problems with the existing enclosure construction, building massing and program. As such, each skin had an individualised and highly customised solution – both customised to the program within, be it offices, classrooms or labs as well as customised to sun orientation and envelope problems. The use of mechatronics in many cases gave an advantage to the designers in their ability to be effective and respond to variations in environment and in variations in user requirements and desires, even varying across a very short distance.

4. PS2 transformers[3]

The second problem set (PS2) dealt with the resolution of contested public space by an infrastructural intervention at any scale, be it building, bridge or seat. This problem set was broadly open to students' initiative but it addressed some aspect of transformation metamorphosis, disambiguation or shapeshifting. These themes are more common in mythology or science fiction than architecture but have a broad capability for engaging us and are therefore particularly suited to architecture. This process takes place when something undergoes a radical transformation. The electronically assisted metamorphosis of form or transfiguration is no longer so mythical.

Figure 6. PS2: Robotic bridge / ferry hybrid by Lori McGillivray and Arta Alagheband.

Figure 7. PS2: Robotic configurable plaza by Dylan Gilmore and Sina Sajavian-Mousavi

The site was a busy public space with multiple modes of transport and contested space due to its popularity as well as its constrained land area. The site has also undergone change over time, from an industrial site to its current multi-use condition. Each project encouraged use of structure to define space as well as consideration of the interaction with the body.

Students' projects ranged from those using acoustic information to shape a music hall in real time to a hybrid robotic bridge / ferry which responded to oat and pedestrian traffic and used the occupants to power the crossing.

5. Conclusion and future research

In running the ROBO studio in the fall of 2009, a clear idea of how the engineering course and architecture studio enhance each other's learning was obtained. The courses, while clearly allowing the students to work in their area of expertise, also allow an environment where a mutual respect and interaction is developed for the completion of the design. Whereby normal studios and courses address issues within their own disciplines, the opportunity to work in a collaborative environment is challenging to arrange in an academic environment. This studio attempted to offer collaborative learning by setting up an academic framework, with the supporting technical web based infrastructure required to support the academic endeavour. In terms of computational tools, geometric modeling software like Rhino or 3Dstudio was used, while motion models were simulated in Inventor or Solid Works. Program-

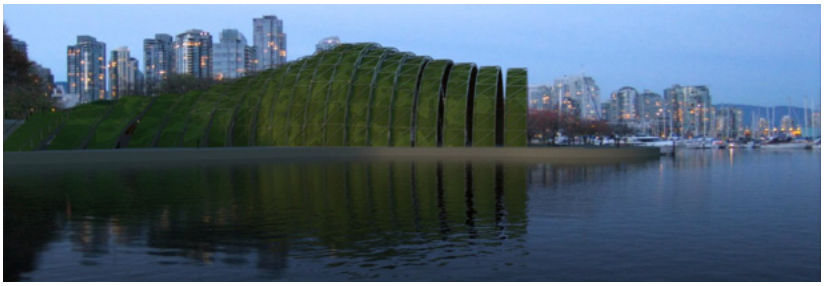

Figure 8. PS2: Acoustically responsive adaptable performance space, Esteban Matheus.

ming of controllers, incorporating use of sensors and actuators, was required for the development of the working models illustrating the principles of each project.

This investigation highlighted range of possibilities for interactive environments in architecture. The projects demonstrated a breadth in possible applications of control systems which was unforeseen. To narrow the field for further study, it was noted that some of the most beneficial investigations involved applications of mechatronics to sites where more than one program was desired across time, and this transformation of architecture allowed the space to accommodate a variety of uses. Another approach to narrow the study focused on use of only one economical and simple actuation to produce interesting investigations. It was noted by the engineers during the course of the study that sensors were inexpensive and actuators were costly so the more sensing and less actuating that takes place, the more economical the overall system. This type of economic reality applied to architecture could, as shown in other related architectural explorations, result in highly innovative systems and spatial consequences.

Endnotes

1 Mechatronics is the combination of mechanical engineering, electronic engineering, computer engineering, control engineering, and systems design engineering to create useful products (Wikipedia, http://en.wikipedia.org/wiki/Mechatronics, 13 Nov 2009).

2 Robotics, while having a range of definitions, generally is more specifically related to the replacement of the human and providing a tool which does repetitive tasks that a human would previously have performed.

3 Understood not as device that transfers energy. Transformers, Masters of Disguise, originally a toy system popular in 1970's Japan, later theme for cartoons and movies, where alien cars become robots.

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STUDYING DESIGNERS' BEHAVIOUR IN COLLABORATIVE VIRTUAL WORKSPACES USING QUANTITATIVE METHODS

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Abstract. This paper presents a case study comparing the behaviour of designers in a collaborative 3D virtual environment with those in a face-to-face environment using quantitative tools to examine their design protocols. It starts with depicting a design ontology along with two methods of analysis for this investigation. The results in this case show that the 3D environment increases the designer's Structure activities. The rate of meaningful design communication is slower than the base-line face-to-face session. This communication reflects the rate of design cognition when the design process is "close coupled". Reviewing the design protocol suggests that the 3D design session composed of both "loosely coupled" and "close coupled" periods. This is consistent with other studies that 3D collaborative tools may encourage "loosely coupled" design process.

Keywords. Design behaviour; virtual workspaces; protocol analysis; quantitative methods; design ontology.

1. Introduction

The concepts and technologies of using collaborative virtual environments have aroused researchers' and designers' interest since the nineties (Wojtowicz, 1995). However, virtual collaborative design environments, especially

3D environments, remain mainly in the academic research and teaching arena. They are not as popular as social virtual environments. We suspect this is due partially to the intention of those environments but also there is a lack of relevant tools to support design activities. On the other hand, our understanding of how tools impact design activities is limited. Over the past three decades, protocol analysis has become one of the most widely used methods to study human design activities and cognitive design processes (Christiaans and Dorst, 1996; McDonnell and Lloyd, 2007). Protocol analysis has also been used as a tool to study human behaviour in virtual environments (Maher et al., 2006). However, there is a lack of uniformity in both the method and coding of protocols when studying design activities and hence it is not possible to compare the results of the various studies. This paper explores the designers' behaviour by comparing two sets of protocol data – a 3D virtual world design session and a face-to-face design session – using generic methods and a generic coding scheme based on the FBS design ontology.

1.1. FBS ONTOLOGY AND GENERIC ONTOLOGICAL CODING SCHEME

The FBS ontology (Gero, 1990) models designing in terms of three classes of variables: function, behaviour, and structure. In this view the goal of designing is to transform a set of functions into a set of design descriptions. The function (F) of a designed object is defined as its teleology; the behaviour (B) of that object is either expected or derived from the structure (S) which is the components of an object and their relationships. A design description cannot be transformed directly from the functions, which undergo a series of processes among the FBS variables. Figure 1 shows the relationships among those processes and variables. The eight processes: 1) formulation, 2) synthesis, 3) analysis, 4) evaluation, 5) documentation and 6–8) three types of reformulations, are claimed to be the foundation of all design processes.

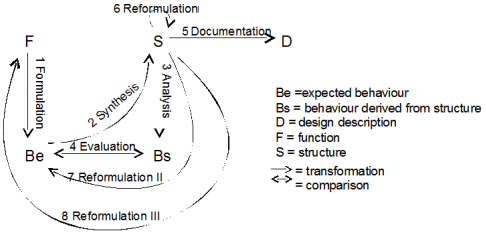

Figure 1. The FBS ontology of designing.

The generic coding scheme consists only of the function (F), expected behaviour (Be), behaviour derived from structure (Bs), structure (S), documentation (D) and requirement (R) code categories. The protocols are segmented strictly according to these six categories. Those protocols, utterances, which do not fall into these categories, will not be considered nor coded; these may include jokes, social communication, management, etc. Examples of these codings are given in figure 2 and table 1 in section 4. These fundamental FBS classes denote the state of affairs of designing of each coded segments. We anticipate this will capture the essence of design activities. Unlike many other complex coding schemes, this simple ontological coding scheme provides the foundation for further analysis. The eight design processes will be investigated using Markov analysis (Kan and Gero, 2009) and linkography (Kan, 2008) as outlined in the following subsections.

1.2. TRANSFORMATION PROCESSES: DERIVED FROM MARKOV CHAINS

Markov chains examine the sequence of events; they analyse or describe the probability of one event leading to another. A Markov chain is a discrete-time stochastic process with a number of states such that the next state solely depends on the present state. In the protocol analysis of design activities, McNeill et al. (1998) treated analysis, synthesis and evaluation as Markov states. They found that the most likely event to follow analysis is a synthesis event. Also the most likely event after synthesis is an evaluation event but the most likely event after an evaluation event is a synthesis event. In this paper, each coded segment is considered as an event of a Markov state. A 6 × 6 (the six code categories) transition matrix is used to describe the FBS Markov chain, as in (1), with which each row summing to one. P_{ij} is the probability of one state leading to another. For example P_{FBe} is the probability of having a Be event after an F event. This transition is likely to be a formulation process.

$$P = \begin{matrix} P_{RR} & P_{RF} & P_{RBe} & P_{RBs} & P_{RS} & P_{RD} \\ P_{FR} & P_{FF} & P_{FBe} & P_{FBs} & P_{FS} & P_{FD} \\ P_{BeR} & P_{BeF} & P_{BeBe} & P_{BeBs} & P_{BeS} & P_{BeD} \\ P_{BsR} & P_{BsF} & P_{BsBe} & P_{BsBs} & P_{BsS} & P_{BsD} \\ P_{SR} & P_{SF} & P_{SBe} & P_{SBs} & P_{SS} & P_{SD} \\ P_{DR} & P_{DF} & P_{DBe} & P_{DBs} & P_{DS} & P_{DD} \end{matrix} \quad (1)$$

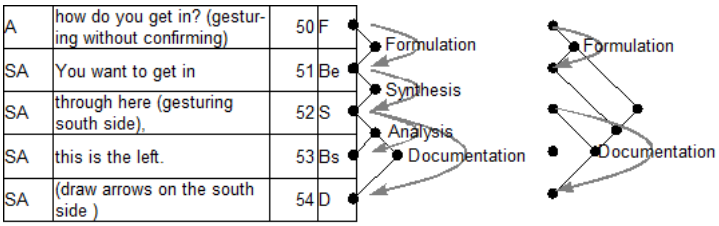

Figure 2. FBS processes derived from linkograph.
(a) Code protocol and human constructed linkograph; (b) WordNet generated.

1.3. TRANSFORMATION PROCESSES: DERIVED FROM LINKOGRAPHY

Linkography was first introduced to protocol analysis by Goldschmidt (1990) to assess the design productivity of designers. The design protocol is decomposed into small units called "design moves". A design move is "a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move" (Goldschmidt, 1995). A linkograph is then constructed by linking related moves, using common sense. The first order Markov analysis only considers the intermediate step but not the previous ideas. We expect by constructing a linkograph, connecting related segments, we will be able to capture the design processes in more detail. Figure 2(a) shows the annotated coded protocol together with its linkograph. The first column records the participants, A: the architect and SA: the senior architect. The second column contains the verbal protocol together with the annotations in brackets. The third column is the segment number and the fourth column contains the code. The dots represent the segments and the links and the grey arrow lines represent the derived FBS processes. The four links represent four FBS processes. Segment 52 has two links that indicate it spawns two processes: analysis (S to Bs) and documentation (S to D). This documentation process is not picked up by the Markov analysis.

Linkography has been criticised for the lack of objectivity in the construction of links, which is primarily based on the discernment and interpretation of the analysts. The process of constructing a linkograph is very time consuming and cognitively demanding, making it difficult and impractical to study and compare large data sets (Kan, 2008). Some analysts utilise the search function to help finding "moves" with similar semantic contents (Bilda, 2006). We propose to automate the construction of linkographs by connecting "moves" using an English lexical database, WordNet (Fellbaum, 1998). WordNet uses the concept of cognitive synonym to group words into sets. A program was written to connect the segments with similar meaning. Figure 2(b) shows the four connections that WordNet finds, only two of them matched the human constructed one. Not withstanding the differences, it picks up the "documenta-

tion" process that Markov analysis leaves out. We explore the WordNet generated linkographs and use it to complement the Markov analysis of the two sessions.

2. Virtual workspace benchmark against face-to-face design sessions

Two in-vitro architectural design sessions were conducted. The 3D session was benchmark against a face-to-face base line session. The participants remained the same in both sessions as did the complexity of the design task. Each session lasted for 30 minutes and was video recorded. The participants consist of a senior architect and an architect from the same company.

1. **Face-to-face design session.** In this experiment the designers were asked to design a university student union gallery. The senior architect took the leadership role, made most of the decisions, and did most of the sketches. This session can be divided into four stages or episodes, based on the design activities. In the first episode they dealt with the brief and site (about 3.5 minutes). In the second episode they analysed, planned and developed concepts in the plan (about 9 minutes); issues like location of main entrance and service entrance, icon to capture attention were discussed. In the third episode they developed the 3D form in elevation (about 9 minutes); ideas like "ribbon", "hole in the middle" were suggested. In the final episode they worked on the layout, calculated the required areas, in the plan until the end (about 8.5 minutes), but they did not finish it within the 30 minutes allocated

2. **3D virtual world design session.** A customised Active Worlds, an avatar-based multi-user virtual environment (http://awportals.com/), was used in this experiment, and both participants received prior training. The design task was to generate a conceptual design of a dance studio. The senior architect organised most of the activities. The stages were not as well defined as in the face-to-face session. This session can be characterised as "designing through making". Sometimes they subdivided the tasks and worked individually. They were given predefined elements – space, slab, wall, column, and beam – in various sizes. They decided to start with the biggest space element to represent the "largest" spaces, the four studios. At around 12 minutes, they discovered they could not have all the studios on one level because of the site coverage constraint. The senior architect decided to stack the blocks, the studios, and create an atrium to join them together. They tried to further develop this concept to accommodate the requirements but did not finish the design. Besides designing, time was spent on design support activities, such as discussing what elements were available and organising what to do. Also, time was spent on the technical aspects of learning how to do things, such as changing the colour of the blocks, how to "fly", and how get out when "trapped inside" those blocks.

Table 1. Example coding from the sessions.

Code	Face-to-face	3D Virtual Workspaces
R	(read brief) Permanent collection is 200 ...	They want four studio's mate, two one hundred each.
F	Hang on, that's a public building.	If it's a dance school it might still need a loading space.
Be	Can we say this is sort of external?	We need to, the obvious thing we've got... the generic space...
Bs	So these guys are coming across, they will be ...	that's very small area, court yard terrace and rough space ...
S	This is the Guggenheim	I don't know what size they are.
D	(draw arrows)	(insert box)
Not Coded	How long do we have?	"I can't see you though"

3. Coding and results

Table 1 shows examples of segments from the two design sessions in relation to the coding categories. In this exploratory case, the first sheet of drawing was studied. The coding was self-arbitrated with 90% agreement. In another study of over 1,000 segments, the inter-coder agreement with the arbitrated set was about 90% and the inter-coder agreement was about 80%. The biggest disagreement appeared in the Be and Bs codes. Out of the 205 segments in the face-to-face session, 192 of them contain FBS code.

The virtual world session contains 155 segments and 94 of them have FBS codes. Fig. 3 shows the frequency and the percentage distribution of the FBS codes, only consider those segments with FBS codes.

Chi-tests reveal that the FBS frequency distributions of the codes do not bear any relation. The segment per minute of the face-to-face and the virtual world sessions are 18.6 and 14.1 respectively. However, the FBS segment per minute of the face-to-face and the virtual world sessions are 17.5 and 8.5 respectively. This is a rough indication that the rate of design activities of the face-to-face session is two times faster than the 3D session.

Code	Face-to-face	3D
R	16 (8)	7 (5)
F	19 (9)	2 (1)
Be	32 (16)	5 (3)
Bs	25 (12)	7 (5)
S	65 (32)	53 (34)
D	35 (17)	20 (13)
Not Coded	13 (6)	61 (39)

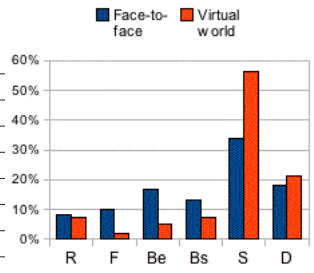

Figure 3. Frequencies and percentages (in brackets) distribution of FBS codes.

3.1. MARKOV TRANSITION OF THE SESSIONS

Equations (2) and (3) show the transition matrices of the two sessions.

$$P_{f2f} = \begin{array}{c|cccccc} & R & F & Be & Bs & S & D \\ R & 0.00 & 0.00 & 0.40 & 0.00 & 0.40 & 0.20 \\ F & 0.00 & 0.18 & 0.45 & 0.00 & 0.27 & 0.09 \\ Be & 0.00 & 0.08 & 0.00 & 0.04 & 0.20 & 0.68 \\ Bs & 0.12 & 0.00 & 0.35 & 0.24 & 0.18 & 0.12 \\ S & 0.02 & 0.04 & 0.15 & 0.10 & 0.46 & 0.23 \\ D & 0.06 & 0.15 & 0.15 & 0.18 & 0.42 & 0.03 \end{array} \quad (2)$$

$$P_{3D} = \begin{array}{c|cccccc} & R & F & Be & Bs & S & D \\ R & 0.14 & 0.00 & 0.00 & 0.43 & 0.43 & 0.00 \\ F & 0.00 & 0.00 & 1.00 & 0.00 & 0.00 & 0.00 \\ Be & 0.00 & 0.00 & 0.00 & 0.00 & 0.60 & 0.40 \\ Bs & 0.43 & 0.00 & 0.00 & 0.00 & 0.43 & 0.14 \\ S & 0.04 & 0.02 & 0.02 & 0.06 & 0.60 & 0.27 \\ D & 0.00 & 0.05 & 0.10 & 0.05 & 0.65 & 0.15 \end{array} \quad (3)$$

If we rank the probabilities, the highest is the F to Be in the 3D session that is 1.00. This mean whenever there is an F event a Be event will follow. This transition represents the formulation process, assuming most of the consecutive events were related. Both the Be to S and S to S are 0.60. The Be to S probability can be seen as the probability of a synthesis process when a Be event occurs. Similarity, the S to S transition probability can be seen as type 1 reformulation probability when an S event occurs. The type 2 reformulation is lower than type 1 reformulation in the two sessions. Type 3 reformulations are very rare. The probability of an analysis process from an S state (S to Bs) is surprisingly low in the 3D session. Figure 4 shows the probability of the eight FBS processes, as depicted in figure 1, triggered by the FBS events of the two sessions. For the evaluation process, we added the Bs to Be and Be to Bs transition probabilities. The distribution of the probabilities of the FBS processes of the two sessions look very different.

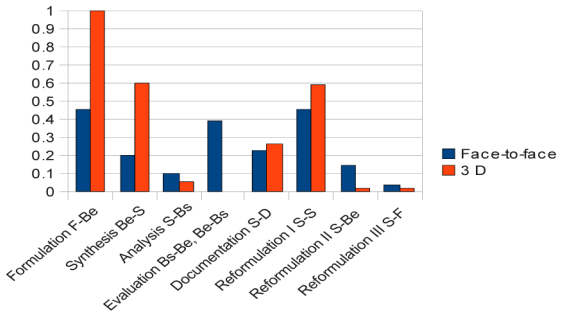

Figure 4. The probability of the FBS design processes triggered by events.

The mean first passage time is the average number of steps traversed before reaching one state from another state. The mean passage time can be obtained from the transition matrix (Kemeny and Snell, 1960). Equations (4) and (5) show the mean first passage matrices of the two sessions.

$$M_{f2f} = \begin{array}{c|cccccc} & R & F & Be & Bs & S & D \\ R & 49.96 & 16.85 & 5.38 & 10.86 & 3.24 & 4.07 \\ F & 50.32 & 14.23 & 4.86 & 11.19 & 3.74 & 4.39 \\ Be & 49.35 & 15.48 & 7.06 & 10.19 & 3.73 & 2.95 \\ Bs & 46.11 & 17.21 & 5.24 & 8.68 & 4.09 & 4.42 \\ S & 49.03 & 16.54 & 6.54 & 9.80 & 3.05 & 4.33 \\ D & 48.05 & 15.22 & 6.15 & 9.32 & 3.27 & 5.02 \end{array} \quad (4)$$

$$M_{3D} = \begin{array}{c|cccccc} & R & F & Be & Bs & S & D \\ R & 23.04 & 59.66 & 22.54 & 9.35 & 2.58 & 6.11 \\ F & 31.21 & 59.15 & 3.64 & 18.46 & 2.97 & 4.70 \\ Be & 30.21 & 58.15 & 20.85 & 17.46 & 1.97 & 3.70 \\ Bs & 20.42 & 59.33 & 22.16 & 14.37 & 2.51 & 5.52 \\ S & 28.81 & 57.65 & 20.58 & 16.26 & 2.05 & 4.37 \\ D & 29.80 & 56.40 & 18.75 & 16.76 & 1.96 & 4.75 \end{array} \quad (5)$$

The longest mean passage time is from R to F (59.66) in the 3D session and the shortest is from D to S (1.96) also in the virtual world session. The average mean passage time of the face-to-face session and the virtual world session are 14.72 and 21.06 respectively. The minimum of this average occurs when all the events are evenly distributed, that is the transition probabilities are all equal. The virtual world session is comparatively more disproportionate. It has a fast occurrence of structure (the column of S in (5)) and slow occurrence of function (the column of F in (5)). The face-to-face session has also a fast occurrence of structure but the slowest occurrence is requirement (the column of S and R in (4)).

3.2. TRANSFORMATION OF FBS LINKOGRAPHS OF THE SESSIONS

WordNet finds 4,261 and 2,929 links in the face-to-face and the virtual world sessions respectively and their corresponding average links per segment, also called link index, are 20.79 and 18.90. Table 2 shows the number of links

Table 2. Number and percentages (in brackets) of FBS processes derived from WordNet.

Links	Face-to-face	3D	Links	Face-to-face	3D
R-F	45 (2.37)	8 (1.11)	F-Be	65 (3.42)	2 (0.28)
Be-S	269 (14.16)	21 (2.92)	S-Bs	178 (9.37)	34 (4.73)
Be-Bs	79 (4.16)	1 (0.14)	Bs-Be	101 (5.32)	7 (0.97)
S-D	238 (12.53)	25 (3.48)	S-S	562 (29.58)	542(75.38)
S-Be	200 (10.53)	46 (6.40)	S-F	163 (8.58)	33 (4.59)
Others	2361	2210	Total	4261	2929

that are considered to be legitimate FBS processes. The 3D session has much higher non-legitimate FBS links and a much higher percentage of S to S links. Figure 5 groups those processes into the eight FBS processes. The virtual world session is not only predominantly biased towards *structure*-related activities, but 75.38 % are *structure*-to-*structure* activities. Evaluation activates are rare (1.11%) so are the formulation activates (1.39%). This maps well with our observation of "designing through making" as depicted in section 2. Comparatively, the face-to-face session has higher percentages of all the FBS processes except for the type I reformulation (S to S). The face-to-face also has a high percentage of *structure*-to-*structure* activities (29.58%), followed by synthesis (14.16%) and documentation (12.53%). Formulation has the lowest percentage (5.79%). The percentage of other processes ranges from 8.5% to 10.6%. The result is also consistence with our observations and qualitative analysis of the first and second episodes briefly mentioned in section 2.

4. Conclusions and discussions

The speed of meaningful communication exchange, number of FBS segments over time, is much higher in the face-to-face baseline session (17.5 against 8.5). This speed in some way reflects the rate of design cognition. The most possible explanation is that there is a cognitive resources overhead in using the virtual environment.

The Markov transitions provide an indication of the distributions of the eight FBS processes by assuming that high percentages of the consecutive segments indicate a direct relation. The distribution of the probabilities of the FBS processes of the two sessions looks very different. The probability of an analysis process and evaluation process are surprisingly low in the 3D session. The mean first passage time matrix shows that the *structure* is the dominant

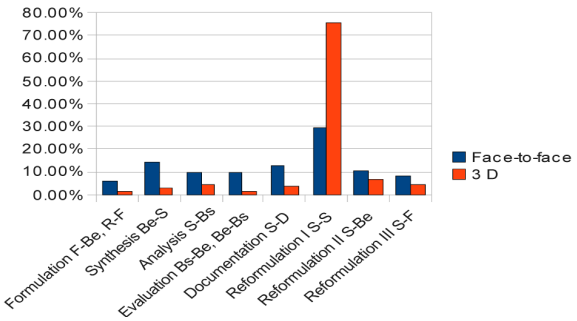

Figure 5. The percentage of the FBS design processes derived from WordNet.

state in the 3D session. The links and FBS processes derived from WordNet linkographs are consistent with the Markov analysis.

Acknowledgements

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References

Cross, N., Christiaans, H. and Dorst, K.: 1996, *Analysing design activity,* John Wiley & Son.

Fellbaum, C. Ed.: 1998, WordNet an electronic lexical database, MIT Press, Cambridge, May 1998, available from: Open Source Repository: <http://mitpress.mit.edu/catalog/item/default.asp?ttype=2&tid=8106>.

Gero, J.S.: 1990, Design prototypes: a knowledge representation schema for design, *AI magazine,* **11**(4), 26–36.

Gero, J. S. and McNeill, T.: 1998, An approach to the analysis design protocols, *Design studies,* **19**(1): 21–61.

Goldschmidt, G.: 1990 Linkography: assessing design productivity, *in* R. Trappl (ed.), *Cybernetics and system '90,* World Scientific, Singapore, 291–298.

Goldschmidt, G.: 1995, The designer as a team of one, *Design studies,* **16**(2): 189–209.

Kan, J. W. T.: 2008, Quantitative methods for studying design protocols, PhD thesis, Faculty of Architecture, Design, and Planning, The University of Sydney, Sydney.

Kan, J. W. T. .and Gero, J. S.: 2007, Using the FBS ontology to capture semantic design information, *in* J. McDonnell and P. Lloyd (eds.), *DTRS7,* University of the Arts, London, 155–165.

Kan, J. W. T. and Gero, J. S.: 2009, The effect of computer mediation on collaborative designing: using a universal coding scheme to study cognitive differences, *CAADRIA09,* National Yunlin University of Science and Technology, Taiwan, 411–419.

Kemeny, J. G. and Snell, J. L.: 1960, *Finite Markov chains,* Van Nostrand, Princeton, New Jersey.

Maher, M. L., Bilda, Z. and Gul, L. F.: 2006, Impact of collaborative virtual environments on design behaviour, *in* J. S. Gero (ed.), *Design computing and cognition '06,* Springer, Dordrecht, The Netherlands, 305–321.

McDonnell, J. and Lloyd, P.A.: 2007, *Design meeting protocols: proceedings from design thinking research symposium 7,* 19–21 September, London.

McNeill, T., Gero, J. S. and Warren, J.: 1998, Understanding conceptual electronic design using protocol analysis, *Research in engineering design,* **10**(3): 129–140.

Wojtowicz, J.: 1995, *Virtual design studio,* Hong Kong University Press, Hong Kong.

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PATTERNS, HEURISTICS FOR ARCHITECTURAL DESIGN SUPPORT

Making use of evolutionary modelling in design

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Abstract. Software used by architectural and industrial designers has shifted from becoming a tool for drafting, towards use in verification, simulation, project management and remote project sharing. In more advanced models, design parameters for the designed object can be adjusted so that a family of variations can be produced rapidly. With the advances in computer aided design (CAD) technology, design options can now be generated and analyzed in real time. However the use of digital tools to support design as an activity is still at an early stage and has largely been limited in functionality with regard to the design process. To date, major CAD vendors have not developed an integrated tool that is able to leverage specialised design knowledge from various discipline domains (known as expert knowledge systems) as well as to support the creation of design alternatives that satisfy different forms of constraints. We propose that evolutionary computing and machine learning be linked with parametric design techniques in order to monitor a designer's cognition and intent based on their design history. This will lead to results that impact future work on design support systems which are capable of supporting implicit constraint and problem definition for wicked problems that are difficult to quantify.

Keywords. Design support; heuristics; generative modelling; parametric modelling; evolutionary computation.

1. The use of computers in architectural design

This paper outlines a conceptual framework and ideas centred on an evolutionary design support system that interfaces between human inputs through the traditional CAD process in order to monitor and respond to the designer's process. This system may include the following capabilities: performing composition, specifying relations, constraints, styles, and suggesting improvements by providing the more optimised solutions.

The conventional design approach in a building construction project involves iterative processes of design, modelling, analysis, development and optimisation steps, which are executed separately. Given the complexity and diversity of the disciplines involved in a building design, this conventional approach requires numerous successive iterations in order to generate even the most trivial design changes and hence is considered as inefficient and time-consuming. This also leads to sub-optimal design in areas such as energy performance. If we consider the benefits associated with intelligent passive design an increase in efficient in the order of 50–75% can be expected through better design alone (Clarke, 2001). More streamlined processes in generating and visualising design options are required which not only meet design constraints and point towards optimised solutions, but also allow designers to work collaboratively, with the benefits of expert knowledge and with the opportunity for reflection and continued learning.

This paper does not cover the feasibility of utilising evolutionary systems with regard to energy, lighting or structural analysis. Writings verifying the feasibility of such systems are available given by Caldas (2006), Keene (1996), Frazer (2002), and Janssen (2006). The key topic discussed is the integration of such a system into the design process, especially the very early design stage. This is when the building forms are still malleable and the cost incurred by generating design changes is less significant. By aligning the computational process with the human design process, the aim is to work towards systems that are more articulated and intelligent. This is distinct from models that contain sophisticated but 'heavy' virtual constructions representing the building in high degrees of detail. The examples given in this paper are simple massing models, opening discussion on representation and the stratification and hierarchy of data as is needed for a designer. Finally, this paper does not deal with 'auto-generated' design options or how such a strategy can be made feasible. This is not due to the ethical problems associated with the auto-generative approach for example as critiqued by *whom* but due to the simplifications and abstractions that arise in the consideration of this topic. Leaving aside the lack of engagement with cultural and contextual conditions, there are many purely formal and spatial limitations that seem 'hard-wired' to

many approaches that are given. While no introduction is given to the methods of evolutionary, parametric, generative or associative modeling – there are full definitions given by the authors mentioned so far.

2. The design process

As an activity, architectural design relies heavily on intuition, preconceptions, heuristics and 'guiding principles' (Lawson, 1990) which cannot always be reduced to first principles, fundamental laws or epistemology in the way that the sciences can. Each designer's own principles can be unique and suited to their own personal preferences and history. The traditional ways in which computer-aided design (CAD) processes are utilised are centred on drafting, documentation and verification.

Robert Aish (2000) criticises the current fragmentation of design documentation from the holism of design as the result of the paradigm given by the personal computer where each file is a 'discrete' document stored as a file. While this is not so different from the earlier, manual design processes – each architectural drawing on a separate sheet of paper – there is an internal need to view the project holistically – to consider many things at the same time and to draw on knowledge from prior experience. Hence the danger being considered, is that with CAD, we may go 'too fast', to a developed design. We are at this point making little mention of the obvious hybrid process of beginning with manual sketches and then digitising these into computer data. This has been critical in the world of many renowned architects such as Frank Gehry or Santiago Calatrava due to the complexity of their designs. Such practices however display a strong 'visionary' point of leadership and reference where the design intent follows through from conception through to design. Furthermore such projects which only utilise the computer for the purpose of documentation are unrelated to the topic discussed. They do however, along with the initial observation highlight the inherent need for 'design direction' and the concept of 'intent' which has had little consideration in the primary literature of digital architectural design and design support.

2.1. DESIGN INTENT

Treating design as a 'search space' problem – which dominates artificial intelligence literature – is of little interest to fostering good design. Even a very simple case has so many possible states that there is very small statistical possibility that the solution will meet enough of the criteria that *were not explicitly stated*. A summary of headings from Lawson's (1990) writing on *problems and solutions* provide an overview of this:

Design problems cannot be comprehensively stated.
There are an inexhaustible number of different solutions.
There are no optimal solutions to design problems
The process is endless.
There is no infallibly correct process
The process involves finding as well as solving problems
Design inevitably involves subjective value judgments.
Designers work in the context of a need for action

With regard to the work of architect / engineer Santiago Calatrava, Lawson (1988) points out that a single design idea must be explored to the exclusion of all others. While we cannot give a complete systematic and complete account of *intent* – we can elaborate on how it be related to the digital process and to do so we need to consider some of the internal issues of design:

- Being able to move between part and whole.
- Being able to consider a range of entities in isolation, such a view shall be described as a *Perspective* in this paper.
- Being able to utilize a set of abstract procedures for a specific task – such a function shall be described as a *Pattern* in this paper. A perspective may be a specific instant of a Pattern.
- Being able continually re-define and re-use new perspectives and new patterns.
- Being able to relate two dimensional and 3-dimensional data coherently, i.e., to be able to articulate *composition.*
- Being able to articulate rules without a formal description – referred to in this paper as a *heuristic.*

2.2. PERSPECTIVES AND PATTERNS

The choice of terms ‘perspective’ was adapted from the work of Haymaker et al. (2008). It is used to describe a certain ‘point of view’ during the design process and can range from an orthographic drawing, a perspective projection or a symbolic list. While it may seem a trivial point to give a name to something so basic to design, it should be noted that certain constraints related *directly to the perspective* where it is created. An example of this would be facade composition. The term ‘pattern’ stems from the seminal work of Christopher Alexander (1977) as well as Gamma et al. (1994) and Woodbury (2007). A pattern is described as a general solution to a recurring problem. Figure 1 gives an example of a perspective. In this case the task is set to modelling a timber framed wall and can thus be named as a ‘wall-building’ perspective. Several patterns are utilised to allow the necessary geometrical data to store an instantiation of such an object. The dominant one would be a ‘grid defined by spacing’ (as opposed to defined by parameter) as well as its projection onto

a surface. The second would be the shape Boolean operation subtracting the space where the windows are to be. The third step in logic is for the special treatment of the entities around the opening – the lintel, headers, and trimmer studs. Finally the replacement of the model lines with sized elements or wall studs in this case. Note that if the grid was not *projected* then it would not allow for the elevation of the wall to appear as anything other than a rectangle. The data that is needed as an *input* to this perspective is either a line which represents the path of the wall in plan or an outline shape that represents it in elevation. Both have their limitations with regard to three-dimensional geometry, but together they form a very robust system. This can be further generalised for the outline to be a 3D curve. But it is a necessary that the wall view can operate in 2 dimensions and 'wrap' itself to a three-dimensional situation. During the final pattern of replacing the abstract with the material, meta-data can be set to reference material properties, i.e., conductivity values for thermal analysis, colour for lighting and strength for structural analysis. The perspective which in turn runs a visualisation-pattern can automatically present the wall at different levels of detail, showing only the outer-skin when constructing a model for viewing in 3D or rendering, but allowing for a detailed model when needed, i.e., for collision detection with ductwork.

Figure 1. Perspective for building a timber wall.

Once such a perspective has been instantiated, the evolutionary process is free to manipulate the length of the wall; its profile based on manipulated the outer corner points or the sizes and placements of windows.

2.3. CONSTRAINTS

The placement of constraints that do not exist mislead the design process, for example a non-existent boundary. Equally, the exclusion of constraints that should be there – such as minimum room size – not simply by area, but also accessibility, i.e., an acute triangular space is hard to access at the corners. There are also degrees of constraints – for example, having grids largely orthogonal, but not completely rigid. In the wall-builder perspective given previously there might be an explicit requirement that windows are all of the same size, are of a certain proportion or are defined as a *percentage* of the total wall area. In a traditional CAD system, it would be very unusual for a child object to be able to access data from the parent object containing it or to have *dynamic* data used to specify it. Section 2.4 gives mention of the query language used to remedy this. Section 3.1 will describe a case where a constraint is not explicitly stated but instead is inferred from test data.

2.4. COLLABORATIVE DESIGN

Until now, we have been describing the 'designer' as a single being. It is naïve to assume that any design collaboration could keep all members of the team happy unless there is some communication between the designers and overall intent is reached through some team effort. As yet, it is very difficult to know when something has been over-constrained or certain constraints clash with each other without seeing some outputs. The reason for this difficultly is that the evolutionary cycle begins with a solution that approximates the solution and starts to move towards an optimum. As in most cases we do not know what would constitute an ideal situation – or what satisfies the majority of criteria. We cannot be sure that a lack of progress is due to a problem with the constraints or that the best solution has in actuality already been reached.

2.5. AN OPEN FRAMEWORK

The evolutionary models of the past had a tendency to be constructed with a system 'hard-wired' to a set of operations. Attempts have been made to keep all parts of the system as open and upgradeable as possible. The idea of a single integrated tool has repeatedly failed in the past and therefore there is a need for more focus on interoperability. The software used for analysis is freely available and both the recombination and shape description schemes are referenced through external files in an XML schema which allows for easy verification and upgradability, as are the wrappers that allow access to the simulation software. An entity might be described as follows:

```
<SUBDIV> <COMMENT text= 'Villa Thiene at Cicogna'></
COMMENT> <Grid size = '500,300,4' newname = 'A'></Grid> <S
selection = 'A'></S>
    <DivideHorizontally divisions = '.25,.75,1'newnames='A,B,A'></
DivideHorizontally>
```

This representation shows the relationship between natural language and computation operations. The description allows for the intuitive manipulation of geometry parametrically as given in parametric grammars, i.e., Stiny (2006) while still being able to codify this relatively quickly. Note that this differs from the traditional genetic algorithm where the population member is described by a bit-string sequence.

3. Case studies

It is necessary to work at different levels of abstraction and detail in the design process. It is also noted that the practicalities of 'designing', working from the ground up, is very different from the top-down (management) view of design that may reduce it to a smooth, controlled process! Therefore it is necessary to speak of actual case studies to articulate further some of the issues.

3.1. THE NINE-SQUARE GRID PROBLEM

The example of the nine-square grid was chosen because it has an established place in architectural theory, being described by Rudolf Wittkower (1949), John Hejduk (1979) and Greg Lynn (1992.) Lynn raises the point that the grid gives the discourse on Palladio by Wittkower an *origin* which in turn could be used to read the work as well as give it to a *body*.

The sequence of steps described uses the specification of a grid as its primary means of description. Operations of merging or removing cells to make the spaces deviate from the original grid. Note that in this case concepts of being 'orthogonal' or symmetric are not specified but instead are inherent to the formation of the entity. This may or may not be desirable. Should a property such as 'symmetry' be explicitly stated as being a fitness criteria (an operation involving symbolic logic targeting specific design goals) or should it (in this case it is desirable) be inferred by using test data that all contain a large amount of symmetry? We opt for the latter as a more generalised solution as other criteria are not as easy to notice or to define as that of symmetry. This then forms a 'heuristic' function in the systems' evaluation function. In regard to this process of data-mining patterns and descriptions, the next problem lies in regards to the relatively few examples that were left by Palladio (figure 2). In relation to the high amount of data required by most data

mining algorithms, this can be solved by modelling a few examples in the schema and allowing it to generate variations with no topological changes.

The schema was later adapted for use in the specification of Mosque descriptions with the aim that they be optimised with regard to environmental

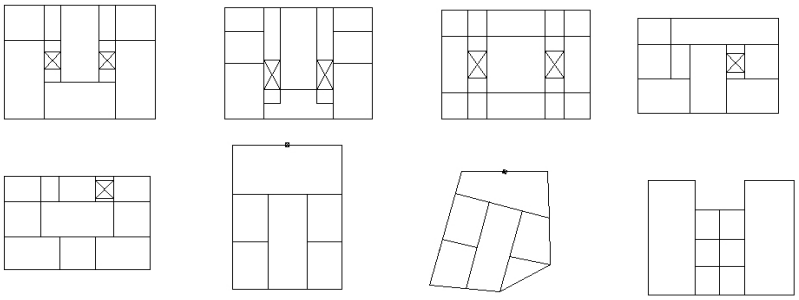

Figure 2. The top four images show digitisation of Palladio's villas, the lower four are computer generated variations using the schema.

performance which followed through with the problems in constraint definition that have been mentioned before. The rule stated that the Quibla wall was to face towards Mecca as depicted in the lower four images of figure 2. If the evolution specified by the description is limited to orthogonal forms then the orientation (as a rectangle) is very static with the long axis being elongated along the axis closest to north–south finally stopping at the minimal area of a space (in this case we are considering a very basic analysis limited only to heat gain.) However if we take away that constraint altogether, our solution may ignore cultural references such as the aesthetics of symmetry and produce undesirable results. With more sophisticated evaluation such as buoyancy flows come more levels of differentiations and possible solutions.

3.2. PAVILLION DESIGN

In the second case, support was provided for the conceptual design of a pavillion made of precast concrete modules. The aim for evolutionary modelling was to have as much repetition as possible, i.e., minimise the number of panel types while at the same time having as much variation as possible in the assembled units. It was also desirable to have as much variation in the assembled units as possible and to have an organic composition. Figure 3 shows an image of the precast concrete units. In this case, two descriptions were difficult to formally state – the overall composition and whether the shapes were tiling. The scene description began with hexagons – ensuring that they were able to tile and then applied distortion to make the shapes more regular. This could only be done when there weren't any fully enclosed polygons and that at least

2 shapes change with every distortion.

As fitness criteria could not be easily defined, the work flow involved having the generated designs sent to modelling software and sending the ren-

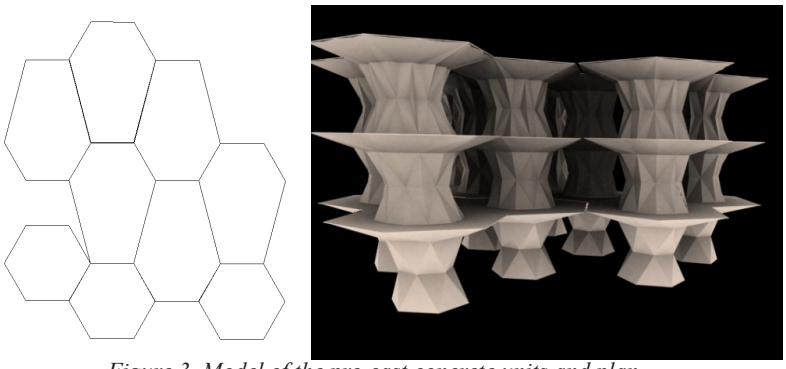

Figure 3. Model of the pre-cast concrete units and plan.

dering to the architects for their subjective opinion. The quick visualisation of complex form did however prove to be very useful. In such a case, we have no way of being certain whether our solution was optimal. It did however provide a solution that was 'good enough' which was helped by being able to isolate the problem from all the other considerations. The second task was to look for variations where the top part of the column meets with the floor plate. In this case a regular hexagon was explored in isolation and later projected onto the irregular shapes. In this case the symmetry shown in figure 4 was inherent to the description. No criteria were used to differentiate the design other than the designer's opinion.

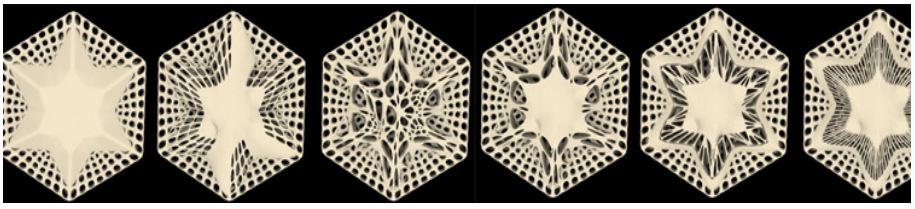

Figure 4. Variation of column capitals for the pavilion structure.

4. Conclusion

As an activity, design relies on being able to work with an intuitive understanding of problems and their possible solutions. It is important to be able to break a problem into parts, but also to be able to work holistically. Attempts have been made to follow through the architectural process in an integrated and multi-disciplinary way. New methods of generative, associative, paramet-

ric and evolutionary modeling may speed up the time spent modeling as well as make it easier to create variations at an early stage and fine tuning at a later stage. By utilising the data that is provided by previous cases or in the designer's own prior work, CAD systems can work more intelligently such as to provide auto-generation of parts.

By analysing the heuristics used in the designer's prior work in response to structural, lighting, energy, environmental and building services modeling, a diverse range of perspectives are quantified. The proposed approach in this paper offers design reuse through providing performative reflection on design. In this way, stakeholders involved in a building design are able to weigh on the cost, performance, and aesthetics of the design options presented.

References

Clarke, J. A.: 2001, *Energy simulation in building design.* Butterworth-Heinemann, Oxford.

Alexander, C.: 1977, *A pattern language: towns, buildings, construction,* Oxford University Press, New York.

Flager, F., Somerekun, G., Welle, B., Haymaker, J. and Bansal, P.: 2008, Multidisciplinary process integration and design optimization of a relocatable classroom building, CIFE Technical Report #TR175, *International journal of information technology in construction.*

Frazer, J.: 1995. *An evolutionary architecture,* Architectural Association, London

Gamma, E.: 1994, *Design patterns: elements of reusable object-oriented software,* Addison-Wesley, USA.

Haymaker, J., Kunz, J., Suter, B., and Fischer: 2004, Perspectors: composable, reusable reasoning modules to construct an engineering view from other engineering views, *Advanced engineering informatics,* **18**(1), 49–67.

Hejduk, J.: 1979, *7 houses,* Institute for Architecture and Urban Studies, New York.

Keane, A. J. and Brown, S. M.: 1996, The design of a satellite boom with enhanced vibration performance using genetic algorithm techniques, *in* I. C. Parmee (ed.), *Adaptive computing in engineering design and control '96, proceedings of the second international conference,* University of Plymouth, 107–113.

Lawson, B.: 2006. *How designers think: the design process demystified,* Architectural Press, Oxford.

Lynn, G.: 1992, *Multiplicitous and inorganic bodies,* MIT Press, **19** (Dec. 1992), 32–49.

Stiny, G.: 2006, S*hape: talking about seeing and doing,* MIT Press, Cambridge, Mass.

Wittkower, R.: 1952, *Architecture in the age of humanism,* Tiranti, London.

Woodbury, R.: 2007. *http://www.designpatterns.ca.*

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BIM + HEALTHCARE

On the view of a primary healthcare renovation project

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Abstract. Currently BIM is at the forefront of the building industry. While useful for various building types the definitive nature of healthcare design benefits from the BIM process largely in comparison to other building types. In this paper BIM is employed for phasing the design process of the healthcare project, creating modelling prototypes and making reference to a baseline model in order to increase the overall success of the healthcare design project.

Keywords. Building information modelling; healthcare; evidence-based design; prototype; baseline model.

1. Introduction

Building information modelling (BIM) is cooperative actions between building industry professionals and client user groups, all using available 3D applications and other digital media for simultaneous and consistent data sharing in an on-going design project (Eastman, 2008; Park, 2008; Ozel, 2008). BIM provides the capabilities of interfacing and correlating multiple layers of various kinds of information. The categories of information are 1) visual representation, which is the information consisting of object properties and object-oriented graphic components database entries, 2) calculated information which includes specifications, costs and drawings schedules and 3) documentation of relationships and responsibilities consisting of contracts, warranties, maintenance information, etc. (Kennedy, 2008). Ideally, BIM would be fully integrated among all professions with various collaborative projects having a functional information processing linked to one another. While BIM has been applied to various building types, the methods used are not fully

developed for healthcare projects. In the case of healthcare design projects, utilising BIM is an efficient process which supports the coordination of multiple variables found in healthcare facilities. Furthermore, the collected data from credible research, evaluations and evidence gathered from the operations of the patients, doctors, clients and other partakers of the health facility become critical factors to make design decisions. This type of design method has been developed as "Evidence-Based Design (EBD)". Since Ulrich (1984) pioneered the study of EBD in 1984 with his paper, "View through a window may influence recovery from surgery," EBD has become prevalent in healthcare design. Weill Greenberg Center in New York (Gaerig, 2008) is recognised for the exemplary use of EBD. In this paper, issues regarding healthcare facilities are presented and various strategies of using BIM are explored based on the specific nature of healthcare through a case study of a primary healthcare facility renovation.

Figure 1. Images of the case study for the renovation of a primary healthcare facility.

2. Case study

The case study is to renovate a primary healthcare clinic, one story building, approximately 8900 gsf of existing structure, housing facilities which provide basic examinations, imaging, pharmacy, laboratory, and minor surgical needs. The beginning phase is considered new construction adding to a total of 14,650 gsf by the end of the design project. While this building is undergoing renovation the design is managed in construction phases throughout the existing structure using AutoCAD 2D applications. The comparison comes from using a customised BIM process to perform the same tasks involved in the renovation project. Reflecting on the comparison between the traditional process and using BIM reveals the effectiveness of how information is managed. BIM is employed as a liaison in the design process for developing optimised BIM strategies in healthcare design.

3. Need for BIM in healthcare design

Healthcare design has a direct and intentional purpose to ally with healthcare professionals for promoting wellness. The consistency of the goals and repeti-

tive activities that occur within the building, leads to regular processing of information (Ozel, 2008). BIM will support and permit advances in healthcare as a library of information relative to the building. In light of this, BIM also influences the quality of EBD. Healthcare design benefits from BIM because even with multiple layers of design data BIM guides a healthcare design direction toward promoting wellness effectively. The critical nature of healthcare corresponds to the methods of treating patients, providing functional space and housing tools and equipment.

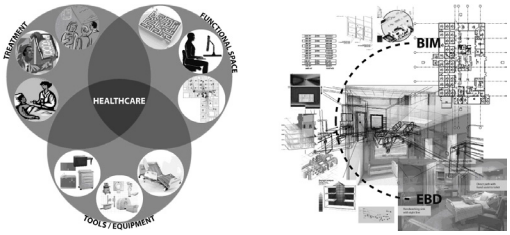

Figure 2. Nature of healthcare and BIM for evidence-based design

First, treating patients includes discussions, examinations, operations, and/or checking results. Treating patients revolve around the initial actions when a patient first arrives to a healthcare facility and any actions that may follow as a result of the patient's condition. Miscommunication and delay in productivity occur from the consultation between healthcare professional and patient, or administrative reasons such as form-filling, note-taking, and the clerical errors (Patel, 2002). Second, providing the functional space for healthcare professionals is another essential part in healthcare. The spaces for these departments are shaped differently based on activity, equipment and other specific needs. Third, housing the sophisticated tools and equipment also has a significant role in the nature of healthcare. Designing for healthcare equipment is vital because healthcare is so dependent on these sophisticated tools for diagnosis and readings' results. The difficulty comes with space designed rigidly to one piece of equipment when technology advances and redesigning for updated equipment or new equipment is required. Designing with anticipation of future developments in healthcare technology remains to be an issue (Maione, 2004). These issues make healthcare design more challenging.

4. BIM + healthcare

BIM has the capacity to amalgamate a bridge between the healing environment and the services of the healthcare professionals. As a tool for evidence-based design, BIM is employed as a liaison between patient outcome data and specific building conditions and locations.

4.1 ENVIRONMENT OF PATIENTS AND CAREGIVERS

A few healthcare challenges centre on maintaining environmental control for patient safety in areas such as air quality, energy control, noise factor, communication and infection control. Solutions are developed by adapting healing patterns which are achieved by monitoring quality of design which can be done so by establishing parameters under BIM tools (Ozel, 2008). Also, administered by a hospital's facilities management department, a BIM model can be the reference library for all product and equipment information enabling the creation of maintenance schedules, standards manuals, and purchase orders (Kennedy, 2008).

4.2 HEALTHCARE MODULES USING BIM

Once BIM is able to network facilities data with financial analysis of the hospital services, BIM has the potential to be used as a powerful tool for strategic planning (Kennedy, 2008). A healthcare module is an assembly of organised components, based on healthcare department needs, contained together and maintaining an independent nature (Miller, 2009). Each department becomes a module integrated into BIM which contains specific combinations of building components needed for the specialise activities. The decomposition of BIM modules entails breaking down the hierarchy of groups, prototypes, components and further if necessary to objects and artefacts for isolated inquiry of design or redesign (Li et al., 2008). The decomposition is based upon the teamwork of the components. The possibilities for detaching information with the decomposition may pertain to further development or replacement of new and/or advanced information. Based on isolating the modules, future development can be focused on independent areas of a healthcare facility, avoiding disruption or distraction relative to other spaces and supporting scenario testing on various scales. Instead of the current method of seeking researched knowledge in hopes of validating a design approach, BIM would reveal all sorts of correlations of the modules and provide the evidence to facilitate long term controlled studies of a given design project (Kennedy, 2008).

4.3. MANAGING TOOLS, EQUIPMENT, AND OTHER DETAILS

Currently BIM has opened up opportunity to make collaboration more effective with provision of real-time data exchanges, which are detailed scheduling, geometric coordination of healthcare equipment along with mechanical, electrical and plumbing (MEP), and by providing an explicit library of information for future strategic planning (Manning, 2008).

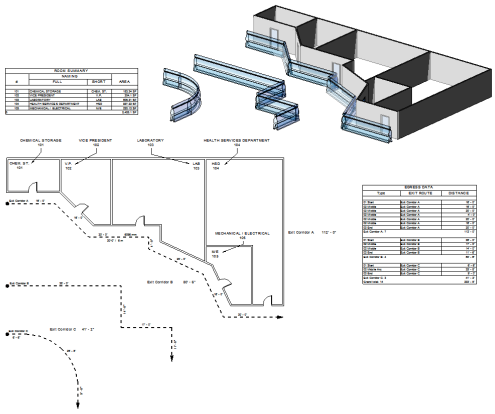

Figure 3. BIM coordination of egress routes along with schedules (from Stafford, 2008)

Figure 4. Full-scale mock-up (from Bell, 2007) and BIM simulation of patient room

BIM used for the special characteristics of healthcare design also include accurate as-built information of facility which can be critical to future renovations. BIM potentially reduces the need for full scale mock ups of patient rooms, surgical suites, etc. BIM is a repository of initial information provided by the client such as site information, area requirements and so forth which supports scenario testing for clients (Ozel, 2008). Creating a realistic scenario using BIM offers hard data information. This is useful for calculation and analysis to further develop healthy environments. Rather than creating a static full scale mock up, a much more flexible and transportable full scale virtual reality experience can be arranged by means of simulation provided through BIM (Bell, 2007; Dunston et al., 2007).

5. BIM strategies

Three BIM strategies for healthcare design suggested in this paper include phasing, prototyping and application of baseline model.

5.1. PHASING

Phasing process with BIM provides the ability to forecast the development of on-going design project and its schedule. Each control system includes a "look-ahead window," which is part of a scheduled structure. Activities according to a master schedule are advanced through the look-ahead window. It gives a preview of the next phase before the phase commences. With the ability to look ahead, assignments are made according to the project units' capacity. Completing sound assignments maintains productivity through each phase of the project. The confidence comes from testing and then evaluating operations by exploding the activities in accordance with the BIM model (Ballard, 1999b).

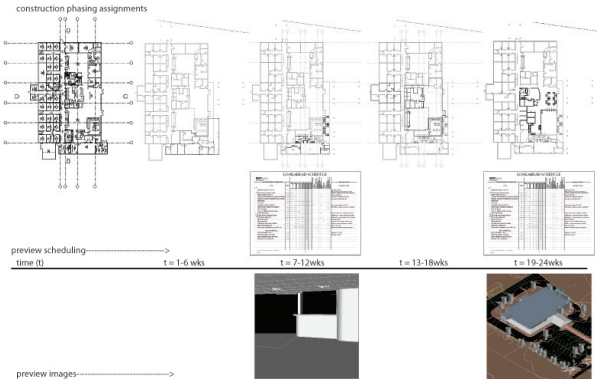

Figure 5. Overview diagram of forecasting/proceeding through BIM phasing.

Using BIM to evaluate phasing assignments before they are implemented supports necessary safety precautions. Previewing a phase helps prevent loose ends in design or scheduling before work is in motion. In a traditional design process, most project teams attempt to adhere to the long-term master schedule very closely. Decision-making and maintaining consistent drawings throughout the duration of the project can become tedious and can take up a lot of time and effort. The traditional design process has less accountability of the project activities and causes less accuracy in drawings and production. Specifically, coordinating phases is challenging in healthcare projects due to complexity and liabilities that regularly drive the healthcare market. Challenges arise especially during construction and even more so in renovation projects. During healthcare renovation projects, it is difficult to build out interior spaces of an occupied medical facility, safety is a high priority and managing ingress/egress routes, infection control, required operational downtime and managing temporary spaces are examples of some of the challenges (Sullivan, 2007). For instance, a MRI machine weighs approximately 30,000

pounds. Transporting this massive, expensive piece of healthcare equipment takes pre-planning. BIM can be used to find a precise date in the construction schedule and the optimal ingress route can be determined to ensure successful installation (Condit, 2006). Phasing in BIM provides an integral and prompt coordination between systems within the design documentation. It greatly reduces the contingency of delivering design intent with unaddressed coordination issues between building systems. In the healthcare design industry most of the problems occur in MEP construction coordination. Its cost increases to about 45%–55% of the total costs of the entire project (Sullivan, 2007). In the case study, phasing is arranged by setting up stages of evaluation. The reliability of data outputs is dependent on input setup of rules in BIM tools and how they communicate. Delineating design tasks in phases are enhanced remarkably when schedules are supported by prototype modules reviewed throughout the later phases.

5.2. PROTOTYPING

Defining a prototype starts from understanding a category. A category is made up of families and within families there are types. A type may exist in a family, singularly or multiple times, and each is known as an instance (Revit, 2009). This relationship exists on different scales but regardless of scale, the relationship is consistent. In the case of healthcare design, the category is healthcare and the families are specialised spaces such as the exam room, patient room, etc. Types of exam rooms are general purpose examination room, special purpose examination room, observation room, and treatment room; from these prototypes are generated. As prototypes are formulated, they are assigned to projects and the option to refine prototypes is available. Prototyping in BIM maintains certain levels of organised information preventing confusion or inconsistencies during the design process. It makes information accessible after the completion. The primary computer application utilised for this case study is Autodesk Revit 2010. In its database, Autodesk Revit stores the reference to *Design and construction of health care facilities* by the Facility Guidelines Institute (FGI) and the American Institute of Architects (AIA). Outcomes from the case study reflect that prototyping includes the availability for being useful in new and ongoing projects to be used and developed as is, or by specialists looking to identify environmental issues in a specific setting. The reference supports foundational parameters for the development of healthcare design. It provides close review of the development of selected spaces in this project.

Furthermore, parameters according to these guidelines are implemented through simulation function in the evolving process of prototype. In this

process, most basic attributes are accounted for and included into an initial prototype. Further detail to the initial prototype relative to any project becomes a new level of prototype. A later stage of an evolving prototype results in a physical product. Variances and errors are likely to occur during and after the physical construction of the building. The reality of a building is reviewed and taken into account to consider for further development of BIM prototypes.

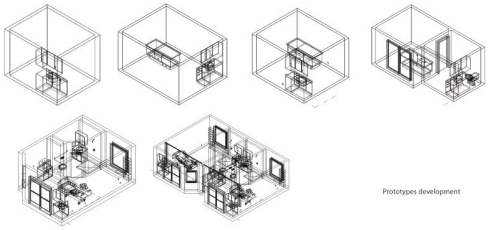

Figure 6. Diagram depicting iterations of BIM prototyping.

5.3. BASELINE MODEL

A baseline model is a post-construction BIM model that was originally developed during the design of the building as a new construction project or initially integrated into a project of a building as a renovation project. This model contains the previous design work and provides accurate information regarding the building's functions. Figure 7 illustrates a visual comparison between a redesign project using tradition methods and the one with a BIM baseline model. By the end of a project in a traditional design process, several connections of information are lost or kept within the boundaries of specialised groups who worked on the project due to the absence of a baseline model. However, a baseline model in BIM becomes the basis of the well coordinated building information model through various design phases. Passing on a baseline model for future design work or renovations prevents uncertainty regarding the current state of the building. At the completion of the design project the BIM model serves as a resource for future inquiry. Using a baseline model for the case study reveals the need for healthcare designers and professions to be in agreement concerning quantity and level of detailed information to be shared for future reference. Referring to the BIM model as the baseline model for any future alterations makes possible access to ready information to be extracted from the model and a record of ongoing work. The BIM baseline model becomes the key to the whole BIM process with consolidation of large amounts of 3D data from different applications into one model (Sullivan, 2007).

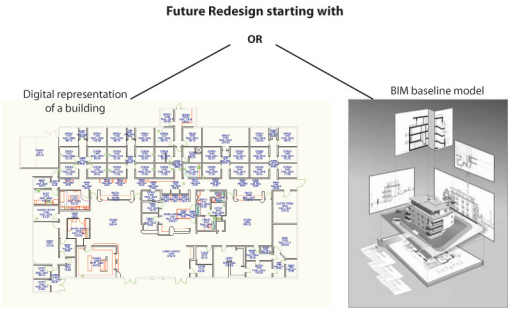

Figure 7. Comparison between digital representation and BIM baseline model

6. Discussion

In this research, the initial setup for applying building information modelling (BIM) in the healthcare design took a significant amount of time. This involved making decisions about what types of information are foundational and have priority throughout the design process and affect important decisions. Both building and healthcare professionals are responsible for continuous information exchange in order to utilise the collected data with BIM for applying evidence-based design (EBD) in the process of healthcare design development. The phasing, prototyping, and baseline model of BIM become a solid foundation for updating future redesign projects and as a standalone report of collected data for contributing to EBD. Results from the case study using these strategies reveal the learning curve for using BIM tools and applications in healthcare design is still challenging even though the productivity and quality of this healthcare renovation project increase remarkably with the

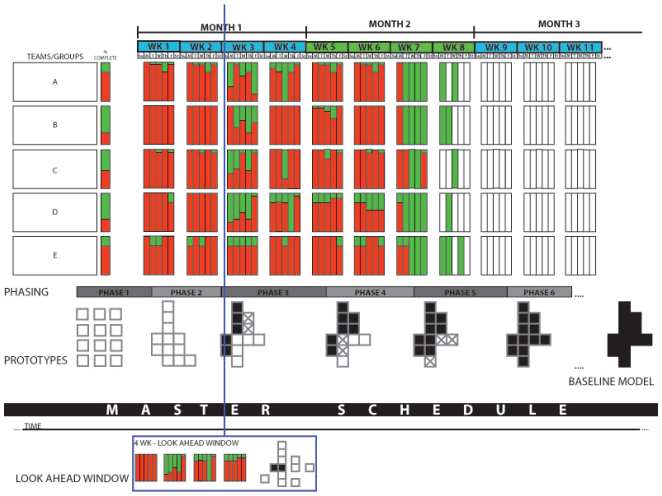

Figure 8. Diagram of combined BIM strategies

suggested methods of BIM. Currently BIM tools adequately support information transfers among building professionals compared to healthcare professionals. Therefore, each profession must be represented by its own BIM manager to facilitate the information and guide the BIM process for healthcare design. Until now, sharing of information is recognisably seamless when Autodesk applications are the main tools for design. However, in order to truly achieve promises of BIM, the sharing of information should not be exclusively based on the setup of the specific computer applications. BIM needs be brought down to raw data for their redistribution among other BIM tools outside of Autodesk package.

References

Ballard, G.: 1999a, Can pull techniques be used in design management?, *Concurrent engineering in construction,* Helsinki, Finland.

Ballard, G.: 1999b, Improving work flow reliability, *IGLC-7,* Berkeley, California.

Bell, K.: 2007, Mock-ups: giving hospital clients the ultimate reality check, *Healthcare design,* **7**(5).

Condit, G.: 2006. Complex projects call for virtual construction, available from: Daily journal of commerce <http://www.djc.com/news/co/11184025.html> (accessed 14 October 2009).

Dunston, P., Arns, L. and McGlothlin, J.: 2007, An immersive virtual reality mock-up for design review of hospital patient rooms, *7th international conference on construction applications of virtual reality,* West Lafayette, IN.

Eastman, C. et al.: 2008, *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors,* Wiley, John & Sons, Hoboken, NJ, xi–xiv.

Gaerig, C. (ed.): 2008, *Healthcare design,* Weill Greenberg Center, Polshek Partnership Architects / Ballinger, New York.

Kennedy, M.: 2008. Great expectations: BIM for healthcare, available from: The Samborn Report, <http://www.ssoe.com> (accessed 11 April 2009).

Li, H. et al.: 2008, Integrating design and construction through virtual prototyping, *Automation in construction,* **17**(8), 915–922.

Maione, O. (ed.): 2004, Open building: a new paradigm in hospital architecture, *AIA academy journal,* **7**(5).

Manning, R. and Messner, J.: 2008, Case studies in BIM implementation for programming of healthcare facilities, *ITcon,* **13**(18), 446–457.

Miller, G. et al.: 2009, Princeton University WordNet, Available from: Princeton University WordNet <http://wordnet.princeton.edu/> (accessed 14 September 2009).

Ozel, F.: 2008, Building information modeling for healthcare facilities, *ASU lecture,* Phoenix, AZ.

Park, H.-J.: 2008, EVOLUTION + BIM: the utilization of building information modeling at an early design stage, *CAADRIA 2008,* Chiang Mai (Thailand), 552–559

Stafford, S.: 2008, Room Name – Full or Abbreviation, available from: Revit OpEd http://revitoped.blogspot.com/2008/12/room-name-full-or-abbreviation.html (accessed 4 November 2009).

Sullivan, C.: 2007, Integrated BIM and design review for safer, better buildings, available from: McGraw Hill Construction <http://continuingeducation.construction.com/article.php?L=19&C=213> (accessed 17 October 2009).

Ulrich, R.: 1984, View through a window may influence recovery from surgery, *Science,* **224**, 420.

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INTEGRATIVE PARAMETRIC FORM-FINDING PROCESSES

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Abstract. The recent developments in digital technologies and contemporary design tools are initiating new approaches of form-finding based on parametric development of multiple geometries with simultaneous consideration of various aspects. This paper focuses on the use of advanced parametric CAD systems and reformulated construction logics to enhance the potential and possibilities of form finding processes. This approach is exemplified through the "Greenhouse Trauttmansdorff project". The project demonstrates a form finding approach which is based on defined parameters that not only fulfil aesthetic and functional aspects, but simultaneously take structural properties and the resulting sun shading behaviour into account. We will explore within this paper how – next to the functional and contextual building requirements – required illumination levels inside the greenhouse create a feedback loop between the structural system and its cladding system.

Keywords. parametric representations; digital technologies; digital fabrication; variable systems; load bearing construction.

1. Introduction

Michalatos and Kaijima underline in their paper 'Structural information as material for design' (2007) the importance to approach an informed design consistency and respect the "criteria of efficiency, architectural intentions as well as intrinsic properties of the geometry" rather than simple structural optimisation of a certain design. Our paper investigates this consistency between architecture and structure within the framework of parametric modeling, which requires architects, engineers and constructors to re-evaluate the feedback loop between how things are designed and constructed.

As Mario Carpo (2008) points out CAD and CAM technologies have overthrown the "Albertian paradigm" which claims that architects should not make things, but should just design and annotate them. As digital tools can be used to design and fabricate at the same time, CAD-CAM technologies have already started to bridge the gap between designers and makers. One of the most influential form-related factors on the lighting situation inside the building is – due to its shading behaviour – the dimension and position of the supporting structure of the façade. It is important to investigate these positions at the beginning in depth, since they serve as hypothesis for the entire planning process. In order to compare a catalogue of various design approaches and different designs in a timely manner, a parametric model has been built defining the rough form of the design.

2. The greenhouse project

The project which is used for the described approach is a Greenhouse in Meran, Italy, with approximately 370 m² gross area. The building has two programmatic parts: one smaller exhibition space and a big exhibition hall.

These two spaces are separated by technical rooms. The transition between the two main spaces is visible in the outer shell of the building: here the shell

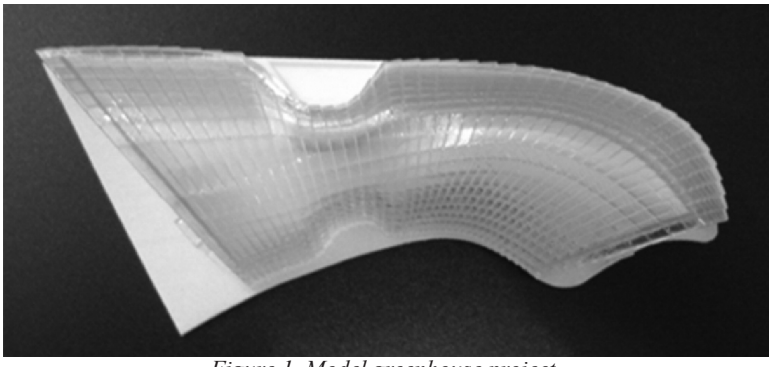

Figure 1. Model greenhouse project.

tapers and emphasises the transition zone. The section of the two exhibition halls varies. The arch system which is used for both exhibition halls has a maximum height of 10 m in the area of the big exhibition space and is 3 m lower in the area of the small hall. Therefore the arch system is more pointed in the big exhibition space than in the small. Towards the South the arch system rests directly on the concrete slab, whereas towards the North the arch system is lifted up by a 3m high concrete wall. Next to the structural system the second main feature of the project is a faceted skin which uses rectangular planar panels to achieve the double-curved geometry.

2.1. STRUCTURAL MODEL

All parameters of the NURBS based geometry need to be editable and accessible in the architectural design software and the structural calculation software. The initial design development follows a constant loop between texture, structure and massing – each form study undergoes the following automated definition of the geometric parameters.

1. parametrisation of the structural calculation model.
2. evaluating the structure versus light conditions.
3. looping back to 1.

The result of this parametrisation has been a rectangular grid of beams lying on a NURBS surface with editable grid densities, which is applicable to any given form. The structural calculation model contains not only geometry, but also loads resulting from various sources. Some of the loads directly result from the geometry, such as the weight of the structure itself. Others are indirectly related such as the weight of the glass panels, which depends on the grid size. As a consequence all changes in the geometry result in changes in the applied loads, the load distribution and lead therefore to a completely different model. In order to automatically create calculation models, loads must be realistically calculated and applied to the structure on the basis of algorithms. Additionally, further geometric information such as the element's profile orientation has to be calculated. A computer program using the .Net interface has been self-developed to connect the CAD software and the calculation software. The final calculation models do not cover all loads and load combinations, such as wind loads, thermal expansion or imperfections, which had to be incorporated manually. As a result a set of different grids is structurally evaluated giving visual feedback to the dimension of the structural elements. Therefore it has been possible to compare the aesthetic of the design on the basis of realistic dimensions, while analysing also the lighting requirements.

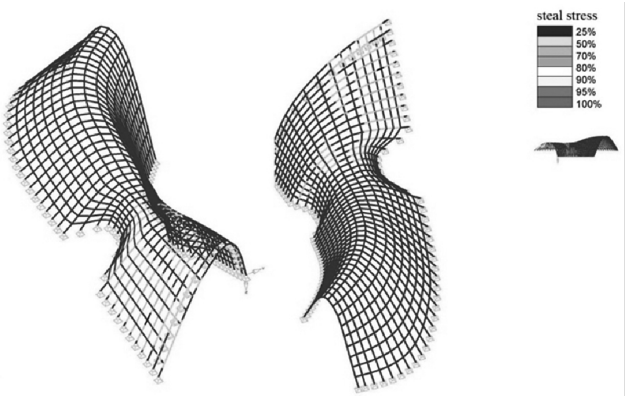

Figure 2. Stress fields of the steel construction.

2.2. DEFINITION OF GEOMETRY MODEL PARAMETERS

To be able to compare different designs in a timely manner, a parametric Grasshopper (McNeel Rhinoceros) model has been built, which defines the basic logic behind the structure of the given form. The final structure consists of flat steel elements aligned in a quadrangle grid. The grid consists of two different kinds of beam types: The primary structural beams, which span in the short direction and the secondary structural beams, which form a linear connection between two adjacent primary beams at several points. The secondary members correspond in size with the glass element, while the beam sections of the primary structural beams and the secondary structural beams may vary. To keep an even appearance of the structure the beam sections do not differ within the beam category.

The steel element sizes, the grid density and the resulting glass panel sizes have been explored under consideration of load bearing capacity and the resulting lighting condition.

The parametric model has been based on a NURBS Surface, representing the outer shell of the building. Onto the surface a rectangular grid of curves has been applied, which represent the axes of the beams. The main beam curves

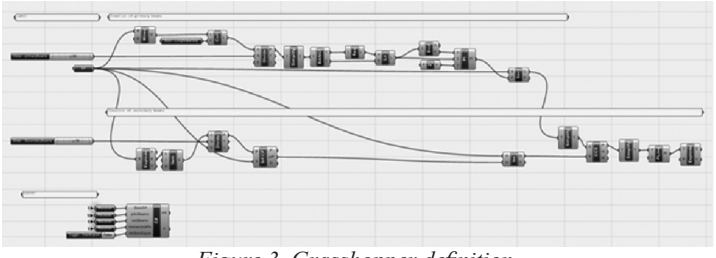

Figure 3. Grasshopper definition.

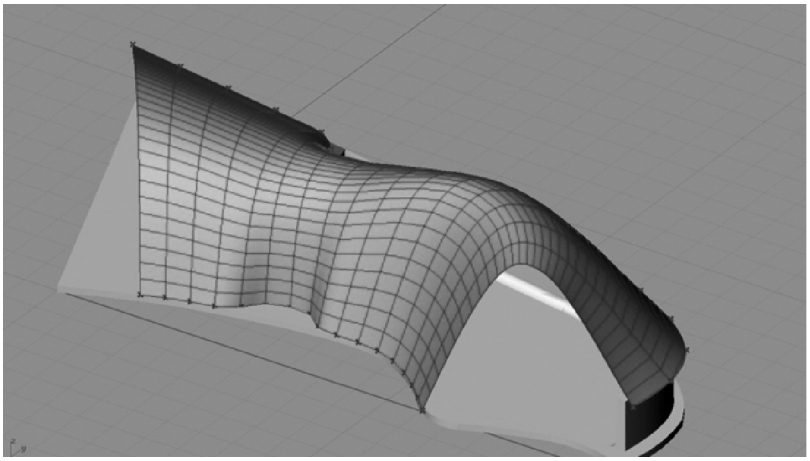

Figure 4. NURBS surfaces with grid lines

are defined by dividing two opposing surface edges into a parameter controlled number of elements, resulting in evenly spaced division points. Through two opposing division points a plane oriented in z direction has been created and intersected with the NURBS Surface creating the main beam curves. The location of the secondary structural beams is defined by ISO-Curves in V Direction of the surface using parameters resulting from equal division of one surface.

2.3. ADDITIONAL DATA EXTRACTION

The parametric grasshopper model is used as a base to create a structural model within the calculation software R-Stab (Dlubal). In our case the calculation software only interprets nodes and lines between these nodes, representing section beams. Nonetheless information bases on surfaces would be very useful to the program. In our approach the section rotation degree has been calculated on the base of the surface and applied to the subordinate structural beams within the structural model.

Other non-static, geometric properties have been defined to be interpreted differently in the calculation model. For example the start points and end points of the main beam curves are defined as hinged supports as well as the connection between the main and the subordinate structure is defined as a hinged connection. Next to the geometric information, loads resulting from geometric properties are reinterpreted and applied to the structural model. This approach has been used to calculate the distributed load of the panel weight and the snow load.

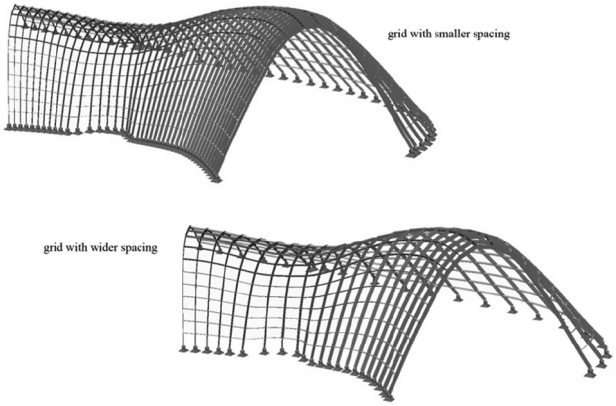

Figure 5. Calculation model with different grid densities.

2.4. AUTOMATED LOAD CALCULATION

The structural model which derives from the parametric model has to be able to calculate the load cases by the parameter definition. The load cases which have been automatically created are:

1. own weight
2. distributed load of the panel weight
3. snow load

In addition to the automated load cases, load case combinations were automatically generated under consideration of the German standards (DIN 18800) and second order theory.

The own weight of the structure has been automatically calculated by the structural calculation program and only requires the sections as input. The weight is an important factor, because when changing the element section sizes, it significantly can change the outcome of the calculation. The distributed load of the panels though depends on the size of the panels and therefore has to be calculated for each parameter set separately. Based on each beam's allocated load area intersection points have been calculated which results, multiplied with a predefined area load of the panel weight, in the distributed load. The calculation of the allocated load area though is not a trivial problem. In order to calculate the area for an intersection point in a quadrangle grid one need to know the four closest points in all 4 directions and their relative position to the point in order to connect them. There is the need to implement a sorting algorithm based on the geometry. The first step has been to sort the unsorted list of beams and store the adjacent beams for each beam, by evaluating the U value of each start point and connecting it with the beam object. So

the curves with the next higher and lower U value are the ones lying next to the main curve. All division points in the grid lie on a main beam curve and have different t-values. Their relative linear position is therefore defined and is separately stored in an index manner corresponding with the point location on the curve. Through the index of each point it is possible to get the next point (i = i + 1), the previous point (i = i – 1) and the points on the left and right with the same index on the left or right neighbor curve.

By knowing these four points, which all lie on the base surface, it is possible to get the UV coordinates of the points and create the new four corner points of the load area by overlaying the coordinates. The interpolated lines on the surface connecting the corner points define the edges of the load area surface.

To calculate the load area for snow load the surfaces simply need to be projected to the XY-plane. This approach does not consider snow sliding down the sides of the roof.

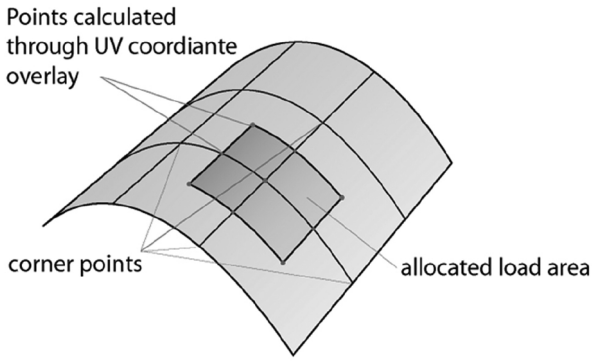

Fig 6. Load area diagram.

3. Workflow

After the creation of the parametric model and the setup of the interface to the structural calculation program a process had been manually triggered, which creates a structural calculation model on the basis of the current parameter set. The calculation model then is automatically calculated.

In an iterative process the section dimension is optimised to the applied loads. The result is saved in the native file format of the calculation program, giving a feedback to the dimension of the structural elements. With this realistic estimate of the structural dimensions a visual evaluation of the lighting requirements is possible.

3.1. ERROR AVOIDANCE

While automatically creating structural calculation models, it is very important to avoid calculation errors. A calculation error produced by non diverging load combinations in later iterations leads to a back step in the section size.

3.2. QUALITY OF THE CALCULATED RESULTS

The created calculation models do not cover all loads and load combinations, such as wind loads, thermal expansion or imperfections. Nonetheless the resulting section dimension is very realistic. The section optimisation process does not optimise the elements to the highest degree of stress utilisation of 100 percent, but a maximum utilisation of 70 percent. Therefore there still is a buffer of 30 percent, which is very unlikely to be exceeded. However the result is not a complete structural analysis and additional load cases and load combinations would have to be added to reach the final state. The automatically created model though can be used as the basis for the final model. That alone is a great advantage in comparison to a non-automated approach, since the modeling of a structural calculation model is a time consuming procedure, with a significant percentage of the overall editing time.

4. Roughening of the skin system

The structural system was has been used as a starting point for the modeling of the glass panels. Usually tessellation is a phenomenon that architects and engineers try to prevent. In case of the glasshouse an early decision was made that the tessellation of the skin needs a lot of intention. During the process a solution has been found which does not hide the tessellation, but places additional emphasise on the facets of the skin.

A script has been written which always affected four points at a time. First a plane has been created through the first three points and has been rotated outwards in direction of surface normal in order to increase the discontinuity between the adjacent panels. Afterwards all four points were projected onto that plane, so that all four points meet in the same plane. This method ensures planar panels and creates an additional roughness of the panels.

The jaggedness of the skin is also affecting the main structural beams which now need to accommodate the jagged profile on the outside, whereas they can remain smooth on the inside. It is proposed to fabricate the main beams using water jet cutting technology.

The jagged main beams also allow attaching the glass directly to the structure. The insulated glass layer consists of laminated safety glass on the inside and toughened safety glass on the outside. The glass panel is glued to a support

bracket which is connected to the structure. The additional roughening of the façade allowed integrating a sun shading device on the outside. Each glass panel has its own shading element.

5. Conclusions

Through this integrative form finding process, a set of different grids was structurally evaluated giving feedback to the dimension of the structural ele-

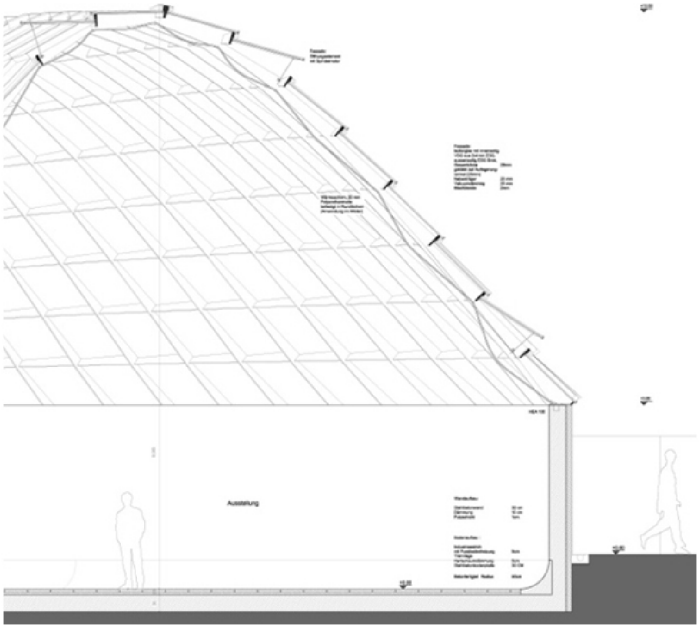

Fig7. Facade section.

ments. It was possible to compare the aesthetic of a design on the basis of realistic dimensions of the supporting structure and through that assure that the lighting requirements resulting from the structure are met.

However the described workflow could be further extended in many ways. Especially the automated load calculation leaves room for further development. The goal would be to reduce the amount of manual editing time, for example by defining different wind load application areas on the surface to which a parameter set can refer to and automatically apply wind loads to the generated structure.

Another promising approach would be to include illumination data as an additional numeric parameter by connecting an evaluation tool such as Ecotect

to the developed software. Both of approaches mentioned above are currently investigated by us.

References

Carpo, M.: 2008, Monstrous objects, morphing things, in Monster, edited by Jacob Reidel et al., *Perspecta,* **40**: 16–21.

Carpo, M,: 2008, Non standard morality: digital technology and its discontents, *in* Anthony Vidler (ed.), *Architecture between spectacle and use,* Yale University Press, New Haven, CT, 127–142.

Manegold, M.: 2008, Design tools for structural analysis early design stage, thesis at the University of Karlsruhe.

Michalatos, Panagiotis and Kajima, Sawako: 2007, Structural information as material for design, *Expanding bodies: art • cities• environment, proceedings of the 27th annual conference of the association for computer aided design in architecture,* Halifax, 84–95

Tessmann, O.: Structural analysis as driver in surface-based design, Session 03: Collaborative Design and Presentation, *eCAADe 25.*

Turrin, M., Kilian, A., Stouffs, R. and Sariyildiz: 2009, Digital design exploration of structural morphologies integrating adaptable modules, *in* T. Tidafi and T. Dorta (eds.), *Joining languages, cultures and visions: CAAD futures 2009.*

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INFORMATION DEPENDENCIES BETWEEN ARCHITECTS AND SERVICES ENGINEERS FOR EARLY DESIGN EVALUATION

A framework for an energy design tool for architects

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Abstract. Effective strategies for the design of efficient and environmentally sensitive buildings require a close collaboration between architects and engineers in the design of the building shell and environmental control systems at the outset of projects. However, it is often not practical for engineers to be involved early on in the design process. It is therefore essential that architects be able to perform preliminary energy analyses to evaluate their proposed designs prior to the major building characteristics becoming fixed. Subsequently, a need exists for a simplified energy design tool for architects. This paper discusses the limitations of existing analysis software in supporting early design explorations and proposes a framework for the development of a tool that provides decision support by permitting architects to quickly assess the performance of design alternatives.

Keywords. Performance-based design; energy simulation; decision support; design process; information dependencies.

1. Introduction

Contemporary awareness of global environmental concerns reinforces the imperative to construct buildings that minimise energy consumption and associated carbon emissions. Consequently, there is an increasing pressure on architects to be more environmentally responsible in their designs. Despite this, building services, one of the largest contributors to energy usage, complexity and cost, are rarely considered in the conceptual design phase, let

alone conceived of as potential driving influences behind architectural form.

Presently, on a global scale, the buildings sector is responsible for 33% of all energy-related carbon emissions (Intergovernmental Panel on Climate Change, 2007). Furthermore, in Australia, 18% of the nation's emissions can be attributed to commercial buildings (Intergovernmental Panel on Climate Change, 2007), with the ongoing operation of heating, ventilation, and air-conditioning (HVAC) systems accounting for over 60% of the energy consumption responsible for these emissions (Department of Sustainability and Environment, 2006). However, it is atypical for the performance implications of thermal comfort strategies to be explored in any detail in the early modelling of a building proposal, despite the potential environmental and financial benefits that stand to be gained from this approach (Drogemuller et al., 2004). If more sustainable built environment outcomes are to be achieved, then performance-based strategies that integrate architecture and services must be implemented in order to generate building designs in response to considerations of energy efficiency.

This paper reports on findings from the first year of embedded-practice Ph.D. research being undertaken within Project Services, a building design and project management division of the Queensland Government's Department of Public Works. As such, the conclusions are not yet finalised. Rather, this is a work in progress that summarises the explorations to date and outlines the developments to be embarked upon over the next two years.

2. The need for an energy design tool for architects in early design

Decisions made in the conceptual phase of architectural design have the greatest impact on building performance outcomes, as they determine the flexibility, effectiveness, and efficiency of the design solution (Hensen, 2004). During this earliest stage the general form, orientation, and construction of the building are defined, from which all subsequent decisions are derived (Ellis and Mathews, 2001). Consequently, while these decisions initially provide direction for the project, they simultaneously generate constraints that become difficult and costly to alter as the design progresses (Maassen et al., 2003). This can jeopardise the viability of a project if a poorly made decision needs to be rectified late in the design.

Frequently, these early decisions are based on information that is complex, incomplete, and, at times, incorrect (Maassen et al., 2003). Design solutions are often guided by experience and intuition, rather than based on quantitative prediction of multidimensional performance indicators such as operating costs and energy consumption (Struck and Hensen, 2007). While these decisions have implications for all disciplines involved in the design, the decision-mak-

ing process is conventionally led primarily by architects, usually without an adequate decision support environment to effectively evaluate multidisciplinary criteria (Bleil de Souza and Knight, 2007). Often choices are made with limited comprehension of the impacts that alternatives have on the design's performance (Flager and Haymaker, 2007).

Ideally, all the design professionals required to complete a project would be appointed at the same time. This, however, does not typically fit within the scope of current design practice (Ellis and Mathews, 2001). It is therefore essential that architects be able to quickly and accurately evaluate the energy performance of their conceptual designs without the need for expert assessment.

3. Problems with existing energy analysis tools

Presently, there is a lack of tools that have the capacity to support the rapid interactions between architectural design and services engineering needed early in the design process (Flager et al., 2009). Traditionally, services engineers have not been involved in building projects until the documentation stage of the design process, and subsequently, the majority of energy simulation tools that do exist have been developed to support tasks associated with this phase of development (Maassen et al., 2003). As a result, performance evaluations are generally time-consuming and complicated to carry out, requiring detailed information about the building construction and services before a simulation can be performed (Ellis and Mathews, 2002). To undertake even an indicative energy analysis requires information for inputs that may not yet be available during the preliminary design stages, which is paradoxically when the evaluation is most influential (Punjabi and Miranda, 2005).

In addition to the complexity of the software acting as a deterrent to its use by architects, the interface for these tools is typically cumbersome, non-visual and unintuitive (Punjabi and Miranda, 2005). The inputs and outputs are largely numeric, and, consequently, the translation of model descriptions and simulation results is a non-trivial task that often constrains the designers' ability to understand and decide between design alternatives, as well as consuming large amounts of time and effort (Prazeres et al., 2009). While there is some capacity to map design representations into the required domain representations in certain energy analysis applications, these transformations are highly limited, and the reverse process of mapping performance solutions to design models is largely unsupported, leaving iterative explorations to be undertaken manually (Kolarevic, 2003).

The energy simulation tools available do not successfully reconcile the relationships between design actions and performance outcomes, rendering

them incapable of supporting design decision-making in any significant manner (Attia et al., 2009). As such, they have largely failed to be incorporated into general design practice (Warren, 2002). What is instead needed is a performance evaluation process that parallels the characteristics and logical relationships of the design process, and permits smooth transitions between domain-specific representations (Yan and Jiang, 2005).

4. Performance-based decision support in early design

There is a compelling rationale to overcome these obstacles impeding the use of building simulation tools for decision support in early design. The spate of energy codes and rating schemes emerging, such as Section J of the Building Code of Australia (Australian Building Codes Board, 2009) and Green Star (Green Building Council of Australia, 2009), along with their equivalents in other countries, are creating common objectives for architects and engineers. In addition, recent improvements in both modelling and simulation software are giving rise to more tangible opportunities for direct links between design and analysis processes (Attia et al., 2009). At present, however, there is very little guidance available to architects for understanding and incorporating energy analysis as a decision support tool (Bambardekar and Poerschke, 2009).

Defining the criteria and procedures necessary to connect these design and evaluation activities is very much a human problem of process and understanding, independent of specific modelling or analysis tools (Bleil de Souza and Knight, 2007). While architects are typically familiar with general environmental concepts and rules of thumb, methods for structuring the data and process necessary to perform simulations have not been formalised into common standards (Bambardekar and Poerschke, 2009). In order to successfully bridge this gap, a unified framework that identifies and redefines key simulation parameters as design-related criteria must first be established, so that information crucial to determining performance outcomes is placed in a context easily understood by architects (Ellis and Mathews, 2002).

A modified version of the design approach suggested by Todesco (1996) is suggested here as the structure by which to develop an energy-based design strategy (figure 1). As well as an example of a clearly formalised process that is reflective of common opinion within recent research (Ellis and Mathews, 2001), Todesco's approach is also well aligned with the sustainability initiatives of Project Services. Minimising building loads is the first step. Building loads are largely affected by building shape, spatial organisation and thermal characteristics. Therefore, architectural decisions can consequently be directly translated into the inputs required for early performance evaluations (Ellis and

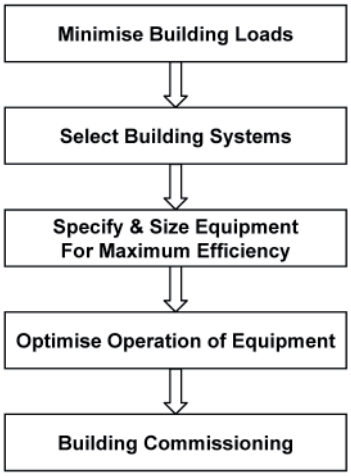

Figure 1. Design approach for energy-efficient buildings, based on Todesco (1996).

Mathews, 2001). Engineering decisions tend to then be concerned with the steps following.

In this approach, it is important that architects recognise the building envelope as being either a barrier or a filter (or a combination of both) moderating the effects of weather, surroundings, and internal occupancy (Bleil de Souza and Knight, 2007). The objective is then to design a building envelope that offsets as much of the energy transfer through it as is appropriate, responding to and accommodating variations in external and internal conditions (Bachman, 2003).

In order to gain a better understanding of this construct of the building and its envelope, the software eQUEST was recently employed as an evaluation tool on a live project within Project Services. In spite of the program being intended for use in an American context, eQUEST was chosen due to its implementation of design wizards for the preparation of analytical models, which clearly lay out the minimum information required to perform a simulation. From this demonstration, seven groups of parameters have been identified as necessary in constructing an early energy model. These are defined to reflect an architectural perspective, as follows:

- **Thermal zones:** are used as the geometric construct rather than rooms, characterised in terms of shape, orientation and program, and grouped and positioned to minimise thermal loads that require mechanical offsetting to maintain interior comfort.

- **Construction types:** are selected and located according to their conductance to moderate the energy flows between thermal zones and the external environment.
- **Glazing and skylights:** are selected and positioned to permit natural light internally while avoiding undue solar heat gain.
- **External shading:** is positioned to shield glazing and highly exposed external walls from excessive solar radiation.
- **Internal heat gains for occupancy, equipment and lighting:** are determined for each thermal zone by both a load and a schedule of operation associated with the allocated program, which are derived as constant values from building codes and rating scheme guidelines.
- **HVAC systems:** are chosen in collaboration with a mechanical engineer, in order to determine the type of system best suited to the building form and function and the architectural implications of this system, then set as a default, to maintain focus on the performance impacts of the architectural decisions.
- **Weather and surrounds:** are independent of the building, and set as constants throughout the performance evaluation.

The performance impacts of these seven parameters are highly interdependent, and must be recognised as a dynamically interconnected system if they are to be evaluated adequately (Bleil de Souza and Knight, 2007). Although it has been shown that performance outcomes are particularly sensitive to the factors of orientation, window area, wall construction and roof properties (Ellis and Mathews, 2001, Attia et al., 2009), it is vital to recognise that simulation results will not directly point to a single building element to adjust for better results (Sanguinetti et al., 2009). Rather, all parameters must be considered in combination to gain a complete understanding of building performance.

5. Requirements of an energy design tool for architects

In order to successfully make use of energy analysis as a decision support tool in early architectural design, simulation must be recognised as a social discipline, as it involves both human–computer interaction and knowledge processing, while simultaneously facilitating the definition and exploration of design space (Attia et al., 2009). From this perspective, not only must an energy design tool support the proposed framework to successfully target use by architects, but it must also address issues of interaction and understanding specific to this design discipline.

As Pedrini and Szokolay (2005) have revealed in recent research, architects rank experience and intuition as their preferred decision-making techniques, followed by guidelines and rules-of-thumb, while the use of simulation models ranks amongst the lowest methods used. Despite lacking the capacity to evalu-

ate climate and design-specific idiosyncrasies, resources such as guidebooks are favoured because they are simple to navigate and require little detail about the design, making them time and cost effective (Bambardekar and Poerschke, 2009). What is therefore needed is a simulation-based tool that combines its inherent analytical capability to handle dynamic and iterative design investigations with the ease of use associated with resources like guidebooks. The operation of such a tool should not necessitate that architects learn a new skill set, but rather be intuitive and reflective of the design process.

A number of criteria for 'architect friendly' simulation tools have been identified by both the architecture and simulation communities in recent years (Attia et al., 2009, Warren, 2002, Crawley et al., 2008, Maassen et al., 2003). The following features have been the most frequently suggested:

- A user-friendly interface that represents simulation inputs and outputs graphically, allowing for simple navigation and flexible control.
- The ability to quickly compare and track design alternatives and 'what-if' scenarios, as well as visualise the potential impacts that different design decisions have on energy performance.
- A design knowledge base that facilitates learning by supporting users with the following – tutorials; online help; assistance in recognising and modifying conflicting criteria; and a library of case-based example buildings for reference.
- Default templates and parameter values to facilitate data entry, combined with the flexibility to control whether parameters are set or variable.
- Links to building codes and rating schemes, to check code compliance and energy credits, respectively.
- The capacity to build the simulation model in a 3D environment by linking the energy simulation tool directly to an existing 3D modelling program, through the use of an automated bidirectional mapping procedure to transform between design and analysis representations.

This last point is particularly important, as one of the main challenges in achieving the integration of simulation with design lies in how to formulate associative interconnections to current building information modelling processes. Current implementation of the Industry Foundation Class (IFC) export is not conducive to an interactive concurrent design environment as its "top-down" hierarchical structure necessitates the transfer of the entire model file rather than permitting the selective export of only required building elements (Dong et al., 2007). Additionally, the semantics of IFC exchange are too ambiguous to allow for seamless integration between design and analysis representations (Petrinja et al., 2007), and very few energy simulation programs support it as a file format for this reason. Instead, Green Building XML (gbXML) is the preferred file format for the exchange of data between CAD

and energy analysis software, as it is an extensible and robust non-proprietary format that expresses building geometry as rectangular surfaces, the representation required for energy simulation (Dong et al., 2007). It is therefore anticipated that future development of the framework will be based upon the gbXML schema.

In addition to these features, the performance of individual scenarios needs to be accounted for in absolute terms, to allow for quantification against energy rating scheme criteria, as well as in relative terms, to compare design alternatives (Donn et al., 2009). This suggests the use of a single, robust performance evaluation tool throughout the design process, to eliminate inconsistencies in results caused by the use of different methods of evaluation (Morbitzer, 2003). A single tool approach allows the same model to be progressively refined throughout the different design stages, providing a common construct to support the integrated development of both the architectural and services designs from the outset of the project onwards (Maassen et al., 2003).

Project Services have recently demonstrated the practical benefits of engaging in energy simulation early in the design process with their Joint Call Centre (JCC) project, a 5100m² office building located in Brisbane for non-emergency police calls and general government services. This project has been awarded the highest Green Star rating ever given to an office building in Australia, achieving 92 points out of a possible 105. The exceptional outcome can largely be attributed to the fact that the services engineers were heavily involved in the early design process, performing numerous simulations (each one having to be modeled individually) to explore tradeoffs required between spatial organisation, and HVAC and lighting systems, to obtain an optimal design solution. Due to the expert nature of the analysis and interpretation required, the architects had minimal involvement in this process, making apparent that the tools being used did not adequately support an interactive concurrent design environment. Despite these obstacles, however, this strategy demonstrated the effectiveness of integrating simulation in the early design process as means by which to improve building performance.

6. Conclusion

While the range of available performance analysis tools is increasing, there is no single program that meets the needs of architectural users. This paper presents a framework for an energy design tool that will address these needs, the development of which will be undertaken in future work. The next stage in this process will be the selection of a simulation program on which to base this development, a non-trivial task that will involve consideration of how different software might be adapted to accommodate the Australian climate and

regulations, which is largely unaddressed in the current research and development concerned with energy design strategies. We will assess Ecotect, IES Virtual Environment and Energy Plus, amongst others, for their potential to be extended to accommodate the front end of the design process, as well as for the accuracy of the results that they generate.

Energy simulation is a potentially powerful decision support tool for architects that offers a new frontier in the exploration of design processes affecting more energy efficient design solutions. By reducing the complexity of simulation tools and simultaneously improving their ability to accommodate performance enquiries typical to the early design stage, energy design processes will begin to present themselves as potential generators of innovative and sustainable building solutions, rather than acting as deterrents to their own use. This will open up a dialogue between architects and services engineers and assist in the development of mutually responsive objectives and processes that have the capacity to resolve design and performance constraints simultaneously and subsequently result in a more sustainable built environment.

Acknowledgements

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References

Attia, S., Beltran, L., De Herde, A. and Hensen, J.: 2009, Architect friendly: a comparison of ten different building performance simulation tools, *Building simulation '09*, Glasgow, 204–211.

Australian Building Codes Board: 2009, *BCA 2009: building code of Australia*, Australian Building Codes Board, Canberra.

Bachman, L.: 2003, *Integrated buildings: the systems basis of architecture*, John Wiley & Sons Inc., Hoboken.

Bambardekar, S. and Poerschke, U.: 2009, The architect as the performer of energy simulation in the early design stage, *Building simulation '09*, Glasgow, 1306–1313.

Bleil De Souza, C. and Knight, I.: 2007, Thermal performance simulation from an architectural design viewpoint, *Building simulation '07*, Beijing, 87–94.

Crawley, D. B., Hand, J. W., Kummert, M. and Griffith, B. T.: 2008, Contrasting the capabilities of building energy performance simulation programs, *Building and environment*, **43**(4), 661–673.

Department of Sustainability and Environment: 2006, Residential and commercial energy use, available from: <http://www.dse.vic.gov.au/CA256F310024B628/0/985CF492586F061BCA25748E000609DA/$File/Residential+and+commercial+energy+use.pdf> (accessed 21 May 2009).

Dong, B., Lam, K., Huang, Y. and Dobbs, G.: 2007, A comparative study of the ifc and gbxml informational infrastructures for data exchange in computational design support environments, *Building simulation '07*, Beijing, 1530–1537.

Donn, M., Selkowitz, S. and Bordass, B.: 2009, Simulation in the service of design – asking the right questions, *Building simulation '09,* Glasgow, 1314–1321.
Drogemuller, R., Crawford, J. and Egan, S.: 2004, Linking early design decisions across multiple domains, *European conference on product and process modelling in the building and construction industry,* Istanbul, Turkey.
Ellis, M. W. and Mathews, E. H.: 2001, A new simplified thermal design tool for architects, *Building and environment,* **36**(9), 1009–1021.
Ellis, M. W. and Mathews, E. H.: 2002, Needs and trends in building and HVAC system design tools, *Building and environment,* **37**(5), 461–470.
Flager, F. and Haymaker, J.: 2007, A comparison of multidisciplinary design, analysis and optimisation processes in the building construction and aerospace industries, *24th international conference on information technology in construction,* Maribor, 625–630.
Flager, F., Welle, B., Bansal, P., Soremekun, G. and Haymaker, J.: 2009, Multidisciplinary process integration and design optimization of a classroom building, *ITcon,* **14**, 595–612, available from: <http://www.itcon.org/cgi-bin/works/Show?2009_38> (accessed 1 September 2009).
Green Building Council of Australia: 2009, Green Star, available from: <http://www.gbca.org.au/green-star/> (accessed 8 November 2009).
Hensen, J.: 2004, Towards more effective use of building performance simulation in design, *7th international conference on design and decision support systems in architecture and urban planning,* Eindhoven.
Intergovernmental panel on climate change: 2007, *Climate change 2007: mitigation of climate change,* Cambridge University Press, New York.
Kolarevic, B.: 2003, Computing the performative in architecture, *Digital design: 21st eCAADe conference proceedings,* Graz, 457–464.
Maassen, W., De Groot, E. and Hoenen, M.: 2003, Early design support tool for building services design model development, *Building simulation '03,* Eindhoven, 761–768.
Morbitzer, C.: 2003, Towards the integration of simulation into the building design process, unpublished thesis, University of Strathclyde, Glasgow.
Pedrini, A. and Szokolay, S.: 2005, The architects approach to the project of energy efficient office buildings in warm climate and the importance of design methods, *Building simulation '05,* Montreal, 937–944.
Petrinja, E., Stankovski, V. and Turk, Z.: 2007, A provenance data management system for improving the product modelling process, *Automation in construction,* **16**(4), 485–497.
Prazeres, L., Kim, J. and Hand, J.: 2009, Improving communication in building simulation supported projects, *Building simulation '09,* Glasgow, 1244–1251.
Punjabi, S. and Miranda, V.: 2005, Development of an integrated building design information interface, *Building simulation '05,* Montreal, 969–976.
Sanguinetti, P., Eastman, C. and Augenbroe, G.: 2009, Courthouse energy evaluation: BIM and simulation model interoperability, *Building simulation '09,* Glasgow, 1922–1929.
Struck, C. and Hensen, J.: 2007, On supporting decisions in conceptual design addressing specification uncertainties using performance simulation, *Building simulation '07,* Beijing, 1434–1439.
Todesco, G.: 1996, Super-efficient buildings: how low can you go?, *ASHRAE journal,* **38**(12), 35–40.
Warren, P.: 2002, *Bringing simulation to application: IEA ECBCS annex 30* (Technical Synthesis Report No. 0-9542670-2-8), FaberMaunsell Ltd on behalf of the International Energy Agency, Hertfordshire.
Yan, D. and Jiang, Y.: 2005, An overview of an integrated building simulation tool – designer's simulation toolkit (DeST), *Building simulation '05,* Montreal, 1393–1400.

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URBAN MICRO-INFORMATICS

A test case for high-resolution urban modelling through aggregating public information sources

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Abstract. Our contention is that the city is a rich collection of urban micro-ecologies in continuous formation that include information types outside the traditional boundaries of urban design, city planning, and architecture and their native data fields. This paper discusses working with non-standard urban data types of a highly granular nature, and the analytical possibilities and technical issues associated with their aggregation, through a post professional masters level research studio project run in 2008. Opportunities for novel urban analysis arising from this process are discussed in the context of typical urban planning and analysis systems and locative media practices. This research bought to light specific technical and conceptual issues arising from the combination of processes including sources of data, data collection methods, data formatting, aggregating and visualisation. The range and nature of publicly available information and its value in an urban analysis context is also explored, linking collective information sites such as *Pachube*, to local environmental analysis and sensor webs. These are discussed in this paper, toward determining the possibilities for novel understandings of the city from a user centric, real-time urban perspective.

Keywords. Urban; informatics; processing; ubicomp; visualisation.

1. Introduction

Our research tests the possibility of publicly available information sources and the resolution of this data towards novel forms of urban analysis. Our

contention is that the city is continuously developing a rich field of disarticulated information types and sources that operate as an ecology of information outside the traditional boundaries of urban design, city planning, architecture and locative media practices and their native data fields. These new data resources include social networking sites, environmental systems and monitors, individual and institutional information sets of various kinds, RSS news feeds, and so on, and are understood as non-standard in urban terms. Working across a multitude of heterogeneous data types requires the development of novel methods of collection and visualisation appropriate to developing urban understanding. Equally it is our contention that by virtue of their heterogeneous and non-standard nature, these information sources promote new questions of urban environments.

1.1. CONTEXT OF URBAN INFORMATICS

The desire to understand and systematise the city for management, planning and analysis purposes was explored by Jay Forrester in the Urban Dynamics movement of the 1960's and underpins the development of contemporary urban information systems such as GIS, simulation and satellite mapping technologies. Laurini (2001, 1), underpins a typical formulation the city as a system, noting, "A city can be described as a general system with different interconnected subsystems." The development of complex geospatial databases has also enabled combined geospatial data platforms or Spatial Data Infrastructures to be established such as those developing under the EU INSPIRE directive and the US National Spatial Data Infrastructure (NSDI) protocol. Interestingly, the ecological metaphor has been used to describe urban situations (for example Jacobs, 1961) but only recently has it begun to be implemented as a means through which analysis and testing are possible (Batty, 2005). In contrast to Laurini, Watt describes a system in ecological terms as "An interlocking complex of processes characterised by many reciprocal cause and effect pathways." (Watt, 1966, 2) Watt notes "that a principal attribute of a system is that we can only understand it by viewing it as a whole." The ecological foundation to Watt's description offers a more complex and strictly non-lineal formulation of urban relationships in contrast to the computational hierarchy model of Laurini. For our purposes, the ecological model serves well to articulate a bottom up approach to urban issues, where the boundaries to causes and effects cannot be assumed and therefore cannot be systematised in a general systems model.

GIS and agent based simulations are common foundations to contemporary urban planning and urban design strategies. These rely on large database sets in the case of GIS, or specialised code based environments for agent sim-

ulation. GIS offers a layered overview of the urban realm, while agent based simulations attempt to capture the dynamic qualities of urban environments in action. Both of these approaches require the formulation of an abstract intellectual model of urban space based within the planning disciplines and employ disciplinary specific frameworks for identifying and incorporating appropriate data sources. A variation to this is the citizen reporting methods as discussed by Paulos (2008).

Urban informatics has begun to be tested in design practice also, typically in projects employing parametric systems and specialised disciplinary information for the creation of city information models (CIM). These models operate in the same mode as Laurini's, through structuring hierarchies of relationships in order to develop a balanced urban position according to the authors range of interests and information sources. CIM offers the possibility to test and refine urban models through versioning and analysis of a very high order, but suffer from a necessary abstraction in information translation and the need for complex hierarchical models.

Locative media strategies that tie location based information typically to a single user experience through personal media devices and their application within the city are also not new ideas to urban design, being discussed in media, art and architecture circles since at least 1996 (Townsend, 2008; Paulos, 2007; Foth, 2008; Mitchell 1996, 2004; Hill 2008). Location in this sense activates the availability of information to a single user.

1.2. THE RESEARCH

This research explores a distinctly different path to those forms of urban research described above, based on the premise of uncovering non-hierarchical cause and effect relationships at a very small scale. Through capturing a range of non-traditional information sources, the intention is to gather user centered, non-simulated information types through hybridising various formats. An example of the granularity and dynamic possibilities of this kind of urban mapping was captured by in the project *Cabspotting* by Stamen Design (2005) who used a high resolution GPS trackers to visualise the invisible dynamic of San Francisco through the movement of their yellow cab fleet. Another more recent example of this strategy is the New York Talk Exchange study conducted by the Sensible Cities Lab at MIT. Through looking at high resolution patterns of phone use in New York, a startlingly different picture of the urban and social fabric and its relationship to telecommunications was possible (Ratti, 2008).

This research seeks to build on these kinds of initiatives by establishing a broader cross-section of information types that range across physical, social,

and material orders so as to provide novel urban analysis opportunities. *We feel fine* (http://www.wefeelfine.org/) is an example of an application that visualises written statements of emotion along with contextual information regarding the time of writing (temperature, rainfall patterns), becoming a barometer of the emotional state of people on the Internet. The immediate impact of cross-comparing disassociated sets of data to gain new insight into the 'lived' properties of places has been demonstrated (Harris and Kamvar, 2009); with one shared element in all examples being the presentation of locative feedback of the data collected.

Our critique of existing urban planning models is with the relatively narrow bandwidth of information sources and types used to develop urban analysis, in an age of massive information expansion. Responding to urban environments through urban based systemic models also presupposes the questions involved in urban understanding and decision making. In this research, no planning or computing model was 'strategised' as a whole, rather, our interest is in emergent understandings through developing combinations of publicly available information at the highest resolution possible. This research began with an open enquiry into the range and nature of public information broadly linked to the precinct of study. Other questions about information handling across information types, methods of information gathering and techniques for hybridising and visualising data to maintain an urban analytical focus are also raised.

This research specifically aimed to test the following questions:

- What alternative formal and informal information sources are publicly available for mapping the city?
- What is the quality of these sources and at what resolution is it possible to understand the city?
- What visualisation techniques and possibilities present themselves with new forms of information when they are aggregated?
- What does this mean for urban design?

The remainder of this paper discusses the design research studio created to explore these questions.

2. The street as platform project

The intensive studio comprised of instructors from planning, architecture, interaction design and media design and students of a post professional advanced architecture degree in 2008. The goal was to explore the limits of information fidelity of a very small urban area, a pedestrian bridge over a busy 5-lane inner city road at UTS in Sydney, and 'paint the fullest picture' possible for a public audience. Of particular interest was discovering what

alternate sources of information of the city were available, and what issues were raised when transcoding many and various sets of information towards more complex informatic assemblies. The project required designing techniques for visualising real time data, and methods for evaluating information feeds that were found to be freely available and numerous. The data collection methods used included web-scraping algorithms, RRS feeds, purpose built and third party environmental sensor networks and online open data sharing communities services (Pachube, 2009). The sources of information included local urban planning statistics, Australian interest rates trends, new feeds, social media networks, published institutional and governmental timetables and highly specific local, regional and global environmental data. Issues such as methods for collection, sources and evaluation of data were raised in this urban informatic context, as was the role of visualisation and the interpretation of data as information (Whitelaw, 2008). The project was presented to an audience of approximately 1000 people as part of an exhibition event as a projected animation.

3. Data sources

Most data sources provided large amounts of highly granular dynamic data that required converting into information through several stages of processing. Collecting, parsing and formatting information from dynamic and static data sources such as RSS feeds, data logging websites or by decoding raw HTML code raised issues of update intervals, reliability and format. Once acquired, the data needs to be parsed and converted into a format that is suitable for visualisation, which may involve delimiting the data into CSV files or applying pattern-matching techniques to extract and format the data. Once formatted, the data needs to be filtered to extract the relevant information to understand the specific layer of the urban fabric and temporal correlation to other data sets. In this way the collection of data can be seen as an accumulation of individual sources, growing over time and not limited by top-down requirements that all variables be known at the start. In this process a view to an 'ecology of techniques' was developed over the development of specific tools.

A series of visualisations were developed around the specific urban environment, with the data being categorised by the particular temporal and geographic scale to which it related. Visualisations were constructed from local sensors detecting real-time activity, web data indicating suburb activity and global data including news feeds and financial movements.

3.1. STREET SENSING

The setup of a system to gain an understanding of the actual use and context of pedestrian movements over the footbridge allowed site-specific localised data to form part of the information ecology. A series of sensors were located on and around the footbridge, measuring ambient environmental changes in temperature, light, and humidity. These sensors logged to centralised data locations, available for use as live data in the information visualisations. The sensors were an experimental remote location setup, utilising a new prototype board which reported its' data wirelessly over a radio protocol (designed and produced by David Lowe of CRIN at UTS). These sensors were used to relay data from the bridge to a nearby receiver computer and aside from a relatively short battery lifespan, were robust and active throughout the full period of measurement.

To visually analyse the street a camera was placed within the DAB building, simultaneously observing both the roadway and footpath in a single image. This camera was programmed to save an image every minute. These images were saved to a local storage location, which was also available for image processing and analysis. These images were analysed to outline patterns of motion from the street, including human, plant and vehicular movements. These images were saved with date and time stamps, allowing the images to be considered and used in context with the other sets of data being collected. To measure ambient sound levels a microphone was installed facing the street. The analog microphone signal was translated into a digital audio signal and converted into an audible range by a simple audio mapping algorithm. These levels were collected as an average level each minute and logged with the other sensor data.

To observe and visualise the invisible aspect of on-street activity, a number of ambient radio frequency scanning techniques designed to detect and report on radio activity (such as WIFI, mobile activity or Bluetooth) were explored. Eventually a piece of dedicated Bluetooth scanning software was selected which was able to passively scan for visible Bluetooth devices, within a range of 10-20m. This software would also log the detected devices to a centralised location, for use in the visualisations of the street. This technique was later refined and used in a site-specific data visualisation project in Sydney, *Smart light fields*.

In addition to the street sensing techniques employed for the project which were understood to be only one part of the informational e-cology, remotely accessed data was incorporated into the live visualisations. Information sources were drawn from three different scales of relevance: local, regional and global. These scales required specific translation both in time period and

data format, but also in terms of context, since traditionally isolated sets of data were being drawn in parallel to observe their overlap.

3.2. LOCAL SCALE

Local data was measured by the sensors, cameras and Bluetooth loggers discussed above. Wherever possible this data was published in real-time to online data sources (Pachube, Twitter), contributing to the community with our data feeds. The use of web cameras and Bluetooth loggers were most successful at this scale of detecting dynamic information such as human activity in the space. The collected visual logbook was analysed by custom software algorithms, which applied a threshold filter to each image, converting the base images to outlines based on the amount of light in each pixel. The silhouette of each image was then pieced together as an animated video of the street – as seen through the filtered process of abstraction (Gachadoat, 2008).

Manipulating the fade time and speed of playback allowed a vivid construction of the spatial dynamics under the bridge. Movement in the tree foliage provided an alternate description of local wind patterns (figure 1). Traffic and car movement was easily detected, and by focusing pixel analysis on the road area of the image, we could determine traffic patterns through light intensity variations on a 24-hour basis. It also allowed monitoring of student access patterns into the building.

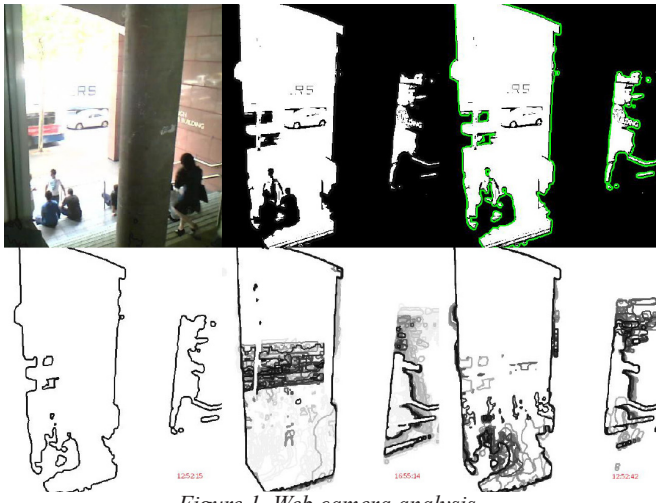

Figure 1. Web camera analysis.

3.3. REGIONAL DATA

Web-scrapping techniques were used to collect information at the regional level, with the easiest method to extract data being through readily available RSS feeds. The data comes preformatted and the text can quickly be read into Processing by loading the data as text and splitting it line by line directly from the webpage. The direct link to the website means that any updates will automatically be registered in the visualisations. Designing for this required an understanding of the type of data and ability to strategise for error checking. Understanding the format of the data allows the information to be organised as it is parsed, making it available more readily for visual analysis.

At a suburban level, it was possible to extract data from the local planning authority website in regards to development applications including lodge dates, status, address, descriptions and staff member responsible. Data was also available in regards to local weather, university class timetables and traffic flow. This information was not as readily available as the local sensors, being updated daily or weekly. Construction of an overall visualisation for the area required the extrapolation of values for this data or the display of a visual cue within the visualisation process when new data arrives. This technique was experimented with the suburb wind data, which updated every 15 minutes with scripted particles bursting on the screen and flowing across the visualisation in the direction of the wind each time new data was retrieved. The data was also represented historically through a feather like time graph indicating wind strength, direction, gust, humidity and temperature (figure 2).

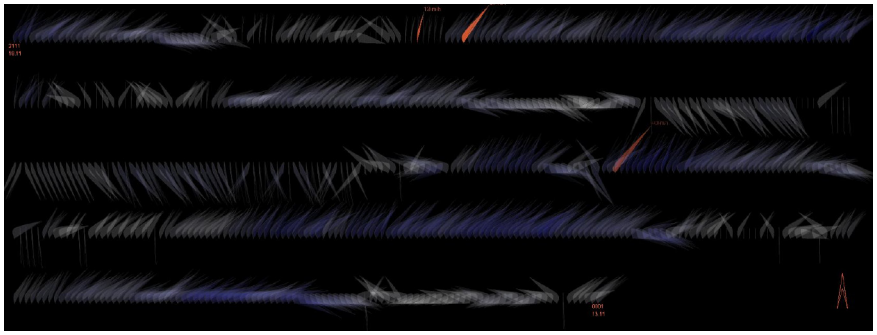

Figure 2. Historical wind graph.

3.4. GLOBAL DATA

At the global scale, there was an opportunity to extract news feeds and economic data into visualisations. Stock exchange data can be read simply as a line graph that fluctuates over time. The interesting applications occurred when we were able to parse through the financial fluctuations over time whilst

correlating other data over the same time period. This was explored by connecting the financial variations over the last four years with development applications in Ultimo. We were able to map a complex relationship between the global economy, lodge and completion dates for building applications along with their approval status, down to the responsible planning officer performance records. Constructing a visualisation that provided useful data required innovative graphic techniques that allowed animation and user interaction to extract and display relevant information.

4. Conclusion

This project revealed several ways in which real time public data can be visualised, prompting us to explore two modes of visualisations; integrated data correlations (such as interest rates and housing approvals), and non-integrated or collaged information such as 15-minute wind-bursts that would pop up while viewing a different data source. In other cases such as interest rates and housing approvals being plotted simultaneously, the vastly different scales of information in combination with the depth of the local council information allowed us to speculate, down to the state of mind of a particular planner during a period became startling.

We also speculated on two immediate effects in planning and urban design as a result of this research. One is the untapped capacity of non-specialist and local participation in providing valuable and forceful local information without the need to employ expert systems. In this sense citizen agency is made highly potent in collecting and distributing data. The other impact on urban design is the overlapping of dynamic states of qualitative and quantitative data which reaches beyond traditional urban metrics, and interestingly opens speculations on possible new forms of urban indexes or metrics. We note our ability to correlate university class times with an out of synch bus schedule which may speak to "institutional fit" as a possible metric for future exploration, which is of immediate interest to local traffic planning and ambitions to foster 'campus life'.

By using publically accessible information streams from a variety of sources, it is possible to begin to visualise new forms of urban dynamics that would not be visible through traditional urban visualisation systems. Understanding the urban condition as a continuously developing rich field of disarticulated information types and sources that operate as an ecology of information offers the potentials for low cost high gain urban information of a unique type. Non-traditional urban information sources are capable of being used for urban analysis processes, if new methods for incorporating scrapping, RSS feeds, sensor webs etc in complex assemblages can be developed.

By approaching urban informatics not as an urban system but as a broad and emergent information ecology, and by virtue of their heterogeneous and non-standard nature, these information sources promote new questions of urban environments.

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References

Batty, M.: 2005, *Cities and complexity,* MIT Press, Cambridge, Mass.

Foth, M. (ed.): 2008, *Handbook of research on urban informatics: the practice and promise of the real-time city,* Information Science Reference, New York.

Gachadoat, J.: 2008, BlobDetection library, available from: V3ga.net http://v3ga.net/processing/BlobDetection/ (accessed 20 November 2008).

Greenfield, A.: 2006, *Everyware: the dawning age of ubiquitous computing,* New Riders Publishing, Berkeley.

Harris, J., Kamvar, S.: *We feel fine: an almanac of human emotion,* Scribner, New York.

Hill, D., 2008: The street as platform, available from cityofsound.com, < http://www.cityofsound.com/blog/2008/02/the-street-as-p.html> (accessed 11 February).

Jacobs, J.: 1961, *The death and life of great American cities,* Random House, New York

Laurini, R.: 2001, *Information systems for urban planning: a hypermedia co-operative approach,* Taylor & Francis, London.

Mitchell, W.: 1996, *The city of bits: space, place and the infobahn,* MIT Press, Cambridge, Mass.

Mitchell, W.: 2004, *Me++: the cyborg-self and the networked city,* MIT Press, Cambridge, Mass.

Pachube: 2009, Pachube:: connecting environments, patching the planet, available from: Pachube.com <http://www.pachube.com>.

Paulos, E., Honicky, R. J. and Hooker, R.: Citizen science: enabling participatory urbanism, in M. Foth (ed.): 2008, *Handbook of research on urban informatics: the practice and promise of the real-time city,* Information Science Reference, New York: 441–436.

Ratti, C.: 2008, *New York Talk Exchange,* Sensible Cities Lab, Cambridge, Mass.

Stamen Design: 2005, *Cabspotting,* project sponsored by the Exploratorium San Francisco, http://cabspotting.org/ (last accessed 14 November 2009).

Townsend, A.: 2009 Preface, in M. Foth (ed.): 2008, *Handbook of research on urban informatics: the practice and promise of the real-time city,* Information Science Reference, New York, xxviii.

Watt, K.: 1966, *Systems analysis in ecology,* K. E. F. Watt (ed.), Academic Press, New York.

Whitelaw, M.: 2008, Art against information: case studies in data practice, *Fibreculture* **11** (Jan. 2008).

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DIAGRAMS AS PARAMETRIC SYSTEMS IN URBAN DESIGN

Parametric systems applied to conceptual design

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Abstract. The paper describes how parametric systems have been used to help students bridge from conceptual design to descriptive results. Specifically, it describes projects set in two cities, Hong Kong and Melbourne, to address substantive urban design issues and illustrate that the approach is not scale or culturally bounded. The project undertaken in Hong Kong establishes interdependency models for dense urban structure and examined urban systems that contribute positively to their contextual setting. Parametric models were used to develop diagrams of site potential through models of air movement, light and sun exposure, in particular addressing air quality in one of the most polluted places in Hong Kong. The Melbourne case studies examine urban systems as self-organising systems. In these, the case studies identify parameters that determine two patterns: material pattern of the city and cognitive pattern of the city. The paper illustrates the use of a parametric system as a diagramming tool to explore urban propositions from an urban system.

Keywords. Urbanism; systems thinking; parametric; diagrams.

1. Setting up the objectives

This paper presents two studio experiences in which digital systems were employed to explore the development of design ideas from conceptual to descriptive stages using parametric systems. The particular context was that of urban design; this was selected as the scale of the problems is enormously rich in opportunity yet prevents the designer (or student) from focusing on description or form alone as the outcome. Instead, urban design offers the

opportunity to approach design description as a framework from which form is established, reflecting the principles of parametric description.

The two studios described here both address an urban transportation problem, a railway station, and both use the same software strategy but are set in different cultural and physical contexts and are carried out by students from different institutions. The first was conducted in The University of Hong Kong in 2005, the second in The University of Melbourne in 2009. The authors ran the first design studio to explore new morphologies of Hong Kong as an element in a larger research project on urban design during which it became evident that students were finding it difficult to bridge their computer skills, learned in elective courses, to conceptual design thinking at a large scale. The studio approach here allowed us to explore the bridge from conceptual to descriptive design and, in this context, we identified a potential for parametric design processes beyond their popular form making or BIM applications.

The work described here therefore addresses three questions. Firstly, to what extent can parametric systems be applied to conceptual design processes as diagrams? Secondly, is the earlier experience of introducing students to digital systems continued or do parametric systems demand different approaches? Thirdly, can these systems be used in culturally neutral manner?

1.1. THE URBAN DESIGN CONTEXT

The use of digital systems needs to be grounded in broader theories of their application. This paper starts, therefore, with a description of the urban theories and then describes the design intents and outcomes of each studio before reflecting on the use of the digital systems.

In urban design contexts, Modernism has been promoting separation and segregations and this in turn has led to remoteness and loneliness of many cities inhabitants. Cities have been analysed by breaking them down to identify underlying structures as discrete parts from which they are composed and then analysing these parts in as much detail as possible. In this manner, the separate sub-elements are individually understood and separately optimised. For example, traffic engineers optimise the roads, developers optimised the financial return and politicians optimise their ability to win next election. This phenomenon follows on the principles of reductionism and it is clear that reductionism can constrain a system's emergent properties. Experience suggests that optimising road configuration, transport interchanges or other individual urban infrastructure results in underperforming urban areas. We can observe that our newer urban areas underperform when compared to more complex and socially more engaging places. As a result we have created too many places which alienate us rather than invite us to participate. The process

of spatial segregation, the formation of barriers and the reduction in free movement due to a predilection for prioritising car oriented developments have incrementally reduced opportunities for such rich engagement with place.

With this background, we established goals for our projects that the idea of architecture as an object should be rejected and replaced with the idea of architecture as elements in larger complex adaptive urban systems. These were defined as systems that have ability to learn or systems that have property of emergence, in other words, the ability to result in more rewarding opportunities than available in the elements from which it is assembled (Wootton, 2004). By contrast to engineered or biological systems where goals are relatively low, cities as complex adaptive system have high aspirations. We therefore proposed that the result of urban design is a system with underspecified goals that constantly evolves and is never complete (Sorkin, 1996); this approach is not dissimilar to the approach used in 1960s for the design of *Fun Palace* with Cedric Price (Pask, 1962).

1.2. THE PARAMETRIC CONTEXT

In the past five years we have been using digital systems to explore parametric urbanism from the premise that cities are open, complex, self organising systems, unpredictable and uncontrollable and inherently unplannable (Castells, 1996). From this basis we have sought to establish interdependency models that guide, not determine, the growth of the urban systems. In this investigation we have directed students to ask the question: what strategy creates better answers – dependence on planned system changes or anticipating new properties and behaviour which can emerge from unpredicted interactions within the system and with external environments? These studios have engaged the possibilities of parametric design in a fundamentally different manner that the normal manner of using such a digital capacity. Parametric design has been defined as: “An experimental design in which the amount of the independent variable is systematically varied across several levels” (Rotheroe, 2002). Parametric design has been taken up also by urban designers who can now manipulate road widths with building heights, setbacks etc (Sharpe, 2008). In these studios, we have extended parametric applications into urban diagrams. The work has been carried out using a number of digital platforms including Digital Project and Rhino, demonstrating that the approach is not platform specific.

Diagrams, including data and symbolic representation, are an important mode of exploration and representation in design, allowing the designer to move beyond preconception and, by working in an abstracted manner, explore

the potential in the opportunity rather than solving the problem. In other literature, this is “problem framing” rather than “problem solving” (Schon, 1984).

2. The Hong Kong project

These urban design principles were adopted in redeveloping Mong Kok station as part of the Linear City Research Project. Here, we decided that we will not be just looking and designing the station as an object but trying to develop an interdependency model for the station as a part of bigger system which could be parametrically controlled.

The Mong Kok KCRC Station is one of the busiest stations on the major rail connection through the city but is separated from the neighbourhood’s primary commercial and living area by a large but relatively slender strip (500m × 60–80m) of land occupied mostly by schools and government buildings. This block offers limited access to the public and is consequently a barrier between the station and neighbourhood, crossed at only one point by a route that is neither easily read nor particularly pleasant to use. The area is extremely popular for its entertainment, shopping and food, well connected to a variety of transportation system and, as a consequence, heavily congested and with poor air quality. The community potential for this railways station site is not achieved so improving this and the air quality were primary goals of the proposed changes.

2.1. THE APPROACH

Analysis of the community identified that it is greatly under-provisioned with recreational space (19 ha less than needed) and facilities that enhance quality of life. There is a well established need to provide a healthy environment for children to study, exercise, socialise, and play; for elderly to participate in society; for residents and workers to enjoy the environment. The dynamic nature of the neighbourhood is better supported by an environment for changes, not carefully designed spaces where prescribed activities take place. What was needed was a framework for the community to claim as its own. Within this framework we were able to address the issues of quality of life and density of habitation.

Further analysis suggested that the reason behind poor air quality in the area was due to the barrier created by the station and government buildings around the station which prevented the prevailing wind from penetrating the urban structure of Mong Kok. Better conditions can be achieved by simply providing a more porous structure. The smaller urban grain at the street level needed to be maintained yet a larger structure accommodates recreational

facilities more readily. With appropriate attention, the design of the KCRC station together with surrounding buildings can contribute to increasing air movement in the area to the west and therefore substantially improve the air quality in the area as would use of plants to moderate the environment.

Our research documented that Hong Kong cannot be analysed with common vocabulary of urban discourse (Karakiewicz, 2005). For much of its urban history, Hong Kong has engaged in layering, superimposition, co-existence of unlike parts, and collage of unexpected, all long-standing features of Hong Kong's urban structure. The implication of systems thinking philosophy for the assignment was clear: our objective was to propose a strategic approach to urban and station design that aimed to facilitate emergence of that interpretation of a redeveloped Mong Kok station that would satisfy the agreed and reasonable functional objectives of all legitimate stakeholders. This required that no one particular aspect of the redeveloped station was optimised at the expense of achieving a facility that was more than the sum of its parts. In this context, we note that parametric software enables us to develop a bottom up approach by which we specify the interactions and relationship between parts of the city. Using components and data, we were able to engage with parametric design methods to explore conceptualisation of these relationships through unpredictable outcomes through progressive parametric abstractions as diagrams.

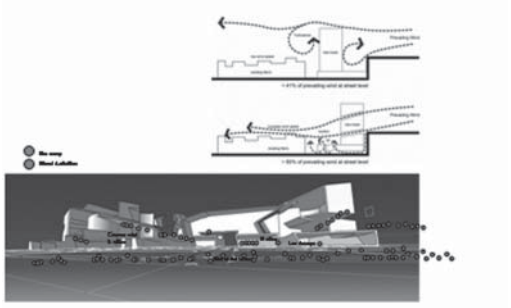

Figure 1. Airflow analysis and possible form (Angus Ngai).

2.2 THE PROPOSAL

The current model for station development encourages the station to take the form of an object and container. The container solution is an example of the Modernist's reductionist slogan form follows function. It is a singular solution that solves one problem while often creating others. Is there an alternative to the current KCRC railway/property development model? Narrowly interpreted, this represents a mechanism to finance railway development. Broadly interpreted, the question raises the possibility of changing the relationship of

a station to the city and hence the role of rail transport as a primary mode of transportation. To achieve this, however, we clearly need to move away from a prescriptive approach of legislating permitted solutions and move toward an underspecified goals oriented approach. In our research we found out that all the problem listed by us at the beginning (pollution, overcrowding, accessibility, lack of recreational space, facilities for the elderly and the community) are all interrelated and could be solved better if treated together than separately one by one.

Figure 2. Green wall (Justyna Karakiewicz).

We proposed a "green wall" as a three-dimensional air filter in which sport activities can take place, with transpiration from the plants in the wall and channelled airflow inducing breezes and lower temperatures in the surrounding area. Thus, the proposal not only contributed to improved air quality entering the urban structure, but also managed to provide much needed recreational space. A station should not be conceived as a container, but rather as a heart of the district that allows other parts of the city to grow. And even if the station as an object is design parametrically, it is still an object without any or very little possibility to influence wider area. In order to work as a heart of the district the station cannot be just simply a transit location, a point for processing people through and away from the station as soon as possible. The station as a heart of the district must be conceived as a destination in itself, the point for community interaction.

3. The Melbourne experience

In 2009 we decided to deal with the similar problem in a different location. The station has been proposed by government as part of new 17 km. Metro tunnel to link the growing western suburbs to the city and providing increase in capacity of the railway network. At the edge of the CBD, the station is

intended to link three separate communities: the university, adjacent hospitals, residential and commercial precincts. Focusing most narrowly on station functions, the opportunities for breaking barriers have been ignored.

Although our conceptual framework remains the same, however the site could not be more different than one in Hong Kong. In Hong Kong we were dealing with extreme densities at many levels: extreme plot ratio, extreme pedestrian densities, extreme residential density, and extreme vehicle densities at the road level. In Melbourne it is the other extreme; residential, pedestrian, and built form densities in Melbourne are extremely low. Introduction of some extra densities to the site in form of residential, commercial or even recreational facilities maybe useful, but how do we make sure that intensification will be beneficial to the area and not only to running of the train station?

Higher densities and compact developments can promote casual, unstructured interactions, but in the same time they can also create barriers and exclude possibility of interactions with outside. Hillier (1989) believes that spatial organisation plays very important role on the way people move through the space and interact with each other. Spatial form can either promote or discourage interactions so how do we create a form that can promote interaction, dismantle the barriers and create an urban system which can learn?

3.1. THE APPROACH

Our studio was divided into three parts: precedent study of Melbourne railway stations; site analysis from systems thinking point of view; designing and testing the system. The first step was to analyse four precedents within the Metro area. All four stations are very different and operate in different ways although their location is always at the edge of the city grid and therefore one could assume that their performance will be much the same. Students were asked to look at the stations through systems thinking and define the following: the system itself, its boundaries, the main elements of the system, and the rules which determine system survival. This exercise led to findings that some of the station operates very much as closed systems, having very little impact on the surrounding areas and closure of the station may cause some inconvenience but the larger area around the station will not be affected.

Complex adaptive systems exist by absorbing energy from outside environment through the system boundary. This energy is used to maintain the system. The system also needs to get rid of energy that is no longer desired or have negative effect on sustainability of the system. Therefore the boundaries of the system need to be flexible and porous enough that this process needs to be maintained. This process will hopefully will allow the system to adapt to changes and therefore allow it to learn. Students had to define environment

and parts of the system which will have most impact to maintain system life by interacting with bigger system.

3.2. THE PROPOSALS

One student decided early on to increase the catchment area to redefine the boundary of the system (figure 3). A quick exercise of the catchment area within a 5 minute walk illustrated that the catchment area diminishes from 502,654m^2 to 177,205m^2. Further analysis showed that existing land uses around the station determine a predominantly health precinct employees (over 15,000) and the sizeable student population (approximately 35,000). This population is split geographically by a major road and the largest catchment population will also be absent for during non-teaching periods (up to 5 months of the year). The proposed catchment area also includes predominantly day-time activities suggesting that the potential catchment population will not support the operation of train services into the evening. Some parametric testing led students to believe that proposed location for the new station may not be the best for its successful operation.

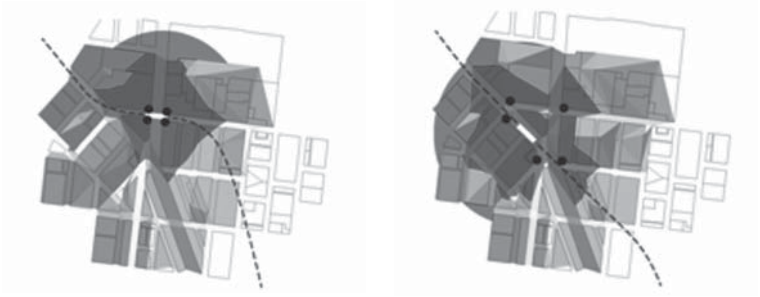

Figure 3. Station catchment analysis (Leanne Hadyl).

Second project (figure 4) applied Digital Project and Vonoroi diagrams for neighbourhood analysis and then design and a third (fig 5) identified that location of the tunnel and station platforms 50 m below the street level opens up opportunities for intensification not only above the ground but also below the ground level. The proposal used swarm analysis to define the location and role of the attractors. The system responded to the changes not only associated with immediate site but also with most of the stations and their surroundings in bigger part of the city.

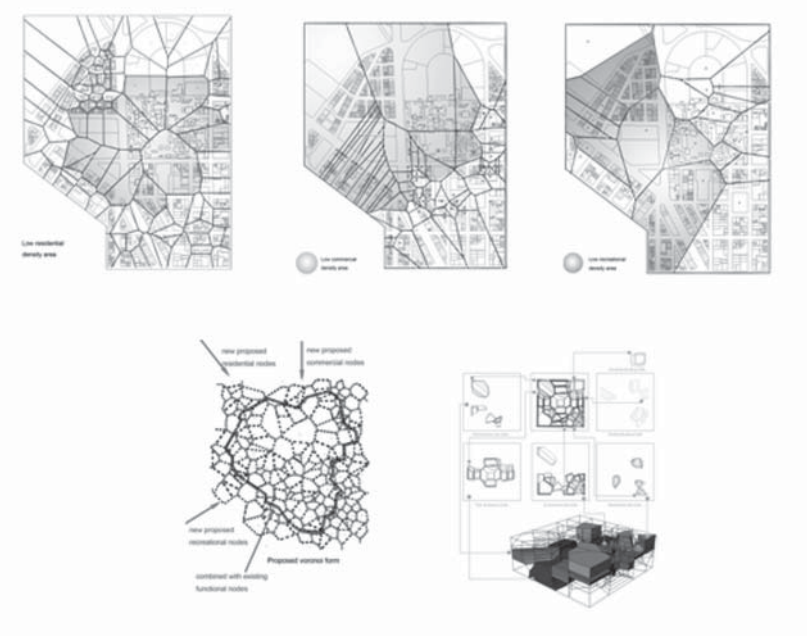

Figure 4. Voronoi mapping and diagramming (Zhao Fei, Yan Jun).

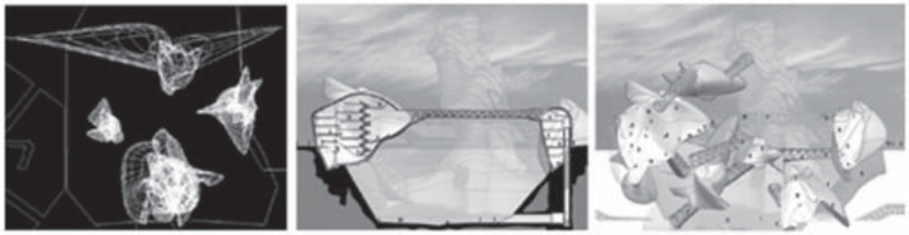

Figure 5. Swarm station (Alex Wilson).

4. Discussion

Students demonstrated a capacity for abstraction and diagramming techniques using these tools (Portugali and Hanken, 1992), not only form making. We found that one of the biggest problems was students' understanding of parametric implications and defining relationships that could guide their design beyond a literal mapping, in other words seeing beyond what they have been taught in their digital media classes. Hong Kong experience showed us that driving skill acquisition through design purpose was effective. It allows students to test what they learn in digital media class through their design. Therefore the knowledge that they gained is reinforced through experience. Also the possibility to test design ideas through pushing conceptual underpinning of computational ability can go much further. The parametric systems brought

out the diagrammatic nature of data and students acquired capacity to sketch through data and parametric relationships. The approach worked in very different contexts of density, culture and institution. Most importantly, students learned that parametric systems can be applied to diagramming, not only form making or BIM modeling.

Acknowledgements

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References

Arida, A.: 2002, *Quantum city,* Architectural Press, London, UK.
Castells, M.: 1996, *The rise of the network society* (*The information age: economy, society and culture*, volume 1), Blackwell Publishers, Malden, MA.
Cuthbert, A. R.: 2003, *Designing cities: critical readings in urban design*, Blackwell, Oxford
Hillier, B.: 1989, *The social logic of space,* Cambridge University Press.
Kelly, K.: 1994, *Out of control: the new biology of machines, social systems and the economic world,* London: FourthEstate.
Pask, G.: 1962, *An approach to cybernetics,* Harper.
Portugali, J. and Haken, H.: 1992, Synergetics and cognitive maps: geography in environment and cognition, *Geoforum*, **23**(2), 111–130.
Rotheroe, K.: 2002, A vision for parametric design, *Architecture week,* 10 July <http://www.architectureweek.com/2002/0710/tools_1-1.html> (accessed 13 November 2009).
Schön, D.: 1984, Problems, frames and perspectives in designing, *Design studies*, **5**(3), 132–136.
Shakespeare, W.: 1985, *Coriolanus,* T. Parr (ed.), Macmillan, London.
Sharpe, C.: 2008, Parametric urban design software explained, <http://www.ecademy.com/node.php?id=116421>.
Sorkin, M.: 1996, *Local code: the constitution of a city at 42^{o} N latitude,* Princeton Architectural Press.
Wootton, B: 2004, Cities as complex adaptive systems, <http://www.generation5.org/content/2004/complexCities.asp> (accessed 13 November 2009).

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SUPPORTING 3D CITY MODELLING, COLLABORATION AND MAINTENANCE THROUGH AN OPEN-SOURCE REVISION CONTROL SYSTEM

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Abstract. The creation of a 3D city model is usually a very time-consuming process and due to the constant development of the city it also has to be updated accordingly. One of the problems with large 3D city models is that they contain a huge amount of data that has to be stored and processed when it is used. The storage and management of the models are therefore a very important issue. The management issue is often that many people are collaborating and working on the 3D city model at the same time and are located at physically different locations. In this paper we present an application for collaboration, maintenance and storing of 3D city models using an open-source subversion controlled system. It is a client server based with a file-based structure on the client side. This system is not as complex as the Oracle database and is not limited to a specific file format. We have integrated the revision control system into our VR application but it is also possible to have external revision control using a default file manager, such as Explorer in Microsoft Windows. The system has been tested in three different virtual reality projects, all applied to urban planning.

Keywords. Collaboration; 3D city modelling; management; visualisation; virtual reality.

1. Introduction

3D models of cities are more and more common and are often used in urban planning, building design, virtual reality and virtual tourism, etc. (Horne et al., 2007). In urban planning and building design there are communication difficulties between planning authorities and designers and this problem leads to uncertainty and lack of consistency in the design process, according to Hall

(1996). This may be the main reason why VR is more and more used in urban planning and building design (Greenwood et al., 2008; Horne et al., 2007; Kjems, 2005). VR is a good communication tool that allows different actors in the planning process to understand the project and hopefully each other better. This gives them better opportunities to identify and analyze problems and also to coordinate the project together in order to improve their decision making and thereby the final built environment and the drive for a sustainable city.

The development of 3D models of the city and effective 3D visualisation tools such as VR, that assist planners and decision makers, is of importance for improving the quality of building design and sustainable urban planning as well as ensuring effective communication with the general public. The creation of a 3D city model is usually a very time- and cost-consuming process (Jobst and Döllner, 2008; Lubanski, 2007), and due to the constant development of the city it also has to be updated accordingly. One of the problems with large 3D city models is that they contain a huge amount of data that has to be stored and processed when it is used. The data is often aerial photos, façade photos, geometry of the terrain and buildings. The storage and management of the models are therefore a very important issue. The management issue is often that many people are collaborating and working on the 3D city model on the same time and are located at physically different locations. One solution to the collaboration problem is to use external reference and split the model into different parts or work sets. But this gives management issues: Where is the model stored? What is the latest version? Who changed or created that part of the city? These issues also have a tendency to become even worse during the deadline rush of a project as more people are assigned to and working in the project.

The CityGML file format tries to be a 3D city model standard and by connecting it to an Oracle database it is possible to get a version-controlled system for management of the 3D city model (Kolbe et al., 2009; Stadler et al., 2009). However, this type of system sets high demands on the end user such as high cost and high level of knowledge expertise in the field. The setback with CityGML is that it is text-based and fairly complex to implement. It uses an XML schema, and for that reason the files get very large in size (Curtis 2008; Stadler et al., 2009). The processing of data from a 3D city model in a Oracle database takes a very long time and it is therefore not the best solution when different users are working towards a deadline and in daily work. In this paper we present another solution for collaboration, maintenance and storing of 3D city models by using an open-source subversion-controlled system called TortoiseSVN (Küng et al., 2009). This system is not as complex as the Oracle database and is not limited to a specific file format. It is a client server based

system with a file-based structure on the client side which gives the user the possibility to have external revision control using a default file manager, such as Explorer in Microsoft Windows.

1.1 THE CONSTRUCTION OF 3D CITY MODELS

Today most of the geographic information about the city is created from using GPS and airborne laser scanning or aerial photos. The aerial photos can be used with a technique called stereophotogrammetry which makes it possible to estimate the three-dimensional coordinates of points on an object. The result from these techniques gives a spatial data model that contains the three-dimensional space of the city. This data is often integrated into GIS applications that often are used for a more large-scale or macro usage of the data. The result from these types of data is often 2D maps or processed images of different analyses. New technologies such as Pictometry (Wang, Schultz, and Giuffrida, 2008) use semi-automatic image processing for applying façade photography on 3D buildings in the 3D city model. The façade photography is taken from airplanes and helicopters and is a fast way to process and construct large areas of the city. The limitation with the technique is the resolution of the photographs. These types of 3D city models works excellently when the viewer of the VR model is located about 150 meters away from the façade texture. However, if the 3D city model is used in a VR application in a context of urban planning and building design the important part is to capture the experience from a pedestrian point of view. In this case the mentioned technique lacks in resolution and looks blurred and diffuse. The façade texture is particularly important because it provides visual cues for orientation and determining the scale of the model and for obtaining an accurate sense of motion in VR applications. The Pictometry textured model works great when the viewer is a distance away from the façade. In our projects when we have used Pictometry textured model we have replaced the façade textures close to where the viewer is supposed to be viewing the model with more detailed façade textures.

In urban planning and building design projects it is very common that creation of new and modification of existing 3D environments have to be done. The creation and modification of these 3D environments often ends up with hands-on modelling where different 3D artists or users have to collaborate and work on the same 3D model.

1.2. COLLABORATION AND MAINTENANCE

The collaboration and management issue appears often when many people are

trying to collaborate and work on the same 3D city model at the same time and the users could even be located physically at different locations around the world. One common solution to this type of collaboration problem is to use external reference and split the model into different parts or files that later have to be joined together. The external references or files have to be shared between the different users by using email or ftp. This process could be problematic and give administrative problems such as: Where is the model stored? What is the latest version? Who changed or created that part of the city? Have you sent me the latest model? This type of process is very sensitive when people are absent or are not able to answer the requests from the other users. The outcome from such process is unnecessary delay and wasted time for different users. These issues also have a tendency to become even worse during the deadline rush of a project as more people are assigned to and working in the project. In software development projects they are solving this type of issues by using a version control system.

2. Subversion (SVN) as version control system for 3D city models

Version control system, such as SVN (Collins-Sussman et al., 2007), were initially created for software development when different users are collaborating on projects that consist of line-based text files, such as program source code. In the source code projects the users are collaborating by using a *"copy-modify-merge"* approach. This means that the users have a local copy of the source code on the local computer and when changes have been done they *merge* or *check in* the changes to the server version of the project. This type of approach works great with a line-based text file but does not work when the files consist of binary data. The binary datasets are much more difficult or impossible to trace changes in. The mentioned approach could be used when it comes to text-based 3D file formats such as VRML or CityGML. However, there could be problems due to the fact that the 3D software could re-order the information in the file during usage and as mentioned before this type of text based files could become huge and therefore could take very long time to *"copy-modify-merge"* in the version control system.

The most common way for working with binary data files in version control system are the *"lock-modify-unlock"* approach. The guideline for this approach is that only one user is allowed to change or work on a specific file at a time. This is accomplished by the users by *locking* the specific file before modifying and *unlocking* the file then the user is finished modifying it. The outcome from this is that the other users only have *read-only* access to the file during the locking and modifying phase. The downfall with this approach is that the user could forget to unlock the file and therefore cause

administrative problems such as unnecessary delay and wasted time for other users. The locking approach can also cause unnecessary serialisation of the creation process of the 3D model. However, this can be solved by separating the 3D model or project into multiple files. If the user forgets to *unlock* the file, another user can use the *force unlock* command to solve this problem. However, when this happens the users are taking responsibility over the version control of the file.

Another interesting feature in the SVN system is that the administrators for the SVN server could give different users different access and authorisations for different files or sub-file directories. What this means in reality is that the 3D city model could be split up into different users or user groups with different access levels. The access could be either read-only or read/write or no access at all to certain part of the files or sub-directories. If this tool is applied on a 3D model, which is split up into different external references or files, the access control could be achieved on different sub-files or sub-areas of the 3D city model. By creating user-groups that are specific for different project and sub-area of the 3D city model a similar *"PlanningManager"* as described by Gröger et al. (2005) could be implemented. However, in comparison, Gröger et al. (2005) used CityGML and an Oracle database for this purpose.

All the above mentioned features in the SVN system are possible to use in Microsoft Windows file manager. The next section describes our approach to integrate SVN tools into a VR application that handles the editing and version controls of the 3D city model.

2.1. IMPLEMENTATION

Our aim with this study was to try to find a way for different users to collaborate in the same 3D city model. The issue with huge 3D city models is the amount of data that has to be processed by the computer. Our system is arranged in a hierarchical structure with multi-resolution of textures and geometries of the terrain. Handling textures of arbitrary size is done by splitting the aerial photos into smaller sub-textures, each sub-texture being small enough to be displayable by the graphics hardware. The geometry is cut and simplified against the sub-texture boundary. A paging system is used in combination with a level-of-detail system to makes it possible to render huge terrains or 3D city models that exceed the graphic memory. The editing of the 3D city models has been solved by using the above mentioned database with sub-files and sub-directories for different areas of the model. Each sub-area is arranged into sub-directories that contains sub-files with files for different level of details for the area(see figure 1).

The user interface for editing the 3D city model is created in a way that the

user has to load the sub-area of the model. The main reason for this is to make it possible to load the sub-area of the model that is small enough to be editable and displayable by the computer hardware. The interface for loading the sub-area is through an *"*area-palette*"* were the users choosing what sub-areas

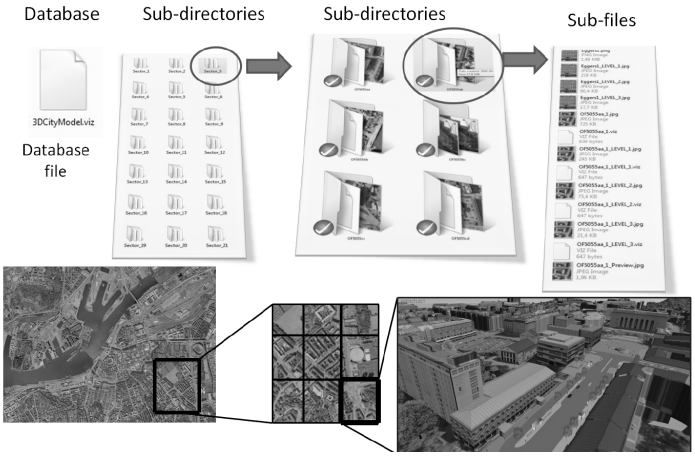

Figure 1. The 3D city model has been cut up into sub-areas. Each sub-area is arranged into sub-directories and sub-files as described in the figure.

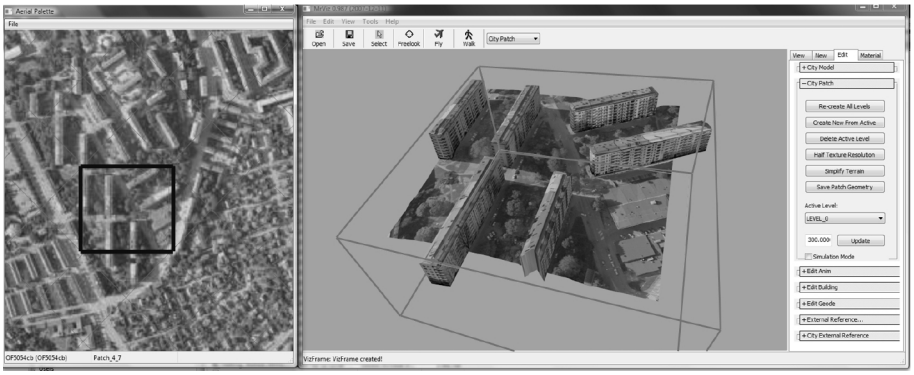

Figure 2. From the "area-palette" the users are choosing what sub-areas to load and edit.

to load and edit.

As the database used in our software for 3D city models is essentially a number of external references stored on disk, it is very well suited for use with SVN. The next section describes our integration of SVN.

2.1.1. Integration of SVN

The implementation of SVN support was integrated into our software MrViz. This was done mainly because we wanted to create a semi-automatic user-

friendly interface to the SVN system. The main framework for the version control system of the SVN was implemented in the area-palette. When the user loads a sub-area of the model, the implemented SVN framework looks for updates at the server and if anyone else is working on that specific sub-area of the model the user get a message that there is limited read-only access. If the user gets read/write access, the sub-area from the server and its sub-files

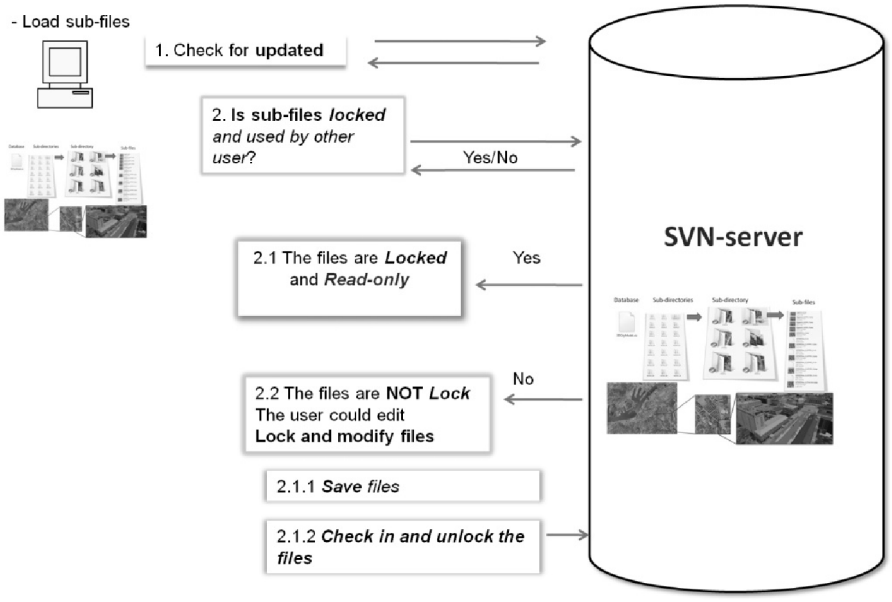

Figure 3. In the "area-palette" in MrViz a semi-automatic interface to the SVN system is implemented and the system is checking for updates and if anyone else is working on the same specific sub-area of the model that the user wants to load.

get *locked* by the user which gives limited write access for the other users.

If another user is working on the sub-area the user could send a message and ask if it is possible for the other user to unlock area. If the other user has forgotten to unlock the sub-area the user could *force unlock* but if he is doing this the users taking over the responsibility over the version control of the specific sub-area and files.

We first started using the SVN as external revision control using a default file manager, Explorer in Microsoft Windows. However, this approach is setting higher demands on the end uses. This was the main reason why we further implemented a semi-automatic user-friendly interface to the SVN system. Our implementation has been tested in three different Virtual reality projects all applied to urban planning (for more details see table 1). The size for the different 3D city models was about 8 × 8km. The most common editing

activity during the projects was the applying of façade textures on the building geometries. The average file size for the geometry files was 0.3 Mb and for the façade photos about 0.76 Mb. The final database size for the SVN server for Project 2 was about 2 Gb.

Figure 4. The figure show one of our test models that have been built using the implemented SVN-framework. Top image: Shows the user-interface for editing of the sub-areas through the area-palette. Bottom image: The final result when the 3D city model is viewed with a paging-database. The paging-database makes it possible to view huge3D city models.

Only the most detailed level-of-detail of the sub-area and its files was added and processed in the version control system. For example Project 2 had an actual total file size of 3.16 Gb if the complete level-of-detail system was considered. As the statistics in Table 1 show, the implemented SVN framework was very useful during the deadline rush of the projects when it came to handling many updates and number of versions of the model. The statistics also show the large amount of individual files that typically have to be managed when large urban 3D-models are considered. If this has to be per-

formed manually, the management itself easily becomes an issue. Compared to our previous approach, using external references stored locally, less time was spent on collaboration and management issues as the current state of the complete model is managed at a single location.

Table 1. SVN statistics from the three test projects.

Project statistics	**Project 1**	**Project 2**	**Project 3**
Duration (week)	27	91	5
Number of users	4	5	3
Number of files	2886	4186	1040
Number of file changes	5509	6527	2280
3D model in file size *(in the SVN Database)* (Gb)	1.17	1.62	0.451
Number of *versions* during project	256	406	156
Deadline rush statistics			
Max number of *versions* updated during *one day*	76	64	54
Number of *files changed* during *one day*	331	302	263

3. Conclusions and future work

In this paper we have presented a simple and efficient approach for multi-user management of large 3D city models. The solution is based on the open-source version control system Subversion (SVN). This system is not as expensive or complex as the Oracle database and it is not limited to a specific file format.

In order to make the implementation more user-friendly we have integrated the version control system into our VR application MrViz. However, it is still possible to use the power of SVN manually. The only requirement is that the 3D model in focus be represented as a number of external references. Given this, the version control system can be managed through Windows Explorer, for example. As such, it can be implemented for any type of project where multiple users are working on the same dataset together. Although the manual approach puts more responsibility on the actual users, it is still effective and helpful in order to have global revision control of a large dataset.

The system has been tested in three different Virtual reality projects, all related to urban planning. Compared to our previous approach, using external references stored locally, less time was spent on collaboration and management issues as the current state of the complete dataset is managed at a single location.

For future work we would like to utilise the functionality of giving different access and authorisations to different users and test how this would work in practice. In a certain way this would be similar to the “PlanningManager”

as described by Gröger et al. (2005), but with the use of Subversion instead of an Oracle database.

References

Curtis, E.: 2008, Serving CityGML via web feature services in the OGCWeb services – Phase 4 testbed, *Advances in 3D geoinformation systems,* Springer, Berlin, 331–340.

Collins-Sussman, B., Fitzpatrick, B. W. and Pilato, C. M.: 2007, available from: Version control with subversion <http://svnbook.red-bean.com/> (accessed 12 November 2009).

Greenwood, D., Horne M., Thompson E. M., Allwood, C. M., Wernemyr, C. and Westerdahl B.: 2008, Strategic perspectives on the use of virtual reality within the building industries of four countries, *Architectural engineering and design management,* **4**(2) , 85–98.

Gröger, G., Kolbe, T. H., Schmittwilken, J., Stroh, V. and Plümer, L.: 2005, Integrating versions, history and levels-of-detail within a 3D geodatabase, *Proc. of int. workshop on next generation city models,* EuroSDR publications, Bonn.

Horne, M., Thompson E., and Podevyn, M.: 2007, An overview of virtual city modelling: emerging organisational issues, *CUPUM07, 10th international conference on computers in urban planning and urban management,* Iguassu Falls, Brazil.

Jobst M. and Döllner J.: 2008, 3D city model visualization with cartography-oriented design, *REAL CORP 008 Proceedings,* Tagungsband, Vienna.

Kjems, E,: 2005, VR applications in an architectural competition: case: house of music in Aalborg, *I realitat virtual a l'arquitectura i la construcció: Taller 2,* Barcelona, Khora ll, 47–58.

Kolbe T. H., Knig G., Nagel, C. and Stadler, A.:2009, *3D-geo-database for citygml, version 2.0.1,* Institute for Geodesy and Geoinformation Science, Technische Universität Berlin.

Küng, S., Large, S. and Onken, L.: 2009, available from: Tortoisesvn Project home <http://tortoisesvn.tigris.org/> (accessed 12 November 2009).

Lubanski, O.: 2007, Raummodelle: Vergleich real analoger und virtuell digitaler Modelle aus der Landschaftsarchitektur und dem Städtebau, Thesis at the University of Natural Resources and Applied Life Sciences in Vienna.

Stadler, A., Nagel, C., König, G. and Kolbe, T. H.: 2009, Making interoperability persistent: a 3D geo database based on CityGML, *3D geo-information sciences,* Springer Berlin Heidelberg, 175–192.

Wang, Y., Schultz, S. and Giuffrida, F.: 2008, Pictometry's proprietary airborne digital imaging system and its application in 3D city modelling, *The international archives of the photogrammetry, remote sensing and spatial information sciences,* **37**, Part B1, Beijing, 1065–1070.

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COMPUTATIONAL FLUID DYNAMICS FOR URBAN DESIGN

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Abstract. Computational fluid dynamics (CFD) is a method of solving and analysing problems that involved fluid flows. In the field of architecture, urban design and urban planning, CFD is useful for the analysis of ventilation and airflow in the built environment, especially in very dense cities. This paper will look into the possibility of making CFD more accessible to the general design and planning field. A simulation is done on a urban design proposal to quickly see how air flow behaves around it. From there, it looks into the future where technology will make CFD simulation more easily adopted and the possibilities of integrating the ventilation analysis with other environmental analysis results into the urban design arena.

Keywords. Computational fluid dynamics; sustainability; high density; urban design; airflow.

1. Introduction

Today, compact and high-density environments are often advocated to accommodate more people in urban cores to prevent urban sprawl as well as wasteful use of land and natural resources. However, such environments do generate high levels of heat and consequently require more energy for artificial lighting and air-conditioning to make the spaces conducive and comfortable for work as well as living. Therefore, efficient urban design and planning is required to overcome these concerns.

Traditionally, land use planning addresses urban functional and intensity issues through two-dimensional zoning approaches. In dense urban areas where urban form and cityscapes are important concerns, such land uses are

simulated in urban designs and then translated to planning guidelines that establish the relationship of form, mass, space and function, particularly as they affect the quality of living environment for inhabitants. However, issues such as air stagnation and airflow in the immediate context are usually not analysed at this stage, and very often, this is left to designers at the architecture/building design stage to assess the need for ventilation design interventions at the final stage, particularly where this has an impact on the assessment rating for sustainable designs. We propose that CFD can be done at the urban design stage at a bigger scale as shown in figure 1.

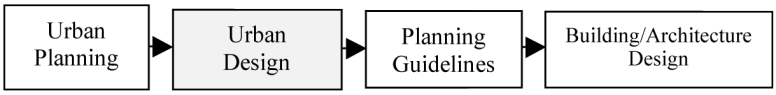

Figure 1. Planning and design process.

Today, sustainability has become a major concern in urban areas as energy consumption, excessive waste and pollution are threatening the resource equilibrium of the world. Issues such as urban heat islands, overcrowding, traffic congestion, uncomfortable pedestrian spaces and inadequate open spaces are resulting in deteriorating living and working conditions which affect human health and wellbeing.

One of the ways to mitigate high energy consumption is to plan and design urban spaces with due regard to existing ventilation patterns and heat concentration of the specific urban area. This can be done by appropriate studies at the urban design stage, using computational fluid dynamics (CFD), a technique pioneered by Harvard Lomax (Lomax et al., 2002). The technique can be used to analyse prevailing wind direction and speed as well as heat radiation patterns. It is particularly useful in high-density and high-rise contexts where the built environment has extensively altered the natural ventilation of the space.

1.1. OBJECTIVE

The aim of this paper is to look at making CFD more accessible to the planning and design practice as well as the architectural, urban planning and design researchers. At this stage, CFD is still beyond the reach for many, and at the university level, it is mostly offered on a shared platform between the academic and research community like our university's High Performance Computing (HPC). The problem with this situation is that there is usually a contention for the simulation facility, with queuing time taking away valuable research time.

The platform running in the HPC is in both Linux and UNIX mode. Most of the application software that is currently being used in the computer -aided

architectural design (CAAD) world is running on either the Windows or Macintosh platform. This is a major incompatibility issue that makes it difficult to integrate to the workflow. Apart from that, most commands are inputted line by line without a graphical user interface (GUI). This makes it very tedious for designers who are used to operating on GUI mode. Even if the more traditional approach of using wind tunnels is resorted to, investment is required in terms of the space and physical facilities required, which again poses a problem when space and funding resources are constrained.

Therefore, CFD analysis is not commonly done in design, let alone at the earlier planning and urban design stages. Den Hartog et al. (2009) highlighted that CFD will provide architects with insights into the effects of unusual architectural forms on the climate to give clues on potential building services problems. Architects can plan their designs efficiently just by analysing these results, especially in the initial stages, if they can understand the general patterns of the airflow.

Many researchers or practitioners in the field often sub-contract the CFD simulation work to consultants or specialists. However, this usually takes too much time and does not allow for interactive responses given that design is always evolving according to many factors. There have been intentions to integrate it into the design studios but the results were not satisfactory (Tsou, 1998; Tsou et al., 2001a). Today, we are living in an exciting time as the technology has reached a stage where local desktops and workstations are starting to be able to do some degree of complicated simulations which a few years ago remained in the realm of supercomputing. This opens up new opportunities to consider the integration of CFD simulation at the earlier stages of the planning and design processes.

Our main research focuses on the density thresholds of urban environments and their corresponding environmental factors. As mentioned, CFD is one of the parameters we look into to assess good ventilation for the urbanscape. In other words, we propose to improve the urban design parametrically, with regard to building intensities, heights, forms and other morphological attributes, based on the environmental analysis inputs. Malkawi et al. (2005) had done similar work in this regard by getting the form generation to respond to CFD analysis results. There are also other researchers who already try to combine it with other environmental parameters, for example, energy with CFD simulation (Zhai and Chen, 2003), solar with wind (Capeluto et al., 2003) as well as various physical parameters (Murakami, 2006).

2. Related works

CFD simulations have been done for both outdoor and indoor environments. In both cases, the aim is to understand airflow so that heat gain can be minimised and to generate good cross ventilation. In the indoor environment, CFD is used for analysis to design for efficient ventilation system management (Somarathne et al., 2005) and ventilation systems for damage control (Steeman et al., 2009). In the outdoor environment, CFD has been used to look at the effects of heat gain from material, air-conditioning condensers and building geometry in the urban environment (Priyadarsini et al., 2008; Priyadarsini and Wong, 2005). We intend to look into the effects of CFD in the indoor environment as well as the effects of materials and air conditioning condensers when we proceed further into the research at a later stage.

Research has validated that CFD results are quite reliable by comparing with wind tunnel and site measurement results, although there are some differences under strong and mild wind conditions (Yoshie et al., 2007). Tominaga et al. (2008) did the same validations and found CFD techniques particularly useful for predicting wind environments in pedestrian areas.

With regard to our research, which focuses on high rise and high density environments, there are many strategies to plan and design well for good ventilation and airflow. These include façade design and articulations, window vent size, shape and location, envelope insulation, balcony provision, natural ventilation, centralised heating and cooling systems, building material selection and micro-environment design (Niu, 2004). In addition, building height response to heat (Takahashi, 2004), good city planning incorporating air paths (Ng, 2008a), smart building orientation in regard to prevailing wind (Ng, 2008b) will help to improve ventilation.

Still, most of the CFD results are done in two-dimensional mode and lack visualisation of how the air flow pattern looks like in 3D. We aim at doing three-dimensional CFD simulations to give a more complete picture since air flows are volumetric and three-dimensional. Most CFD research is also very independent on other inter-related environmental issues which we intend to address at a later stage of our research.

3. The site

Our site of interest for this initial CFD testing is a planning area situated at Kallang River, as shown in figure 2. It is one of the four growth areas identified in the Singapore Master Plan 2008. It is an inner urban area with a site area of 64 hectares of prime developable land, with the Kallang River running through it. The site is divided into four parts for which different themes have

been identified for their respective developments. The themes are: "Life in The Open," "Life's Beach," "Buzz on the Green" and "A Unique Work–Live Place" (Urban Redevelopment Authority, 2009). We note that all the four themes focus on good outdoor living and recreation. In general, the planning is intended to create local environments that are conducive to outdoor activities and pedestrian linkages. Hence, it is crucial to have good ventilation in and around the site to support these themes. Given Singapore's hot and humid tropical climate, it would be difficult to realise the planning vision to encourage people to want to come out and use the open areas if the air flow is poor.

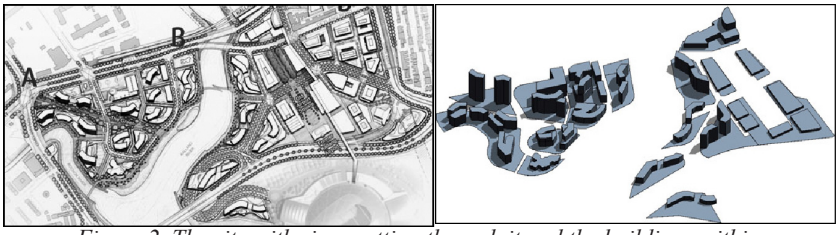

Figure 2. The site with river cutting through it and the buildings within.

The Urban Redevelopment Authority (URA) has already developed a simulated block model for the development area. The proposed plot ratio (floor space ratio) for the site as stated in the master plan ranges from 1.5 to 5.6. By referring to the block model, as well as taking the proposal building footprint and proposed plot ratio, we deduced the height of the buildings, which range from 3 to 36 stories.

4. The CFD process, result and validation

Figure 3 shows the entire CFD process from modeling to virtual reality (VR) visualisation. The CFD simulation requires the usage of solid modelling. There are several types of computer-aided design (CAD) software that do solid modeling, including AutoCAD and Revit Architecture. For the CFD simulation itself, there are a few well-known ones in the market, namely COMSOL Multiphysics as well as ANSYS Fluent and CFX. Since our research has just started, we experiment with COMSOL because it has the educational version, accepts major CAAD formats and far more affordable than ANSYS products. We managed to obtain CEI EnSight, which is the software for post-processing CFD virtual reality visualisation (Monroe et al., 2006) but it was too late to integrate this into the test for this paper.

Solid models have to be meshed (Asfour and Gadi, 2007) and scaled (Srebric et al., 2008) correctly for the simulation, as shown in figure 4. For the initial testing, we use the incompressible Navier–Stokes steady-state analysis

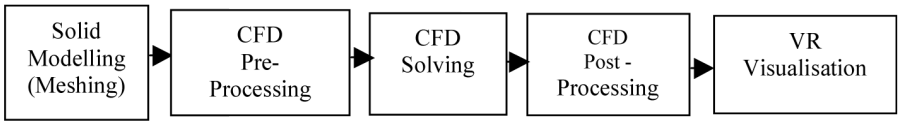

Figure 3. The CFD process.

in 3D, which deals with incompressible isothermal fluid flow. We took four key climatic data for analysis, which are the annual mean temperature, the annual mean wind speed and direction, the air density and its dynamic viscosity of the annual mean temperature. The National Environment Agency provides the average temperature for the area, which is 26.925 degree Celsius, about 300 Kelvin. The air density is 1.184 kg/m^3 and dynamic viscosity is 1.983 x 10^{-5} kg/ms at 300 Kelvin. There are two predominant wind directions from the north-east at 2.4 m/s and south-east at 1.9 m/s. The middle picture shows the site model being contained in a solid cuboid with the correct surface defined to represent the wind direction. The entire scene has to be meshed before CFD solving takes place.

The results of the CFD analysis are shown in figure 5. We can immediately notice that the current urban design highlighted with the square dotted line is creating a space where heat and air flow will be trapped, regardless of whether it is the northeast or southeast wind. We can thus respond with recommendations to alter the initial proposal based on these results so as to improve the ventilation through the site, especially at all the identified problem areas. Various planning and design variations can be generated and further tested.

After that, we did a validation in the HPC supercomputing environment to generate results using ANSYS Fluent as shown in figure 6. It validates the lack of air movement at the same zone. Although it can do much higher resolution airflow analysis in a shorter time, there is much work in constructing the 3D model in ANSYS Gambit (3D modeling tool) to export to Fluent as it does not support most CAAD 3D CAD formats. However, the benefit is more other smaller zones around buildings with stagnant airflow can be identified too because of the higher iterations that can be done in a shorter time.

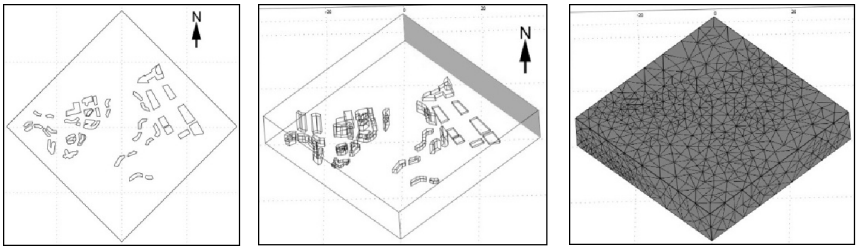

Figure 4. Buildings imported into COMSOL, defining wind direction and meshing.

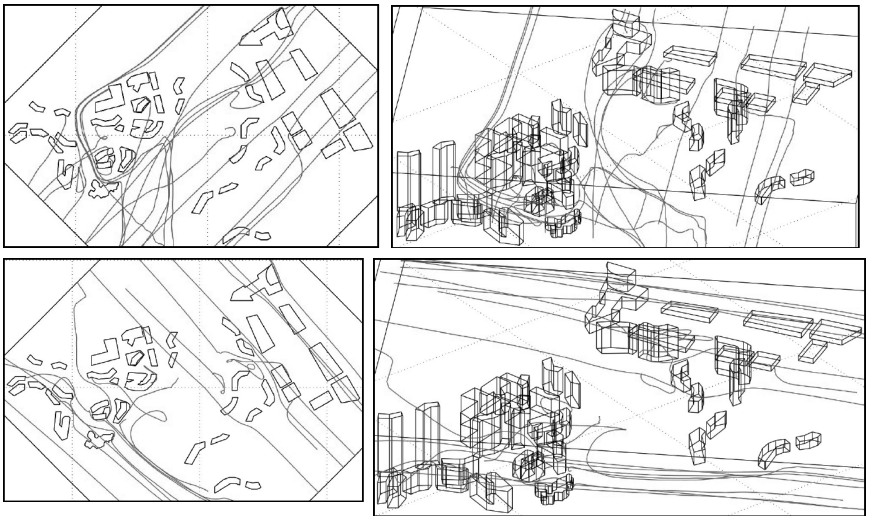

Figure 5. Northeast (above) and southeast (below) wind flow analysis results.

5. Conclusion and future works

Each of the wind direction simulations in COMSOL took about an hour to be completed. This quick process of getting the wind flow is very encouraging and points to the great potential of integrating the process as an integral part of the urban design process. We can already understand the airflow behaviour and improve it at the early stage. Although we can get more accurate results by running more iterations, it is good enough for the conceptual stage. This will be a great improvement from the current process whereby ventilation issues are addressed only at the later architectural design stage when the planning guidelines are already determined.

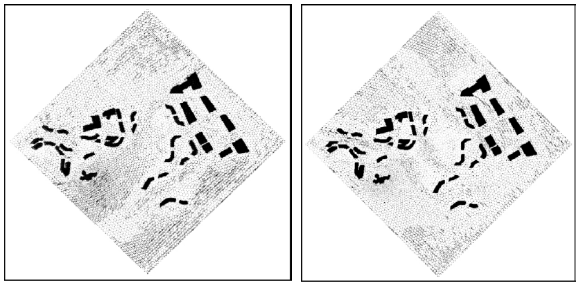

Figure 6. Path lines coloured by velocity magnitude (m/s) of the northeast (left) and southeast (right) wind flow analysis in ANSYS Fluent 6.3. The shorter the lines are, the slower the airflow will be which means the zones are lacking natural ventilation.

Overall, it is getting more affordable, easier and quicker to generate useful results in the local desktops and workstations. Very soon, we will be able to do network CFD simulations in a practice or research work environment just as we do network rendering by harnessing the necessary computing and graphical power.

There are still other factors to test. Firstly, the ANSYS CFD and COMSOL to EnSight connection have to be explored thoroughly. ANSYS has now a framework called Workbench and modelling tool called DesignModeler to support more CAAD 3D CAD formats as well as running on Windows platform too but the license is still too costly. The potential of using VR software for CFD results for a more comprehensive overall visualisation will be explored, especially architects and urban designers are more inclined to view in 3D. They can analyse these results in 3D, propose alternatives and make various decisions before the actual design and implementation processes take place. Then, we need to explore the potentials of Ecotect Analysis' airflow capabilities integration with the National Institute of Standards and Technology's (NIST) Fire Dynamics Simulator and Smokeview (FDS-SMV) as well as EnergyPlus' natural ventilation simulation. Another potential new CFD software to explore is Next Limit Technologies' XFlow which may be faster to implement by using a particle-based, fully Lagrangian approach.

Apart from just measuring wind against urban structures, we would need to take into account more realistic settings where the presence of vehicles and trees canopy cannot be ignored (Mochida and Lun, 2008). We would also need to take into account pollutants, especially from transport (Tsou et al., 2001b), momentum and heat concentrations (Baik et al., 2003). Also, we must have to do the fluid with thermal incompressible flow interaction for transient analysis. With these, we would then be able to get a better overall picture of the airflow with thermal pattern for a sustained period of time (entire day, week, month or year) for the study area. The building facade materials will be taken into account for more realistic CFD simulation (Priyadarsini and Wong, 2005). Finally, the relationship between outdoor and indoor CFD analysis which is lacking in research will be explored too.

Harnessing the combined integration of graphics processing unit (GPU) and CPU power for parallel computing, which is supported by CFD is now a reality. This is the reason that we have equipped our hardware systems with NVIDIA graphics cards. The next step of our research is to connect all the bridges from modeling to VR visualisation of the CFD simulation results by using the CPU and GPU combination processing. NVIDIA Tesla and ATI Stream technology will give more mainstream users the capabilities to produce CFD simulations. The NVIDIA (Compute Unified Device Archi-

tecture) CUDA, which is a general purpose parallel computing architecture that leverages the parallel compute engine in NVIDIA GPUs to solve many complex computational problems in a fraction of the time required on a CPU, is another potential language to embark in to get the fullest potential possible out of the GPUs.

Apart from these, we should not forget about Intel's revelation of Larrabee in the first quarter of 2010. Larrabee, which is a general-purpose computing on graphics processing unit (GPGPU), will be the third competitor in the high performance computing market. Indeed, this is an exciting time where CFD simulations will no longer be in the realm of the inaccessible supercomputers. Finally, testing the simulations in Windows 7 will also be another opportunity to be explored soon. We are keen to experiment with its multi-touch capabilities for VR visualisation.

Acknowledgements

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References

Asfour, O. S. and B. Gadi, M. B.: 2007, A comparison between CFD and network model for predicting wind-driven ventilation in buildings, *Building and environment,* **42**(12), Elsevier, 4079–4085.

Baik, J. J., Kim, J. J. and Fernando, H. J. S.: 2003, A CFD model for simulating urban flow and dispersion, *Journal of applied meteorology,* **42**, 1636–1648.

Capeluto, I. G., Yezioro, A. and Shaviv, E.: 2003, Climatic aspects in urban design: a case study, *Building and environment,* **38**(6), Elsevier, 827–835.

den Hartog, J. P., Koutamanis, A. and Luscuere, P. G.: 2009, Possibilities and limitations of CFD simulation for indoor climate analysis, available from: Repository of Delft University of Technology <http://repository.tudelft.nl/assets/uuid:e06fb7be-e044-4a0d-9682-3aead-af0a947/Koutamanis_2000_2.content.pdf> (accessed 1 November 2009).

Lomax, H., Pulliam, T. H. and Zingg, D. W.: 2002, Fundamentals of computational fluid dynamics, *Structural and multidisciplinary optimization,* **24**(6), Springer, Berlin, 469–470.

Malkawi, A. M., Srinivasan, R. S., Yi, Y. K. and Choudhary, R.: 2005, Decision support and design evolution: integrating genetic algorithms, CFD and visualization, *Automation in construction,* **14**(1), Elsevier, 33–44.

Mochida, A. and Lun, I. Y. F.: 2008, Prediction of wind environment and thermal comfort at pedestrian level in urban area, *Journal of wind engineering and industrial aerodynamics,* **96**(10–11), 1498–1527.

Monroe, L., Stringer, S., Brum, J. and Tomlinson, B.: 2006, Extreme resolution visualization enables new discoveries, available from: Scientific Computing < http://www.scientificcomputing.com/extreme-resolution-visualization.aspx?terms=visualization> (accessed 1 November 2009).

Murakami, S.: 2006, Environmental design of outdoor climate based on CFD, *Fluid dynamics research,* **38**(2–3), Elsevier, 108–126.

Niu, J.-L.: 2004, Some significant environmental issues in high-rise residential building design in urban areas, *Energy and buildings,* **36**(12), Elsevier, 1259–1263.

Ng, E.: 2008a, An investigation into parameters affecting an optimum ventilation design of high density cities, *The International journal of ventilation,* **6**(4), VEETECH, United Kingdom, 349–358.

Ng, E.: 2008b, Policies and technical guidelines for urban planning of high density cities: air ventilation assessment (AVA) of Hong Kong, *Building and environment,* **44**(7), Elsevier, 1478–1488.

Priyadarsini, R. and Wong, N. H.: 2005, Building surfaces and their effect on the urban thermal environment, *Architectural science review,* **48**, 1–12.

Priyadarsini, R., Wong, N. H. and Cheong, K. W. D.: 2008, Microclimatic modeling of the urban thermal environment of Singapore to mitigate urban heat island, *Solar energy,* **82**(8), Elsevier, 727–745.

Somarathne, S., Seymour, M. and Kolokotroni, M.: 2005, Dynamic thermal CFD simulation of a typical office by efficient transient solution methods, *Building and environment,* **40**(7), Elsevier, 887–896.

Srebric, J., Vukovic, V., He, G.-Q. and Yang X.-D.: 2008, CFD boundary conditions for contaminant dispersion, heat transfer and airflow simulations around human occupants in indoor environments, *Building and environment,* **43**(3), Elsevier, 294–303.

Steeman, H. J., Janssens, A., Carmeliet, J. and Paepe, M. D.: 2009, Modelling indoor air and hygrothermal wall interaction in building simulation: comparison between CFD and a well-mixed zonal model, *Building and environment,* **44**(3), Elsevier, 572–583.

Takahashi, K., Yoshida, H., Tanaka, Y., Aotake, N., Wang, F.-L.: 2004, Measurement of thermal environment in Kyoto city and its prediction by CFD simulation, *Energy and buildings,* **36**(8), Elsevier, 771–779.

Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M. and Shirasawa, T.: 2008, AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings, *Journal of wind engineering and industrial aerodynamics,* **96**(10–11), Elsevier, 1749–1761.

Tsou, J.-Y., 1998: Applying computational fluid dynamics to architectural design development: strategy and implementation, *CAADRIA '98 proceedings of the third conference on computer-aided architectural design research in Asia,* Osaka, 133–142.

Tsou, J.-Y., Lam, S. and Hall, T.W.: 2001a, Integrating scientific visualization with studio education: developing design options by applying CFD, *Twenty first annual conference of the association for computer-aided design in architecture,* Buffalo, New York, 302–310.

Tsou, J.-Y., Zhu, Y. and Lam, S.: 2001b, Improving air quality of public transport interchanges: design strategies to integrate CFD simulation in early design process architectural information management, *19th eCAADe Conference,* Helsinki, Finland, 54–59.

Urban Redevelopment Authority: 2009, available from: MASTERPlan 2008 – Kallang River District http://www.ura.gov.sg/MP2008/kallang_riverside.htm (accessed 11 November 2009).

Yoshie, R., Mochida, A., Tominaga, Y., Kataoka, H., Harimoto, K., Nozu, T. and Shirasawa, T.: 2007, Cooperative project for CFD prediction of pedestrian wind environment in the Architectural Institute of Japan, *Journal of wind engineering and industrial aerodynamics,* **95**(9–11), 1551–1578.

Zhai, Z.-Q. and Chen, Q.-Y.: 2003, Solution characters of iterative coupling between energy simulation and CFD programs, *Energy and buildings,* **35**(5), Elsevier, 493–505.

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PLAYING JIGSAW

Finding the underlying structure of assembling ideas within design productive process

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Abstract. Idea generation in design productive process often occurs within brainstorming sessions. Linking ideas is the key mechanism in this process to produce design. Through linking ideas, a graph-like knowledge is representing the individual memories with the nodes and arcs that are the ideas and the links between ideas respectively. Design is the process of puzzle-making, such thinking process is similar to play jigsaw. This research applies a computational tool (called DIM) to produce a graph-like knowledge including diverse jigsaw-like ideas and their relationships. Then we use protocol analysis to understand how designers organise the ideas. The objective is to find the hidden patterns of assembling ideas in the design productive process. Some feasibilities of the game mechanisms are proposed in this paper.

Keywords: design production; linking ideas; graph-like knowledge; protocol analysis; puzzle-making.

1. Introduction

One of important steps in design process is generating ideas. Idea generation in design productive process often occurs within brainstorming sessions with more than two participants involved. Such production of design is often

carried out by two or more members in participation of a group meeting (such as brainstorming) to generate diverse ideas (Goldschmidt 1995). Through assembling the ideas, the assembled ideas can serve as a basis for designers to develop possible conceptual designs for solving a specific design problem.

Linking ideas is the main mechanism during the process of design production. A designer links ideas through his / her individual memory as well as other participants' knowledge which are often graphically linked. Consequently a graph-like knowledge is naturally the representation for representing the individual memories with the nodes and arcs that are the ideas and the association between ideas respectively (Lai and Chang, 2006). To enhance the student's comprehension of design, the graph-like knowledge provides the constructive meaning of design ideas (Oxman, 2004). With its simplicity, this kind of graph-like knowledge is often used in design studio teaching (Goldschmidt, 1995; Oxman, 2004; Lai, 2005).

In addition to the problem-solving model, Archie (1987) believed that design process is also a puzzle-making process. Further, designers often decompose the design into different attributes, and then use specific rules to organise the different attributes in their design spaces. This is similar to putting together the pieces of puzzles to solve the problem. For example, during a process of puzzle-making, a designer often applies the combinational rules to organise different attributes within ideas based on their relationships within the puzzle-like design space for solving problems. Design puzzles (Chang, 2004) map the operation of puzzle games onto specific types of design problems. Among those, the jigsaw is one frequently used design puzzle that can support the purpose of this research. The player will recognise the attributes such as shapes, colors, images from vast amounts of puzzle pieces, and then assemble the puzzle pieces in order to generate a design or a design-like outcome.

2. Design as playing jigsaw

The jigsaw is a kind of puzzle-game. Puzzle-games are a special class of games that will require a player's logical reasoning capability to overcome the obstacle (the puzzle) in order to complete the game (Bates, 2002). For example, "finding a missing information piece" will require players to know the background of the situation and reasoning with the hints in order to solve the puzzle (Chang, 2004). From children's puzzle games, there are basically two kinds of jigsaw-like puzzle games: creative puzzles and traditional puzzles (seen in figure 1).

The goal of traditional puzzles like a normal jigsaw is to assemble the pieces of the puzzle based on the only outcome. Compared to the traditional puzzle, the creative puzzle emphasises open outcomes without limitation on

the final layout of the puzzle. The player will not know the outcome until he / she has completed the puzzle which relies on the hints provided within the puzzle images. Three sequential means to assemble puzzle pieces are as below.

1. **Classification:** grouping the puzzle pieces into several clusters by the hints of the puzzle pieces such as shape, colour or clearly defined images.
2. **Selection:** choosing puzzle pieces with similar hints to assemble a complete image according to the clusters.
3. **Combining:** combining will be conducted when the border and image of the two puzzle pieces match.

Figure1. Creative puzzle (left) and traditional puzzle (right).

Design production focuses on developing diverse conceptual designs for solving a specific design problem. Creative puzzles provide an open-ended process that is close to what the design production process did. Thus we adapt creative puzzles as the metaphor of the design puzzles in this research. Some researchers apply design puzzles as a method to assist students to inspire their designs in the design production process. By using the name of "game," this research tends to focus on the conceptual level of play (Woodbury et al., 2001). Through the playful characteristic of the puzzle, the design is viewed as a playful learning process (Klugman and Smilansky, 1990). Chang (2004) has categorised the elements of the design puzzle into: 'hint,' 'puzzle rules' and 'puzzle goal' which provides a way to describe teaching capability through emphasis in methods of learning through puzzles.

However, the research emphasises the advantage of outcomes of design puzzles (especially jigsaws) in the productive design process. They don't pay attention to the underlying structure of constructive meaning within the assembled puzzle-like design ideas. In addition, due to the limitations of the information processing of the human short-term memory, the completion of the puzzle assemblage cannot be done immediately through classification, selection and combination. Such a situation is similar to the process of

design production. A large number of scattered but related ideas is unable to be effectively linked together for solving design problems. By applying the mechanisms of playing jigsaw, the objective of this research is to find the underlying structure (called hidden patterns) of assembling ideas from a graph-like knowledge in the design production process. Based on the found hidden patterns, some feasibilities of the game mechanisms are proposed.

3. Research tools: DIM and protocol analysis

For finding the underlying structure of assembling ideas via mapping the gaming behaviours of playing jigsaw, one possibility is to observe the behaviours of actual game play. For such an experiment, we need a mapping mechanism and an observation method over the experiment. The mapping mechanism should generate a graph-like knowledge structure which composes a vast amount of ideas (puzzle pieces) and their links (the relationships between puzzle pieces). Thus the DIM (Dynamic Idea Map) proposed by Lai and Chang (2006), which can generate the graph-like knowledge (called *idea map*) of links and nodes, can support the mapping mechanism. Also, protocol analysis can help us to observe and understand design behaviors of assembling ideas in the design production process.

3.1. DIM

In the DIM, an idea map composes of idea entities *(ie)* and three types of linking relationships among idea entities. They are similarity *(SI),* contrast *(CR)* and contingency *(CI)*. Based on the ICF schemata proposed by Oxman (1994), each idea entity includes three attributes. They are issue *(I),* concept *(C)* and form *(F)* which are represented and visualised by keywords, texts and image photos respectively (figure 2). The DIM includes two kinds of components: agent entities and design knowledge. Agent entities are assigned to different sub-tasks that are decomposed from a specific design task. According to different design situations, these agent entities with specific design knowledge collaborate together to generate design ideas and links.

3.2. PROTOCOL ANALYSIS

Protocol analysis is a useful methodology for exploring the understanding of design behaviors (Ericsson and Simon, 1993). Through the process of encoding, recording and data analysis, the design behaviors of designers can be comprehended. Based on the methodology, this research applies think aloud and conceptual sketches to understand design behavior of assembling ideas.

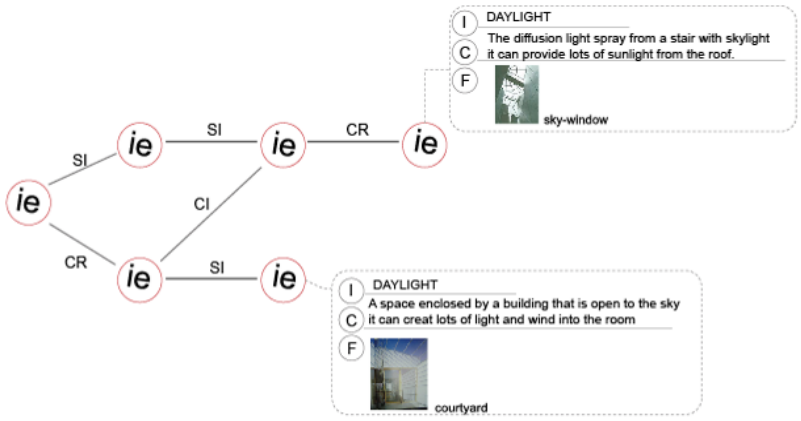


Figure 2. Idea map and ICF (issue, concept and form) representation.

4. Design experiment

In order to understand the puzzle-making process of participants during design, this research conducts an experimental observation on a residential design project. It aims to probe into the structure of the relationship between idea combinations, to observe how participants use DIM as a tool to translate scattered ideas into vast amount of co-related puzzle pieces, and to know the process of forming an integrated image through those image pieces.

The experiment is divided into 2 sessions. The first session discusses the participants' methods in classifying vast amount of information. The same process occurs at the start of puzzle-making when visual searches for distinct features of the pieces. The second session focuses on the process of how participants move forward after classifying information to selecting and organising linked concepts and forms that combine scattered pieces in groups to create idea map. The elements of this experiment are as below:

- **Participants.** Three 3rd-year architecture college students who are equipped with basic architecture training and familiar with the mechanisms of DIM. These students are coded as A, B and C.
- **Design task.** In order to allow the experiment observe directly the thinking transition during designing, the topic is set for simple function on a design project of a residence for two people located by the Tamsui River. How to take the natural lighting is the design problem.
- **Process.** The test is divided into 2 sessions of 45 minutes each. The participant will carry out a DIM experiment warm-up and operation for 30 minutes prior to the test. During the last 15 minutes, he / she needs to draft his / her conceptual sketches whilst thinking aloud. The whole process will be videotaped.

5. Analysis and observations

After the above-mentioned test, a total of 50 design ideas are created by 3 participants within 45 minutes. Through DIM calculation, 29 *SI,* 18 *CR* and 3 *CI* combinations are formed between ICF cards. The DIM map is like the formation of vast amount of puzzle pieces that participants must first find the hidden image fragment and reassemble them to form an integrated image.

5.1. ANALYSIS

Through translation, encoding and information analysis of protocol analysis, the re-assembling of image of forms and concept keywords by the participants leads to the production of new ideas. The experiment discovers that the 3 participants perform similar assembling module in the process of design production. This research takes the design behavior of Participant B as an example in verbal illustration and conceptual sketches.

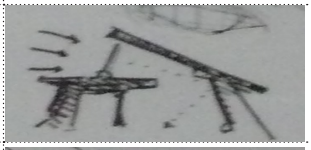
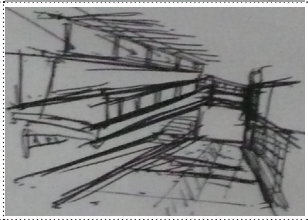
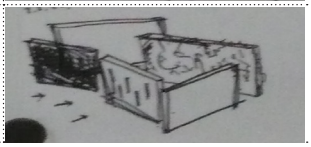
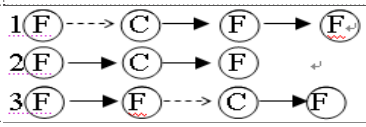
During the first session, each participant is required to select from the ICF database a concept related to the design task, and to place the concept together with the ones selected by the others. In this stage, the link between ICF cards has not yet been established. The observation traces how participants classify and select before graph-like knowledge is created (table 1). It shows that participants produce 3 diverse ideas, and shift from forms to concepts.

During the second session, the participants choose the concept to be applied from the DIM constructed with the linked graph-like knowledge resulted from computation based on 3 principles of similarity *(SI),* contrast *(CR)* and contingency *(CI)*. The participants start their sketches and having their thinking aloud recorded it is to establish the design process in which the organisation concept is similar to the one in puzzle-making (table 2). From table 2, the research presents the process of how participant moves from scattered thoughts towards concentration. It also shows the fragments revealing hidden images, and the image after reassembling.

5.2. OBSERVATIONS

During the first session when the design idea is to be created, the participants will classify forms based on one single key word and image. For example, Participant B selects the image of a slanted roof *(F)* in accordance with personal preference during his / her first design idea, which leads to the finding of keyword in western exposure *(C)*. Further from the slanted roof, it develops the form of sky window *(F)* capable of introducing indirect light *(C)* (table 1, idea 1). The formation of the participant's design is derived after watching the image on the ICF card prior to the search in concept keywords,

Table 1. Protocol analysis in the first session

Idea	Description of idea combination	Sketch
1-1 Idea 1	I would like to add a slant roof on the building, in order to lead indirect light into loft. To avoid facing west of room.	
1-2 Idea 2	At the beginning, I would like to create a linear opening that purpose leading day-light into courtyard. Second, I would put a sky-window on the top in order to create a spray light.	
1-3 Idea 3	This idea is trying to make two volumes embedded with each other. Creating an overhead corridor connected two volume and bringing great view into house.	
1-4 The combination structure of ideas		

followed by going to 2 or 3 more ICF cards before the final decision is made. Similar to the puzzle-making, the eyes will search for a distinct fragment containing more hints. The image leads to the searching of the next piece. But due to the limitation of the short-term memory, the links between concepts are not sufficient. Therefore, the participant develops forms directly from one single concept. Due to the missing links between independent images, fewer combination forms are created, displaying scattered design ideas. The thinking combining pattern is similar to figure 3.

Table 2. Protocol analysis in the second session.

Idea	Description of idea combination	Sketch
2-1 Idea	In this house, the stair is a transitional space that connected loft and second floor. A sky-window on the roof is leading daylight into house that creates a spray light for interior. And I extended a court-yard from second floor with a great view. Then create a corridor to connect another volume.	
2-2 The combination structure of ideas		

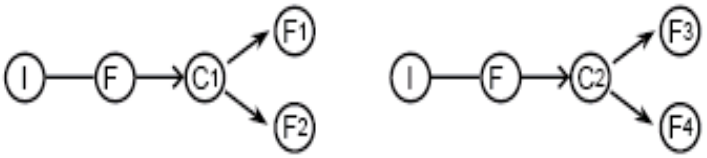


Figure 3. The combining pattern during first stage of the experiment

During the second session, the participants will discover the relationship between concepts through linkage between ICF card given by the calculation results of DIM, providing the participants a platform for continuous correction, displacement, editing and reassembling. Within the participant's thinking pattern, the link between scattered images has begun to form (table 2, 2-1). The idea-linking pattern has shown the extension of ideas from one image *(F)* to concept *(C)* keyword followed by the development of other forms *(F)* of image. During the process of sketching in this stage, the participant create total of 7 forms of image and keywords and 4 key concepts. With convergence, it results in a comparatively more integrated form of production process and unified idea linkage. From analysing table 2, the participants' image organisation formation *(F)* and concept keyword *(C)* can be categorised as the design thinking process of the form of *F-C-F-C-F* (Table 2, 2-2).

6. Hidden patterns of assembling ideas

In the experiment, we can summarise four types of hidden patterns of assembling ideas (seen in figure 4).

- **Pattern 1:** participants first find keywords of concept through the image of form. The linkage of *C1* and *C2* brings out scattered numbers of images of forms *(F1*, *F2*, *F3* and *F4)*. According to the combination of 2 forms *(F1 + F2, F2 + F3,* and *F3 + F4)* to converge the concepts *(C3, C4* and *C5),* the reassembling generates image of forms *(F5, F6)*.
- **Pattern 2:** participants go through the same process as in pattern 1 to find keywords of concept through the image of forms and search for scattered forms through the linkage of *C1* and *C2*. With the different combination of those forms *(F1 + F3* and *F2 + F4),* different concepts *(C3* and *C4)* are produced, which lead to the generation of *F5*.
- **Pattern 3:** participants go through the same process as in pattern 1 to find keywords of concept through the image of forms and search for scattered forms through the linkage of *C1* and *C2*. With the different combination of those forms *(F1 + F2 + F3* and *F2 + F3 + F4),* different concepts *(C3* and *C4)* are produced, which lead to the generation of *F5*.
- **Pattern 4:** participants go through the same process as in pattern 1 to find keywords of concept through the image of forms and search for scattered forms

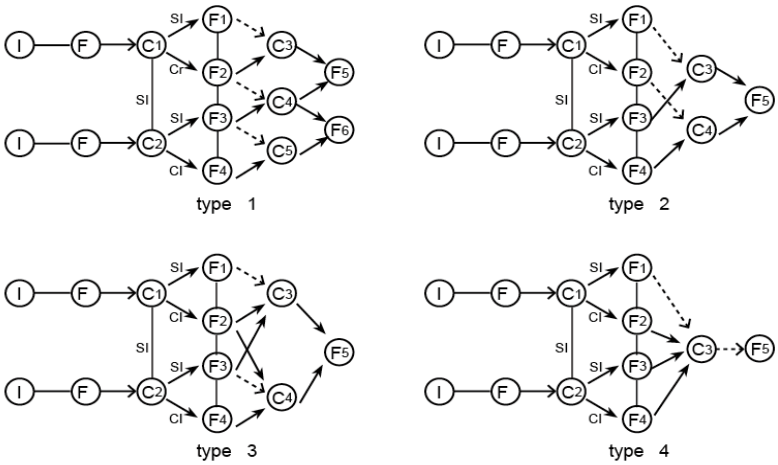


Figure 4. Four types of hidden patterns of assembling ideas.

through the linkage of *C1* and *C2*. With the different combination of those forms *(F1 + F2 + F3 + F4),* different concepts *(C3)* are produced, which lead to the generation of *F5*.

Based on the four patterns of assembling ideas, students can engage in design production, just like putting puzzles together. Such a game mechanism can supports students to reveal the constructive meaning within the graph-like knowledge structure represented by the sequential description integrated with multi-media (figure 5). Besides, it can provide a playful design environment. Three main steps of the game mechanism are:

1. Classifying idea entities based on an issue *(I)* which is a designated design problem in a design task.
2. Selecting idea entities according to preferred values of concept *(C)* or form *(F)*.
3. Combining the idea entities through the linking rules of similarity *(SI)* or contrast *(CR)* between concepts *(C)* or forms *(F)*.

7. Conclusion

In this research, we find that the mechanisms of playing jigsaw provide an effective method to understand the underlying structure of assembling ideas from a graph-like knowledge. Four types of hidden patterns of assembling ideas are found. Based on the ICF representation of an idea entity, issue plays the key role in classifying idea entities. Concept and form are the important attributes for designers to select preferred idea entities. Similarity and contrast links provide rules of combining idea entities. This research will provide an

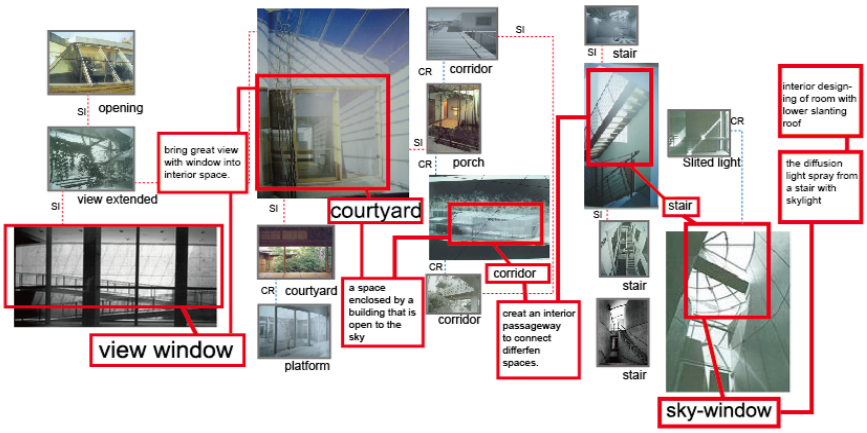


Figure 5. The sequential description integrated with multi-media

essential prerequisite of preparation for supporting design decision in any creative problem solving meeting.

References

Archea, J.: 1987, Puzzle-making: what architects do when no one is looking, *in* Y. Kalay (ed.), *Computability of design,* John Wiley and Sons, 37–52.

Bates, B.: 2002, *Game design: the art and business of creating games,* Premier Press.

Chang, T.-W.: 2004, Supporting design learning with design puzzles, *in* J. P. Van Leeuwen and H. J. P. Timmermans (eds.), *Recent advances in design and decision support systems in architecture and urban planning,* Kluwer Academic Publishers, 293–307.

Ericsson, K. A. and Simon, H. A.: 1993, *Protocol analysis: verbal reports as data,* MIT Press, Cambridge, Mass.

Goldschmidt, G.: 1995, The designer as a team of one, *Design studies,* **16**(2), 189–209.

Klugman, E. and Smilansky, S.: 1990, *Children's play and learning: perspectives and policy implications (early childhood education series),* Teachers College Press.

Lai, I.-C.: 2005, Dynamic idea maps: a framework for linking ideas with cases during brainstorming, *International journal of architectural computing,* **3**(4), 429–447.

Lai, I.-C. and Chang, T.-W.: 2006, A distributed linking system for supporting idea association in the conceptual design stage, *Design studies,* **27**(6), 685–710

Oxman, R. E.: 1994, Precedents in design: a computational model for the organization of precedent knowledge, *Design studies,* **15**(2), pp. 141–157.

Oxman, R. E.: 2004, Think-maps: teaching design thinking in design education, *Design studies,* **25**(1), 63–91.

Woodbury, R. F., Wyeld, T. G., Shannon, S. J., Roberts, I. W., Radford, A., Burry, M., Skates, H., Ham, J., and Datta, S.: 2001, The summer games, *Proceedings of 19th eCAADe,* Helsinki, 293–297.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010,* 381–390. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

STORYTELLING

A computational approach for convergent thinking

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Abstract. Convergent thinking is an important skill in early design process to deal with the complexity and dynamic nature of design. In this research, by exploring the storytelling mechanism as one way to develop an idea generation representation called DIM (Dynamic Idea Map), we investigate characteristics of convergent process during the brainstorming experiments we conducted. A computational platform called Idea Story (Idea as Storytelling) is proposed which produces a narrative and helps generate a meaningful representation.

Keywords. Storytelling; convergent thinking; idea map; design narrative.

1. Introduction

Convergent thinking is an important skill in early design process to deal with the complexity and dynamic nature of design. By assuming that design is organised as different ideas, we turn this problem into representation of organisational strategies over a set of graphs that represents different ideas of a design. Based on the mechanism of DIM (dynamic idea maps) and DARIS (Lai and Chang, 2006), each idea is represented by a group of nodes called idea

entities and linked together to frame a complex map. How can we organise idea entities and make them usable for designers? A computational approach is adopted in this research to support convergent thinking strategy, storytelling, and develop a narrative and meaningful representation.

In real practice, designers often spend more time generating. Generating design solutions requires narrowing down the selection from a pool of ideas generated. Idea convergence in design involves reduction of a large number of ideas to a meaningful range. We use this approach of idea convergence as a way of storytelling in this research.

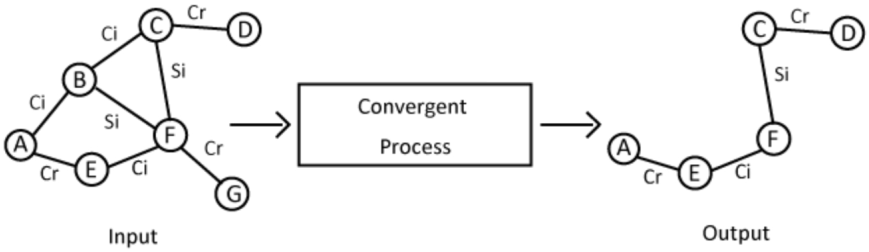


Figure 1. A convergent process over idea entities.

Why storytelling? People like listening to story and stories appeal to people. Stories and design have some similar elements: problem, approach and solution.

We believe that "Idea convergence" will allow us to move from disordered ideas to organised and meaningful sequence (so called "story of design") which is regarded as the final design outcome in the design stage we are interested, and the initiation for other design decision convergences.

The objective of this study is to explore and define a convergent method for idea generation based on the mechanism of storytelling. In order to achieve this goal, experiment and analysis are conducted and described in details in the sections below.

2. Literature reviews

Design convergence is complex in terms of its problem space. Based on the representation and approaches for finding the solution, two main concepts in this research are DIM (for representation) and storytelling (for mechanism).

2.1. DIM

DIM (dynamic idea map) is a way to describe the behaviours and thinking patterns of designers during the brainstorming sessions. The fundamental element of DIM is called idea entity (IE). In addition to the simple ICF

representation (issue, concept and form) adapted by (Oxman, 2004), each IE contains four elements (ICF + preference). The associations between each pair of IE are based on the linkages and form a large map called idea map (Lai and Chang, 2009). Following internal/external interplay with IEs, these maps are then generated.

2.1.1. DIM elements

(1) Attributes of idea entity. The basic element of DIM is called IEs (idea entities) that constitute the knowledge related to design problems. Each IE is comprised of four attributes: issue, concept, form and prefers (Lai and Chang, 2006). Briefly:

- **Issue:** design problem that describes the problem for a domain issue.
- **Concept:** abstract design concept, which contains domain concept vocabularies.
- **Form:** the actual product in response to one domain concept vocabulary and media presentation.
- **Preference:** designer's IE preference value.

(2) Linkages of IEs. Each pair of IEs is linked via three linkages: similarity (SI→), contrast (CR→) and contiguity (→) (figure 2).

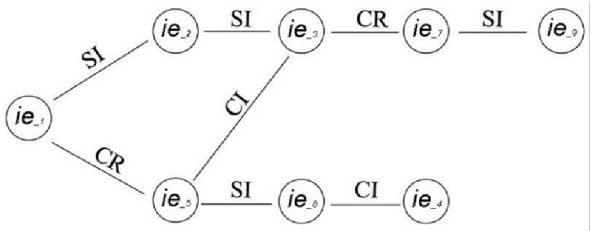


Figure 2. The graph-like knowledge structure via three linkages in idea map.

2.2. STORYTELLING

Storytelling is the basic human ability. We usually tell life experience to explore the experience or deep feelings, and to attract listeners' attention (Barton, 2000; Sullivan et al., 2008). Three major roles in a storytelling process are audience, writer, and storyteller. They affect each other.

2.2.1. Storytelling for audience

The audience is someone the story is told to. The audiences' reactions lead writers or storytellers think over elements of stories, for example, why do audiences relate more with some stories? What attracts them? What makes

audience willing to spend time watching or listening to a story? (Glebas, 2008b)

2.2.2. Storytelling for writer

Writers compose story in their minds and use their excellent storytelling ability to express them. Each writer establishes a personal style of storytelling. Writer (Lewis, 2001).

The important tool for writer must be their imagination. What kind of strong idea could catch audience's attention? In general, the ideas originate in past personal experiences, visits to somewhere, or encounters (Scott, 2002b; Wright, 2005b). Or ideas are found from the everyday encounters (Wright, 2005b), out of the debris from those familiar, interesting and things for that move people. Also, inconspicuous thing can become specific sources for ideas. Scott Jeffrey proposed, "Old idea + new time, place, or characters = fresh idea" (Scott, 2002a).

How can we to piece together a story from these elements? A typical story contains an unsolved problem that provides a hint to seduce reader to continue reading (Wright, 2005a) that is similar to the design problems in DIM above. Normally story usually uses three-act structure (Glebas, 2008a; Wright, 2005a):

1. **Beginning of story.** This act unfolds the story and acts as the background for introducing readers into the setting of story.
2. **Middle of story.** This act comes before the climax, elaborates small signals to guide the design ideas towards the big ending.
3. **End of story.** This act ends in climax and resolution of story. Climax has the characteristics of unexpected transition and resolution.

2.2.3. Storytelling for storyteller

Storytellers create virtual or real images in the audience's imagination in order to immerse audience in a world of imagination and inspire their emotions further. Storytellers use their own skills and tools (e.g., narrator's voice, character voices, singing, sound effects) and nonverbal tools such as facial expression, eye contact, gesture, body language, and so on (Moore, 1999).

3. The experiment

Informed by the reviews above, we investigate convergent processes during brainstorming. An experiment is conducted in which observation and interviews are used for tracing how ideas are generated and further developed.

3.1. PARTICIPANTS

Three architectural undergraduate students with knowledge of DIM are selected for this experiment. The participants are familiar with the concept of DIM as well as its procedure. The duration of experiment is two hours.

3.2. OBJECTIVE OF EXPERIMENT

Experiment process is divided into two stages. The whole experiment was video-taped with interviews afterwards.

Phase one involves generation of design issues for DIM. Each participant was undertook this task and after generating thirty IEs, the linkages of each pair of IEs are decided and produced in Idea Map as the result.

Phase two is the convergent phase. By asking participants to converge the diverse ideas generated from phase one, participants are requested to pick 4–6 IEs with sequential order. Based on some mechanism of storytelling mentioned above, interviews and questionnaire are used to uncover the logic behind the action (as shown in figure 3).

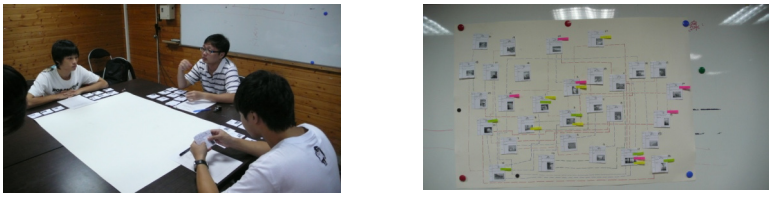


Figure 3. Process and outcome of experiment.

3.3. FINDINGS

Two findings are uncovered during the experiment. One is that the preferences of IEs in the sequence affect participants, choices. Second is that participants tend to select a key IE as a major point of climax in the sequence. After that, participant will pick any other IE based on the association with the existing IE in the sequence. Further linking will be followed from the existing IEs incrementally to accomplish the whole process.

4. Idea story mechanism

Based on this research, we developed a mechanism, Idea Story (Idea as Storytelling), which assists designer to converge ideas similar to storytelling. Idea Story is divided into two parts: Story components and procedure.

4.1 IDEA STORY COMPONENTS

A main component of Idea Story is story sequence.

4.1.1. EvenIE and linkage: the basic elements of story sequence

Every story sequence is composed of a series of "EventIEs" (figure 4). Three factors of IE relate to problem of story, conceptual process, and final result of event.

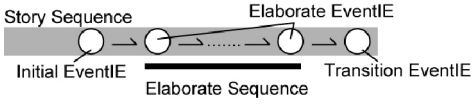
DIM	Story
IE	Event
Issue	Problem
Concept	Process
Form	Result
Preference	Writer's Preference
Linkage	Relationship of event

Figure 4. Mapping from DIM to story structure.

4.1.2. Data structure of story sequence

There are three types of EventIE: "Initial EventIE", "Elaborate EventIE", and "Transition EventIE". And one story sequence has one Initial EventIE, one Elaborate Sequence, and one Transition EventIE (figure 5).

1. Initial EventIE is an IE which has the most linkages in a map. Initial EventIE is the event in the beginning of story (figure 6). Most Ideas which are generated by designers are around Initial EventIE.
2. Elaborate EventIE is an event in the middle of story (figure 6) Many Elaborate EventIE makes up an elaborate sequence.
3. Elaborate sequence is a path or sequence that with many EventIEs connects Initial EventIE and Transition EventIE. This sequence must match two conditions:
   - Do not allow that any two related EventIEs of concept and form are the same. It is necessary that two same events occur again.
   - To keep more EventIEs with larger preference value in generated story sequence.
4. Transition EventIE is the IE with the most preference value. Transition EventIE is an event in end of story (figure 6). Transition EventIE is the most important



Story	Idea Story
Event	EventIE
Event in beginning of story	Initial EventIE
Event in middle of story	Elaborate EventIE
Events in middle of story	Elaborate Sequence
Event in middle of story	Transition EventIE

Figure 5 (left). The structure of story sequence. Figure 6 (right). Transform from story to idea story.

event of story and also what designers want to pursue in design. This study suggests three factors to assist designer to set IE preference value in DIM:

- Favourite: depends on designer's favourite IE.
- Importance: the IE is more important for designer.
- Special: the IE is significantly different from others in idea Map. And it might be a breakthrough or turning point in the story.

4.2. IDEA STORY PROCEDURE

In this study, we model the Idea Story Process based on storytelling process (figure 7). The Idea Story System, Designer, and Users play different roles in three stages. Furthermore, designer plays three different roles in each stage.

4.2.1. Step1: simplification stage

In the first stage, we simplify a huge DIM to several story sequences.

1. Find Initial EventIE and Transition EventIE.
2. Search one path as Elaborate sequence, search the path by computation according to existing Initial EventIE and Transition EventIE. Elaborate EventIE of Elaborate sequence is assigned better preference value.
3. Compose the computation results and story sequence.

4.2.2. Step2: combination stage

At this Stage, we assist designer to process ideas through four steps: display, collect, confirm, and synthesise.

1. Display the story sequence: a series of pictures represent the EventIEs of story sequence shown one at a time. Based on montage theory, designer self-

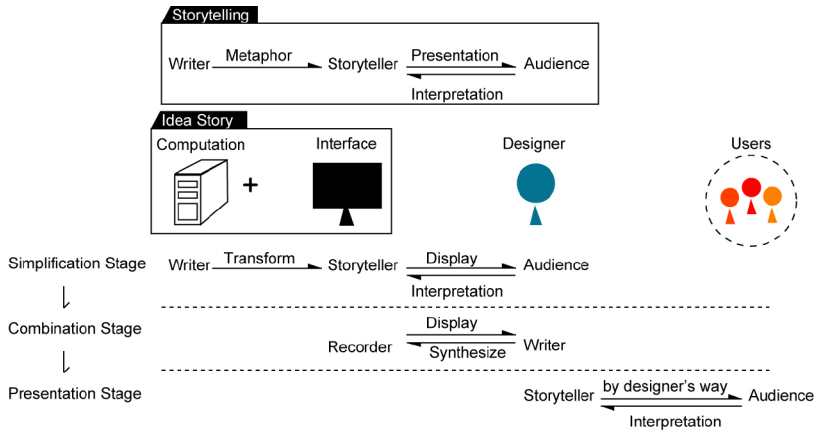


Figure 7. The vv process.

interprets the blanks between two pictures.
2. Collect the story sequences and approximate to design prototype.
3. Confirm main story sequence: After collecting many story sequences, designer has to decide one story sequence as a primary focus.
4. Synthesise the final story sequence based on the main story sequence. Designer must deeply think some things. Designer could add new EventIE, delete existing EventIE, or replace existing EventIE in order to make the main story sequence become better. During this period, designer may need to note some messages and synthesise a satisfactory resolution.

4.2.3. Step3: presentation stage

In the final stage, designer must make a conclusion for Idea Story via final resolution of story sequence.

5. An example

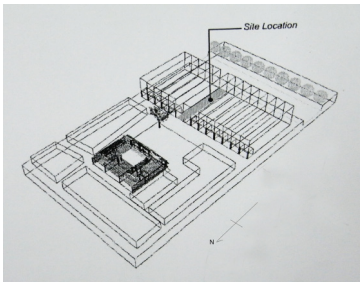
We follow the sequence and test in a practical project with an architectural designer. The given problem is to design a low rise (2–3 floors) street-house. The site is 4.5m × 30m (figure 8). The primary design issue is circulation.

With given DIM that has 30 IEs and linkages, designer sets the preference of every IE. System then generates 21 story sequences according to designer's preferences. From these results, designer picked up 4 story sequences as favourite sequences. One of these sequences then became the main story sequence. The IEs of main story sequence are ie3, ie21, ie25, ie15, ie16 and ie13. Then, designer changed the IEs in the main story sequence. He deleted ie25, and replaced ie22 and ie30. The IEs of final story sequence are ie3, ie21, ie22, ie30, ie15, ie16 and ie13 (figure 9). Finally, designer draws the sketch and describes the final story sequence (figure 10).

There is a courtyard with plants in the middle of street-house. In this way, residents could see the outdoor space through French windows in every floor. They also go to the outdoor platform and enjoy this garden in the courtyard. The main stair of street-house is also in the courtyard. The main stair and the outdoor platform of every floor are connected to each other for connecting each living unit. The public circulation is the front section of street-house on 1st floor. As a result, residents interact in the front section of street-house whereas the back section of street-house remains for private circulation.

6. Conclusion

This research provides a computational approach, Idea Story, to realise one way to develop convergent thinking of ideas. By exploring the storytelling



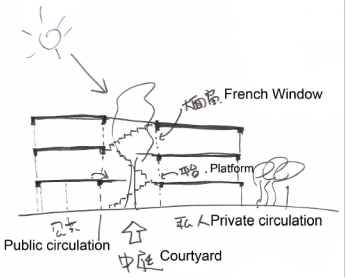


Figure 8 (left). The site location image. Figure 9 (right). Designer records Idea Story by sketch.

Figure 10. The final idea sequence is close to what designer has in mind.

mechanism via DIM, we conducted an experiment for investigating the incremental unfolding of convergent processes during design brainstorming.

The Idea Story mechanism not only converged from large number of ideas in DIM to a simple story sequence but also provides a way to inspire designers in the "Combination" stage. It provides a story sequence by computation to enable designers to interpret, compare, and modify ideas for finding a final solution. Further, designers would discover their own track as they build design knowledge increasingly.

However, the result of the convergence by only one designer might not be suitable for team situation. Further research on team idea convergence will be invaluable to justify the concept of Idea Story in more use cases.

References

Barton, B.: 2000, Introduction, *Telling stories your way: storytelling and reading aloud in the classroom,* Pembroke Publishers, Ontario, 7.

Glebas, F.: 2008a, The big picture: story structures, *Directing the story: professional storytelling and storyboarding techniques for live action and animation,* Elsevier/Focal Press, Boston, 293.

Glebas, F.: 2008b, The goal: why do we watch? *Directing the story: professional storytelling and storyboarding techniques for live action and animation,* Elsevier/Focal Press, Boston, 15–19.

Lai, I.-C. and Chang, T.-W.: 2006, A distributed linking system for supporting idea association during the conceptual design stage, *Design studies,* **27**, 685–710.

Lai, I.-C. and Chang, T.-W.: 2009, One map many ideas: how novice designers generate conceptual designs from an idea map, *CAADRIA09,* Taiwan, 341–350.

Lewis, I.: 2001, Script, *How to make great short feature films: the making of Ghosthunter,* Focal Press, MA, 26.
Moore, R.: 1999, Venturing out: learning the language of voice, motion, and gesture, *Creating a family storytelling tradition: awakening the hidden storyteller,* August House, Little Rock, 33–57.
Oxman, R.: 2004, Think-maps: teaching design thinking in design education, *Design studies,* **25**, 63–91.
Scott, J.: 2002a, Basic overview, *How to write for animation,* Overlook Press, NY, 36.
Scott, J.: 2002b, How to prosper in Toon Town, *How to write for animation,* Overlook Press, NY, 189.
Sullivan, K., Schumer, G. and Alexander, K.: 2008, Story background and theory, *Ideas for the animation short,* Focal Press, MA, 8.
Wright, J. A.: 2005a, Basic animation writing structure, *Animation writing and development: from script development to pitch,* Elsevier, MA, 111–115.
Wright, J. A.: 2005b, Finding ideas, *Animation writing and development: from script development to pitch,* Elsevier, MA, 39.

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OBSTACLES OF UTILISING REAL-TIME 3D VISUALISATION IN ARCHITECTURAL REPRESENTATIONS AND DOCUMENTATION

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Abstract. This paper describes obstacles in using current generation software for real-time 3D visualisations in architectural representations. The obstacles discussed are focused on three areas, controllability of first person view navigation, spatial quality of real-time environment and geometry interoperability. With the increased influence of leading 3D computer games, how can AEC industries leverage the potentials they offer, advanced user interaction and realistic spatial environments. The paper compares CAD and BIM software with current generation 3D computer Game engines.

Keywords. Real-time; visualisation; game engine; architectural representation.

1. Introduction

This paper describes obstacles in using current generation software for real-time 3D visualisations in architectural representations. Real-time 3D computer graphics differ from traditional pre-rendered computer graphics of a still image or sequence of frames by providing rendered 3D computer models of actual or proposed physical environments that allow for user movement, interaction, and information exchange. The freeform views provided in CAD and BIM software packages are designed for modelling, they do not present an intuitive way of understanding and experiencing a digital building. Computer game engines enable a first person view that gives a stronger understanding of scale and relationships of a proposed building. “Drawings are fundamentally paper-based in format. Drawing symbols and formatting conventions have

evolved primarily because paper is a two-dimensional medium" (Eastman, 2008).

The builder has to translate the 2D information into 3D, as building information modelling becomes the default 3D modelling methodology in architectural practice. How can the intelligent BIM model be leveraged to supplement or replace traditional paper-based documents with real-time 3D visualisation formats?

Currently a number of software packages are available such as Navisworks by Autodesk or modifications (mods) of commercially offered 3D computer games (Unreal Tournament by epic, Half-life2 by Valve) that are being utilised to enable real-time navigation and interaction of proposed and existing building projects. At present there are still a number of obstacles that result in an unsatisfactory final output or a complex workflow that is required to provide an engaging environment.

The construction of digital models for real-time visualisation currently requires optimising of geometry, lights and textures to run smoothly. Due to the real-time rending process, geometry optimisation plays a significant role in the final quality of real-time 3D visualisation. The geometry created in standard CAD and BIM applications can result in excessively complex models once translated into real-time 3D software. To date the gaming industry has overcome this problem with the use of intelligent skinning of the model geometry with textures to provide the illusion of detail. Using textures to offer detail does not provide the accurate information required for the construction industry.

Interoperability between software packages is a major impediment in an efficient workflow. The purpose built applications begin to smooth out the transfer of model data compared to modded game engines but the resulting output is not as compelling as is possible with the current generation computer game engines.

These findings come from a body of research that has been dealing with methods of using real-time-3D visualisations to supplement construction documentation. To date the research has been centred on overcoming the current obstacles of interoperability with CAD and BIM data for real-time 3D visualisation. Research to date has begun to demonstrate that use of real-time 3D visualisation in architectural and construction workflow could be used to enhance understanding of proposed buildings for all parties involved. The possibilities that this technology presents are considerably more advanced than 2D paper-based documentation. Further research needs to be carried out on the usability and requirements of real-time 3D visualisation in architectural and construction industries.

2. Software

The software has been reviewed as part of ongoing research into methods of utilising 3D CAD and BIM models to supplement construction documentation. The software has been split into two categories, commercial 3D computer game engine and commercial CAD or BIM software. The software packages reviewed in this paper are listed in table 1.

The criterion of comparison of the software focused on three areas, controllability of first person view navigation, spatial quality of real-time environment and geometry interoperability. The paper is the result of research with and from teaching undergraduate students different CAD, BIM and 3D real-time computer game engines over the last 6 years.

Table 1. Reviewed software

CAD and BIM		**Computer Game Engine**	
Software	Company	Software	Company
SketchUp	Google	Half-life 2	Valve
VectorWorks	Nemetschek	Crysis	Crytek
Revit	AutoDesk	Unreal engine 3	Epic
Navisworks	AutoDesk	Esperient Creator	Esperient

3. Controlling view

Autodesk Research states in a paper titled Safe 3D Navigation, “Typical commercial 3D CAD tools provide modal tools such as pan, zoom, orbit, look, etc. to facilitate freeform navigation in a 3D scene. Mastering these navigation tools requires a significant amount of learning and even experienced user can find learning confusing and error prone.” (Fitznaurice, 2008). These types of navigation tools can affect any sense of scale, context and relationships between items. Gravity and sense of ground are often reduced or suspended. This may be fine for constructing 3D models but for viewing and understanding an unseen or proposed building can result in confusion and frustration.

Computer game engines enable a first person view that provides a consistently scaled view of a digital space that is navigated by walking or flying. This mode of navigation provides the viewer a stronger understanding of scale and relationships within a proposed building than standard modal navigation tools.

Of the commercial CAD and BIM software packages that provide a controllable first person view, most resort to using the mouse as the primary method to manage navigation. This is a complicated and confusing navigation method to learn and control. The mouse can only control view direction or view location (movement) at a time resulting in an awkward navigation

technique, supporting navigation control only and having to change tools to interact with the model.

With an emerging generation of AEC workforce have grown up immersed in complex and sophisticated 3D computer games that are controlled by typical keyboard keys WASD ('W' to move forward, 'S' to move backward, 'A' to move left and 'B' to move right) and the mouse to control view direction and enable interaction with the model. This system is used by millions of computer gamers globally and replicated by console video gaming systems hand-held controls such as the Microsoft X-box and Sony Playstation. These methods need to be utilised to provide the next generation of workforce with a digital 3D environment they are comfortable navigating within.

Johns and Lowe (2005) "found that through experiencing their designs in the first-person and within the constraints of a 'physical' system [real-time 3D computer game engine] students were able to gain a much-enhanced understanding of the landform, spaces and structures and seize time-based design opportunities not present when working in other media. Four major benefits of using real-time modeling over physical scale modeling identified by the students were: comprehension of scale, engagement of other senses with sound, understanding space and time, and the ability to interact with others in a virtual landscape."

4. Spatial quality

The final image quality of a digital 3D model has an impact on the viewer's comprehension of its spatial properties. One of the benefits of current generation of real-time 3D computer games engine is their ability to produce near realistic rendered digital environments, see figure 1. However, CAD and BIM software has stayed focused on paper based outputs and functional realism, see figure 2. Kalay (2004) explains "much of the information that is conveyed by drawings is implicit and relies heavily on interpretation…the relationship between the walls and the space they enclose is a matter of interpretation…" Within real-time digital environments textures, physics, lighting and shadows are important in providing an increased spatial cognition, which together, are not present in current CAD and BIM software.

The use of textures to help provide detail without the increased polygon count and reduced processing power has provided the gaming industry with a convincing method to give the illusion of detailed spatial environments. This method does not provide the required accurate detail for construction interpolation; currently only a select few building projects provide a completely detailed single 3D model. The digital model construction techniques used in AEC industries predominantly rely on providing the detailed construction

information in 2D drawing format. Not discussed in this paper in any detail is the ability of computer game engines to enhance spatial comprehension with 3D sound and physics.

Figure 1. Example of real-time rendering engine of Crytek.

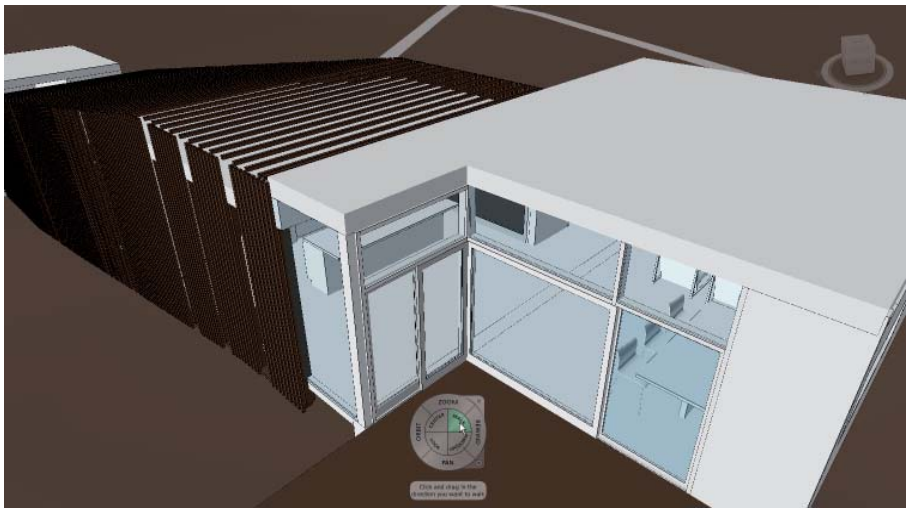

Figure 2. Building model as viewed in Autodesk Navisworks.

5. Geometry optimisation

Almost all CAD and BIM software packages use boundary representation or B-rep for representing model geometry. The B-rep model consists of more than just geometry (shape), additionally containing topology (how things are connected), and tolerances (how closely do they actually fit together). This combination of model data is then accessed by the CAD systems to define a valid B-rep model. Most real-time 3D software requires a triangulated polygon mesh model. Objects created and sorted as polygon meshes are constructed of vertices, edges, faces, three and four sided polygons and surfaces. However many renderers may only support 3-sided faces or polygons.

The process of translation from CAD and BIM software to a real-time 3D computer game engine may work smoothly in theory but in practice can cause major problems when converting the model data to a format that can run efficiently in real-time 3D software. The translation process often returns unexpected results that can cause major difficulties in running a real-time digital environment. Model geometry can be triangulated further dramatically increasing polygons, decreasing frame-rate and producing slow unresponsive navigation. In some situations model geometry can be relocated completely. Figure 3 shows examples of geometry triangulation of a door frame and model components relocated within a Revit Architecture model translated for use in a game engine.

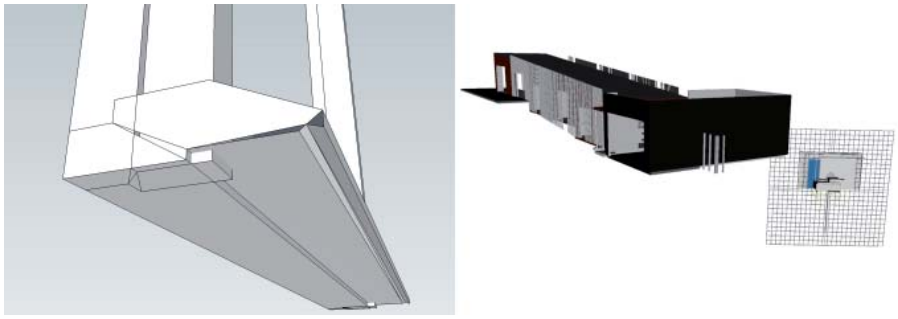

Figure 3. Translated geometry from REVIT.

"However there are governing aspects of the game environment that tends to emphasise an economy of polygons. The frame-rate at which the processor is able to render scenes is directly proportional to the amount of complex polygonal faces it needs to surface and the lighting effects associated with them. For this reason, geometries that are composed of simple triangulations are more efficient than complex 3D surfaces" (Pickersgill, 2007).

Current BIM software use components that consist of 2D/3D elements. A 2D symbol for representation in plan view and a 3D model, enabling drawings to comply with 2D conventions while working on a single 3D model with 'live' 2D drawings, is being used. The author proposes that an option to reduce the required translation time from BIM software to real-time 3D software is that BIM components should have a third element which is a reduced polygon representation that enables smoother workflow between software types.

9. Conclusion and future work

There are work-rounds or methods to deal with all of the obstacles listed above; currently all require a multi-step process unusually involving a number of different software packages (and are unidirectional) or optimised remodelling of building geometry. The benefits of being able to access proposed and existing buildings in real-time 3D digital environment are beginning to outweigh the stated complications; navigation control, spatial quality and geometry interoperability. Number of polygons and spatial quality will become less of an obstacle as processing power continues to increase.

CAD and BIM software is focused on modeling and 2D output. Only recently has the software started to develop 3D digital methods of view and navigation control in real-time for spatial cognition of an unfamiliar buildings. These viewer control methods and spatial quality are still underdeveloped compared to the current generation of 3D computer game engines. Interoperability of CAD and BIM is still not a smooth process unless the user is working within a software suit such as Autodesk. It is still a major obstacle in utilising real-time 3D visualetation in architectural representations and documentation.

As software and hardware continue to improve so will the required amount of information and detail digital models will need to provide, requiring new methods of interaction. Additional research needs to be conducted to test the usability of first person navigation and interaction.

References

Kalay, Y. E.: 2004, *Architecture's new media: principles, theories, and methods of computer-aided design*, MIT Press.

Eastman, C. et al.: 2008, *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers and contractors*, Wiley, New York.

Fitzmaurice, G., Matejka, J., Mordatch, I., Khan, A. and Kurtenbach, G.: 2008, Safe 3D navigation, *SI3D '08: proceedings of the 2008 symposium on interactive 3D graphics and games*, Redwood City, California.

Johns, R. and Lowe, R.: 2005, Unreal editor as a virtual design instrument in landscape architecture studio, *Proceedings of the 6th international conference for information technologies in landscape*, Dessau, Germany, 330–336.

Lowe, R.: 2007, Computer gaming, biotechnology and architecture: embedding the intersection within an architectural curriculum, *Proceedings of the 2007 Association of Architecture Schools Australasia conference*, Sydney.
Pickersgill, S.: 2007, Unreal studio, *Proceedings of the 12th international CAAD Futures conference*, Sydney, Australia.

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MIXED REALITY AT THE SKETCH DESIGN STAGE

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Abstract. We discuss the use of multiple design representations to enhance decision making at the early stages of design. Our particular interest is in the way in which context can be extended by two interrelated approaches: (1) the incorporation of the temporal; and (2) through the concurrent evaluation of qualitative representations and quantitative information. Outcomes from a practice survey are used to formulate approaches to the use of mixed reality (MR) technology that reflect design-specific modes of working. We propose two approaches – studio MR and site MR – reflecting the distinction between the act of design and the process of a design review. The implementation of a studio MR application and illustrative design project are presented.

Keywords. Design representations; mixed reality.

1. Introduction

Our previous research in the field of design representations has explored the potential of hybrid approaches to support design conception and review. Mixed reality technology that combines real time context with digital models, offer the potential to further this research agenda. Our particular interest is in the way in which the representation of 'context' can be extended by two interrelated approaches: (1) the incorporation of the temporal; (2) through the concurrent evaluation of qualitative representations and quantitative information typically relating to functional performance. In relation to the temporal aspects of design context we distinguish between two approaches. The first builds on a long tradition in which architecture is conceived in terms of temporal sequence, as celebrated in the Villa Savoye where architecture is best appreciated, according to Le Corbusier "on the move" (Bois and Shepley, 1984). Here time is considered from the viewpoint of the mobile observer where architecture is surveyed as a temporal sequence of form, space, surface

and the event of occupation. The second considers multiple time scales and the capacity of architectural experience and performance to be transformed within a dynamic environment. Central to both the peripatetic and scalar aspects of temporal context is our interest in the concurrent evaluation of the qualitative and quantitative attributes of a design. Our previous research in multiple design representations, and evidence from a recent survey of practice, suggest there is much to be gained by the co-presence of visualisations that capture the formal attributes of a design alongside quantitative measures, such as environmental and structural performance.

Currently there is growing activity within the CAAD community and beyond in 'performative architecture,' which typically maps functional data directly to digital models. This trend has been facilitated by the recent availability of graphics programming interfaces where performance data can be mapped to geometry variables. While it is encouraging to see the development of designer orientated programming interfaces, there has been criticism of performative architecture as a return to functional determinism (Pellitteri et al., 2008). Clearly it would be naïve to ignore the qualitative aspects of a design when evaluating designs, in particular the impact of design proposals in a wider design context. It is with this agenda of temporal context and concurrent evaluation that we are exploring ways in which mixed reality technology can be integrated into design practice at the early stages of design.

The research is based on a method of practice survey, the specification and prototyping of technology and strategies that respond to current practice evident or implicit in this survey, and an evaluation of the potential benefits that may arise out of adoption of such technologies by design practices. The practice survey has been undertaken and the next section summarises observations from the survey transcripts and examples of work collected. A subsequent section summarises the range of mixed reality technologies and articulates two approaches that we consider offer potential for practice: a studio-based and on-site configuration. The second part of the paper reports on the technical development of a prototype studio system. In order to partially illustrate the potential of this approach, the prototype has been used to enable the sketch design of dynamic sun shading for a high rise tower.

2. Practice survey

As has been reported elsewhere, the practice survey involved 22 Melbourne-based design practices of various types and sizes (Dave and Moloney, 2009). Using the format of a structured interview the designers were asked to respond to a series of questions relating to the use of design media to incorporate temporal context. In addition practices were requested to provide examples of

projects in which consideration of temporal context informed design development in the form of sketches, photographs, drawings or writing. The survey revealed a full range of analogue and digital media with design representations ranging from abstract lines and figures to the highly detailed and photorealistic. This overlaying of abstract and 'real' representations evident in the survey, to our minds, foreshadow functionalities that would be desirable in future mixed-reality applications.

The central observation is that for new digital technologies such as mixed and augmented reality to be effectively integrated into existing practice at the early stages of design, they need to enable the concurrent use of analogue media and a range of digital techniques. Secondly designers require a continuum of representation fidelity, from the abstract to the photorealistic and ideally, to be able to integrate visualisation with functional performance simulations. Below are some more specific observations from on the use of digital technologies within the surveyed practices.

- **Peripatetic movement.** The classic strategy of key-frame sketches in context is carried through in the form of fixed path animations, and interactive 3D exploration (e.g., VRML, game engines, etc.) (figure 1A).
- **Site- and time-dependent changes.** Continuous phenomena such as light, shadows, sound propagation, energy and wind flow, etc. are used in design to both inform and evaluate design alternatives. Whereas discrete representations at one spatial frame of reference (as sketch, graph, etc.) were the traditional vehicles, various digital modelling tools now support analysis and reading of these changes over space and time (figure 1B).
- **Situated view cones.** This is a way for designers to locate themselves at a point in space to see what is visible as a way to confirm the fit between spatial elements and qualitative experiences (view, protection, continuity, etc.) (figure 1C).
- **Volumetric morphing between points.** Complementary to the above design explorations is the strategy of morphing spatial changes between situated view cones or animating parametric assemblages (figure 1D).

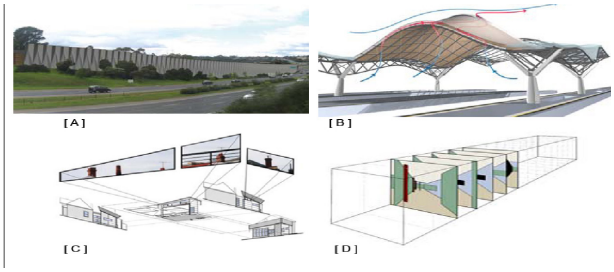

Figure 1 A–D. Sample projects from practice survey.

3. Mixed reality: two scenarios for architectural design practice

In order to support such fluid inquiries and augmentation of design process, mixed reality applications need to integrate and support functionalities that reflect discipline-specific modes of working. Mixed reality as a term allows a wide range of technologies and the consideration of appropriate technology is central to our research inquiry. The taxonomy of Millgram and Kishino (1994) is a robust classification that articulates soft boundaries between fully synthetic digital space and the video display of real environments using what they term a "virtuality continuum." This allows a distinction between displays that combine the real and the synthetic, of which there are two primary types – augmented reality (AR) and augmented virtuality (AV). Within the primary distinctions of AR and AV are a number of other approaches that have been classified along the continuum including amplified, mediated and virtualised reality (Schnabel et al., 2007).

Building on observations from the practice survey, the second stage of our project is to locate opportunities along the virtuality continuum for the particular focus of this research – the concurrent evaluation of qualitative and quantitative representations in a temporal context. What mix of technologies will enable design ideas to be evaluated in relation to a dynamic context, from multiple motion paths, and at the same time allow the superimposition of functional performance data? Perhaps more importantly for design practice, how might these technologies be implemented in a studio design environment? In relation to these questions the survey of Schnabel et al. (2007) usefully clarifies the issue of suitability of technology for specific activities. Their review evaluated technology along the continuum in terms of two factors: (1) correlation between perception and action; and (2) level of interaction with real artefacts. The first factor is based on human computer interaction research that demonstrates the more we can use our everyday motor activities in interacting with virtual objects, the better the performance. The second factor is based on research in activity theory that takes the perspective "that the computer is just another tool that mediates the interaction of human beings with their environment" (Kaptelinin, 1996). In contrast with earlier cognitive theories of human computer interaction, activity theory takes into consideration the impact of traditions with non-computer tools and the social context in which digital tools will be used. These factors are of particular importance to architectural design at the early stages. In this regard, we should be clear on the distinction between the individual act of *designing* – the formation of early ideas on paper, and with physical and digital models – and the process of *design review* in which these sketch designs are evaluated. Typically designing is a reflective activity, the individual designer(s) developing ideas as an internalised conver-

sation with a range of media. The design review by contrast is a group activity, in which design options from different designers, are compared and discussed in relation to a range of issues.

In recognition of these two modes of design activity we propose two approaches to mixed reality applications in architecture. The first is orientated towards designing that we refer to as studio MR. The second is directed towards undertaking a design review in context, and which we refer to as site MR. In both systems we reject the use of head-mounted displays as they restrict the incorporation of analogue media and interaction between designers. As illustrated below (figure 2A) the studio-based system is envisaged to allow designers to integrate design models with a database of site video, more abstract virtual environments and integrates quantitative analytical simulations with the visualisation. The emphasis is on co-locating multiple views and data types and has some resonance with the research of Lee et al. (2008). The second system (figure 2B) is intended for a design review on site. A large-scale LCD incorporating a touch screen interface is mounted on a mobile platform. Design models are superimposed onto streaming video with ambient and directional lighting been updated by sampling the video feed and accessing a database of sun paths. As the location on site can be pre-calculated there is no requirement for full motion tracking. Instead a motion sensor allows pan and tilt and the video camera zoom is synchronised with the design model. The level of interactivity is under review. Prior to the survey we had envisaged interactively substituting design models with simple transformations (move, rotate, scale). However with the growing uptake of parametric computer models evident in the survey, we are considering the capacity for more model interactivity to enable more on site editing of design options.

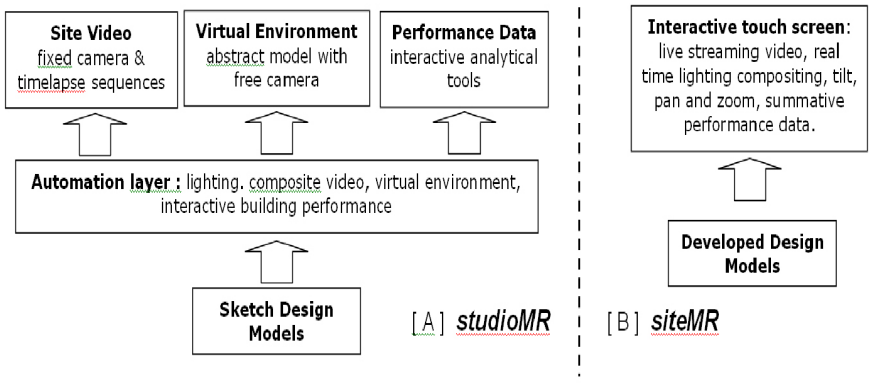

Figure 2 A–B. Overview of studio- and site-based mixed reality.

4. Studio MR development

The objectives of the studio-based mixed reality system is to provide a design interface that allows an understanding of temporal context in relation to qualitative and quantitative data. Below are what we consider key requirements for a studio-based mixed reality system

- **Navigation.** Provide both real time navigation and multiple camera paths that align the digital model with pre-recorded site video. This requires the combination of AR and AV in the one visualisation environment.
- **Dynamic environment.** Develop a database of site video taken from key viewing points. Link design models to environmental performance software that considers a range of time scales. In real time (AV mode) animate lighting and skybox relative to range of time scales.
- **Concurrent evaluation.** Develop an export module that converts the design model into a format compatible with environmental performance software. Import the performance data and store in local database to enable continuous update of performance.
- **Interactivity.** Enable users to swap between the navigation modes (real-time or via pre-recorded camera paths). Design models should be able to be swapped in and out on-the-fly, and entities should be editable in terms of translation, rotation and scaling.
- **Lighting.** Export module that automates the lighting of design models in external graphics animation software in relation to the pre-recorded video; supplement this with interactive lighting in real-time mode.

4.1. TECHNICAL IMPLEMENTATION

The technical implementation was initially attempted using open scene graph and some progress was made in developing a prototype application that meet the above requirements. However one of the factors that became more obvious from the survey outcomes was the need for a visualisation environment with a wide range of file formats and the desirability of a networked design space to store and easily retrieve design options. For these and other reasons of expediency, a hybrid design environment that uses a web interface to utilise a range of commercial applications has been developed. The current implementation strategy is to link existing technologies with bespoke web and script interfaces: 3D Studio Max and Backburner to produce the composite video and rendered images; Esperient Creator provides a fully featured virtual environment with excellent file interoperability; Energy Plus is utilised for environmental performance analysis; the web interface is developed in Python allowing access to a large number of interface libraries.

4.2. ILLUSTRATIVE PROJECT

To illustrate some of the potential of studio MR and to identify areas for more detailed evaluation, a design project has been undertaken. The design scenario is the development of a sun screening system that is required to perform environmentally, but also act as a large-scale information interface and urban art work. This design scenario explicitly requires the concurrent evaluation of functional performance in tandem with the capability of the system to in effect act as a large scale 'display' screen that allows the embedding of information and abstract kinetic art. The design is for the re-cladding of an existing high rise tower located in a prominent position in the Melbourne CBD.

4.2.1. Performance measures and design modelling

For the purposes of the study the quantitative data from which functional performance is measured is the impact of sunlight on internal temperature. Clearly there are other variables that determine comfort levels for occupants (air movement, relative humidity, light glare), but the shading of glazed areas from direct sunlight is the primary functional requirement for externally mounted screens. After testing two commercially available applications that integrate geometry modelling and environmental simulation (Ecotech, IES) we decided to use the open database approach of Energy Plus. At the moment commercial applications such as Ecotech and IES provide poor file interoperability. Moreover, all environmental simulations requires the calculation of discrete volumes that dictate either the designer thinks in this way as they design, or it necessitates remodelling after a design idea has been developed. A clear outcome from the practice survey is that designers work across a range of modelling applications and require a workflow between idea and performance that allows this. For this illustrative project the key factor is the percentage shading produced by the sun screens and the impact this has on internal temperature. Rather then constantly translate the design model to an environmental model, we have developed an approach that evaluates the design model in terms of percentage shading. This percentage is then linked to the energy plus database and using weather history files for Melbourne the impact on internal temperature is calculated for daily and seasonal time scales. This approach allows designers to work in their favored design applications and obtain accurate feedback on performance, in this case impact of shading on internal temperature. In a similar way we also provide feedback on the impact of the external screens on internal light levels. The design model is imported into 3D Studio MAX which has the capacity to generate accurate luminance visualisation. A simple script automates the production of plan views which

are analysed to produce the percentage of floor area receiving acceptable luminance.

4.2.2. Qualitative evaluation and visualisation

There are three qualitative factors for this particular design illustration: (1) the capacity to embed information within the dynamics of the screen; (2) the capacity of the dynamic screen to support kinetic art works; (3) the visual impact of this dynamism on the internal spaces. As evidenced by the practice survey there needs to be a range of visualisation approaches from the abstract to the photorealistic. Moreover, the above factors require visualisation from multiple viewpoints and time scales. In terms of factor 1, this capacity to embed graphic or textural information will be dependent on viewing position within the Melbourne city grid. There is a similar requirement for factor 2 as kinetic artists will need to evaluate how their artworks are perceived from multiple viewing angles and distances. With factor 3, the visual impact on the screen dynamism on the tower interior spaces, there is less variability given the constraints of the internal plan area. None the less, it would be useful to be able to manipulate internal viewing position to evaluate the impact from different areas of the plan. In order to facilitate visualisation for these factors two visualisation environments were developed. A video survey was undertaken and eight strategic viewing positions within the city grid were established. Design models were superimposed on to these strategic viewing positions to enable evaluation in a photorealistic context. Supplementing this was a virtual environment which allowed interactive visualisation in an abstract 'cardboard-like' model. This allowed free camera movement and multiple speeds (pedestrian versus motorist). In addition a time lapse feature linked to sun paths was incorporated to allow visualisation from multiple time scales and seasonal lighting conditions. The virtual environment included the facility to view the dynamic screens from within typical floors within the tower. These internal visualisations used a combination of baked in ambient lighting and real time shadow projection to provide a quasi-realistic visualisation of the impact of external dynamism.

4.2.3. Web interface

A web interface was developed to allow designers to submit design models and review design visualisation and performance. Designs from typical modelling environments identified in the survey (Rhino, Sketchup, Maya) were converted to a 3D studio MAX file which was then merged with a site file. The upload interface allowed users to select multiple days and times and choose

to run a partial or full visualisation / performance simulation. Using a render farm and a scripted interface to energy plus designs were processed to produce the range of qualitative visualisations and graphed representations of impact of shading on internal temperature and lighting. Given the number and range of design representations, a primary challenge is presenting this information to the designer. A review interface has been developed that allows a designer to easily access composite video animations, temperature and lighting graphs in one interface. Selecting a design iteration also automated the display of the relevant virtual environment, which is accessible as separate re-positional window with its own navigation interface and interactive controls for the dynamic shades and sun paths. Linked to each design is a scoring and comments interface that allows the input of qualitative assessment in relation to the three factors identified in the previous section. As various design options are processed and evaluated, a summary page tracks the progress with each option presented as a screenshot and summative graphs charting qualitative and quantitative assessment.

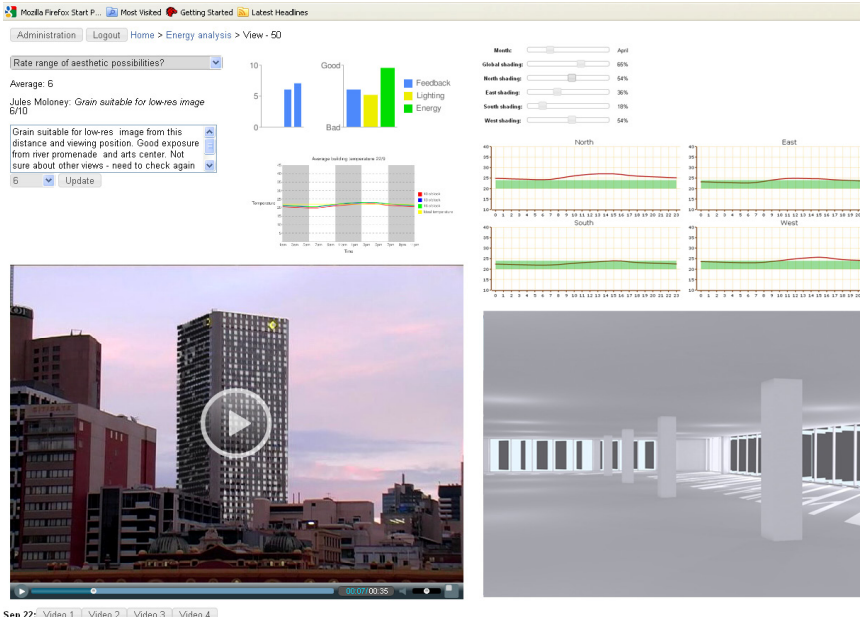

Figure 3. Screenshot from studio MR prototype web application, which allows the concurrent evaluation of data on environmental performance, composite videos, and a real time virtual environment allowing external and internal evaluation. In order to track design iterations and enable collaboration a comments and scoring interface summarises the evaluation of each design.

5. Further work

The project illustrates one specific example of how qualitative evaluation and quantitative information can be integrated into the early stages of design conception and review. Building from the practice survey, the primary drivers were to enable design to be undertaken in typical geometry modelling applications, automate the production of abstract and photorealistic representations and present these alongside key quantitative performance measures. The project is illustrative only as the 'designers' are at this stage are the project team. Clearly there is a need for evaluation of the approach by a wider sample of potential users (ideally including some participants from the survey), which will be undertaken in a subsequent project stage.

We are also making progress on the implementation of the site-based MR approach outlined in the first half of the paper and a preview of this work will be available for the conference presentation.

6. References

Bois, P. and Shepley, J.: 1984, A picturesque stroll around Clara-Clara, *October,* **29**, 32–36.

Dave, B. and Moloney, J.: 2009, Augmenting time and space in design inquiries, *in* T.-W. Cheng, E. Champion, S.-F. Chien and S.-C Chiou (eds.), *Between man and machine: proceedings of the 14th conference of computer-aided architectural design research in Asia,* National Yunlin University of Science and Technology, Taiwan, 22–24 April, 523–532.

Koutamanis, A.: 2000, Digital architectural visualisation, *Automation in construction,* **9**, 347–360.

Kaptelinin, V.: 1996, Activity theory: implications for human computer interaction, *in* B. Nardi (ed.), *Context and continuousness,* MIT Press, Cambridge, Mass.

Lee, Y., Lertlankhanakul, J, Choi, J. and Kalay, Y.: 2008, Dynamic architectural visualization based on user-centered semantic interoperability, *ACADIA 08,* University of Minnesota, Minneapolis, 16–19 October, 406–414.

Milgram, P. and Kishino, F.: 1994, A taxonomy of mixed reality visual displays, *IEICE transactions on information systems,* E77-D.

Pellitteri, G., Concialdi, S. and Lattuca, R.: 2008, Performative architecture: new semantic for new shapes?, *CAADRIA 2008, proceedings of the 13th international conference on computer-aided architectural design research in Asia,* Chiang Mai, Thailand, 9–12 April 2008, 300–208

Schnabel, M., Wang, X., Seichter, H. and Kvan, T.: 2007, From virtuality to reality and back, *IASDR 07,* Hong Kong, China.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010,* 413–422. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

DIGITAL ARCHI FOR HUMANITARIAN DESIGN

A case study of applying digital technologies in post-disaster reconstruction

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Abstract. This paper describes the context and proposal for applying digital technology in humanitarian design for remote areas of developing countries that are the most technologically challenged. It presents a case study of on-going post-disaster reconstruction in the Solomon Islands. A system of digital tools, in particular parametric modelling, was devised to optimise the exemplar design for site and project specific needs, and reduce time and cost required in the overall design and construction process. Shelters developed under this system will start construction in 2010.

Keywords. Optimisation of design; parametric design; post-disaster; algorithmic modelling; developing countries.

1. Introduction

Digital technologies such as BIM (building information modelling), parametric modelling, CNC (computer numerically controlled) fabrication and GA (genetic algorithm) have been increasingly employed in the field of architecture. Nonetheless their applications are yet to be applied in the challenging field of humanitarian design.

This paper presents part of an ongoing research on the application of 'high-tech' digital technologies to humanitarian design in the 'low-tech' context of developing countries. It focuses on the use of parametric modelling, and its BIM capabilities when coupled with spreadsheets.

Starting from the premise that the constraint-bound context of humanitar-

ian design particularly suit the rule-based nature of parametric modelling, and that any level of automation to reduce time for expatriates' tasks would assist in optimal use of project funds, we devised and tested a system of various digital tools through a real case study of post disaster development work in the Solomon Islands.

2. Theoretical issues of generative design and humanitarian design

2.1. PARAMETRIC / GENERATIVE DESIGN AND HUMANITARIAN DESIGN

Digital tools such as generative modelling are increasingly used in architectural design, but ironically their major applications lie in unbuilt proposals due to the cost-prohibitive nature of the complex geometric forms enabled by the software. Many question if such form-driven design process is ethical (Ostwald, 2009). Barrow and Kumar (2007) argued that obsession with 'free-form' generation has undermined the powerful function of advanced modelling to perfect performance and mass-customisation - these functions, rigorously exercised in industrial design, should be applied to housing design – retaining the principles of achieving higher buildability from simplification, standardisation, and modularisation, but moving from mass production to mass customisation with the new digital tools available. Hecker (2006) further illustrated this potential with CNC fabrication.

Likewise, humanitarian designs for developing countries and post-disaster areas overlook the potential benefits of these digital tools and suffer the same problems found in all mass-prefabricated, one-size-fits-all solutions. These often involve expensive foreign materials transported to site that are hard to replicate, such as Shigeru Ban's Paper Tube Emergency Shelter for Rwandan refugees (Sinclair and Stohr, 2006). Though justifiable for the case of immediate response to emergency relief, the potential of customisation has not been fully explored for transitional or permanent applications.

2.2. CURRENT GAP IN RESEARCH

From our literature review, little research addressed the opportunities raised by digital technology in the valid application of humanitarian architecture – where the demand is the most pressing and the constraints most challenging. Out of the available research material, all are hypothetical proposals, and none addressed application for remote locations, nor for providing sustainable long-term solutions.

Sener and Torus (2009) proposed a parametric system to arrange shipping container shelters randomly within a site envelope for immediate post-disaster relief. However like most prefabricated solutions, it relies on adequate infra-

structure to deliver the containers, and would not be viable for developing countries or remote locations where logistics present a real issue.

Other research proposes using different digital tools such as generative algorithm (Wen and Chen, 2004) or interactive 3D virtual environment (Jinuntuya and Theppipit, 2007) for decision making support systems but not for producing architecture.

We aim to address the issues above and open up a field for further research. Through the case study presented below, we examined existing constraints, user requirements and a proven successful model of delivery. Opportunities for computer aids to improve various processes were identified, and a system of digital techniques devised for the next stage of construction. This is scheduled to begin in mid 2010, and any findings will be followed up to inform our ongoing research.

3. Case study: reconstruction in the Solomon Islands

3.1. CONSTRAINTS, USER REQUIREMENTS AND MODEL OF DELIVERY

The reconstruction from the 2007 tsunami and ongoing development work in the Solomon Islands are constrained in many ways. Human habitation is geographically spread out with minimal infrastructure, limiting choice of material and lengthening time for transportation. Material availability is sporadic and local builders use only very basic and inexpensive non-powered tools like handsaws and hammers.

Typically, assessment of site and needs, building design and supervision of construction are led by expatriates with a high cost base, until sufficient capacity can be built up locally. Any means to alleviate reliance on expatriate experts would allow funds to be spent more directly on construction and ensure programs continue after disengagement with international agencies. Engagement terms of field expatriates are often limited to a year. Moreover the pressing nature of field work inhibits proper documentation and transfer of the knowledge gained from field experience to local staff members and succeeding field workers.

Currently the most successful delivery model involves international aid agencies designing and building exemplar prototypes as a way of transferring knowledge to communities. Funding and drawings are supplied to communities for the next build. However the prototype often requires further modifications to suit site and project specific requirements. The field architects and engineers must then manually repeat the calculations and documentation, lengthening the process.

In summary, a successful design would require economical use of simple

locally obtained material that can be built easily and quickly with the most basic tools and skills, and allow participation by everyone in the community. The system should be designed to adapt various site and user requirements, and to absorb unforeseeable circumstances such as shortages in certain materials. To ensure long-term viability of the projects, designs should also be easily replicated by communities with minimal external assistance.

3.2. PARAMETRIC OPPORTUNITIES IN HUMANITARIAN DESIGN

The constraints and user requirements discussed above often call for innovative solutions that have not been tested. However the repetitive nature of the work from one prototype raises opportunities to evaluate the design and construction process and incorporate users' feedback to improve subsequent sets of designs.

Similarly, application of digital technologies such as parametric modelling lacks built examples. The few built works tend to be expensive one-offs and require a long time to design and construct, limiting application of lessons learnt to new projects. In contrast, development work from one prototype has the potential to allow these technologies to be tested and refined on comparable basis over time.

Figure 1. VIP latrine project in the village of Keigold, Ranongga, from which sequential design for the Wash and Sanitation Project in the schools of Guadalcanal were based on. From left to right: (a) delivering roof sheets by dugout canoe; (b) one of the twenty VIP latrines during construction; (c) finished VIP latrine.

3.3. VIP LATRINES IN RANONGGA AND GUADALCANAL

In addressing the above, we selected the Sanitation and Wash Project in Guadalcanal for the Ministry of Education and Human Resources Development and World Vision for this research. An exemplar VIP (ventilated improved pit) latrine had been designed by EAA (Emergency Architects Australia) and built (figure 1); with many more still to be erected within a short time. So, timely evaluation data can be gathered to inform sequential design on a consistent and comparable basis for advance modelling.

The project requires assessing schools and improving water and sanitation within a strict budget. EAA had completed the site and requirement assessment and the BOQ (bill of quantities) for four schools in Guadalcanal, to which the output from our system was compared. We focused on two school sites requiring VIP latrines and modified the existing exemplar design to suit.

4. The system, design and design parameters

From the built VIP latrine project in Ranongga, we identified areas where digital technology can significantly benefit the overall process. The urgency of aid works prompts us to approach the problem by introducing a number of small packages of digital tools, with the intention of improving and adding more varied tools over time, analogous to inserting acupuncture needles at various points throughout the design and construction process as shown in figure 2.

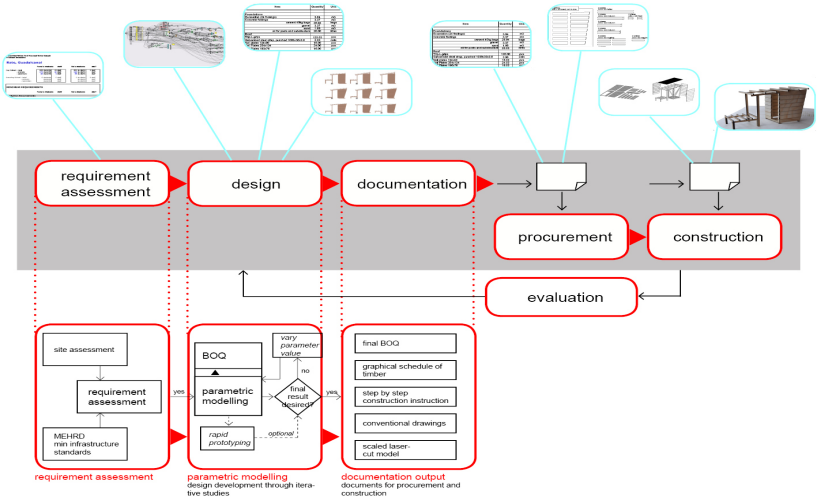

Figure 2. Digital archipuncture - flowchart summarising the system and its components.

4.1. ASSESSMENT OF REQUIREMENTS INTO PARAMETRIC MODELLING: DESIGN DEVELOPMENT THROUGH ITERATIVE STUDIES

The data gathered from site assessment was fed into a spreadsheet which calculates the additional water and sanitation requirements for the schools.

The values from the requirement calculation spreadsheet are fed into the design parameter spreadsheet which stores all the parametric values for the digital model. This spreadsheet is bi-directionally linked with Grasshopper - allowing the model to be updated by values in the spreadsheet or directly con-

trolled with sliders in Grasshopper. The link enables instant updating of the quantity and cost of material and fuel, and estimates of how many deliveries are required to transport all the material, as shown in the BOQ.

Study of the model and adjustment to the parameters gives the user the ability to attain a final desired outcome through informed decisions. Various options can be captured for rapid prototyping, allowing further study and comparison in reality. The model and the BOQ also inform the user of potential areas for cost savings, as well as opportunities for increasing amenity with a very slight increase in cost, as seen in figure 3.

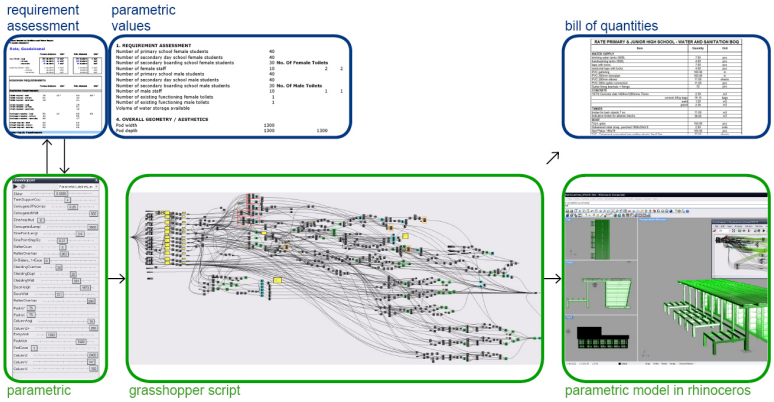

Figure 3. Flowchart summarising the parametric description of the system. Top row from left to right: (a) requirement assessment; (b) parametric values in Excel spreadsheet; (c) BOQ generated by the parametric model. Bottom row from left to right: (d) slider for selected parametric values in grasshopper; (e) grasshopper script; (f) parametric model interface

4.2 DESIGN AND DESIGN PARAMETERS

There are many parameters and constraints in the Grasshopper script. The major inputs are the number of female/male students and staff (to generate the capacity required), the size of the modules, availability or selection of material, and slope of the roof and inclined wall.

All parameters are interrelated to various degrees, but can be classified into five categories:

1. Required capacity: number of toilets and water storage required.
2. Overall geometry / aesthetics: to determine the form of the building.
3. Material availability or selection: the supply of material.
4. Funding and procurement: time and budgetary constraints.
5. Constraints, tolerance, miscellaneous.

4.3. OUTPUT: DOCUMENTS FOR PROCUREMENT AND CONSTRUCTION

Once a desired final design is achieved, the data from the model generates the following documents for procurement and construction:

- **Final bill of quantity** based on major elements in their nominal dimensions.
- **Graphical schedule of timber members** – with dimensions, quantity and description of all the timber members required for milling and cutting in the bush and on site.
- **Graphical step-by-step instructions** for the construction process – show how the building is built in 3D, similar to an 'Ikea' instruction.
- **Conventional construction documentation** cut from the 3D model for skilled carpenters, and for community members wishing to learn how to understand conventional construction drawings
- **1:1 paper / plastic templates** for building elements where they need notching or trimming in specific ways
- **File for laser cutting** of all major elements for a 1:10 model. The model will aid understanding of how to assemble the building.

5. Evaluation

5.1. DESIGN DEFINITION: ADAPTABILIITY AND OPTIMISATION

The system enables a high level of automation throughout various stages of the project. Time spent performing tasks such as requirement calculations, BOQ and documentation are significantly reduced, and errors that could occur during the otherwise manual procedures are minimised.

The direct link between design parameters and cost allows instant and accurate cost implications to be analysed. Potential savings can be identified and a balance struck between such parameters as material quantities, structural analyses, transportation and desired amenities, without compromising the design and preventing over-provisioning of materials using volumetric calculations. Based on the digital model, our system found the timber requirement to be forty percent less than the initial assessment.

In the parametric definition created, many known and perceived constraints have been included to increase the flexibility and application of the system to a range of possible situations. This gives a designer control of the parameters, and allows quick iterative digital sketches to be developed based on permitted variables.

As a result of the visual variable control afforded through the Grasshopper interface, mixed with the information-rich input from a spreadsheet, the designer is able to quickly determine an optimum solution for a given scenario, work within the computed constraints and develop a sensitive design

solution. More factors can be considered in this way than if done without the aid of the developed digital tools.

Iterative studies of building proportions and formal relationships of the building elements, as shown in figure 4, produces a more refined architecture. This process would have been prohibitively time consuming if performed manually. Better visualisation tools and rapid prototyping also enable the designer to make more informed decisions for the final design.

Figure 4. Iterative studies for Rate Primary and Junior High School, Guadalcanal.

5.2. INNOVATION IN CONSTRUCTION DOCUMENTATION

Parametric modelling facilitates innovation in construction documentation to better suit the scale of the building and the local context. The *graphical schedule of timber members* assists accurate procurement and expedites an often lengthy procedure. Timber members can be cut to the correct lengths at the mill allowing easier handling during transportation, minimizing off-cut waste and cutting by handsaw on site.

Figure 5. The 'construction documents' for Rate Primary and Junior High School, Guadalcanal – graphical schedule of timber and 1:10 laser cut rapid prototype model.

The g*raphical 3D step-by-step instructions* is easily understandable, regardless of prior training or literacy level. The *laser cut model* further assists in visualising how individual elements are assembled. These visual aids assist in understanding and encourage community participation.

Ease of construction provided by the *one-to-one scale templates* for slabs

and junctions allow local carpenters and people from the community to construct a more complex building than was previously feasible.

5.3. RETENTION AND ACCUMULATION OF KNOWLEDGE

The spreadsheets outlining the rationale for establishing user requirements, parametric design variables, the BOQ, and any additional data such as post-occupational evaluations are all interlinked with the parametric model. This acts as one platform for the retention and accumulation of knowledge for even temporary field volunteers, and allows disparate disciplines such as structural engineering and sanitation to operate on the same model. Further, this coherent body of growing knowledge allows management staff from non-construction related background to make more informed decisions.

6. Future research

We tested the use of digital tools for a simple building type as a start, with the intention of implementing the system on other building types such as classrooms, school halls and dwellings, where the benefit of the system for more complex buildings might be expected to be greater. Effective means of further optimisation in areas such as material and structural stability, sunlight and ventilation, will be implemented.

For the ongoing water and sanitation projects, we will expand the model to allow an even higher level of automation in various processes. For example, site selection based on wind and terrain data supplied locally in addition to GIS information; more detailed assessment criteria; inclusion of other toilet types. Evaluation of the effectiveness of the system onsite will be carried out when construction starts in 2010.

7. Conclusion

We started with the aim to apply ‘high-tech’ digital technology to support humanitarian architecture in a ‘low-tech’ constraint-bound context for those most in need. In the course of bridging the gap in generative modelling and humanitarian design, we found ourselves in an emerging field of research, and perhaps addressed some of the criticisms raised on the current use of digital tools by opening up the field to work in more pragmatic but challenging contexts.

Our developed methodology emphasises the need to understand contextual constraints, user requirements, and learning from experience. Building upon existing best practice developed from fieldwork, a system of digital tools was introduced in various stages of the project where opportunities arose.

The system improved accuracy and shortened time required to perform quantitative tasks. The parametric definition allows application of the prototype to adapt to a range of possible scenarios. Iterative studies linked to cost analysis enabled optimisation of solutions otherwise not feasible within time constraints. Construction documentation tailored for local needs improved procurement processes and encouraged community participation. Further, the model allows a growing, coherent body of knowledge for permanent and temporary aid staff to ensure highly skilled outcomes.

Overall, the system contributes to allowing more funds to be spent directly to the project and ensuring the reconstruction programs continue beyond expatriate presence. Further refinement of the system and evaluation of its benefits, as well as its implementation with other typologies will be carried out during and after construction in 2010.

Acknowledgements

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References

Barrow, L., Kumar, S. and Arayedh, S.: 2007, Emerging technology: dilemma and opportunities in housing, *CAADRIA 2007,* Nanjing, 301–308.

Caldas, L. G. and Norford, L. K.: 2003, Shape generation using Pareto genetic algorithms: integrating conflicting design objectives in low-energy architecture, *International journal of architectural computing,* **1**(4).

Chakraborty, S.: 2003, Automated generation of residential room layout within a constrained covered area, *CAADRIA 2003,* Bangkok, 85–100.

Hecker, D.: 2006, Dry-in house: a mass customized affordable house for New Orleans, *Proceedings of the 10th Iberoamerican congress of digital graphics,* SIGraDi 2006, Santiago de Chile, 359–362.

Jinuntuya, P. and Theppipit, J.: 2007, Temporary housing design and planning software for disaster relief decision support system, *CAADRIA 2007,* Nanjing, 639–644.

Kaga, A. and Miyagawa, A.: 2007, Construction of a participatory community space design system, *25th eCAADe conference proceedings,* Frankfurt am Main, 99–106.

Love, T.: 2009, Between mission statement and parametric model, available from: The Design Observer Group <http://places.designobserver.com/entry.html?entry=10757> (accessed 11 September 2009).

Ostwald, M.J.: 2009, Evaluating digital architecture: ethics and the auto-generative design process, *Ethics and the built environment 2009 conference proceedings,* Adelaide.

Pena-Mora, F. and Mills, J. W.: 2001, Component-based architecture for online collaborative disaster relive mission planning environments, *CIDAC,* **3**(2).

Sener, S. M. and Torus, B.: 2009, Container post disaster shelters: C-PoDS, *27th eCAADe conference proceedings, The new realm of architectural design,* Istanbul, 599–604.

Sinclair, C. and Stohr, K.: 2006, *Design like you give a damn: architectural responses to humanitarian crises*, D.A.P. and Distributed Art.

Wen, K. and Chen, W.: 2004, Application of genetic algorithms to establish flooding evacuation path model in metropolitan area, *CAADRIA 2004,* Seoul, 557–570.

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THAI CHILDREN'S PARTICIPATION IN DEVELOPMENT OF 3D VIRTUAL VILLAGE

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Abstract. This paper present the process of virtual world's adaptation to the vision of the real environment designed by the children of two primary Thai schools – a state school and a private school. The main point of the present paper is presentation of empirical research that is an analysis of four exercises – inquiries in which I asked children to draw the elements of their city and social life. The first task was to represent a route from home to school. Next, children were asked to draw the plan of their school, on which they had to differentiate the places dedicated to them, the common spaces and the spaces for another people. The last exercise done at school was related to the description of their family and their closest friends. At the end, the children were asked to draw an inside of their houses with the maximum of details. The results of representations of the daily life environments analysed and synthesised were rebuilt with the graphic computer tools. They will serve as the base of the conception of a 3D virtual village dedicated to the Thai children.

Keywords. Virtual / real; children; inquiry; drawing; pedagogic platform

1.Introduction

In this paper, I discuss what I call the "potentialities" of children's participation in development of a virtual village. This study represents one step in a complex project of 3D virtual platform's creation; witch will be dedicated to children living in countries at risk of various disasters. The idea of this platform is to assist in apprenticeship of behaviors witch will be essential for children in the case of natural disaster. One intention of this project is to adapt the pedagogic platform's virtual world to the children's idealistic vision of environments. Therefore, it is crucial to question the children of concerned

countries about the aspects of their city life. In this paper, I first present the empirical research on Thai children environment's views and how this differs at private and public schools, justifying it with children's cognitive maps.

I interviewed the children aged from 5 to 9 years old and enrolled in primary school. E.g., Philip Walton (1996), *the child draws that, what it knows and its drawing changes during the learning in school. At the age of adolescence, it begins representing that, what he sees.* As for my research, the idealistic environment's vision (that not the real vision) is important. Therefore, I decided to work with the students of three first primary school's classes.

Through partnership with the Faculty of Architecture of Rangsit University (Thailand), it was possible to make a series of inquiries in two primary schools of the northern suburb of Bangkok: Wat Na Wong School (public school) and Satit Bilingual School of Rangsit University (private school). In the first school, I interviewed 83 students from 7 to 9 years old and in the second school – 73 students from 5 to 7 years old. In brief, I investigated a group of 156 children from 5 to 9 years old, coming from all social circles. The experimental works lasted one month, during which we asked the children in Thailand to make a series of four exercises-inquiries:

- The 1st inquiry: "My journey from my home at my school";
- The 2nd inquiry: "My entourage";
- The 3rd inquiry: "My school's plan";
- The 4th inquiry: "The section of my house (a homework)".

2. Thai children's daily journey

As has been noted, first, I asked the children to draw how they move, which areas they cross, next to which buildings they pass, etc. Indeed, the objective of this inquiry was to study the questioned children's urban environment. As an illustration, the drawing's elements was classified in 7 categories:

- Means of transportation
- Fauna / flora
- Constructions
- Landscape elements
- Natural elements
- Things
- Characters

The analysis demonstrates that the most popular means of transportation are: a car (63% of students from Wat Na Wong School and 97% of Satit Bilingual School), a motorbike (19% and 3%) and a bike (8% of students from Wat Na Wong School). The pie charts (figure 1 and figure 2) shows, that in the

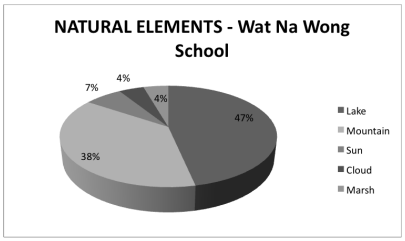

Figure 3. Natural elements – Wat Na Wong School.

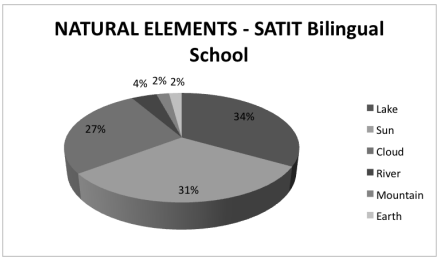

Figure 4. Natural elements – SATIT Bilingual School.

category of fauna and flora, the most represented were trees, flowers, cats and dogs. As the urban environment's elements, two types of constructions were the most often represented by the students of Wat Na Wong School: home (36%) and school (31%). The diversity of buildings drawn by the students of Satit Bilingual School is very remarkable. 23 % of them drew their houses, 22 % – their school, 10 % – a skyscraper (it shows that they come by far).

Afterwards, in the category of landscape elements, a lot of drawings present the traffic signs and the advertising's panels (34% in the School Wat Na Wong and 48% in Satit Bilingual School of Rangsit University). Nevertheless, exterior lighting (25%) and bridges on the road (17%) attracted the attention of Wat Na Wong School's children. Instead, in the drawings of Satit Bilingual School's students we can see: the swimming pools (14%), the green areas (12%) and the bridges (10%).

Figure 3 and figure 4 represent the natural elements, which are well-nigh the same in both of schools. Also, here we see the most often: lakes, mountains, sun and clouds.

However, the majority of children from both schools have designed the flag as the object of their urban environment as shown in the following figures.

This phenomenon is related to the fact that in the Thai schools, the children sing, in front of their country's flag, the national hymn every day. Next, 12% of Wat Na Wong School's students have noticed the presence of a fan and

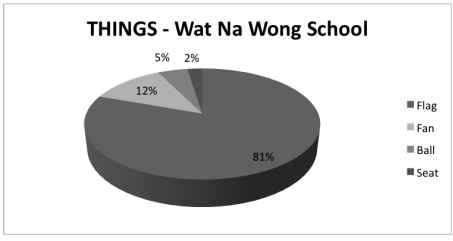

Figure 5. Things – Wat Na Wong School.

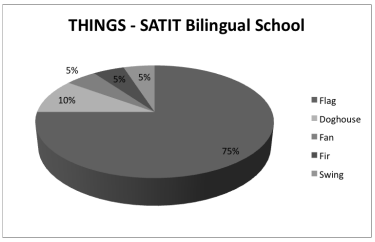

Figure 6. Things – SATIT Bilingual School.

10% Satit Bilingual School's students have drawn a doghouse. According to answers, the children meet the most often every day other children (68 % at Wat Na Wong School and 57 % in Satit Bilingual School).

3. Thai children's entourage

In the basic of 2nd inquiry's data, we can study a child's entourage – its relatives classified by intimacy's degree and relational level. We classified the student's responses in 4 categories:

- Family sphere;
- Relative's sphere;
- Acquaintance's sphere;
- Everyday unknown men's sphere.

I represented the most frequent answers on two diagrams corresponding to the both schools. In figure 7, we can see that the majority of the Wat Na Wong School's students marked their friends in the "family sphere". By comparison, the same children are situated members of their families in the less important positions than their friends. In the "relatives sphere", "acquaintance's sphere" and "everyday unknown men's sphere", they're also the friends, who appear the most often. So, we remark that for this school's students, the friends are most important that their family.

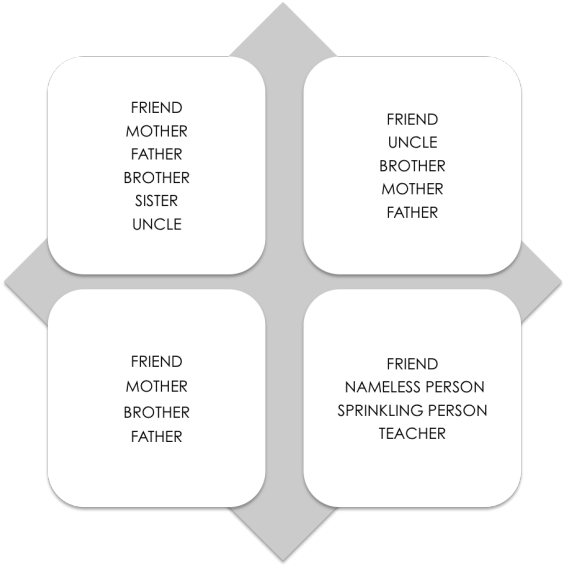

Figure 7. Child's entourage – Wat Na Wong School.

Simultaneously, let's compare the same data of of Satit Bilingual School's students. In the analogous drawings (figure 8), we can found the truth family's member in "family sphere", like a mother (30%) or fathers (28%). In the "relative's sphere" and the "acquaintance's sphere", the majority of children have marked their friends. In "everyday unknown men's sphere", the unknowns are especially found. So, we analysed the persons of which the children would think at the time of a natural disaster and who, in the same situation, would

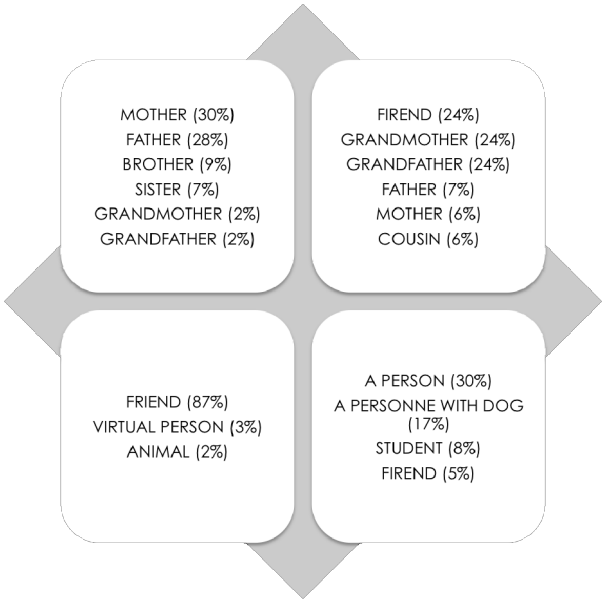

Figure 8. Child's entourage – SATIT Bilingual School.

be likely to accompany them. There is some truth to the argument that these inquiries differ from another three. However, these data are really important for the project of natural disaster's prevention. So, we analysed the persons of which the children would think at the time of a natural disaster and who, in the same situation, would be likely to accompany them.

4. The school's plan

The data of 3rd inquiry are the school's plan, drawn with three distinct colors differentiating the areas where the children feel «as at home», areas "dedicated to everybody" and the areas which their are "forbidden". We classified the student's responses in 3 categories:

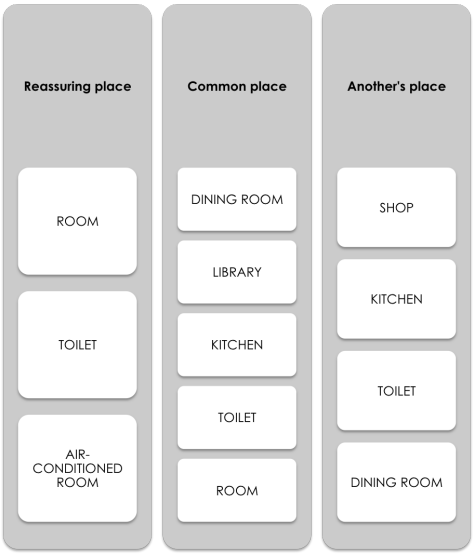

Figure 9. School's plan – Wat Na Wong School.

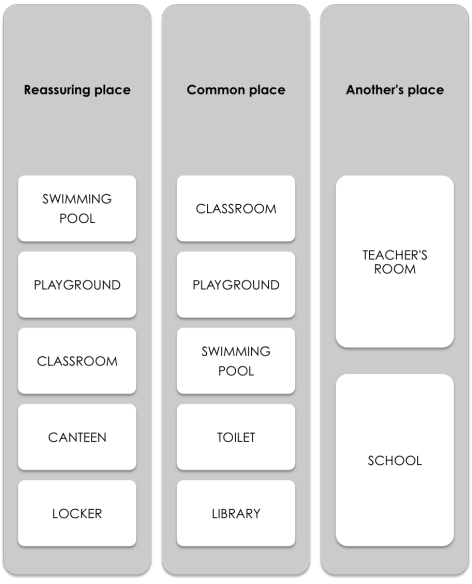

Figure 10. School's plan – SATIT Bilingual School.

- Reassuring place;
- Common place;
- Another's place.

On the diagrams (figure 9 and figure 10), we can observe how the children classified the areas of the school. This allows understanding where, at the school, the children spend the most of time and with which areas they are the most familiarising. Is also interesting to note what different was the answers in the two schools. This proves so those at the private school (Satit Bilingual School of Rangsit University) are many more areas, functions and activities.

5. The representations of house's or flat's interiors

Finally, we asked the children to draw the section of their houses and to represent its interior with the maximum of details. The drawing of the house's interior was the purpose of this investigation. We asked the children to representing the maximum detail. According to pictures (usually, a child has drawn many pieces), we classified the student's responses in 5 categories:

- Bedroom;
- Living room;
- Kitchen;
- Dining room
- Bathroom.

While it's true that just some questioned children deposited to us their drawings (61 students of Wat Na Wong School's and only 15 students of Satit Bilingual School), but it was possible to analyse the sections of all major rooms of the Thai house or apartment. With the details drawn by children it's possible to model the residential buildings and this not only from outside but also from inside. We can than virtually equip them with all things, which the children use in their daily life.

6. Utility of inquiry's results for the development of 3D virtual platform's

The educational application's principles concern the 3D virtual village's creation – a platform in which the children will be able to project themselves in order to integrate different environments, to show there, to move there and to interact there. Great importance will be attributed to the presence of familiar landmarks, which will allow children to feel on known earth and to identify immediately these virtual areas, as if they were in their usual environments. Well, it provide for children, by interactive games, the understanding's bases of different natural risks with which they could be confronted, and the means, which they have to protect themselves from it. Following this first educa-

tional phase, the children will be virtually confronted with real simulation of disasters and of alerts, which they will have to face by proving their aptitude to recognise, to understand and to "know how to react", individually and collectively. The concept of 3D virtual village is based on the rapport with reality.

Therefore, the inquiries made with the Thai children allow modeling a virtual village corresponding to the environment's vision of children. However, this is not by our eyes, then the look of an adult on urban area, which is interesting, but that of future users of the application. So, it is very important that the virtual world reflects the habits of children's living in different countries and that it's related on the best of their real environments.

Well, you could ask in what the results of inquiries led with the Thai children are useful in the development of 3D virtual platform? It is especially necessary to understand the spaces where the children spend the most of time, so the places where, the most probably, they could be surprised by the major events. We could also study their entourage, so the people of which they would think at the time of a natural disaster and who, in the same situation, would be capable of accompany them. Consequently, this study let do take care of children after catastrophe in places where their feel good. With the data's bases collected during these four inquiries, we can develop our research in the field of major risk's prevention and then insert it, as content, in the project of the 3D virtual pedagogic platform.

The virtual village adapted with the method of analysis of environment's childish vision drawings, will allow its young online users to quickly familiarise with the virtual platform's interface and to find their the image of their idealistic world. Without need of adaptation to the strange environments, they can easily enter in the learning interfaces.

7. Conclusion

In brief, I would like to give pause to utility of future user's participation in creation of 3D educational platform. Similarly, this principle is already practiced in architectural or landscape projects. In New York (Flaherty, 2006), the local inhabitants used virtual reality software to participate in the Queen's park conception. This project was updated in virtual space, on the Second Life's site, where a citizen interacted, as an avatar, in adapting of park to their needs. There is some truth to the argument that it will be possible to place the virtual village on one of the popular sites already existing. One of them, Second Life, is a virtual world entirely built and owned by its residents (Webpage without author info, 2009). Its users live there and interact via the 2D or 3D graphic representations of humanoids called "avatars". They promise to respect a series of rules, behaviors and community norms. Blue

Mars (Webpage without author info, 2009) is another popular virtual world already existing. It includes the advanced "futuristic" graphics, the realistic characters and multiple social activities. Its virtual world consists of a network of independent cities in expansion. A reward's system encourages the users to explore, play and make new friends. A city is a theme place, where the users can play, socialise and learn. Each city is represented by a set of independent data and rules. Each city's owner defines its "look" and sets the rules of what is there acceptable. The cities are linked together by a central cities browser that allows to the users to move. The overall reward's system lets the players to earn the points by exploring and playing in different cities. The Second Life and the Blue Mars offer also the education's worlds, which allow the avatars to explore the unlimited choice of distance learning.

Our idea, contrary to the concept of the Second Life or the Blue Mars, isn't based on the desire to create a parallel world imitating a real life. That, we want to develop a 3D virtual village, representing the child's environments, to which we give our purpose – the major risk's prevention. As I have shown, the children's environment studies let do project of virtual platform's world with which the students will identify better.

References

Antier, E.: 2007, *Les dessins d'enfants vous parlent,* Grasset, Paris.

Duborgel, B.: 2001, *La maison, l'artiste et l'enfant,* Publications de l'Université de Saint-Étienne.

Flaherty, E.: 2006, *Public participation in a virtual world, landscape architecture (USA),* **96**(10) Oct. 2006, 136–141.

Jonas, O., Montarou, J., Galmiche, C. (collab.): 2003, *Rêver la ville: utopies urbaines de la cité idéale à la ville numérique,* Editions de la DGUHC, Paris-La Défense.

Lebrun, M: 2002, *Des technologies pour enseigner et apprendre,* De Boeck.

Loupiac, C., Langrognet, J.-L.: 2005, *La ville entre représentations et réalités,* CNDP, Paris.

Lussault, M.: 2007, Les mondes spatiaux du web, *Urbanisme* (France), **357**, Nov. 2007, 69–72.

Sautot, J.-P.: 2006, *Jouer à l'école: socialisation, culture, apprentissages,* CRDP de l'académie de Grenoble.

Wallon, P: 1996, 2004, L'évolution du dessin de l'enfant, *in* A. Anzieu (coordonné par), *Le dessin de l'enfant: de l'approche génétique à l'interpretation clinique,* Éditions La pensée sauvage, France.

Web page without author info: 2009, available from: Open Source Repository http://secondlife.com/ (accessed 20 October 2009).

Web page without author info: 2009, available from: Open Source Repository http://www.blue-marsonline.com/ (accessed 20 October 2009).

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KIDS AND NEW MEDIA

How young people act within virtual architecture

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Abstract. Today's children are familiar with many fields of new media. They can't even resist. Even more they have a more natural approach to new technologies than many of the grown-ups. In several workshops we tried to test how these young students would interact within a virtual environment configured for architectural needs. Providing a special setup equipped with a tracking system and sensors we investigated the children's behaviour and the robustness of our system with regard to the education of elder students and further research.

Keywords. Virtual environment; tracking system; digitised rooms; space sensing.

1. Introduction

These days modern houses consist no longer of bricks, wood, concrete and wallpaper. In fact we find a great deal of large and small computers, controls, electrical devices and small machines, which perform their work mostly unnoticed. These devices change the climate, so that we feel well or produce new acoustic and visual experiences with music and projections. Hence new media already occupied for quite some time our apartments and working environment. Extending Mark Weiser's ideas about ubiquitous computing (Weiser, 1991) even less gadgets like tabs, pads and board-sized writing and displays fill up our spaces (Weiser, 1993). Moreover the "material" (= walls, carpets, furniture, doors, etc.) itself that spaces consist of got intelligent.

But what happens if these areas develop their own life? If a wall isn't any more a wall but a music device? If the floor becomes a meadow? If there grow trees and flowers instead of wallpaper?

We wanted all these fantasies and future experiments to be investigated by children. Our university offers the possibility to invite children of elementary schools to explore everyday life at the faculties in the course of a so called "children's university." So we asked groups of pupils at the age of about 10 years to explore the matter and to try to design virtual rooms and atmospheres. The children came without special preliminaries and were motivated to free up their ideas and fantasies and to think about what future will bring.

Together we tried to explore and investigate rooms and spaces with invisible bricks made out of air, wallpapers made from light and three-dimensional, invisible sculptures one could only hear. Additionally we programmed a kind of a simple space computer using sensors which interacted with our guests to explore how young people react on this matter. Within this environment future humans perhaps may feel just as well as we do these days on a flowering meadow.

Although such environments are still discussed and exist (Greenfield, 2006) we wanted a combination of an interacting room and a kind of independent space computer which enables a creative design of itself. In our opinion this setup is the ideal approach for a future architect and designer to his matter and design needs. One vision is to create a tool wherein he can design with his whole body and bodily expressions. Also setups like this should no longer be reserved for artists and dancers (Zedlacher, 2007).

We adapted and reprogrammed our lab setup (see section 2) which is usually used by grown-ups to meet the requirements of the children, i.e., the ease of handling, understanding, motion and development of creativity. Course after course we adjusted the settings to the findings learned before. In order to draw better conclusions and to keep a better overview of the very complex theme, we divided our investigations into several modules (see section 3), although it is an ongoing and integrated development.

The answer to the question why we invited children to carry out experiments in a highly sensitive and digital world is justified in the nature of young humans. They have a natural and impartial approach to the matter of space and spatial qualities, and they don't distinguish much between analogue and digital media. We discovered that architecture students are already rather fixed in their thinking and prospect of virtual and media environments. They are excellent users and designers within completed modules. But they are not that creative in developing and adapting them to their special needs. In most

cases they "only" use the modules just as tools. They hardly invent or develop "design tools." Human and space are separate identities.

Finally we wanted the outcome (see section 4) to give us more information about virtual and media environments especially how people live and act within. The outcome should also be a benefit for our further research and the teachings with grown-ups (Pan, 2006).

2. Equipment

Our experimentation laboratory "noLAb" is equipped with a Vicon Tracking system consisting of six tracking cameras (figure 1). The experiment space

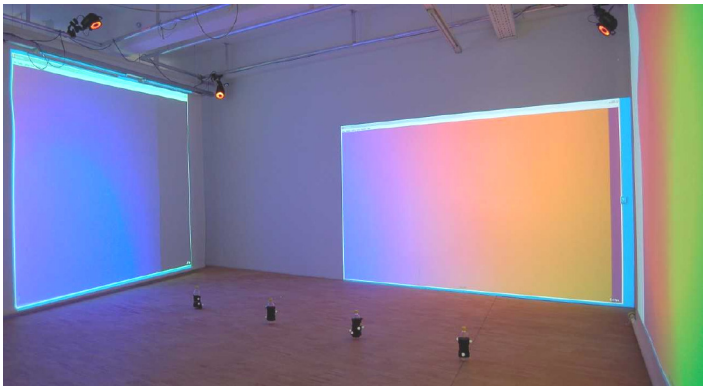

Figure 1. Experimentation laboratory noLAb.

is about 6m × 5m = 30 square meters. For complex tracking setups we can borrow six more cameras from our neighbouring institute which uses them primarily for the tracking of motion in combination with music.

Our cameras track spherically shaped tracking points which can be placed almost everywhere, for instance on a body for full-body motion capturing or simply on a small target just to get the information of one single point in space. The latter we used for the young people. After recording, the tracking data were edited mainly by the software packages "Maya" and "Processing." We wrote a converting tool to format the received Vicon data for our special needs and to facilitate the processing in our desired software. No need to say that the geometry data of the physical room was recorded first and then modeled by CAD software in order to overlap tracked with physical information and to establish an augmented reality setup. This setup enables the use of a head-mounted display (HMD), which we did in fact with undergraduates (at the age of 20). We hold courses with great success and outcome, whereas the practice of an HDM in combination with children at the age of about ten

turned out to be very exhausting. They are hindered in such a way that they are limited in practicing their creativity. And this wasn't our goal. We wanted to create a setup where everyone could interact in a relatively natural way by using gestures, movements of the body, drawing with hands, making own noise, etc.

Further we equipped our lab with canvases on three sides and beamers in order to visualise the interaction of our young "probands." Therefore the canvases were a very important reference tool. They served on the one hand as a kind of walls to give the feeling of a room. On the other hand they served as great windows and offered a virtual view to the environment or nature (fig. 2).

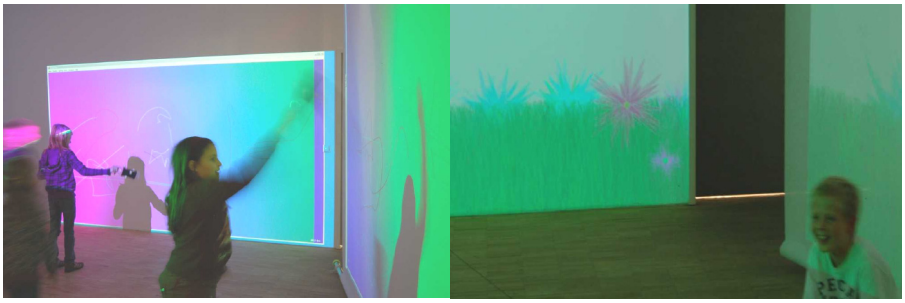

Figure 2. The canvases serve as walls to paint on (left) or as windows to the nature (right).

For audio interaction we used microphones and loudspeakers linked with the tracking system and controlled via MaxMSP.

To take measurements of the physical room conditions we worked with Arduino boards and sensors for humidity, temperature, brightness and loudness. Controlled and analysed was the data by Processing (Fry and Reas, 2007).

3. Modules

We divided our workshops into several modules because on the one hand the interactions could not be yet integrated in one big software package. On the other hand we did not want to mix the various room interactions so that the senses could not be diluted. The level of interaction provided by the system should be related to the experience level of the people using the system (Lidwell, 2003). We started by darkening the room and asked the kids what they would do as future architects to create and enhance their environment. The answers were of course bringing light.

3.1. LIGHT

After discussing what light consists of and how it is produced (of course in a still darkened room) we offered two different possibilities. First we generated "artificial" light by using three tracking targets (figure 3). Each target acted as a kind of virtual pocket lamp emanating red, green or blue light respectively. If two targets came together new diverse colours occurred. All three lamps generated white, which was pretty new for the kids. This was our first approach in creating a mood in the common room.

The next step was to cut virtual windows into the walls (canvases) and to fill the room with "natural" light. Two kids with one target each had to cooperate together and to position the lower left and the upper right vertices of a rectangle in front of the wall (figure 4). They could walk along the wall with the targets and "look through" their window and they stopped as they were satisfied with their choice. To visualise the feeling of looking through a window and to see out we put pictures of famous towns behind. We used this as a kind of riddle to guess what is behind.

Figure 3. Artificial light composed by the fundamental colours red, green and blue.

3.2. SCULPTURES

3.2.1. 2D forms

The next step was to design virtual walls, wallpapers and furniture. The targets were used as brushes and the children painted their own nurseries (figure 5). Very important – as for all workshops – was the possibility for them to act in motion. Almost all creations they built were an expression of their motions. Besides ordinary lines they drew their names, their contours and so on. Surprisingly for us, they started to use their body shapes to form new 2D figures. Although the painted figures looked clumsy, the children started to produce a sort of 3D imagination (see section 3.3.2). To allow more interaction we combined the brushes with sliders which influenced the thickness of the lines and their colours. So the kids had to cooperate again and to adjust their handling on each other (figure 6).

Figure 4. Cutting windows into the walls.

Figure 5. Line sculptures and contours.

Figure 6. Line sculptures influenced by thickness and colour sliders.

Figure 7. The canvases serve as reference media (left). Creating a virtual space sculpture.

3.2.2. 3D forms

We were animating the children to create three-dimensional forms with the targets in our workspace. The basic idea was to draw fantastic virtual furniture in space. The projections on the canvases served again as reference media. Additionally we partially mirrored the workspace on the canvases or showed them the whole room setup on a projection (figure 7, left). It turned out that this three-dimensional task was hard to perform. Although they tried hard they could not get a feeling for the virtual three-dimensionality. This is due to the fact that human space perception is not completely developed at this age (Thurstone, 1938; Anderson, 2009). However nice sculptures were produced by recording the targets paths during interacting between the children (figure 7, right).

3.3. SENSORS

We applied the following sensors in our lab: sensors for humidity, temperature, brightness and loudness. We combined the sensors with our setup in order to facilitate an interaction between the room and the young humans.

3.3.1. Temperature

Space perception is fundamentally connected to temperature which is one of the major tasks a room fulfills. Connecting the temperature that rose with the presence of children in the lab to projected color and patterns was one task to understand the connections between physical space conditions and digital remastered output that ends once more in a physical appearance. More over this opens the possibility for linear and recursive loops, e.g., connecting the temperature sensors through the software with fans and room climate systems. The children learned how the possible interconnections in the noLAb worked.

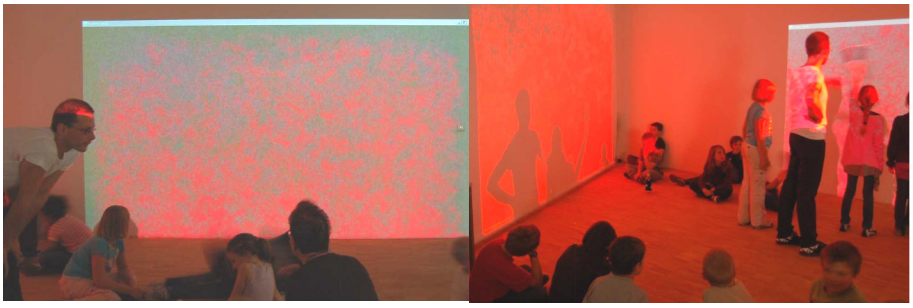

Figure 8. Digital mould scrambles down the walls.

3.3.2. Humidity

To understand the relationship between humidity and mold-infested walls we created "digital mould." While the children were interacting somehow in the lab the humidity factor rose and starting from the corners of the walls some (painted and projected) mould scrambled along (figure 8). As the walls were filled with the mould the question "What shall we do?" came up and was (fortunately) answered with "Let's open the doors and windows!" The humidity factor fell and the walls got white again.

3.3.3. Brightness

According to the example mixing light with physical output (section 3.1) we wanted also to do it vice versa. What about physical light that produces a digital output? We equipped the pupils with pocket lamps and asked them to look for some animals in the darkened room. When the light beam got into the range of one of the brightness sensors a swarm of digital flies started to "swarm" round that point (like they do in real world).

3.3.4. Loudness

The loudness sensor was coupled with nature sound and worked converse to the rough sound level of the room. The more the children were quiet the merrier and louder they could hear the sound samples. In addition we hid the samples in the room so that they had to find and locate them first. Somehow we created dreams for our room that came out if everything else is quiet. In addition to "androids that dream of electric sheep" (Dick, 1968) our space dreamt of electric birds, digital trees and virtual creeks.

3.4. AUDIO

Besides the visual interactions and room reactions we also established also an audible setup. Mankind is such flooded with pictures and videos that the sense for hearing is sometimes forgotten.

3.4.1. Labyrinth

We put "virtual invisible" walls and boxes in form of a labyrinth in our workspace. Kids were divided in groups and had to find the right way through. The targets which they held in their hands served as reference tools. Every time when they got into an invisible wall they heart a sound. By and by they developed a feeling of the labyrinth.

3.4.2. Melody

The second audible interaction used a melody. We divided a popular song for children into several parts and put them somewhere "invisible" in the room. With the help of our targets they could be found which means that if one target was within a special position in the room a melody part could be heard. This was the first goal. The second and more difficult one was to put the parts in the right order so that one could hear the whole song in a correct way. This was possible only if the right target was positioned within its special position and all other targets produced no sound.

4. Outcome and conclusion

After the children got accustomed to the setup they pushed the envelope and the technical equipment operated at full capacity. A new space experience and feeling was developed mainly by motion and interaction. Finally, we drew the following conclusions:

- Children need a short time to become familiar with it, most likely due to their acquaintance with computers, internet, game consoles, etc.
- They accept the digital transformation process which takes place within the environment and let their imagination run wild.
- We realised that they are more capable than grown-ups in accepting the environment as an interacting tool within they can act and "live."
- Children accept a kind of "soul" which is inherent in the environment although they of course know and see that all is virtual.
- While they do not have troubles to interact with 2D worlds, they still have problems with the 3D space. But the use of virtual environments seems to be a good tool to enhance the situation (Duenser, 2006).
- It turned out that the children also have problems with the real scale of interaction. Although they were in motion they could not use their whole bodies to interact. The targets were still foreign objects for them. This we recognised also in various other courses with grown-ups. They seem to be disabled when they should use their bodies to interact.
- We suggest that some kind of "body rituals" must be developed to accustom people to the use of their bodies inside such an environment unless dancers are available (Zedlacher, 2007). We think that it is necessary for architectural students to use their body as a "design tool".
- Plug-and-play quality and perfect operation of the all components – equipment and setup – are indispensable.
- One drawback is still the enormous technical effort including real-time visualisation, cabling, network, beamers, computers, cameras, etc.

And finally: Why these investigations? Because we want to identify our needs and detect the reasons which make a room special and extraordinary. By means of digital media we want to discover why we feel comfortable in a room. Eventually we want to find out how the digital architectural space changes the human being. We think that the help of children is an appropriate way to solve these questions because of their impartial view and approach. In any way one benefit is the use of the developed modules in courses for students, mainly for "Digital form and sculpting motion."

5. Future work

Future questions which we will investigate in a similar way are the followings: How can we communicate with the room in a better way? How can we communicate with other rooms? How can we stash walls? How can the room act more autonomously and react better to our needs? Will the integration of game engines enhance the setup? And finally pushing the architectural students to a new work around: Building the tools they use instead of using the tools non-architects built for other purpose.

Acknowledgements

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References

Anderson, J. R.: 2009, *Cognitive psychology and its implications,* Worth Publishers, New York.

Dick, P.: 1968, *Do androids dream of electric sheep?* Doubleday, United States.

Duenser, A. et al.: 2006, Virtual and augmented reality as spatial ability training tools, *in* M. Billinghurst (ed.), *Proceedings of the 7th ACM SIGCHI New Zealand chapter's international conference on computer–human interaction: design centered HCI,* ACM, Christchurch, 125–132.

Fry, B. and Reas, C.: 2007, *Processing: a programming handbook for visual designers and artists,* MIT Press, Cambridge, Mass.

Greenfield, A.: 2006, *Everyware: the dawning age of ubiquitous computing,* New Riders, Berkeley.

Lidwell, W., Holden, K. and Butler, J.: 2003, *Universal principles of design,* Rockport, Mass.

Malnar, J. M. and Vodvarka, F.: 2004, *Sensory design,* University of Minnesota, Minneapolis.

Pan, Z. et al.: 2006, Virtual reality and mixed reality for virtual learning environments, *Computer and graphics,* **30**, 20–28.

Thurstone, L. L.: 1938, *Primary mental abilities,* University of Chicago Press, Chicago.

Weiser, M.: 1991, The computer for the twenty-first century, *Scientific American,* 94–10.

Weiser, M.: 1993, Some computer problems in ubiquitous computing, *Communications of the ACM* (reprinted as 1993, "Ubiquitous computing," *Nikkei Electronics,* 137–143).

Zedlacher, S.: 2007, Spacensing: a new method sensitizing users and their interactive environments, *CAADFutures 2007,* Sydney, 211–222.

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OPEN-SOURCE, PARAMETRIC ARCHITECTURE TO PROPAGATE HYPER-DENSE, SUSTAINABLE URBAN COMMUNITIES

Parametric urban dwellings for the experience economy

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Abstract. Rapid developments in societal, technological, and natural systems suggest profound changes ahead if research in panarchical systems (Holling, 2001) is to be believed. Panarchy suggests that systems, both natural and man-made, rise to the point of vulnerability then fail due to disruptive forces in a process of 'creative destruction.' This sequence allows for radical, and often unpredictable, renewal. Pressing sustainability concerns, burgeoning urban growth, and emergent 'green manufacturing' laws, suggest that future urban dwellings are headed toward Gladwell's 'tipping point' (2002). Hyper-dense, sustainable, urban communities that employ open-source standards, parametric software, and web-based configurators are the new frontier for venerable visions. Open-source standards will permit the design, manufacture, and sale of highly diverse, inter-operable components to create compact urban living environments that are technologically sophisticated, sustainable, and mobile. These mass-customised dwellings, akin to branded consumer goods, will address previous shortcomings for prefabricated, mobile dwellings by stimulating consumer desire in ways that extend the arguments of both Joseph Pine (1992) and Anna Klingman (2007). Arguments presented by authors Makimoto and Manners (1997) – which assert that the adoption of digital and mobile technologies will create large-scale societal shifts – will be extended with several solutions proposed.

Keywords. Mass customisation; urban dwellings; open source standards; parametric design; sustainability.

> Today's architecture is at a turning point. The big trends of the last decade are outlived and only a few buildings in the world manifest architectural perfection while paving new ways into the future (Otto, 2003).

1. Introduction

Rapid developments in societal, technological, and natural systems suggest profound changes ahead, paralleling research findings in panarchical systems (Holling, 2001). Systems, both natural and man-made, rise to the point of vulnerability then fail due to disruptive forces in a process of 'creative destruction'. This process allows for radical and often unpredictable renewal opportunities. Pressing sustainability concerns, burgeoning urban growth, and novel 'green manufacturing' laws, suggest that we are at a point for urban dwellings described by Gladwell as a 'tipping point' (2002). In this state, unmet desires – unknown and not yet articulated – are rapidly adopted once a solution is presented.

Over a decade ago, authors Makimoto and Manners (1997) asserted that continued adoption of mobile technologies will create large-scale societal changes, many of which have already come to pass in the last decade. Emerging trends suggest the need for a new type of living environment for urban dwellers. For the past century, many have proposed flexible dwellings; however, today a new range of solutions are now possible due to parametric design and digital fabrication combined with open-source standards to encourage the creation of diverse free-market components that are prefabricated and easily combined in different ways by consumers. Such a system would permit the creation of urban dwellings that are flexible, adaptable, affordable, sustainable, recyclable, and mobile. Flexible, tall urban structures follow the same logic advanced by John Habraken in *Supports* (1972). Habraken observes, "The problem lies not with architecture, but with the circumstances that lead to architecture."

These new circumstances may enable developments of, and variations on, visions laid out during the past century by the likes of Le Corbusier, Buckminster Fuller, Archigram, Superstudio, and others. Trends that support this conjecture are examined first. Then, several projects by architecture students at Penn State University illustrate the urban dwelling reconsidered as a nomadic consumer product seen through the lens of branding, as postulated by Anna Klingmann in *Brandscapes: architecture in the experience economy* (2007).

2. Trends in urban growth

In 2008, for the first time in human history, over half of the world's population (3.3 billion people) resided in urban environments. Explosive urban growth is projected for Asia and Africa where it is expected to double by 2030. Urban population worldwide will grow to 4.9 billion by 2030, with slower urban growth expected in developed countries. By comparison, the world's rural population is expected to decrease by some 28 million in the next twenty years, with 81% of the world's population projected to live in urban areas. This requires a paradigm shift for housing.

2.1. THE INCREASING COST OF LIVING IN URBAN ENVIRONMENTS

Among many environmental and social consequences, increased housing cost is a hallmark of urban growth. In the U. S. during the period from 2000–2005 the number of cities with housing expenses at or above 50% of one's monthly income increased 330%, from ten to thirty-three. This is of great concern, especially for low-income people.

2.2. URBAN SPRAWL

The number of US cities with more than half of their residents living more than 10 miles from the center has more than tripled in the last thirty years. Urban centers are becoming both more expansive, and more expensive. Will existing urban models serve this sprawl, or are evolutionary changes necessary?

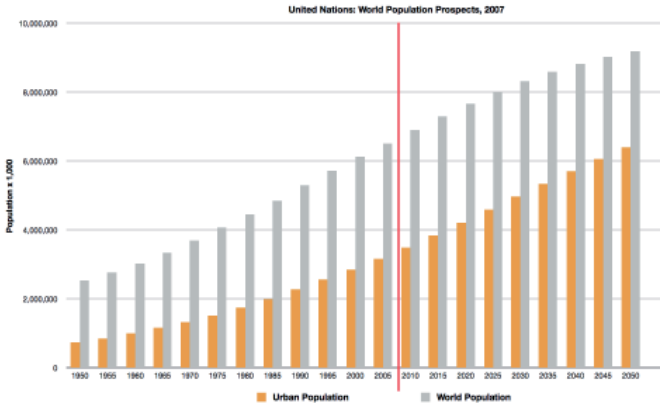

Figure 1. Urban population exceeds 50% of world population (United Nations 2007)

Figure 2. U.S. Cities with monthly housing costs over 50% of monthly income (Joint Center for Housing Studies of Harvard University, 2005).

2.3. PROJECTING FUTURE NEEDS FOR URBAN DWELLERS

The most affordable urban dwelling solutions are provided through rental apartments; a solution which does little to further personal equity. Today, with almost one third of the adult U. S. population renting their dwellings, increasing home ownership for low-income people is an important concern. The average price of new homes in the U.S. is $290K, while the average wage is $58,029. New house payments are approximately 1.5 times more than most workers can afford.

Simultaneously, Americans are moving more frequently, with one in five moving annually. This, too, escalates dwelling costs and productivity is diminished due to the time-intensive nature of moving. Many people in urban environments seek a more affordable and responsive dwelling solution than is currently provided. Prefabrication has long aspired to address similar concerns, but not as substantively as hoped. Due to technological advances, the time may have arrived for this pattern to shift. Digital fabrication and parametric design are poised to provide a new type of technologically savvy dwelling that is versatile, affordable, desirable, and sustainable

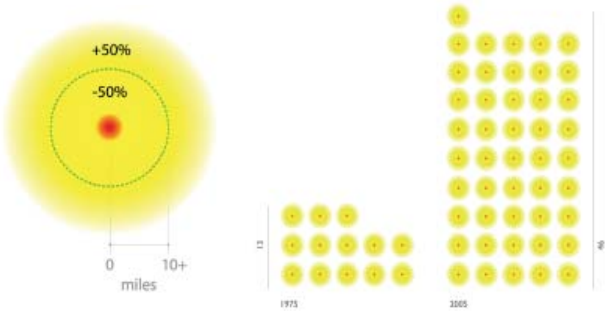

Figure 3. Number of U. S. cities with more than half of residents living more than ten miles from center 1975–2005 (Joint Center for Housing Studies of Harvard University, 2005).

3. The context for prefabrication

Prefabrication is decidedly not new. Over the past century, notable efforts include: Le Corbusier in 1919 writing *Mass production houses;* Walter Gropius and Adolf Meyer develop *Building blocks* in 1923; Buckminster Fuller introduces the *Dymaxion House* in 1929; Frank Lloyd Wright introduces *Usonian House* in 1936; industrial designer Henry Dreyfuss and architect Edward Larrabee Barnes collaborate on the design of a prefab house for Vultex Aircraft Company in 1947; Jean Prouvé is commissioned by the French government to create twenty-five housing units in Meudon, France in 1950; numerous imaginative works by Archigram are proposed in the 1960s; Richard Rogers invents *Zip-up enclosures* in 1968; MIT Architecture launches *House_n* in 2003; and a number of emerging works in the past decade are designed by Kieran Timberlake, Marmol Radziner, LivingHomes, Michele Kaufmann, Resolution 4 Architects (winner of the *Dwell* magazine competition), and many others of note.

Prefabrication has been accepted by the lower end of the housing market (in the form of "mobile homes") but has struggled to gain acceptance at mid- to upper-income levels. While there is renewed design inquiry in the area of prefabrication – as evidenced by MoMA's recent exhibition *Home delivery: fabricating the modern dwelling* – the majority of these solutions are for rural or semi-urban areas. Despite a few bold proposals (by Greg Lynn, Kol/Mac, and others) prefabrication is still largely absent from dense urban settings. One of the significant barriers to greater adoption of prefab – beyond the inaccurate but durable perception of 'inferior construction' – is that each system is unique unto itself, with little cross-platform compatibility. Additionally, sole-source fabrication is required due to intensive tooling for each model. Unique design strategies are ultimately self-limiting as they violate the basic premise of the 'bus-model' of compatibility, which has proven quite successful in computer design. In this model, components from various manufacturers may be easily assembled regardless of brand (Pine, 1992).

4. Prefabrication and Mobility

While prefabrication inherently entails some degree of mobility (since products are manufactured off-site), it does not necessarily *encourage* mobility. Ninety-seven percent of prefabricated structures move just once from factory to installation. On the other end of the spectrum, the RV (Recreational Vehicle) is made *for* mobility but is generally overlooked by architects as a respectable form of prefabrication. This is a mistake. Pre-recession research performed in 2005 by Dr. Richard Curtin of the University of Michigan reveals that

one in six automotive owning families planned to buy an RV in the next five years, while one in twelve already own an RV (Curtin, 2005). These statistics suggest that the RV is quite possibly the most widely accepted and most desirable form of prefabricated dwelling in existence – a consideration which is widely overlooked by both architects and the predominantly "stick-built" prefabrication industry. Makimoto and Manners would contend that the rise of RV purchasing is in part due to the greater liberties offered through mobile computing and cellular phones which began to be widely adopted in the early 1990's (Makimoto and Manners, 1997).

Given that tax codes and financing instruments both consider RVs as second homes, it seems an oversight to disregard the significance of these consumer products and to overlook their status as prefabricated homes. Not surprisingly, due to the ease of mobility and the capability for people to remain 'connected' electronically, increasing numbers are making RVs their full-time homes. With the average ownership age being forty-eight, it is clear that RVs appeal to far more than retirees. RV lifestyles are becoming so popular that the US postal service announced Premium Mail Forwarding five years ago (United States Postal Service, 2005). This is a service that continually forwards mail for the frequently mobile. However, the one main drawback to RVs is that this typology is unwelcome in urban environments. Can we build structures that accommodate urban mobile dwellings?

5. Is urban mobility an oxymoron?

Given current urban growth, along with increased interest in prefabrication, sustainability, and an increasingly nomadic culture resulting from tech-

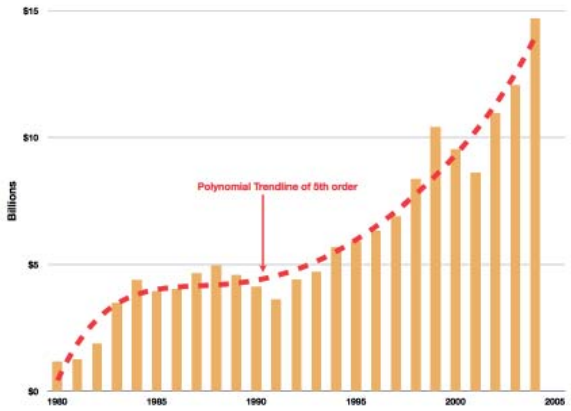

Figure 4. Recreation vehicle revenue 1980-2004 (Curtin, 2005)

nological freedoms, some type of prefabricated mobile dwelling for dense urban environments seems on the surface to be highly desirable; however no such option exists. The necessary ingredients for a solution seem worthy of consideration.

5.1. A RECIPE FOR URBAN PREFABRICATION.

Three ingredients are necessary. If carefully implemented, these suggest possibilities for urban prefabrication for sustainable hyper-dense environments. The first, and most critical, is the development of a set of *universal standards*. In the absence of any overseeing body, an *open-source solution* would easily provide a number of benefits. Due to universal ownership of such standards, this strategy would easily accommodate incremental and proven developments following a number of successful models utilised by the software industry. In some ways, this approach resembles the work by GM for

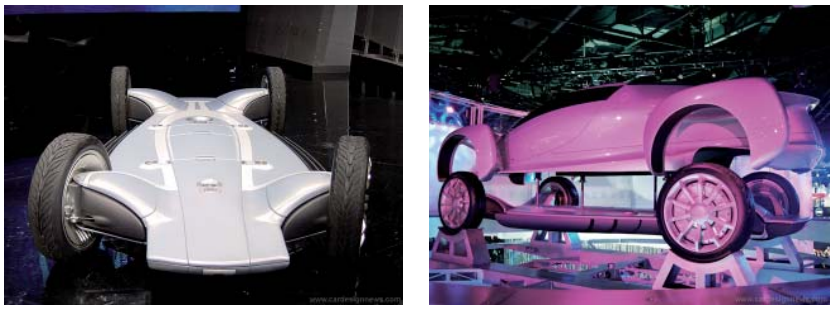

Figure 5. Hy-Wire chassis by GM (photo by cardesignnews.com)

the Hy-Wire Chassis that permits a standard chassis to accommodate multiple parametrically designed bodies. If open-source standards were implemented, tall-buildings could be constructed to accommodate dwellings of the same dimensions as those used by over-the-road vehicles which must fit through highway 'keyholes.'

Second, interchangeable components, based upon these standards, could be uploaded to web-libraries permitting web-based configurators to pre-visualise interchangeable designs complete with pricing and web-based ordering. This method would enable diverse variations designed and / or manufactured by unlimited parties while appealing to consumers eager to easily mass-customise their dwellings in a fashion that parallels purchasing expectations shaped by positive experiences with web-based ordering systems.

Third, *stimulation of consumer desire* is required to overcome the stigma associated with prefabricated dwellings. Banwari Mittal, professor of marketing at Northern Kentucky University, writes that our culture relies heavily

upon brand-name products for self-identity. Membership in today's consumer collective is gained through the purchase of celebrated popular products (Mittal, 2006). These observations have also been applied to architecture by Anna Klingman (2007), who views designers such as Frank Gehry, Zaha Hadid, Rem Koolhaas, etc. serving as brands in and of themselves. Co-branding is also an area offering opportunity, with successful examples by Martha Stewart working with KB Homes, Michael Graves with Target, and Christopher Deam with Airstream.

5.2. GLOBAL INFRASTRUCTURE FOR SHIPPING

No inquiry regarding innovative dwellings would be complete without considering the broad number of works that reconsider shipping containers by the likes of Wes Jones, Jennifer Segal, Hybrid Design, LOT-EK, etc. While inventive dwellings made from these modules makes some sense from a purely economic point of view, these solutions offer limited aesthetic appeal no matter how much they are customized. However, shipping containers do offer a valuable lesson for prefabrication; not the container itself, but rather, the standardized chassis that has enabled a global transportation network. Thus, these dimensional standards, closely resembling dimensions for RVs, seem a likely candidate for a starting point for an open-source chassis. Widely varied solutions that conform to this standard could easily be transported via ship, train, and truck, while tall buildings could utilize hoisting mechanisms (interior or exterior) that easily permit these mobile urban dwellings to easily slot into structural bays in a fashion that resembles an apartment building with removable apartments much like a slip that hosts various boats.

6. Conclusions

This inquiry attempts to cover a broad range of topics in an admittedly limited amount of space, which regrettably prohibits substantive breadth and depth to satisfy all concerns and criticisms. Even so, several hurdles may be difficult to surmount. These are likely to be less technological or societal, but rather governmental.

Governing institutions are historically modeled on settlement patterns founded upon agricultural and manufacturing conditions that no longer exist. Among these are voting boundaries, land ownership laws, tax structures, zoning laws, school districts, and land based utility infrastructures. Increased mobility is simply not factored into this historical model. However, in light of current technological considerations, the cost and popularity of urban habitation, predicted environmental changes, and occupational fluidity, fixed dwell-

ings may at some point in the near future become less desirable for some than options that more easily enable greater mobility for urban settings. Despite many challenges, it appears that if demand is indeed as predicted, it will only be a matter of time for the market to advance governmental models that better accommodates societal needs and / or desires.

However, what is clear is that *uniform standards* are required to realise the possibilities proposed here in order for solutions to broadly propagate. What follows are several parametrically designed proposals, exploring the use of branding for various types of mobile urban dwellings with sustainable construction techniques. Should this tipping point indeed come to pass, a process using parametric design and digital manufacturing techniques could support a new product for dwelling that is more culturally relevant and more consistent with expectations forged through positive experiences with consumer products, thus enabling hyper-dense sustainable urban communities which will be in flux for the foreseeable future.

Figure 6. Puma by Gino Colan, Penn State University

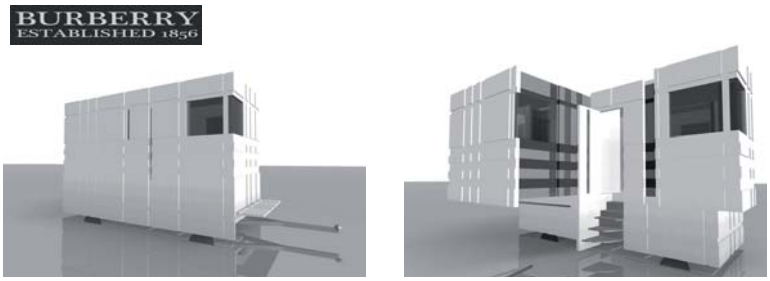

Figure 7. Burberry by Terri Garlewicz, Penn State University

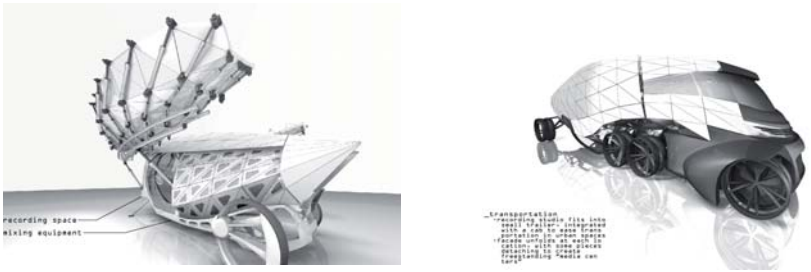

Figure 8. BET (Black Entertainment Television) urban recording studio, by Matt Hoffman, Penn State University.

Acknowledgements

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References

Curtin, R.: 2005, *The RV consumer: a demographic profile 2005 survey,* Recreation Vehicle Industry Association, Surveys of Consumers, University of Michigan.

Gladwell, M.: 2002, *The tipping point: how little things can make a big difference,* Back Bay Books, Boston.

Habraken, N. J., 1972, *Supports: an alternative to mass housing,* Diemer & Reynolds Ltd., p. 80.

Holling, C. S.: 2001, Understanding the complexity of economic, ecological, and social systems, *Ecosystems,* 390–405.

Joint Center for Housing Studies of Harvard University: 2005, *The state of the nation's housing 2005.*

Klingmann, A.: 2007, *Brandscapes: architecture in the experience economy,* MIT Press, Cambridge, Mass..

Makimoto, T. and Manners, D.: 1997, *Digital nomad,* John Wiley & Sons.

Mittal, B.: 2006, I, me, and mine: how products become consumers extended selves, *Journal of consumer behaviour,* **5**(6), 550.

Otto, F.: 2003, Shigeru Ban, *in* M. McQuaid (ed.), *Foreword,* Phaidon Press, New York.

Pine, B. J.: 1992, *Mass customization: the new frontier in business competition,* Harvard Business School Press.

United Nations: 2007, World urbanization prospects: the 2007 revision population database, *Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat,* from http://esa.un.org/unup/p2k0data.asp.

United States Postal Service 2005, *Premium mail forwarding,* from http://www.usps.com/communications/news/press/2005/pr05_043.htm.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010*, 457–466. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

URBAN DIGITAL MEDIA

Facilitating the intersection between science, the arts and culture in the arena of technology and building

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Abstract. The research presented in this paper investigates ways of providing better design applications for technologies in the field of Urban Digital Media (UDM). The work takes an emergent approach, evolving a design strategy through the early engagement of stakeholders. The paper discusses research in a design-led creative intersection between media technology, culture and the arts in the built environment. The case study discusses opportunities for the enhancement of a university campus experience, learning culture and community, through the provision of an integrated digital presence within campus architecture and urban spaces. It considers types of information architecture (Manovich, 2001) and designs for use in urban settings to create communication-rich, advanced and interactive designed spaces (Haeusler, 2009). The presented research investigates how to create a strategy for display technologies and networked communications to transform and augment the constructed reality of the built environment, allowing new formats of media activity.

Keywords. Urban design; outdoor digital media; information architecture; multidisciplinary design; augmented reality; media facades.

1. Introduction and research background

1.1. MOTIVATION

Historically, the built environment has been based on centuries-old materials, construction techniques, and static functionality. Traditional buildings invariably do not change, respond or adapt: they are following an alloplastic mode

of operation, are determinated and static (Goulthorpe, 1999). However, the recent history of the built and urban environment is, to a great degree, about advances in building technologies (Banham, 1984). Late 19th and early 20th century developments in new materials such as steel, glass and lightweight concrete led to a revolutionary transformation of cities and buildings. New complex systems and infrastructures such as elevators, air-conditioning and heating made it possible to inhabit these new spaces.

Contemporary requirements also include adaptability, new modes of communication and transformative environments. Cities around the world utilise the current generation of outdoor urban digital media. These typically include video displays used for commercial advertising. A few cultural buildings have animated art and information media content as part of their fabric (Haeusler, 2009). As cities grow, outdoor digital media has the potential to become a ubiquitous part of our urban environment. There is great interest in the science, engineering and design communities about what will inform advanced urbanism and buildings of the future (Addington, Michelle and Schodek, Daniel, 2005).

Recent developments in advanced digital design software, broadband media and networked design, manufacturing and production processes are now transforming design tools, working concepts and the constructed reality of the built environment (Massumi, 2006). Built environments can have capacity for adaptation and interaction with their users as a result of the augmented technologies built into their initial conception, design, development and eventual operation (Manovich, 2001).

1.2. DEFINING RESEARCH QUESTION

The example of this shift, illustrated in the paper, is centered on the implementation of digital media into an inner city university campus – the University of Technology, located centrally in Sydney, Australia. The presented study aims to consider and answer this key question:

What are the immediate and the future opportunities for a university, as architecture and urban design evolve to take advantage of interactive Urban Digital Media technologies?

The paper first introduces the methodology applied for this research, followed by analysis of interviews, workshops and context studies that presents the backbone of a case study conducted in 2009 as a commission by the university; then work by others to outline the significance and position the research. It concludes with a discussion of the research.

2. Methodology

The research evolved a consultation-orientated emergent strategy, which was favored over a theoretical hypothesis-orientated approach due to the criticality of interactions of the university with its environment and users and thus the need for immediate consultation to inform direction.

It acknowledges that such a process is based on a dynamic mode that inhabits a complex model of actions and reactions (Senge, 1990). Due to applying system thinking, which does Senge define as a process of predicting, the outline of the research method is described in a chronological order following the basis that anything will influence the following steps.

Based on the starting principles, a set of peer information, feedback and ideas initiated a strategy for the research. These evolved from the comparative foundation study, interviews, case studies and brainstorming. The strategy evolved a series of frameworks as scoping categories for project ideas, which can subsequently lead to project applications. Subsequent project outputs will be benchmarked over time using a set of global key performance indices (KPIs), created in consultation with stakeholders. The multidisciplinary evaluation KPI metrics comprise design, technological, environmental, social, economic and cultural criteria.

In detail, the research commenced with a transdisciplinary studio where students were asked to provide foundation studies, case studies and first design sketches. Based on this foundation the authors continued a detailed study of the inner city campus of the university, as well as the building, information technology, social and cultural infrastructure of other universities, enterprises and cultural institutions (such as museums and event spaces). Furthermore, focusing on international case studies, the research continued with interviews and brainstorming with different stakeholders. Four different stakeholders for these sessions were: (1) senior management staff such as vice-chancellors, deans and professors of the university; (2) university staff such as technicians responsible for IT and network infrastructure, as well as marketing staff; (3) industry experts such as event managers, designers, technology experts, curators, amongst others – again on a national and international level with workshops in Sydney and London; (4) students of the university from all faculties at undergraduate, graduate and postgraduate level.

The university is aiming to position itself positively in the following manner: (1) in terms of location in regards to interaction with the city, country and globally; (2) in terms of competing with universities that have a technological focus, locally as well on a national and international level; (3) providing the university with standards and technologies of the 21st century for teaching and learning, and creating a vision for a campus and campus life

in the near future; (4) incorporating the university strategic plan to advance knowledge and learning to progress the professionals, industry and communities of the world.

In the chosen research methodology, stakeholders expressed their ideas, visions and outlooks on how a design-led creative intersection between science, culture and art in the arena of technology and building could be achieved. This consultation involved around 100 people, 50% university staff, 25% students, and 25% external experts and other stakeholders. To ensure a deep investigation, despite the time consuming aspect of this approach, questionnaires were avoided and the consultation was interactive and participative in all instances. The research methodology used facilitated both strategy and project ideas for the enhancement of the university experience, learning culture and community, through the provision of an integrated digital presence within the campus architecture and urban spaces.

3. Case study

3.1. INTRODUCTION

In February 2009 the first step – the transdiciplinary studio, based at University of Technology Sydney, with a mixture of undergraduate and graduate students in architecture, building and design – was run to determinates detail of the institution to be researched. Consequently, later in 2009 the two authors were commissioned by the Chancellery's Planning Group Committee – the body responsible for all new and refurbished building development on the campus – to conduct research that would enable the university to be one of the first in integrating digital media into the campus structure.

At the core of this work was the aim of finding better ways of showcasing, enhancing and encouraging the creativity, vibrancy and energy of the campus users and visitors; catalysing and enhancing a kaleidoscopic rich mix of academic and campus life. The focus of this study was to look at the opportunities for integrating urban digital media (UDM) into the campus. With a $500M AUD comprehensive campus development underway over the next 5 years comprising new buildings and building refurbishment, the timing for this research was perceived appropriate by the university's chancellery.

3.2. REPORTING ON THE STUDY

3.2.1. Foundation studies – student elective 'Esemplastic'

Prior to the research commissioned by the chancellery, the authors carried out a foundation study in the form of a 7-week multidisciplinary student elective

for graduate masters: architecture; and undergraduate: property management, interior design, and visual communication. The elective was titled 'Esemplastic', which is defined as: the power to shape disparate things into a unified whole (Coleridge, 1817). This elective benefited from the input and advice of many university managers and their vested interest in this study. The project criteria were based on a series of advocacies, i.e., design, social, technocratic, political and cultural advocacy.

The elective was formed around a series of four tasks, here explained in four points, each leading towards developing a site-wide urban media strategy; each demonstrating the solutions in a proto typical format. (1) 'Vox pops' – video interviews in which interviewed students and staff could express their view of the campus by responding to question regarding what improvements could be imagined when considering with mobile phone, internet, screens, GPS, RFID tacking, etc. (2) Provide an example of existing Urban Digital Media as a case study, while focusing on public outdoor screening, cultural events and micro market places, to name but a few. (3) In order to gain an understanding of the university context, students where asked to evaluate the existing and proposed master plan of the university and to consider strategically what they would do to enhance these places and spaces, as well as the campus experience. (4) Bring all the interviews, brainstorming and concepts into a design sketch to express and illustrate the ideas for an urban digital media intervention.

All these points led to a development of students' design visualisations, along with argument, supporting information and narrative. The aim of the presentation was an integration of all above points into a diagrammatic design, considering site specific data and a revenue and cost model for the operation.

3.2.2. Urban digital media research

Following the appointment of the authors by the university, the research went into its second stage where the documents collected and provided by students in the first stage of the research were reviewed and then extended in level of detail. Based on the previously described methodology, four steps were undertaken in doing so: (1) analysis and understanding of campus; (2) analysis and research of institutions within the field of enquiry; (3) workshop and discussion of peer review panel and (4) interim review panel for evaluation feedback.

4. Seven frameworks and KPI's

The development of six core strategic frameworks, plus a seventh auxiliary

framework (relating to signage and information, and not covered in this paper), originated through the analysis of ideas, wish lists and strategic suggestions from the consultation exercises. The aim was for any idea to fit within at least one framework. This was demonstrated with over 100 project ideas that were generated during the consultation. Each framework has a set of criteria that any idea must meet. Taken collectively, the frameworks ensure that the campus will be able to benefit from a full and balanced range of UDM applications. The frameworks will become populated over time and brought to life by stakeholders in various locations around the campus. The six frameworks are described, all of which have a highly socio-cultural aspect:

Creative commons: students working in temporary spaces that they have ownership of collaboratively. Located in visible public places, these areas can be made secure. Ideal for outcomes in the arts and design.

Transydney: also creative, a large scale media screen that can be used for events to attract people from across Sydney: student shared work, live global lectures, or simply movies. Outdoor space with provision for 1,000–2,000 people.

Micromarketplace: a business-like layout of screens, podia and meeting spaces that allow students to engage with industry and promote their work in mini tradeshow formats, helping them set up microbusinesses while still at college, or offer consulting freelancing. The university acts sometimes as a broker, sometimes as a host, for the industry partners.

Playsure: mixing up social play and leisure, this framework has a focus on IT for entertainment and engagement: sound system, VJ setups, tiered soft seating for informal talks, plus kids video and game areas.

Social academy: designed for specific outreach programs to engage city locals and visitors, particularly aiming for a mixed ethnic and demographic participation – workshop and event activities will have programmed targets in this sense.

Researchtheque: intended for research collaborations, the researchtheque is where research work can be made visible and have public or audience participation. Ideal for visualising and participative science. Located in very visible places.

An example of a framework project application is shown in figure 1.

Aside from physical space, each framework requires IT and AV equipment of fairly typical format: large screens, projectors, wireless, power, some computers, and various types of bespoke furniture/fit out.

These frameworks have a certain resonance with Cedric Price's ATOM project and his Fun Palace from the 1960's (Price, 2003). However, in the campus project, the proposal is for specifically programmed spaces as opposed

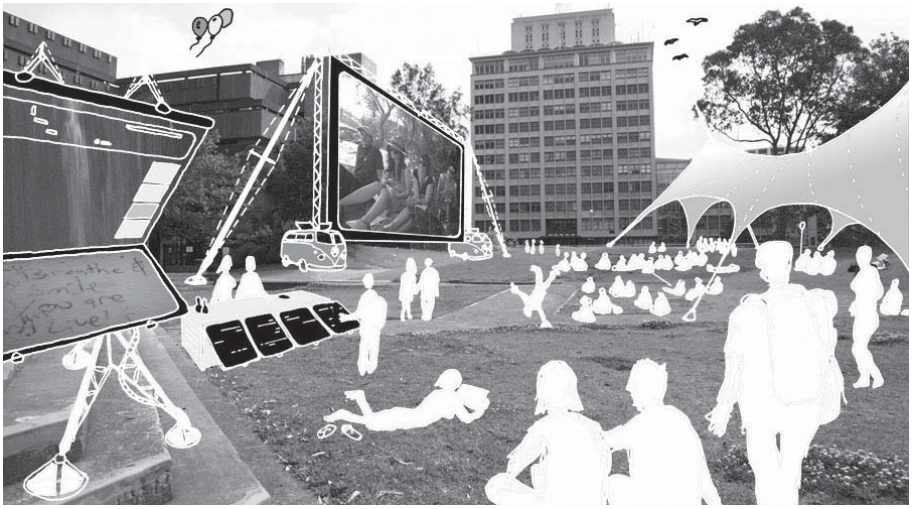

Figure 1. Transydney framework: a project application illustration, showing a giant outdoormedia screen, terminals for logging student work for sequenced group viewing, and a satelliteworkstation for production and scheduling of content. Today's screens can work in daylight.

to generic spaces such as the Fun Palace. This was informed by study of earlier campus interventions that indicated programmed spaces with designed configurations were more readily understood and therefore populated by stakeholders, and hence more vibrant. Programmed UDM spaces were also widely proposed in the work of architect Ron Herron from the 1960's to 90's (Banham, 1994), a member of the seminal Independent Group and Archigram collaborator of the period (Cook, 1999).

The KPI's that span across all frameworks and are monitored over time relate to: funding targets from revenue; sponsored media airtime; green energy sources; maintenance costs; teaching and learning benefits; stakeholder engagement; and media content breakdown by audience. For example: 30% of energy use will come from green energy source, and 30% of media content will be student generated.

The evaluation of the KPI's will take place over 3 years, with adjustment possible during this period. Evaluation will be quantities for numerically measurable aspects, and through stakeholder surveys for the more qualitative aspects. Effectively, the KPI's represent a commitment to the campus stakeholders to ensure that initial intent is met over a continuing delivery period. After 3 years, the KPI's will be fully reviewed with stakeholders and a new set of KPI's may be used.

5. Other case studies in dictating UDM significance

5.1. UBIQUITOUS CITY SEOUL

Since 2007 the central Korean government has been implementing a variety of policies to build a u-Korea. The project is an effort to showcase knowledge information and to enhance the competitiveness of the information industry. It sees the city as a holistic and intelligent system of ubiquitous technologies. According to Choi, a ubiquitous city can be developed through three stages, which are also its three foundational qualities: real-time data gathering; context-awareness (in processing the gathered data to provide the optimum solution within the given context); and finally, 'autonomy in its operation', turning the city into an intelligent and autonomous network system (Choi, 2008). The first and foremost strategy of the IFEZ (Incheon Free Economic Zone) Authority was to create demand through advance investment in public projects. One of them, 'Tomorrow City', is expected to serve as the world's first state-of-the-art u-City (www.koreaittimes.com/story/4371/leading-global-u-city; accessed: October 2009). Here according to *Korea IT Times*, three free ubiquitous spaces – access free space, content free space, and data free space – are built to provide visitors with free opportunity to access, use and exchange content and data. This kind of digital architecture will absorb concepts of augmented reality, GPS location system and ubiquitous robot technology.

5.2. FEDERATION SQUARE MELBOURNE

Though achieving little recognition on the official homepage of the Federation Square (www.fedsq.com/index.cfm?pageID=29; accessed: October 2009) the outdoor LED screen attached to Transport, a distinctive southern entry marker to both Federation Square and Melbourne City, functions as a part of the public space and helps to draw crowds (Haeusler, 2009). The plaza in front of the screen has been designed in such a manner that the LED screen is its center. Due to the positive respond of the public the screen got an upgrade from 38m2 to 65m2 in December 2007. The screen is curated by an own studio manager and lists past, present and future events on a homepage, where one has the possibility to view a program guide and browse the archive for previous events.

5.3. CLOUD COMPUTING

Cloud computing may represent a "missing link" for UDM. Although cloud computing (Knorr, 2008) is not a physical intervention in architectural space, taken in conjunction with pervasive digital networks (eg: wireless internet)

cloud computing can be very advantageous.

How does cloud computing differ from subcontracting UDM computer needs to a mainframe operations model? To answer, the key advantages of cloud computing that contrast with this scenario are: (1) virtually limitless ability to scale both data storage and processing power at short notice, (2) costs are minimal as the revenue models used by the cloud computing providers are based on advertising and not extensive charges, (3) the large user base that shares any given cloud allows economies of scale and greater resource commitment by the cloud operators for innovation investment and upgrades that are shared benefits among the many clients, (4) security against damaged, theft or breakdown of the actual hardware which is mirrored on multiple sites remotely, and (5) quick setup and take-down times for UDM installations that simply need a connection to the cloud.

Currently, the global leaders in cloud computing are: Google, Apple and Microsoft (The Economist, 2009). The largest organisation to switch to a cloud model in 2009 was the UK business Rentokil Initial, with 35,000 employees using Google services (The Economist, 2009).

5.3. CONCLUSION

Two examples show an interest in augmenting public spaces with digital technology. The motivation for both locations can be considered as similar. The aim of both is to combine signage, spaces, and technology to create vibrancy and allow social networking. Cloud computing is not location-based but it offers essential advantages for UDM.

6. Conclusion

The technology components are just a part of each framework: installed screens and other hardware are meaningless without being part of a designed (i.e., space, location and orientation) and programmed (i.e., activities, content and schedules) environment. Successful integration of technology through design and programme into architectural space also reduces the risk of techno-clutter or digital favelas springing up, being visually offensive and compromising other space functions.

Flexibility within strategic frameworks is important. Evidence for the success of the projects will in the end come from user and stakeholder feedback on such criteria: failed project applications will be demounted and reconfigured for use elsewhere. So, the applications can learn from failure over the next 5 years as the university implements the UDM strategy.

Technology is a facilitator and design a catalyst, provided they are used

in well-programmed space. To facilitate the intersection between science and culture, technology must have fitness for socio-cultural purpose. Human physical social networks and culture can still be considered to be the main drivers for this technology.

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The Authors want to acknowledge the contribution of the participants of the workshops in Sydney and London and the staff members of University of Technology, Sydney. They are also in particular thankful for the help of Carli Leimbach (project management), Joanne Jakovich (project researcher) and Mona Lieb (research assistant),.

References

Addington, Michelle and Schodeck, Daniel: 2005, *Smart materials and technologies*, Architectural Press, London, United Kingdom.

Banham, Reyner: 1984, *The architecture of the well-tempered environment*, The University of Chicago Press, Chicago, USA.

Banham, Rener; 1994, *The visions of Ron Herron*, Academy Editions, UK.

Choi, Jaz Hee-jeong: 2008, The city of connections: urban social networking in Seoul, *Proceedings MindTrek: 12th international conference on entertainment and media in the ubiquitous era*, Tampere, Finland, 189–193.

Coleridge, Samuel Taylor: 1817; *Biographia literaria*, vol. 1, chapter 10, 86.

Cook, Peter: 1999; *Archigram*, Princeton Architectural Press, USA.

The Economist, 24 Oct. 2002: *Securing the cloud*, Economist Group Ltd., UK.

The Economist, 15 Oct. 2009, *Cloud computing: clash of the clouds*, Economist Group Ltd., UK.

Goulthorpe, Mark: 1999, Aegis hyposurface: autoplastic to alloplastic, *Architectural design: hypersurface architecture II*, vol. 69, 9–10, Academy Edition, Chichester, United Kingdom.

Haeusler, Matthias Hank: 2009, *Media facades: history, technology, content*, avedition, Ludwigsburg, Germany.

Knorr, Eric and Gruman, Galen: 7 April 2008, What cloud computing really means, http://www.infoworld.com/d/cloud-computing/what-cloud-computing-really-means-031.

Manovich, Lev: 2001, *The language of new media*, MIT Press, Cambridge, USA.

Massumi, Brian: 2006, *Transforming digital architecture from virtual to neuro*, an interview with Brian Massumi by Thomas Markussen and Thomas Birch aka bleep.dk http://www.intelligentagent.com/archive/Vol5_No2_massumi _markussen +birch.htm, (accessed November 2006).

Price, Cedric: 2003, *Re: CP*, Birkhauser, Berlin

Senge, Peter M.: 1990, *The fifth discipline*, Random House Business Books.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010*, 467–476. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

SPIRITUAL AMBIANCE IN INTERACTIVE TEMPLE

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Abstract. This paper introduces a new dimension of *spiritual ambiance* design using a real-world interactive temple design project. The research focus has shifted from users' basic demands for physical design artifacts to the spiritual demands through embodied interaction. Thus, this study aims at enhancing the spiritual reflection in temple design through ambient media in interactive space. The objective of designing spiritual ambiance in temple is to develop a medium for taking the believers into religious contemplation and enhancing understanding of spirit of Bodhisattva Guan Yin. This research develops the design process of interactive space design with spiritual ambiance. Through the three design levels of emotional design principles, the design conceptual model of spiritual ambiance triggers resonances through metaphor association. To verify the conceptual model, the design concept is implemented in the physical space via human-centered embodied interaction. The on-site project not only introduces advanced sensing technology embedded into the temple but also verifies the applicability of human–computer interaction to a new dimension of spiritual ambiance design

Keywords. Human–computer interaction; ubiquitous computing; interactive space; spiritual ambiance.

1. Introduction

It's necessary to reconsider the integration of information technology and architecture due to the change of types and functions in human-being's living

space as the interaction space design popular trend. In recent years, interactive space design has been providing rich digital experience environment for majority people. That means users can experience similar virtual ambiance as physical spaces. Contemporary design trend will not only focus on diversified functional spaces providing, but on human beings' spiritual change. Embodied technology applications for interactive interface are sprung up.

Architects, interior designers, and information technicians have long been working on how to integrate digital technology with the physical environment. This new wave of computer progress provides a reconsideration of the contexture of space. The contexture of space must not only encompass building materials, electronics, and mechanics, but also the consideration of interface forms, user behaviour, environmental psychology and its spatial atmosphere. Moreover, the focus of design research has shifted from physical design to emotional design; likewise, the design focus of interactive space shifts from interaction interface design to experience design, i.e., ambiance design at reflective level. To embody spiritual ambiance in a religious space is not only enhancing the spiritual atmosphere in the temple, but it is also a way to design space at reflective level.

Researchers have worked on various aspects of the integration of information technology and the physical environment. Ubiquitous computing (Weiser, 2002) indicates the third wave in computing where invisible computing technology will be embedded in everyday objects. Works in the sensing-based environment (Culler and Mulder, 2004) try to increase the mobility of information. Sensing-based interactive space takes human behaviour into account, and enables designer to establish an intuitive interactive space. Slow technology (Hallnas and Redstrom, 2001) is concerned about the design agendas for technology aimed at reflection and moments of mental rest rather than efficiency in performance. Their projects, Sound Mirrors and The Chatter Box (Hallnas and Redstrom, 2003), try to let users clearly recognise the hidden significance behind design content. Another related work "The Intelligent Garden" by I.A.Lab (Jeng, 2008) uses virtual images for the reflection of interpersonal relationship.

As part of the environment, information technology is used not only for efficiency but also to enhance the atmosphere of the physical environment through embodied interaction. This research tries to develop the design process of interactive space with spiritual atmosphere for designing users' experience of spiritual reflection. The design process is carried out in a real-world temple to enhance the religious atmosphere in the space for taking the believers into religious contemplation and triggering their resonances of emotional reflection. A Taoist temple, Hu-Ann temple locates at the Lotus Pond in the

east of Zuo-Ying's old community and north of the Kaohsiung City is chosen to implement the study. The interactive setting will be set in the Altar of Guan-Yin of the second floor of the temple. Figure 1 shows the physical conditions of the study site.

Figure 1. The study site is at the passageway of the second floor in Hu-Ann Temple.

2. The concept of spiritual ambiance design

In the book of *Emotional design: why we love (or hate) everyday things,* Donald Norman (Norman, 2005) presents his concept that most objects are perceived on all three levels (dimensions): visceral, behavioral and reflective level. He believes that the objects should be aesthetic and have an emotional impact as well. Regarding a successful product design at reflective level, the designer crosses the gap between users and oneself by "system image" of the conceptual model and expresses the information by physical product. At this rate, for religious space design, the designer's idea may be expressed by messages in spiritual content; likewise, the users enter the ambiance space and understand the thoughts of the designer by spiritual reflection. The diversity of the emotional design and the spiritual ambiance design is that the latter expresses information by abstract religious implication. Therefore, the spiritual ambiance requires more refined process to transform abstract ideas to concrete images as allows users to realise the abstract idea through the ambiance.

The difficulty of abstract idea expression is the deficiency of stimuli to trigger emotions. Such stimuli are touchable, visible, audible or perceivable by nose. The adequate stimuli found by the designer may communicate with the users without fail. The precedent related works indicate that interactive design with ambiance-space theme is able to employ metaphors to trigger human inner emotions. For instance, the project of The Intelligent Garden uses the image of butterflies as the metaphor of the wonderful of interpersonal interaction. Thus, the spiritual ambiance design should pertain to the like of the emotional design.

The metaphor finding is a process of symbols selection and association. The perspectives of affective design (Webpage without author info, 2008) identify that internal feelings generated without external stimuli can be triggered by association to past experience or through deliberation and appraisal. Therein, "association" may help designer find the metaphors as stimuli. In the temple, it is easy to see various Buddhist images, symbols or totems on the wall decoration. With the religious knowledge and cultural experience, people may associate those symbols of decorations to spiritual metaphors without difficulty. For example, in the knowledge of Buddhist culture, symbol of lotus presents much meaning such as reminding temple-goers of the purity of spirituality, inherently pure potential of the mind, religious contemplation or the practice of generosity and opening the heart. The symbol of lions means safe and security; light means stability and peaceful world; dharma wheel presents the historical process of teaching the Buddhadharma; water or dew means to clean our mind.

In order to better deliver the messages to the users, a spiritual scenario with spiritual content would help people to recognise the metaphors easily. Therefore, it would be better to use a folklore story or religious allusion as reference while making symbols selection. The following model of spiritual ambiance design expresses the development of the design concept. The selected religious symbols form a meaningful spiritual content and link the physical and virtual spaces through metaphor association. The spiritual content is transformed to spiritual scenario to enhance the spiritual ambiance in the physical space through embodied interaction. To verify the conceptual model, a real-world example is implemented in the physical space via human-centered embodied interaction.

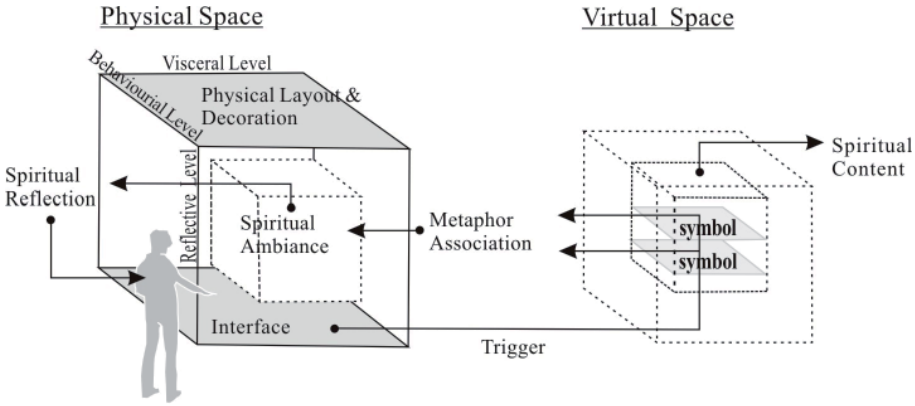

Figure 2. The conceptual model of spiritual ambiance design. The user is able to experience the virtual ambiance through metaphors association while he/she moves in the physical world.

3. A real-world example

The site of the project is a part of the space remodel project in the second floor of the temple. The design process is carried out by a professional team comprised of interior designers, information communication technology engineers, and interactive graphics designers. The interior designer wants to design a transit space linking the ground floor where the Taoist rituals are held and the second floor where people come for complementation and learning. In this project, a proper transit space should be able to make people be quiet before they start to learn Buddhism. The hypothesis for the issue of embodying spiritual ambiance in the religious space is:

Hypothesis: Can the spiritual ambiance be improved through embodied interaction?

3.1. OVERLAYING THE VIRTUAL LAYOUT ON PHYSICAL LAYOUT

Space layout is one of the most critical issues in professional architecture and interior design since smooth mobility render the possible development of space and let users act cosily. Thus, overlaying the virtual layout on the physical space is the problem to be solved first in the interactive space implementation. By space analysis, the physical space is divided into three space units as the front (elevator to overpass), mid (overpass) and rear (overpass to entrance) sections. If the layout of virtual space and the physical space are overlaid, the virtual space shall be altered to be three space units which is a linear space (see figure 3). Likewise, as for the transformation of virtual space, it is more realistic for this case to transform the activity in the space to the idea of walking through a river.

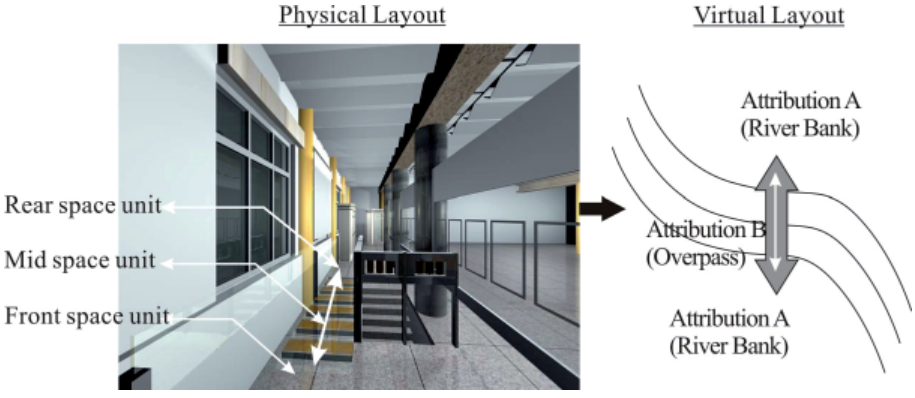

Figure 3. Space analysis helps the match of virtual and physical layout. The physical space is transformed to virtual riverbanks in this project.

3.2. SYMBOLS SELECTION AND METAPHORS ASSOCIATION

In this project, the story of Water-spraying Guan Yin is used as reference to help select the symbols for metaphors association. One day in Sung Dynasty, Bodhisattva Guan Yin held a pure bottle of willows and spayed dew in the pure bottle to the sky for thousand and thousand times to salve the pitiful souls of thousands killed civilians in warfare by Her power. In the story, willows, dews, water reflection seem to represent mental mercies in believers' minds. To make a scenario for the spiritual ambiance, the symbol of dew is selected; meanwhile, a lotus pond and the portrait of Bodhisattva Guan Yin able to let users sense the Bodhisattva's spirits are selected as elements of the scenario. Ideally, dews represent mental purification, lotuses represent Nirvana and the portrait of Guan Yin represents the obtainment of way. Afterwards, the three independent elements are series connected in accordance with the rational sequence to make images and form the scenario:

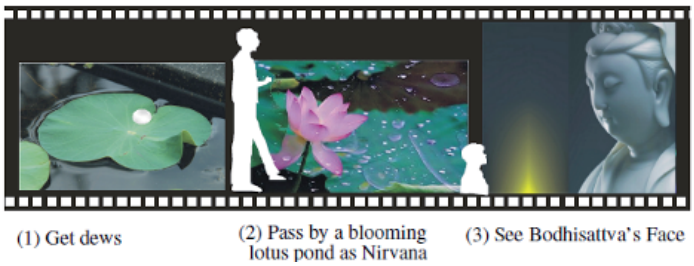

Figure 5. Symbols selection and the metaphors association. The dews creating ripples represent mental purification, lotuses represent Nirvana and the portrait of Guan Yin represents the obtainment of way.

In the process of completing the spiritual ambiance content, the onsite-space realisation renders the close integrity of content and space as if an architect designed the architectural structure in terms of mountain terrains to enable the house to integrate with terrain landscape. The scenario formed with three independent images is the soul of ambiance containing the meaning of spiritual ambiance as well as the language used by the designer to communicate with the users. To enable users interact intuitively with the embodied ambiance, the designer should arrange users' action and movements with coordinate images carefully under the conditions of physical environment.

3.3. TRIGGERS SETTING AND INTERFACE DESIGN

The ambiance content renders the start of designing the device. Upon the advices of the technical team, it is an optimal option to build an environment with automated sensing devices. There are some possible problems in this

phase: 1. How to enable the clerks managing the temple with no computer-related basic knowledge to operate the device? 2. How to fix and hide the sensing device in a safe place? As for technique, we use multimedia player to broadcast images, and a microprocessor to receive the signals transmitted by the sensor for executing the set programs. The first and second images controlled by the capacitive sensor and infrared-rays sensor respectively are presented above the overpass through projecting. Another infrared-rays senor is at the end of the overpass for lighting up the portrait of Bodhisattva Guan-Yin. After the detection model is confirmed, the plot of the entire interactive design is as follows. An image of pond is projected onto the glass of the overpass with lotuses not yet blooming; user stands in front of the lotus pond and put the hand on a 3D handprint mold above a capacitive sensor. At this time, the sound of water dripping and the ripples on the pond are presented. User moves forward and walks onto the virtual pond when lotuses bloom one by one. After passing by the lotus pond, user raises head and sees Bodhisattva in front of him/her. The positions of sensors and correspondent images are indicated in the following figures.

As for the concern of interior and interface design may affect the experience, we design a 3D handprint mold to imply that user can put hand to let sensor detect since it is our expectation to trigger user's curiosity for touching the interactive interface thoughtlessly. The design of the interface is the trigger of the entire interactive device, the first contact point for user to touch

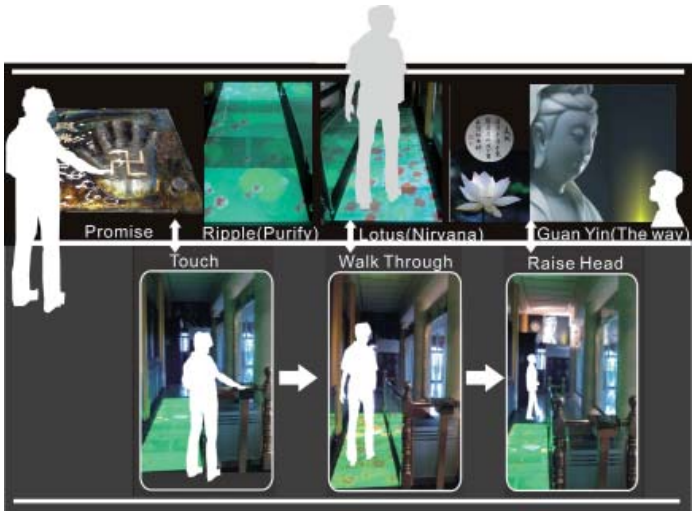

Figure 6. The user's behaviours and corresponding images. User touches the interface in from of the overpass to get dew ideally dripping on the virtual calm lotus pond, and generates ripples. Then user walks through the virtual pond with blooming lotuses. After pass the virtual lotus pond, sensor turns the light on and user raises head for seeing Guan Yin.

the interactive device, which is quite important. In the Buddhist spirits, the handprint of Buddhist symbolises the special mind power and karma. The so-called handprint ties are to realise the mind power and mercy of Buddhist by their actions and behaviours as to expect oneself to generate the merciful mind power and strive for it through the enforcement in daily life routines to benefit the surroundings by affections. Based on the preceding spiritual background, the project of the embodied interaction is named "Mental Touch with Buddhist" which delivers such a design concept.

4. Evaluation

The design process is carried out by a professional team comprised of interior designers, information communication technology engineers, and interactive graphics designers. Integrating multiple disciplines in the temple design project is a challenging work. Besides the difficulties in integrating software and hardware technologies in the temple space operation, gaining the trust and emotions of users are also a challenge. That is, the study must overlay the virtual on a physical setting seamlessly and design the experience in accordance with the daily routines to let users activate interactive software programs intuitively.

To evaluate the usefulness of interactive temple, some believers of the temple are invited to help the usability test and express their feelings about the interactive space. Based on our observations and interviews, most the users show their interests in interactive design in the temple and feel affective with the spiritual ambiance at different degrees. Although users share their understanding about the metaphors, future research is required in the evaluation of users' cognitions.

4.1. RECORD OF TECHNICAL PROBLEMS

In addition to the design concept, there are problems arising from the practical operation worthwhile the references to the future relevant design since this study conducts the research in the daily living space, especially the technical issues involving concerns of plural aspects and levels. Moreover, this study records the technical problems from the test period to the formal use period in one year, and expects to provide the reasons and backgrounds via a sequential lineup as the following figure.

Most technical problems happened in six weeks after the installation was finished. Although there is no big problem discovered in the test term, there are unpredictable conditions after use. One of the manual mistakes is related to operator training, and it happens again when a new staff member is distributed

to in charge with the operation. People tend to click the wrong button instead of the "Open" button. The recording data and conditions are useful for developing future architectural design projects in affective dimension.

5. Developing guidelines for spiritual ambiance in interactive space

One of the basic ideas behind the examples of spiritual ambiance is to use digital information in material in integration with physical and virtual spaces. Taking the interactive temple as an example, the purpose is not to create and exciting visual presentation. The main purpose is to present the material submitted to the temple in a special way. This makes the temple less impressive from a typical decorated point of view. This is a space for spiritual reflection and contemplation. Giving the experience presented here, we propose two basic guidelines for spiritual ambiance in interactive space:

- Focus on the content of spiritual ambiance – the source of ambient elements must relate to users' background or cultural experience so that the elements may become the triggers to lure association; and
- Focus on the spatial integration – the space layout overlaying and interface design will impact the space atmosphere. Intuitive action and movements design help users to involve in the spiritual ambiance.

6. Suggestion for future studies

This study engaged the spatial construction in real world and the participation of actual users in the research. According to the results of the project and the feedbacks from users, the objective improvements are proposed as the references to the future studies. (I) Spatial context: In this study, users used to use the device collectively after the group activity, overloading the original once-a-person design. The negligent spatial use contents affect the usability of the interactive device. The future design shall include the consideration of actual use situation and related data in advance to prevent the gap between the

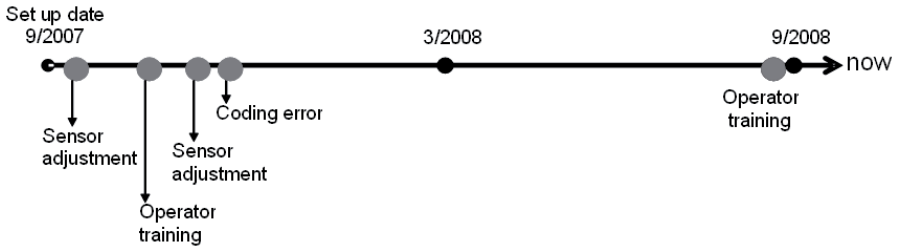

Figure 7. Technical problem and time response table. This study records the technical problems from the test period to the formal use period in one year (9/2007 to 9/2008).

design and actual use. (II) Spatial management context: In this study, the reoccurrences of clicking the wrong buttons resulted from the change of managers affect the working sometimes. This manual fault led to the severe maintenance problems, and shows the importance of operation education. It is better to have a long-term assistance for future work in order to reduce the operated mistake. (III) Cost: In this project, the main expenditures are the construction fees of interactive design software and hardware and spatial reparation cost. Since the education training and continuous maintenance charge are excluded in this project, the long-term complete service is unavailable. Still, it is necessary to designate technical assistants regularly for the participation in the use activity and helping the main users realise further the contents of the interactive design in the beginning year.

In this study, we find that the spiritual ambiance in interactive space plays as the medium of innovation in architecture, which actualised the spiritual world in physical world. Moreover, the design practice provides the HCI researchers with the references of design and execution in the future interactive space and the innovative design process models for inter-industrial and interdisciplinary collaborative experiences.

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References

Aprile, W. and Mirti, S.: 2005, Building as interface or what architects can learn from interaction designers, *Architectural design,* **75**(1), 30–37.

Croci, V.: 2005, Natural methods of interaction or natural interaction in the everyday digital world, *Architectural design*, **78**(1), 120–123.

Culler, D. E. and Mulder, H.: 2004, Smart sensors to network the world, *Scientific American magazine,* June, 85–91.

Hallnas, L. and Redstrom, J.: 2001, Slow technology: designing for reflection, *Personal and ubiquitous computing*, **5**, 201–212.

Norman, D.A.: 2005, *Emotional design: why we love (or hate) everyday things,* 1st ed., Basic Books, New York.

Jeng, Tai-Sheng: 2008, Ambiance design of intelligent interactive garden, *Science development,* **430**, 12–18.

Web page without author info: 2008, available from: Open Source Repository <http://www.affectivedesign.org/archives/199> (accessed 23 Nov. 2008).

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VIRTUAL ENVIRONMENTS AS SITUATED TECHNO-SOCIAL PERFORMANCES

Virtual West Cambridge case-study

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Abstract. This paper focuses on *Virtual West Cambridge* – an interactive multimedia environment constructed to support design and development of a large-scale, long-term urban project. In architecture, such persistent, continuously-growing virtual environments are unusual. Consequently, they pose unique challenges in procurement, development, maintenance and utilization. This paper re-conceptualizes virtual environments as situated techno-social performances rather than software programs or multimedia representations and discusses how this re-conceptualisation can inform their understanding, design and utilisation.

Keywords. Virtual environments; collaborative practice; architectural design; urban design; performative place.

1. Introduction

It is generally acknowledged that interactive multimedia or virtual environments can be useful in many areas of architectural research and practice. And yet, their use in architecture is unusual because they are difficult to make convincing visually, hard to develop, expensive to maintain and awkward to disseminate. The ones that are built cannot compete in visual or functional complexity with those created for entertainment, e.g., for videogames. This paper suggests that some of these challenges can be productively reformulated if such environments are reconceptualised as situated, techno-social performances.

The case study illustrating this argument is *Virtual West Cambridge,* an interactive multi-media environment constructed to support design and development of a large-scale, long-term urban project. At the core of this environment is a three-dimensional digital model navigable in real time. The urban project is located at the West Cambridge site, a growing campus of the University of Cambridge. Construction work there began soon after MacCormac Jamieson Prichard Architects delivered their master plan in 1999 (figure 1)

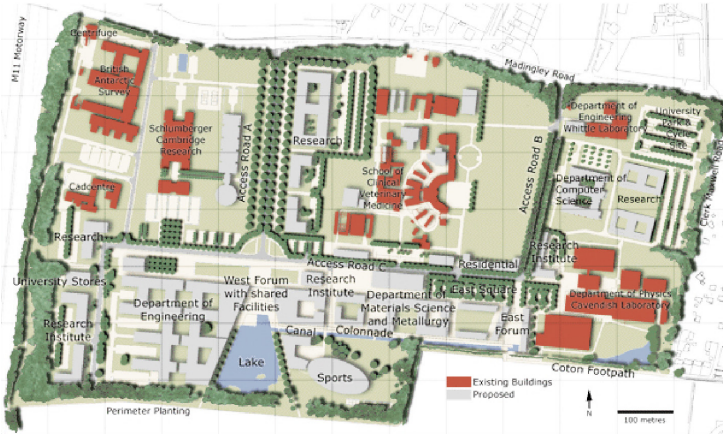

Figure 1. West Cambridge master plan as proposed by architects from MacCormac Jamieson Prichard and approved by the university and the planners in 1999.

Figure 2. Panoramic view of the model.

and the university expects to continue the development for at least 20 years.

Virtual West Cambridge began in 2000 as a sub-project of *The Web-based Participation for Campus-scale Project Design* research initiative (Ruffle and Richens, 2001) and has been periodically updated since to reflect the on-site developments.

Virtual West Cambridge integrates a broad variety of content including terrain model, vegetation model, models of existing and planned buildings, a traffic simulation, weather simulations, avatars of human characters and vehi-

cles, several modes of navigation with specialised camerawork and a context-sensitive interface able to deliver multi-media narratives using text, still images, movies and sound.

2. Techno-social performances

This paper focuses on the situated, techno-social performance of *Virtual West Cambridge* and argues that successful utilization of such environments is dependent on their design as hybrid and dynamic encounters that involve people, objects and places. To provide a brief definition, I understand performance as a *collaborative process of actuating relationships*. This generic interpretative frame can be applied to multiple situations and allows to overcome the conceptual distinctions between human and non-human, technical and social, material and processual by re-conceptualising these phenomena as identifiable by and interesting because of their actions – or performances (on networks of actants and hybridity of technology, see Latour, 2005; on places as situated performances, see Roudavski, 2008).

This focus on performance is useful because it can help to overcome unitary, technical interpretations of virtual environments and suggest new approaches to their appreciation, critique and utilisation. To demonstrate, *Virtual West Cambridge* can be readily discussed as a primarily technical, object-like artefact. After all, at one stage we did plan to distribute it as compact disks or as downloads. However, we found that recipients of these artefacts seldom (if ever) attempted to run the environment on their machines, even when they represented the Estate Management and Building Services, an organisation that acted as the primary client and continuously contributed to the project's funding. Conceptual models that interpret virtual environments as technical artefacts or even as a human-machine interactions lack the tools that can expose, explore and explain these social patterns of acceptance and rejection.

2.1. SERIAL PERFORMANCES

To begin, the focus on performative can emphasise that for the majority of stakeholders *Virtual West Cambridge* appears not as a single-user, desktop application but as a series of staged and spontaneous events of varying frequency and duration. These events are staged in offices, studios, seminar rooms and lecture halls; publicly—in large scale at exhibitions, festivals and open-day events; or in chamber settings—during development meetings, internal presentations or weekly briefings of the West Cambridge site-development team. These events varied in size, longevity, focus, recurrence and composi-

tion flexibly adapting to particular situations and attaining benefits impossible through private, single-user, desktop-access encounters.

Sequences of public performances created a cumulative effect, significant for developers, clients and some of the other stakeholders. Repeated encounters with the virtual environment helped to negotiate long-term issues with different groups of stakeholders. For the developers, regular public engagements served as opportunities to receive instructions or suggestions or respond to comments. These encounters guided the technological experimentation and suggested experimental design decisions, directly contributing to the development of expertise shared by a diverse group of collaborators.

2.2. THE CONSTRUCTION SEMINAR

The paper is too short for an extended comparative analysis of different settings. Instead, the subsequent text will highlight the circumstances of one public staging that occurred when the Estate Management and Building Service asked to include *Virtual West Cambridge* into the program of their Construction Seminar. More than 200 UK and oversees delegates specialising in design, construction and education attended this event that "looked at the affordability of high quality standards of architecture and construction, and challenged attendees to consider their role in the continued improvement of working practice in the industry" (EMBS, 2004).

To participate effectively, *Virtual West Cambridge* had to be transformed into an appropriate form, specific to the host space and the structure of the event. As the description below will show, this event depended on the situation surrounding the virtual environment as much as it did on the content it delivered or on the interface it utilised. In fact, it can be said that the situated social performance into which the software object was submerged, began to function as its extended physical / digital / social interface. In this case, *Virtual West Cambridge* was setup in a niche partially sheltered by temporary screens and connected to the surrounding open space that linked main entrances, exhibition areas and the café. This setting created a stage that was visible and well-defined. In the niche, a laptop positioned on a table ran the virtual environment. A digital projector duplicated the laptop's screen in large format on the white surface ahead of the table. There were several chairs and some empty space behind the table. A poster containing information about the developers hang on the wall and leaflets describing other relevant projects lay on the table.

However common as an exhibition setup, this layout created additional affordances for the virtual environment. During lectures, only a few people remained in or passed through the central core of the building. Between lec-

tures, it became crowded. Two development-team members were usually available at the Virtual West Cambridge niche and in the busy moments, other stakeholders joined in. In quiet moments, the projection showed the virtual environment via an automatically moving camera but most of the time the developers navigated the camera or one of the avatars. The developers' actions attracted attention, demonstrated that the projected images were navigable and invited inquiries from the visitors. In this setting, it was easy to invite visitors to navigate, offer instructions and assistance. The conversations were not limited to those between the developers and the "public." Rather, in the context of the conference where most of visitors had shared concerns, discussions emerged spontaneously from overheard statements, observed behaviour or on-screen events. Compatibly with this atmosphere, the developers, instead of offering formal presentations, improvised, thus retaining opportunities for on-request exploration and serendipity characteristic of interactive environments. Even when not asked directly, they were able to interfere and offer / solicit additional information on the issues that could otherwise remain unexposed. That day, many visitors came to see Virtual West Cambridge more than once. People who first came in a busy moment returned for a one-to-one discussion and a closer experience in less busy times. On the other hand, people who first came in quieter moments returned to see the reactions of others, meet new people and exchange opinions. An immersion into a relevant physical location was also significant because visitors could refer to the character of the surroundings when comparing affordances of various university sites. Such references were relevant because the Centre for Mathematical Sciences that hosted the Seminar was recently completed by the Estate Management and Building Services who also managed the West Cambridge site and were responsible for all other construction work of the university. To summarise, a public performance of Virtual West Cambridge as a hybrid that mixed physical, virtual and social in a relevant location provided a topical forum that fostered meaningful exchanges between stakeholders on a broad variety of issues.

The public socio-technical performance of *Virtual West Cambridge* during the Construction Seminar took place after a series of similar engagement and benefitted from previous experience. However, the interpretation provided above did not exist at the beginning of the project and, even at the time of the event, has not been actively guiding the development. Rather, the theoretical perspective discussed in this paper, emerged as a result of engagements that featured *Virtual West Cambridge*. With hindsight, an implementation of a more systematic strategy designed to explore the characteristics of socio-technical performances and maximise their benefits could usefully inform the

development and utilisation of *Virtual West Cambridge*. What could such a strategy entail?

2.3. THE SOCIAL FIELD

If a similar project were to be attempted again, I would arrange for an analysis of socio-technical relationships relevant to the project. A specific design for such a study would depend on the particular project but would likely take the form of an ethnographic engagement that could uncover unobvious stakeholders, establish significant issues of concern and follow the dynamic interactions between the affected parties. Integrated into the project from the start, such a strategy would support a critical exploration of the issues, enrich and broaden the subsequent public performances of the virtual environments and could result in unexpected contributions and utilisations.

As it is, I find it much easier to trace the technical development of the project rather than the social aspects of its evolution and usage. Like all human endeavours and technical artefacts, *Virtual West Cambridge* is a response to a variety of motivations. Through the years, the project was controlled by a diverse collection of parties with varying interests and goals. Its results were reported to different stakeholders with similarly diverse powers, expertise and criteria for success. During the life of the project, it has been discussed and / or utilised as a three-dimensional component of web-based participation in design; as a pragmatic replacement of a pre-existing physical model; as a test bed for experimentation with interactive narratives; as a publicity instrument and so on. Now, 10 years after the project began, it is difficult to disentangle these goals and motivations, or be clear on their never-ending permutations. While some archaeology of development is possible through interviews and archival analyses, many in-the-moment situations are forever interfused with subsequent authoritative, profit-seeking and partial narratives (including my own) promoting particular interpretations. An important lesson of this experience is that such projects need to be supported from the outset by an interpretative strategy seeking to include all relevant stakeholders and document significant events according to these stakeholders' often startlingly incompatible visions.

2.4. MULTIPLE NARRATIVES

Indeed, the foregrounding of multiple narratives is one of the more interesting achievements of the performative understanding. Reflection on the complex involvements that make up the West Cambridge scheme – or many other architectural or urban projects – suggests that it can be useful to think about

virtual environments as stages for stakeholder conversations (or shared co-performances) rather than pulpits for authoritative argument-making. Assemblies of narratives supported by a variety of representations can better reflect the relational complexities of places than singular interpretations.

Public performances of *Virtual West Cambridge* supported this multiplicity by committing experts and other participants to discursive encounters. Thus, apart from providing support, developers could publicly reflect on the current challenges, critique design decisions, offer information on limitations, explain the political background, share stories of implementation, discuss future possibilities and draw parallels with other projects. Other collaborators (including consultants, clients, site developers, engineers and landscape architects) could support or resist their narratives by providing expert advice on specific issues, contributing alternative interpretations, drawing attention to the concerns beyond those directly represented by the virtual environment and point out the issues on which the virtual environment was incomplete or misleading. A wide range of people beyond those involved with the project could also contribute opinions through discursive public performances. Provoked or encouraged by the virtual environment, various groups of stakeholders were able to question the attending experts.

Public performative engagements cast all of the participants into various, temporary roles: navigators, commentators, advocates, critics and so on. The ability (or need) to change roles in response to challenges arising from the discussions helped the participants to appreciate the spectrum and complexity of the issues making up the West Cambridge development.

Discursive encounters between stakeholders often emerged serendipitously. Navigating or being present next to *Virtual West Cambridge* did not prevent people from overhearing the explanations given by the experts or participating in the discussions. Often, developers navigated through the environment following suggestions of the visitors looking for visual support to their arguments or interested in technical and expressive capabilities of the virtual environment. Other people could hear these suggestions and see their on-screen consequences. Observing the choices and comments of others, visitors often intervened with their own statements of support or disagreement.

Public place-performances of *Virtual West Cambridge* brought together people that normally had little opportunity for communication. For example, researchers and students of the Centre for Mathematical Sciences came to see *Virtual West Cambridge* and were able to enter into conversations with the experts attending the seminar. By presenting the issues in a visual and navigable form, *Virtual West Cambridge* contributed to the task of translation between parties of widely varying backgrounds.

The presence of multiple narratives makes for richer, more rigorous representations. Virtual environments are necessarily constructed by experts (even though new modes of delivery might change this situation) and experts tend to offer narratives that comply with their worldviews or benefit their interests. They do so by focusing on particular aspects, providing targeted visuals, referring to selected examples and presenting their views as logically sound arguments. This focusing on the positive qualities is only natural for designers promoting their projects. However, if unchallenged, experts' narratives can overlook significant issues or ignore important participants. In a public setting, constituents can question the way experts represent design situations, formulate problems and justify design actions.

2.5. DYNAMIC SYMBIOSIS

If, in addition to preparing the software, the developers take into account the circumstances of particular performances, they can, in consultation with other stakeholders, assemble custom configurations to suit the narrative situation, the venue, the audience, the type of intended interactions and the available technical capabilities.

In the *Virtual West Cambridge* project, this attention to specificity of situated techno-social performances suggested a solution that focused on maintaining only one hardware / software implementation. This implementation was developed through multiple field rehearsals and was continuously reconfigured or rebuilt to sustain the ever-growing virtual environment.

Building *Virtual West Cambridge* as a dynamic symbiosis of custom-built hardware and software allowed the developers to save resources while gaining access to the latest technical capabilities (of mainstream hardware). Releasing *Virtual West Cambridge* as an application to be run by generic computers would require more expertise, time and money than non-commercial projects can ever afford. Even developers of high-profile videogames constrain their software to a limited range of hardware to limit the need for testing and servicing. Despite such self-imposed constraints, they usually maintain technical-support departments that provide advice and issue patches long after the initial release. In research or architectural practices, the resources necessary for such provisions are rarely if ever available. Without extensive documentation, institutionalised support or active user communities the *Virtual West Cambridge* software would be exclusionary to people lacking appropriate equipment or unable to make it work.

Logically, a decision to have only one functional instance of a software implementation severely limits its reach. However, in the specific circumstances of this project – seen through the interpretative frame of the performa-

tive conceptualisation – this approach resulted in greater and deeper exposure and utilisation.

Commitment to delivery through public performances delivered through such a continuously supported solution, rather than through the distribution of objects, allowed the stakeholders to utilise a virtual environment in the state of on-going evolution. This exposure of an incomplete environment was possible because the co-presence of developers during public performances eased the entry for first-time or infrequent participants and ensured continuing access to support and guidance during their engagements. The absence of developers from the scene of engagement would necessitate locking *Virtual West Cambridge* into a stable form before any public exposure, as is the norm with most of publicly released software. Commercial software transfers into production only when developers terminate the design development and lock the form of a project into a version number. This closure (temporary if the new version is also planned) enables testing, fine-tuning, debugging, preparation of documentation and the final release. Delivery through managed public performances eliminates the need for closure or explicit development cycles, instead providing the ability to integrate changes quickly thus keeping the virtual environment flexible and open. In *Virtual West Cambridge*, flexibility and openness were essential because the project supported the site in continuing, long-term development. These qualities made updates easy and supported experimentation with technical solutions and modes of representation in parallel with public performances and consultations.

3. Conclusion

This paper used the *Virtual West Cambridge* project to demonstrate how an understanding of virtual environments as series of situated techno-social performances rather than software applications can be beneficial in their utilisation and design. These benefits can help to construct virtual environments that are more economical, efficient, flexible and powerful or, in short, more used and more useful.

In addition to contributing this interpretative frame, the *Virtual West Cambridge* project highlighted a number of difficulties in development and distribution of virtual environments outside of commercial settings that rely on mass sales (of multiple copies, as in the case of traditional videogames, or of subscriptions, in the case of massive multi-player online environments). These difficulties suggest possible directions for future research and design.

These further efforts should be motivated by the desire to actively involve all relevant stakeholders into performative and interpretative events associated with virtual environments. Efforts towards this goal ought to be integrated

into virtual-environment projects from the outset and have to include systematic support and appropriate tools for discovery of hidden actors, unexpected issues/concerns and unobvious interpretations. This work has to be supported by specifically designed methodologies that can integrate ethnographic (e.g., participant observation) techniques that would enable designers / researchers to closely follow the actions of the stakeholders. These methodologies can be informed by the existing work in other fields but will require re-design and adaptation. For example, they will need to incorporate tools able to account for dynamic metamorphoses of socio-technical performances and co-represent their multiple aspects.

Knowing the actors is not enough and sometimes impossible without their direct involvements with the issues at hand. The need to campaign for participation recasts the task of virtual-environment design from the form of a predominantly technical challenge into that of an exercise in curatorship, similar to that necessary for other public events, such as exhibitions, museum displays or even periodic publications.

These efforts to design virtual environments as a series of public events (after all they are intended to be seen) need to be further supported by the technical solutions and conceptual strategies that could flexibly integrate multiple narratives of viewpoints into the representational apparatus of the software/hardware symbioses.

The conceptual model described in this paper and the proposals for future work offered by way of conclusion pose new challenges but also promise rewards for the computer-aided design and research communities.

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References

Estate Management and Building Service: (2009/11/13), *Building for the future*, [online], available from: <http://www.admin.cam.ac.uk/news/dp/2004070702>.

Latour, B.: 2005, *Reassembling the social: an introduction to actor-network-theory*, Oxford University Press, Oxford.

Roudavski, S.: 2008, *Staging places as performances: creative strategies for architecture*, PhD thesis, University of Cambridge.

Ruffle, S. and Richens, P.: 2001, Web based consultation for Cambridge University's building program, *in* W. Jabi (ed.), *Reinventing the discourse: proceedings of the 21st annual conference of the Association for computer-aided design in architecture (ACADIA)*, Gallagher Printing Inc., Buffalo, N.Y., 366–371.

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INTERACTIVE MESSAGE WALL

A public display for collective sharing in real and virtual place

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Abstract. In this paper, we propose a design of an interactive message wall as a public display for large group setting such as a university community to encourage user participation, social interaction and creation of user content. It is a public display for collective sharing of thoughts. It is also a portal for online users to make their presence felt in the physical place. Both users at the physical place and in an online virtual world can post messages to the interactive message wall. The paper will present user studies carried out with a mock-up message wall to establish how onsite users use it, their preferred ways to leave messages, what medium of content (voice, photo, text, video) they are willing to share, and user participation. The results of the user studies will inform the design of the interactive message wall and provide learning points on how to promote user participation.

Keywords. Interactive message wall; public display; ubiquitous computing; virtual worlds; second life.

1. Introduction

Advancement in display technology has resulted in display screens such as plasma, LCD and LED screens being more affordable. There has been a proliferation of digital display screens placed in public places such as shopping centres, office lobbies, university campuses and public buildings. However, they are merely billboards for advertisements, and one-way dissemination of information such as news flash and announcement of events. The viewer is receiving information in a passive manner. With recent developments of technologies for interactive environment, such as sensing and wireless technolo-

gies, new communication services become possible and there is great potential for such public displays to become a medium for social communication among people in the public place and be more engaging for the people.

Use of 3D virtual worlds such as Second Life is increasingly popular but in-world activities exist only in the virtual realm. Users of virtual worlds are disconnected from activities happening in the real-world physical space and people in the real-world space are not aware of the presence of users in the virtual space without turning on their computer. How can we connect these two groups of people using public display medium?

There are many projects that experimented with public displays of digital messages, images or videos. In Joe Blogg (Martin et al, 2006), users send messages and images using mobile phones onto a public display. In TexTales (Ananny, 2004), users send SMS text message captions to a large scale photographic installation. In CityWall (Peltonen, 2007) users send media content using mobile devices to a large public display. Blog wall (Cheok, 2008) displays poems on a screen based on users' SMS. However, none of these projects deals with connection between the virtual and the real space.

We propose an interactive message wall to connect users between the real and virtual worlds. The wall will exist in both the physical world and virtual world. It allows user content to be publicly displayed and serves to promote communication and awareness of presence between users in both worlds. It is a "space" to share collective thoughts of a community whether you are in the real or virtual worlds. People at the physical place and in an online virtual world such as Second Life can post messages to their respective interactive message wall. The message will appear simultaneously in the walls in both worlds.

Before arriving at the design of the interactive wall, we had people use a mock-up message wall to test our ideas and identify problems. The method of study was through surveys, interviews and user observations. A total of 47 persons took part in the survey. The mock-up message wall was placed in a busy area in the university campus. Anyone could walk up to it to leave a message in a few ways, in response to a topic of the day.

2. User study

To develop the interactive public display, previous studies on design methods are reviewed. In Rogers' (2004) survey, most researchers or designers who are working in the human–computer interaction (HCI) field use design methods such as scenarios, storyboards, sketching, low-tech and software prototyping, interviews, field studies and questionnaires. These design methods are important in the early design stage to find out the problem before decision on

the design. In Buxton's (2007) study, many interaction design cases use a low-tech prototyping such as a mock-up that users can experience.

"Low-tech prototypes are especially important as tools to test ideas during early design. This is because they are easy to make, allowing designers to quickly expose the problems before committing to decisions" (Johnson et al., 2008).

Using these initial design methods, user observation data, and user feedback are used to apply to the development of the design. We did a low-tech prototyping model to carry out a user study to find out the following:

1. To understand and analyse user preference of three different methods to input messages. The methods are handwriting, text by mobile phone and voice.
2. To understand how people use the medium of input and their privacy level of sharing information.
3. To observe user behaviour and discover anything we did not expect.

A low-tech prototype model of the initial message wall designed with the basic concept for people to share their thoughts in the public space was set up in a busy area on campus with high pedestrian traffic. A white board simulated an interactive public display (figure 1). Topics were placed at the top of the board to be seen from afar and the tasks are explained below the topics. The participants are requested to leave messages for the following topics: "What is the first thing you will do after the exams?" and "What is your favourite landmark on campus? Why?" Three different ways of leaving a message were available to participants – handwriting using post-it, voice recording using microphone (simulated by a windmill that would have a hidden microphone) and sending SMS using mobile phone. Participants stick their handwritten messages on the board after writing on post-its. But SMS message and voice message cannot be displayed on the board since we are using a prototype

Figure 1. Low-tech prototype model for initial user study.

model. It was explained to the participants that voice and SMS messages would be displayed on the wall in a working message wall.

2.1. DATA COLLECTION

We collected data through questionnaires, interviews and user observations.

Questionnaire. After the participants experienced what they are tasked to do, they were given a questionnaire to fill in order to collect quantitative data on: 1) which ways users prefer to post messages on the public display, and 2) how willing they are to share their contents with the public.

Interview. An interview is used to collect the qualitative data after their participation. The concept and purpose of the message wall were explained to the participants. They were then asked how they felt, how much they understood and their feedback after experiencing the prototype.

Video observation. With the permission of participants, their actions were video recorded. We analysed what they said, how long they took to post their message and what was happening when they were posting or looking at the public display

Post-analysis of user messages. The messages from handwritten message, voice message and SMS message were analysed to compare the three different ways of leaving messages.

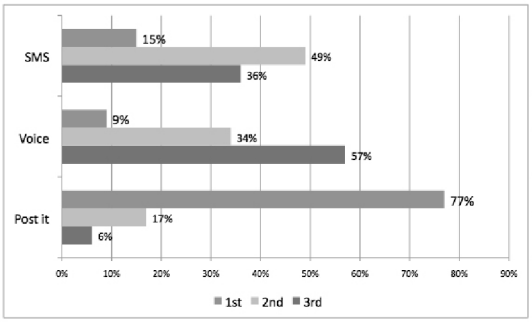
2.2. FINDINGS / DATA ANALYSIS

A total of 47 students of the National University of Singapore took part in the survey over two days. The results of the questionnaire are discussed below.

2.2.1. User preference to post message

Figure 2 shows the user preference of the three different ways. The result of the survey of question 1 shows that most (70%) of them selected handwriting as first choice, followed by SMS and voice recording as second and third choices respectively.

Handwriting. Handwriting is the most preferred method in the survey. Participants said that it is the easiest way to leave messages. It is also found that users can express their emotion easily compared with other different ways. Figure 3 shows the post-its with handwriting and users express their emotion or identity using short word and drawings. Users can identify their message by writing their initials, or it can also be left anonymous. It is observed most users wrote messages without any difficulty and they place their messages where they want on the board.



	Post it	Voice	SMS
1st	36	4	7
2nd	8	16	23
3rd	3	27	17
Mean Ranking	**1.3**	**2.49**	**2.2**

Figure 2. User preference of three different ways.

However, since the interactive public display will need to have the message in digital format to provide interaction functions to users, there is a need to recognise the handwriting message into the computer using tablet, electric board, smart pen and touch screen to input user handwriting message to the computer are options, but these pen-based man–machine interfaces (MMI) are still not very user-friendly (Cheriet et al., 2009) for the interactive public display in this study.

SMS. Short message service (SMS) is a widely used communication service nowadays. It is observed that most participants use mobile to leave their SMS message with ease. It is also easy to input the message to the computer using GSM modem. User can participate in the interactive public display without other extra input device.

However, the result of the duration of creating a message (figure 4) shows that the mean duration of typing a SMS is 70 seconds, while it took 9 seconds to leave a voice message and 37 seconds to leave a handwritten message. There were some negative user comments that using SMS could pose a privacy issue in that using SMS reveals their mobile number to the server or system administrator.

Voice recording. Voice recording is the quickest way to leave a message. Some participants were interested to leave their voice message, but most users

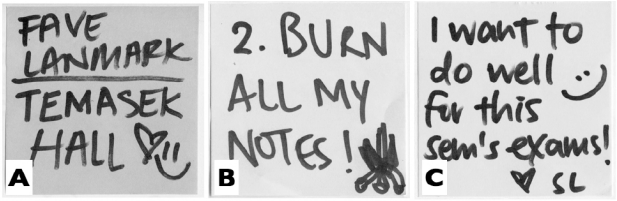


Figure 3. User post using handwriting.

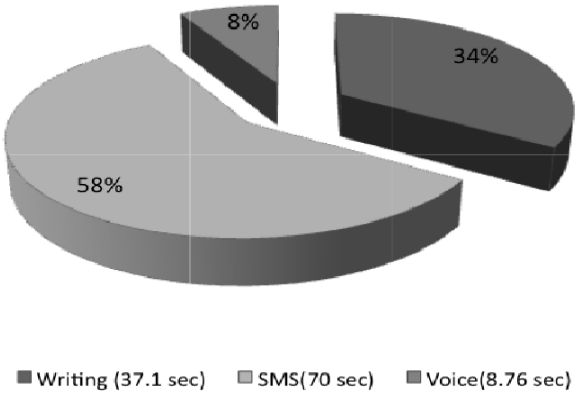


Figure 4. Time taken to create message.

said it is weird to speak to a display board. One participant said he usually speaks to someone present and it is weird when there is nobody to speak to.

2.2.2. Willingness to share with the public

The concept of the interactive public display is to share user-posted contents to a large group. The survey result shows that all participants agree to share their written messages. However, they are against sharing their voice message, photo and movie clip with the public.

2.2.3. User participation

From the video observation, participants' habits, patterns and conversations were observed. Many students who were not participants crowd around the

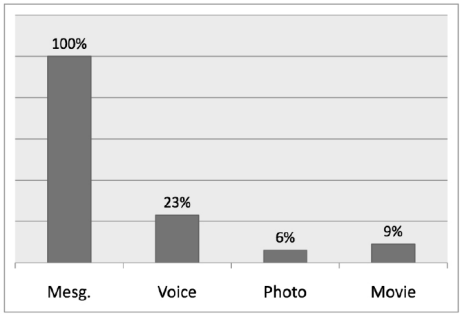


Figure 5. Willingness to share the different media with public.

Figure 6. Interest to read messages and messages trigger conversation among friends.

message wall to read what other students posted. They were interested in what other people want to do after the exam. They were curious enough to stay and read the messages on the board without any prompting from the researcher. We observed that the messages trigger conversations among people as they discussed the messages on the board and it leads them to participate and post messages (see figure 6). As Peltonen (2008) argued, users could be part of creators of public display with their active participation.

The results of the user studies will inform the design of the interactive message wall and provide learning points on how to promote user participation.

3. Communication between real world and virtual world

To design communication between users in the real world and virtual world through the message wall, we did experiments to explore the possible controls between real and virtual. It is possible to connect real and virtual space using sensor network technology. Sensors and actuators in physical space can be used to communicate with 3D objects in virtual space. For example, a controller in the physical space can control 3D objects in the virtual space. A user can change the colour and move the virtual object using the physical controller. It means that users do not need to log on to the computer and use a keyboard or mouse to access the virtual space. It is also possible to control physical objects from the virtual space using this sensor network technology. We successfully tested communication between these two worlds using sensor network technology such as micro controller (arduino) and sensor database in the following examples. For controlling virtual object from real space:

1. Rotation sensor changes the color of a virtual wall.
2. Lighting sensor changes the transparency of the virtual wall.
3. Touch sensor turns on the light in virtual wall.

(See the video clip http://www.youtube.com/watch?v=hxZ-_YnDuDA &feature=related).

For controlling physical object from virtual space:

1. Touching a virtual wall turns on/off the LEDs in real space.
2. An avatar's distance from the virtual wall affects number of LEDS turned on in the real space.
3. Direction of avatar movement rotates a billboard mounted on a servo motor.

(See the video clip http://www.youtube.com/watch?v=0m0XVkF23Zs.)

4. Design of interactive message wall

With the understanding through our experiments in sections 2 and 3, we propose an interactive message wall that exists in both the real and virtual worlds. It will consist of 3 components namely the physical message wall, the virtual message wall and message wall server.

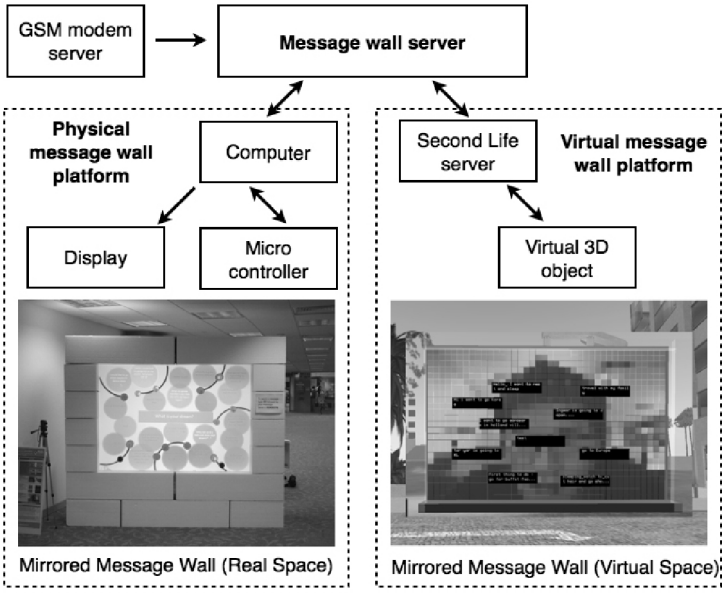


Figure 7. Concept design of interactive message wall. Message wall in physical space (left) and virtual message wall (right).

Messages can only be posted when a person stands in front of the walls. For an initial version of message wall, the input of message will be using mobile phone as it is easier to implement technically. The next development is to use digital handwritten message. In our university's Second Life Campus,

users can post messages by typing a message on the keyboard and posting it onto the message wall in the virtual world.

Messages will appear real-time in both walls. Displayed messages posted from the real world or virtual world will be differentiated by different colour background. The message wall server saves messages and data is sensed from the real and virtual spaces.

4.1. AWARENESS AND PRESENCE

To bring awareness of presence of real time virtual users to people looking at the physical wall, silhouettes of human cut-outs are used. When a virtual user (an avatar) is near the virtual message wall, a LED will be turned on showing a silhouette. The number of silhouettes on the physical message wall indicates crowd size in front of the virtual message wall. A camera at the physical message wall will capture image of people standing in front of it. The image is pixelated and displayed as background of the virtual message wall indicating presence of people at the real world message wall.

5. Scenario and applications

What are possible scenarios for using the interactive message wall? Weekly topics that concern a community can be posted on the wall to solicit reactions. Through public display of the different views of a community, connectedness to the community can be cultivated. For example, for a university with more than one campus, the message wall can be used to connect students in the different campuses. A message wall can be located in the student centre of each campus. Students can post messages and their thoughts will be displayed for all to see at all campuses, even if the viewers are not from the same geographical location. It will serve to connect students from different campuses and provide a shared "space" for all their collective thoughts. A second scenario is to connect current students with alumni and international exchange students who have returned to their home countries. A message wall can be placed in a student centre on campus and a virtual message wall in the 3D virtual campus for alumni and visitors. Through this setup, alumni and exchange students can keep up to date about the sentiments of current students and vice versa.

6. Conclusion

In this paper we started with an idea to use public display of people's thoughts to connect people in the physical and virtual worlds and carried out a low-tech prototype for user studies to understand the issues and problem. From that, we proposed a design of an interactive message wall to be implemented. One

of the interesting findings is that people are very interested to read messages left by others and the messages trigger conversations among people as they discuss the messages on the wall and it leads them to participate and post messages. The next stage is to start building and programming both the real and virtual message walls, implement it and obtain further user studies. The goal is to have a final version of a message wall that can bond a community together, whether they are in the same space or geographically separated or in real and virtual worlds.

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References

Ananny, M., Strohecker, C., and Biddick K.: 2004, Shifting scales on common ground: developing personal expressions and public opinions, *International journal of continuing engineering education and life-long learning,* **14**(6), 484–505.

Buxton, B.: 2007, *Sketching user experience: getting the design right and the right design,* Morgan Kaufmann, San Francisco.

Cheok, A. D. et al.: 2008, BlogWall: social and cultural interaction for children, *Advances in human–computer interaction,* 2008.

Cheriet, M., Yacoubi, M. E., Fujisawa, H., Loperesti, D. and Lorette, G.: 2009, Handwriting recognition research: twenty years of achievement … and beyond, Panel discussion, Pattern recognition, **42**(12), *New frontiers in handwriting recognition,* December 2009, 3131–3135.

Johnson, G., Gross, M. D., Hong, J. and Do, E. Y.: 2008, Computational support for sketching in design: a review, *Foundations and trends in human–computer interaction,* **2**(1), 1–93.

Martin, K., Penn, A., and Gavin, L., Engaging with a situated display via picture messaging, *Proceedings of conference on human factors in computing system (CHI'06),* 1079–1084, ACM Press, Montreal.

Peltonen, P. , Salovaara, A. , Jacucci, G., Ilmonen, T., Ardito, C., Saarikko, P. and Batra, V.: 2007, Extending large-scale event participation with user-created mobile media on a public display, *Proceedings of the 6th international conference on mobile and ubiquitous multimedia,* 131–138, December 12–14, 2007, Oulu, Finland.

Rogers, Y.: 2004, New theoretical approaches for human–computer interaction, *Annual review of information science and technology,* **38**(1), 87–143.

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LIGHTING IN REAL AND PICTORIAL SPACES

A computational framework to investigate the scene based lighting distributions and their impact on depth perception

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Abstract. Architects often use two-dimensional media to represent, visualise, and study the three-dimensional qualities of un-built spaces. Knowledge of pictorial cues is a powerful design tool that can be used to enhance the spatial qualities of built environments. This paper draws from the recent developments in computer graphics (physically based renderings and perceptually based tone mapping techniques) and demonstrates the utilisation of a computational framework to generate pictorial spaces that can mimic perceptual reality. Computer simulation and psychophysical research methodologies are employed to examine the relationship between the lighting patterns introduced by architectural configurations and their impacts on depth perception. The research demonstrates that physically and perceptually based renderings can be used to study depth perception; and luminance contrast in an architectural scene is an effective pictorial cue that increases the perceived spatial depth.

Keywords. Depth perception; pictorial cue; lighting simulation; physically based rendering; high dynamic range imagery.

1. Introduction

Visual space perception is defined as the process of acquiring the three-dimensional (3D) understanding of an environment from two-dimensional (2D) retinal images and/or media. Sketches, drawings, and computer generated images have long been used to study the visual qualities of architectural spaces. Computer environments enable users to easily change the input

data and perform quantitative and qualitative analysis of alternative settings. Every computer modeling, simulation, and visualisation technique is based on approximations and simplifications. However, recent developments have enabled us to generate digital images that can be numerical and visual matches of the corresponding physical scenes. Therefore, these physically and perceptually based renderings provide unprecedented affordance for perceptual studies.

Psychophysics is a field that investigates the relationship between sensations and physical stimuli (Gescheider, 1984). It measures perceptual sensitivity in response to an environmental stimulus. Researchers have studied the effects of various pictorial cues (i.e., as occlusion, familiar size, relative size, and texture gradients) on space perception in real environments through this research methodology. However, perceptual studies in physical environments suffer from many challenges in controlling the complexities of studied environments and/or changing the variables that impact depth perception. Psychophysical experiments in physical environments are particularly challenging with experiments that involve dynamic lighting conditions. Daylighting provides variable luminous environments, where variability is the result of sun movement and climatic conditions. This challenge limited the scope of past research in depth perception.

Early computer graphics examples demonstrate lighting as one of the pictorial depth cues, but lighting is studied only to establish an object's relative location in a three-dimensional layout by the shadow it casts (Hubona et al., 2000; Meng and Sedwick, 2001), rather than to investigate how it is distributed in a scene to inform or enrich the space perception. Schwartz and Sperling (1983) demonstrated the use of perceived luminance as a pictorial cue. O'Shea, Blackburn and Ono (1993) argue that it is the contrast of luminance that cues the distance. However, the use of luminance contrast as a pictorial cue in this study is limited to flat patches, and therefore, does not adequately address to the spatial and luminous complexities of a built environment.

In this paper, physically based rendering and perceptually based tone mapping techniques are utilised to generate pictorial spaces that can provide surrogate models for physical environments to study depth perception. The objective of this study is to utilise a computational framework for investigating spatial depth; and to demonstrate the relationship between the configuration of physical structures, scene based lighting distributions, and perceived spatial depth.

2. Computer simulations

Physically based rendering tools use mathematical models to simulate the

complex physical processes to mimic the physical world (Greenberg et al., 1997). In this research, Radiance Lighting Simulation and Visualization system (Ward and Shakespeare, 1997) is used for generating physically based images. Radiance software models the light transport and material properties based on their governing physical equations; and the resultant rendered scene is a high dynamic range image that encompasses a numerically accurate radiance map. The numerical accuracy of Radiance renderings has been validated through lighting studies (Mardajevic, 2001).

Physical accuracy in rendering does not guarantee that the displayed images will provide a visual match to the corresponding physical environment. Computer hardware limits the dynamic range, color gamut, spatial resolution, and field of view occupied by the displayed image (Spencer et al., 1995). In perceptually based tone-mapping, hardware limitations are addressed with mathematical models that approximate the complex physiological and psychophysical processes to mimic the human visual processes (Ferwerda, 2001; Ramanarayanan et al., 2007). The accuracy and appropriateness of Radiance Renderings for psychophysical research studies have been demonstrated by Ruppertsberg and Bloj (2006) and Radiance has been employed to simulate experimental scenes to investigate visual performance in relation to lightness perception, color perception, and shape perception (Boyaci et al., 2003; Doerschner et al., 2004; Delahunt and Brainard, 2004; Fleming et al., 2004). These studies incorporate various visual aspects of objects in 3D environments. They also attest that psychophysical research studies can be effectively carried out in computer environments, which provide advantages over real world in allowing for controlled replication of variable manipulations and establishing cause-effect relationships.

The authors (Tai and Inanici, 2009) previously investigated whether the depth perception of a 2D representation on a computer screen can adequately predict the perceptual qualities of a real 3D environment. The evaluation is done by repeating a classical research study on depth perception (Holway and Boring, 1941) in a computer generated pictorial environment. By acquiring matching experiment results in physical and virtual environments, the credibility of using computer generated pictorial space is established through psychophysical studies. The computational framework incorporates experimental scenes that were generated by Radiance software as physically based lighting simulations. Subsequently, perceptually based tone mapping techniques are used to compress the high dynamic range pixel data into displayable range such that visual appearance can be reproduced. Although several tone mapping operators have been developed in the past two decades, Photographic (Reinhard et al., 2002) and Photoreceptor (Reinhard and Devlin,

2005) Tone Mapping Operators (TMO) are identified as two viable solutions. This computational framework is also adopted in this paper.

3. Psychophysical experiments

Studies on space perception often ask subjects to view a target in a test scene and then adjust a target in a reference scene to match the perceived distance of the test target. With proper control of the depth cue between the test and reference scenes, the difference between the measured perceived distances could reveal the quantitative effect of the manipulated depth cue. The experimental scenes in this study were presented on an LCD display, where the full-cue conditions were reduced to 2D pictorial cues. The perceived distance measured by this visual matching method is influenced by the two-dimensional characteristics of the images rather than the three-dimensional nature of an environment. Therefore, the reference and test scenes are integrated into one display. Participant's perception of the relative distance between the two disks of each experimental scene was measured using a method that combines the visual matching and verbal reporting.

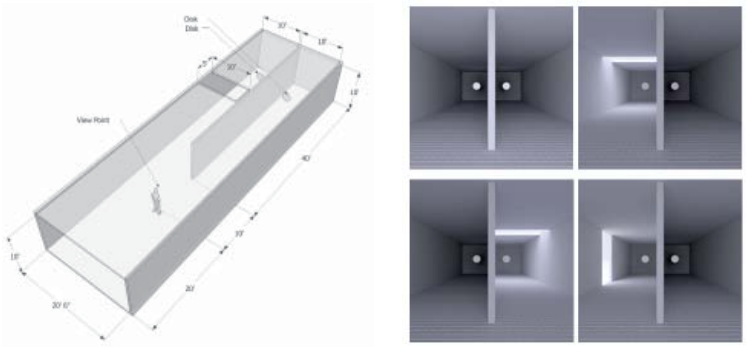


Figure 1. General architectural configuration for the experimental scenes (a, left)); and experimental scenes of four different conditions (b, right).

The experimental setup is illustrated in figure 1a. An elongated space is divided into two hallways, and a floating luminous disk (12″ in radius) is located at the center of each hallway as a visual target. The viewpoint is set towards the center of the corridor. The two disks floating at the center of each hallway have identical sizes. Two major variables are introduced into the experiment: The relative distance between the two disks was varied and architectural configurations were manipulated to create different lighting conditions between the right and left hallways (figure 1b). In the "no skylight" condition, the scene was illuminated by the daylight admitted from the open end of the corridor. In the "skylight at left" and the "skylight at right" condi-

tions, additional 5′x10′ skylight was installed at 24′ away from the viewpoint on the left and right hallways, respectively. In the "window at left" condition, a 5′x10′ window was installed at 24′ away from the viewpoint on the left side of the left hallway.

3.1. EXPERIMENT 1

The objective of the first experiment is to determine if the presence of additional lighting patterns would affect the perceptual judgment of spatial depth in comparison to the base case ("no skylight"). Locations of both right and left disks are varied to achieve 9 different relative distances. In scene "L0R", both disks are located 40′ away from the viewpoint. In scene "L1r", the left disk was shifted 6″ closer while the right disk was shifted back 6″ to create a 1′ displacement. Similarly, the left disk is 2′, 3′, and 4′ closer than right disk in scenes "L2r", "L3r", "L4r" respectively. In scenes "l1R", "l2R", "l3R", "l4R", the right and left disk are shifted to a reversed position to create relative distances such that the right disk is closer 1′, 2′, 3′, and 4′, respectively. These nine configurations of disk locations are rendered with three different lighting conditions of "no skylight", "skylight at left" and "skylight at right" to generate a total of 27 experimental scenes.

The scenes were rendered with resolution of 700x700 dpi. The high dynamic range images were tone-mapped with Photographic (Reinhard et al., 2002) and Photoreceptor (Reinhard and Devlin, 2005) TMOs to generate two sets of test images. Images were displayed on the center of a LCD display in a dark room. Eight subjects participated in this study. Subjects are aged between 21 and 36, had normal or corrected-to-normal vision. They were given time to adapt to the dark environment; they were asked to sit in front of the display at a normal viewing distance and angle. They were instructed that each scene incorporates two identical disks floating at the center of each hallway; and they were asked to use verbal methods to report the disk that appears to be closer. In each session, 27 images were shown in a random order for 10 times. Each subject repeated the experiment for two times with two different sets of tone-mapped images. Each participant's responses were recorded as the number of times that the right disk is reported closer.

3.1.1. Results and Analysis

Perceptual studies on the evaluation of the tone-mapping operators consistently show that Photographic TMOs performs well when compared to real physical scenes (Kuang et al., 2006; Cadik et al., 2008). A more recently developed algorithm, namely Photoreceptor TMO, is also considered since

it is theoretically built to model the human photoreceptor behaviour. As an initial study, the test scene is tone mapped with these two operators and the subject's responses were analysed to determine whether different tone mappings impact the perceived distance. The result of pair sample T-test of the average of the numbers of right disk reported closer for each tone-mapped set shows that there is no statistical significant difference between the experiments results ($\alpha = 0.05$, two-tail, $t_{calc} = 1.862 < t_{crit} = 2.447$). Therefore, it is concluded that the choice of either the Photoreceptor or Photographic TMO does not have significant impact on the experiment results.

Figure 2a illustrates the experiment results from the image set of Photographic TMO. Subjects' responses are plotted as the proportion of scenes on which the right disk is reported "closer" as a function of the relative distance between the right and left disks. Probit regression curves provide an appropriate statistical method for modeling regression of binary responses. They are used to fit a cumulative distribution to each data set. The intersection points of each curve with the 50% proportion line are taken as the point of subjective equality (PSE). The PSE represents when the right and left disks are perceived equal in depth. The result demonstrates that in the "no skylight" condition, the two disks were perceived equal when the two disks were configured at the same locations (PSE = 0.03 ± 0.01). In the "skylight at left" condition, the PSE shifted to left, the two disks were perceived equal in depth when the right disk was actually 1.8 feet away than the left disk (PSE = –1.84±0.11). In the "skylight at right" condition, the PSE shifted to right, the two disks were perceived equal in depth when the right disk was actually 2 feet closer than the left disk (PSE = 2.12 ± 0.11).

3.2. EXPERIMENT 2

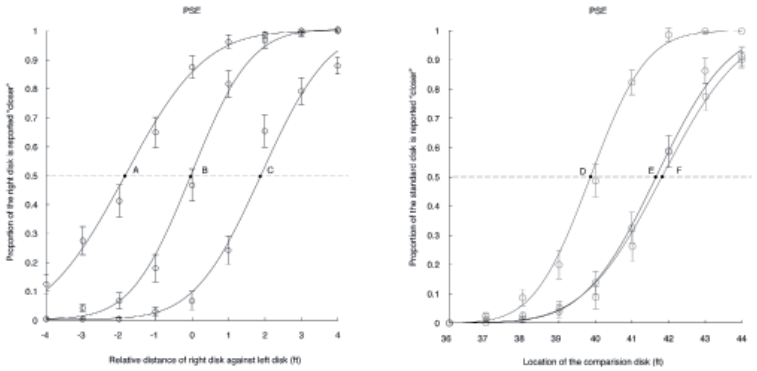
In the second experiment, the location of the left disk is fixated at 40′ away from the viewpoint and it is referred as the standard disk. The location of the right disk is varied to create 9 different scenes (located 36′, 37′, 38′, 39′, 40′, 41′, 42′, 43′ and 44′ away from the viewpoint). Right disk is referred as the comparison disk. The objective of the second experiment is to investigate whether the directional properties of light source impact the resultant pictorial cue. The variation of disk locations were rendered with three different lighting conditions of "no skylight", "skylight at left" and "window at left" to generate a total of 27 scenes. To avoid getting the lighting effect only on the left hallway, the 27 scenes were flipped horizontally to create another set of mirrored images.

The images were tone-mapped by Photographic TMO. Each image was presented 5 times to each subject in a random order. A different group of eight

subjects participated in this study. Subjects were aged between 21 to 36, had normal or corrected-to-normal vision. Participant's responses were recorded as the number of times that the standard disk is reported closer.

3.2.1. Results and Analysis

The results of the experiment demonstrate that the perceived distance of the standard disk is increased around 4% with the presence of the lighting pattern introduced by a skylight or window (figure 2b). In the "no skylight" condition, the two disks were perceived equal in depth when the two disks were configured at the same locations (PSE = 40.14 ± 0.09). In "skylight at left" condition, the PSE is 41.81 ± 0.11, and the perceived distance of the standard disk was increased 4.5%. In "window at left" condition, the PSE is 41.66 ± 0.11, and the perceived distance of the standard disk was increased 4.2%.



a *b*

Figure 2. Probit analysis for experiments 1(a) and 2 (b): A is PSE with "skylight at left"; B is with "no skylight"; C is with "skylight at right"; D is with "no skylight"; E is with "window at left"; F is with "skylight at left" conditions.

4. Discussion

In size–distance relationship, perceived size of an object is derived from its perceived distance in a three-dimensional layout. Therefore, the perceived size can be considered as a source of depth cue. Experiment results from the "no skylight" conditions of both experiments demonstrate this size–distance relationship. The fact that PSE are 0.03 (expected value is 0) and 40.14 (expected value is 40) respectively indicate that subjects were able to judge accurately the relative distance between the two disks based on the pictorial cue dominated by the size perspective. The PSE has significantly shifted when the additional lighting pattern was presented. In the first experiment, the PSE shifted to left in the "skylight at left" condition, and shifted to right in the

"skylight at right" condition.

Figure 3 illustrates the false colour studies of the original high dynamic range scenes with disks configured at the same locations under different lighting conditions. The luminance contrast of the two disks and their backgrounds were identical in the base cases ("no skylight" condition). However, the luminance contrast between the disk and its background was reduced when the hallway was illuminated by additional skylight ("skylight at right" and "skylight at left" conditions). In each instance, the perceived distance was increased. These results are in agreement with O'Shea et al. study (1983), which argued that the higher the luminance contrast, the closer the target appears to be. The additional skylight reduces the luminance contrast between the disk and its background, and therefore, increases its perceived distance.
Results from the second experiment support this analysis, as well. Although the luminance distributions between the experimental scenes were quite different in scenes with skylight and window, the contrast between the standard disk and its background remained similar. The subjects reported similar perceived distances of the standard disks. Therefore, it is concluded that the effect of scene based lighting patterns on the depth perception is dependent on luminance contrast of the visual target and its immediate background. The lower the contrast, the farther away the target appears.

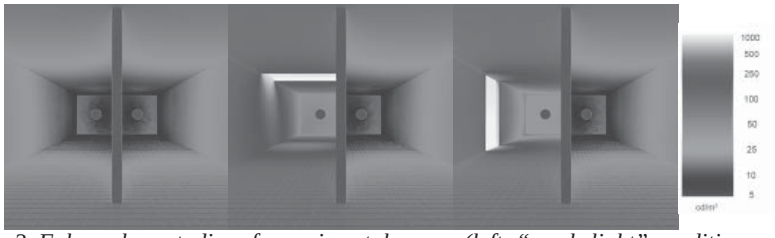
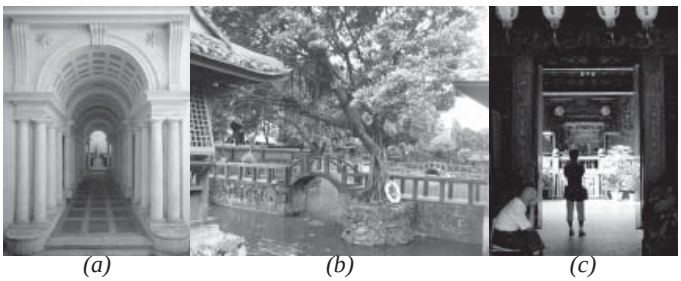


Figure 3. False colour studies of experimental scenes (left: "no skylight" condition; middle: "skylight at left" condition; right: "window at left" condition).

5. Conclusion

Architectural design process is often mediated on two-dimensional representation systems and envisioned three-dimensionally in the pictorial space. Pictorial cues have been used by architects as powerful representation and design tools to visualise and enhance the spatial qualities of architectural space. The Galleria Spada (designed by Francesco Borromini, 1635) is a significant example that utilised the pictorial cue of linear perspective to increase the perceived spatial depth (figure 4a). The height and size of each column, and the spacing between them are decreased gradually as they recede into space. Along with the convergent inclination of the ceiling and tile patterns, a distorted linear perspective is laid out for the entrance view to amplify the

perceived depth of the space. Lin's family garden (designed by Kuan-Cao Hsieh, 1853) is another example (figure 4b), in which the application of the pictorial cue of size perspective can be observed. Bridges were constructed at reduced size, barely allowing one person to walk through. When viewed from the pavilion, the homogenous texture of water provides no further contextual depth information. The observers mistakenly perceive the bridges at normal size, which in return exaggerates the distance between the two bridges and amplifies the overall spatial depth. These examples illustrate that navigation can be guided with planned circulation, and the points of observation can be restricted by framed openings in architectural spaces (figure 4c). Manipulation of physical settings can exaggerate the pictorial cue for expected scenes, and therefore affect the spatial experience of the architectural spaces.



(a) *(b)* *(c)*

Figure 4. Applications of pictorial cues in architectural designs (a: Galleria Spada; b: Lin's Family Garden; c: Tien-Ho Temple).

Pictorial spaces generated with physically based rendering tools and perceptually based tone mapping techniques allow architect to understand the relation of the architectural structure, resultant lighting distribution and perception of spatial depth. Our study demonstrates that scene based lighting patterns affect the perceived distance. Lighting schemes introduced to render scenes with different luminance contrasts can alter depth perception as the occupant explores the space. As a result, the effect of the lighting as pictorial cue can enrich the spatial experience.

The computational framework utilised in this paper offers a powerful tool for architects to simulate the perceived qualities of built environments. It provides a flexible environment where representational and analytical approaches are employed to envision the visual qualities of built environments, and to improve the design decisions.

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References

Boyaci, H., Maloney, T. and Hersh, S.: 2003, The effect of perceived surface orientation on perceived surface albedo in binocularly viewed scenes, *Journal of vision,* **3**(8), 541–553.

Cadik, M., Wimmer, M., Neumann, L., and Artusi, A.: 2008, Evaluation of HDR tone mapping methods using essential perceptual attributes, *Computer and graphics,* **32**(3), 35–44.

Delahunt, P., and Brainard, H.: 2004, Color constancy under changes in reflected illumination, *Journal of vision,* **4**(9), 764–778.

Doerschner, K., Boyaci, H., and Maloney, T.: 2004, Human observers compensate for secondary illumination originating in nearby chromatic surfaces, *Journal of vision,* **4**(2), 92–105.

Ferwerda, J.A.: 2001, Elements of early vision for computer graphics, *IEEE computer graphics and applications,* **21**(5), 22–33.

Fleming, R. W., Torralba, A. and Adelson, E. H.: 2004, Specular reflections and the perception of shape, *Journal of vision,* **4**(9), 798–820.

Gescheider, G. A.: 1984, *Psychophysics: method, theory, and application,* Hillsdale: Lawrence Erlbaum Associates, Inc.

Greenberg, D. P., Torrance, K. E., Shirley, P., Arvo, J., Ferwerda, J. A., Pattanaik, S., Lafortune, E., Walter, B., Foo, S. C. and Trumbore, B.: 1997, A framework for realistic image synthesis, *ACM SIGGRAPH proceedings of the 24th annual conference on computer graphics and interactive techniques,* 477–494.

Hubona, S.G.: 2000, The relative contributions of stereo, lighting, and background scenes in promoting 3D depth visualization, *ACM transactions on computer–human interaction,* **6**(3), 214–242.

Holway, A. H. and Boring, E. G.: 1941, Determinants of apparent visual size with distance variant, *American journal of psychology,* **54**(1), 21–37.

Kuang, J., Liu, C., Johnson, G. and Fairchild, M.: 2006, Evaluation of HDR image rendering algorithms using real-world scenes, *International congress of imaging science,* **4**(2), 1–27.

Mardaljevic, J.: 2001, The BRE-IDMP dataset: a new benchmark for the validation of illuminance prediction techniques, *Lighting research and technology,* **33**(2), 117–136.

Meng, J. C. and Sedgwick, H. A.: 2001, Distance perception mediated through nested contact relations among surfaces, *Perception and psychophysics,* **63**(1), 1–15.

O'Shea, R. P., Blackburn, S. G., and Ono, H.: 1994, Contrast as a depth cue, *Vision research,* **34**, 1595–1604.

Ramanarayanan, G., Ferwerda, J., Walter, B. and Bala, K.: 2007, Visual equivalence: towards a new standard for image fidelity, *ACM transactions on graphics,* **26**(3).

Reinhard, E. and Devlin, K.: 2005, Dynamic range reduction inspired by photoreceptor physiology, *IEEE transactions on visualization and computer graphics,* **11**(1), 13–24.

Reinhard E., Stark, M., Shirley, P., and Ferwerda, J.: 2002, Photographic tone reproduction for digital images, *ACM transactions on graphics,* **21**(3), 267–276.

Ruppertberg, I. and Bloj, M.: 2006, Rendering complex scenes for psychophysics using RADIANCE: how accurate can you get? *Journal of optical society of America,* **23**(4), 759–768.

Schwartz, B. J. and Spering, G.: 1983, Luminance controls the perceived 3D structure of dynamic 2D displays, *Bulletin of the psychonomic society,* **21**, 456–458.

Spencer, G., Shirley, P., Zimmerman, K., and Greenberg, D. P.: 1995, Physically-based glare effects for digital images, *SIGGRAPH 95 conference proceedings,* 325–334.

Tai, N. and Inanici, M.: 2009, Depth perception in real and pictorial spaces: A computational framework to represent and simulate the built environment, *CAADRIA 2009, Yunlin, 543–552.*

Ward, G. and Shakespeare, R.: 1997, *Rendering with Radiance,* Morgan Kaufman Publisher, San Francisco.

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APPLYING AUGMENTED REALITY FOR DATA INTERACTION AND COLLABORATION IN BIM

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Abstract. Building Information Modelling (BIM) is expected to enable efficient collaboration, improved data integrity, distributed and flexible data sharing, intelligent documentation, and high-quality outcome, through enhanced performance analysis, and expedited multi-disciplinary planning and coordination. Despite these apparent benefits, the collaboration across the architecture, engineering and construction (AEC) disciplines is largely based on the exchange of 2D drawings. This paper reports the findings from a research project that aims at developing measures to enhance BIM-based collaboration in the AEC industry. Based on focus group interviews with industry participants and case studies of BIM applications, visualisation was identified as an interactive platform across the design and non-design disciplines. It is argued that visualisation can enhance the motivation for BIM-based collaboration through integration of advanced visualisation techniques such as virtual reality (VR) and augmented reality (AR). An AR interface for a BIM server is also presented and discussed in the paper. AR can open up potential opportunities for exploring alternatives to data representation, organisation and interaction, supporting seamless collaboration in BIM.

Keywords. BIM; augmented reality; design collaboration.

1. Introduction

As the buzzword in the architecture, engineering and construction (AEC)

disciplines, building information modelling (BIM) is an IT-enabled approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project lifecycle in the form of a data repository. BIM is expected to enable efficient team collaboration, improved data integrity, distributed and flexible data sharing, intelligent documentation, and high-quality project outcome, through enhanced performance analysis, and multi-disciplinary planning and coordination (Fischer and Kunz, 2004; Haymaker et al., 2005; Ellis, 2006).

While the potential benefits of BIM in terms of information sharing and project collaboration may seem evident, the adoption rate of BIM has been rather slow (Johnson and Laeppel, 2003; Bernstein and Pittman, 2004). The literature attributes such slow uptakes to both technological and cultural reasons. In a series of large-scale focused group interviews conducted across the AEC disciplines by the authors, data interaction and collaboration issues have been identified as one of the important aspects for future BIM development, echoing some early studies. Like general computer-aided design (CAD) / computer-aided manufacturing (CAM) applications, to a certain extent, current BIM technologies (ranging from domain-specific BIM applications to fully inter-disciplinary BIM technologies such as BIM model servers) lack intuitive modes of data representation and interaction for supporting effective multi-disciplinary collaboration. Such issues have become most critical as BIM utilises much larger data sets with more complex data types shared by a wider range of users, compared to general CAD / CAM systems that often serve a single discipline only (Gu et al., 2009).

This paper discusses an integration framework adopting augmented reality (AR) as the primary interface for a BIM server. This represents a novel approach for data interaction and collaboration in BIM. AR enables a design environment where the digital information generated by a computer is inserted into the user's view of a real-world scene (Milgram and Colquhoun, 1999). AR has been perceived to effectively support collaboration works in the architectural practice (Wang et al., 2008). This can open up potential opportunities for exploring alternative approaches to data representation, organisation and interaction for supporting seamless collaboration in BIM. The paper firstly discusses the technical requirements for a BIM server as a collaboration platform based on: (1) a case study conducted with a state-of-art BIM server to identify its technical capabilities and limitations; and (2) an analysis of features of current collaboration platforms used in the AEC industry. The findings are classified to include (1) BIM model management related requirements; (2) design review related requirements; and (3) data security related requirements. An integration framework is then proposed,

supporting the above technical requirements for design collaboration in the AEC disciplines. The novel use of AR for data interaction and collaboration in BIM can inspire new business cases that foster future innovations.

2. Background

2.1. BIM ADOPTION

Based on relevant works (Johnson and Laepple, 2003; Bernstein and Pittman, 2004; Holzer, 2007; Khemlani, 2007; Howard and Bjork, 2008), and focus group interviews with key industry players, we have identified the main factors that affect BIM adoption (Gu et al., 2008; 2009). The perception and expectation of BIM against the industry's current practice are summarised in terms of the following three main aspects: tools, processes and people.

Tools. The expectations of BIM vary across disciplines. For design disciplines, BIM is mainly an extension to CAD, while for non-design disciplines such as contractors and project managers, BIM is more like a intelligent data management system (DMS) that can quickly take-off data from CAD packages directly. While there are evident overlaps, BIM application vendors seem to be aiming to integrate the two requirements. The existing BIM applications are not yet mature for either purpose. Users with CAD backgrounds, such as designers, expect BIM servers to support integrated visualisation and navigation that is comparable to their native applications. Users with DMS backgrounds, such as contractors and project managers, expect visualisation and navigation to be important features of BIM servers that are missing in current DMS solutions. Hence, these findings suggest that visualisation has become an interactive platform across the design and non-design disciplines (figure 1). Therefore, it is likely that more realistic, accurate and intuitive visualisation capabilities can enhance the motivation for BIM-based collaboration across the different disciplines.

Processes. BIM adoption would require a change in the existing work practice. An integrated model development needs greater collaboration and communication across disciplines. A different approach to model development is necessary in a collaborative setting where multiple parties contribute to a centralised model. Standard processes and agreed protocols are required to assign responsibilities and conduct design reviews and validation. Experience from DMS will be useful for data organisation and management, but organisations will need to develop their own data management practices to suit their team structure and project requirements. Different business models will be required to suit varied industry needs. A BIM model can be maintained in-house or outsourced to service providers. In the latter case, additional legal

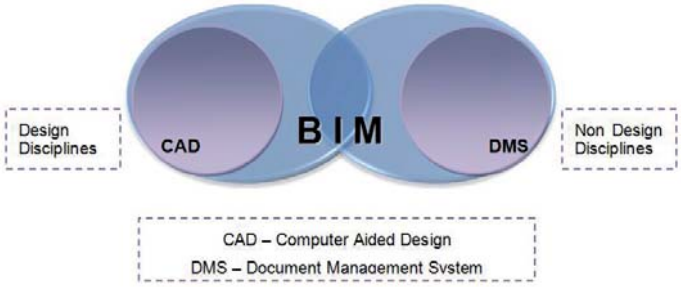

Figure 1. Visualisation as an interactive platform across design and non-design disciplines.

measures and agreements will be required to ensure data security and user confidence.

People. New roles and relationships within the project teams are emerging. Dedicated roles, such as BIM model manager and BIM server manager will be inevitable for large-scale projects. Team members need appropriate training and information in order to be able to contribute and participate in the changing work environment.

In summary, as BIM matures, it is likely to integrate the existing CAD packages and DMS into a single product. For BIM to succeed and be adopted widely in the industry all stakeholders have to be informed about the potential benefits to their disciplines. Earlier works show that (1) the lack of awareness, (2) the over-focus on BIM as advancement of CAD packages only, and (3) the relative downplaying of BIM's document management capabilities have inhibited the interest of non-design disciplines of the AEC industry. A user-centric BIM research has to be more inclusive, since the success of BIM adoption lies in the collective participation and contribution from all stakeholders in a building project. For our research, the above understanding of BIM adoption highlights that building data representation and interaction is one of the most important aspects of BIM. Like general CAD applications, current BIM servers lack intuitive and flexible interfaces for supporting customised needs from different disciplinary users and the effective collaboration among them. This has become most critical as BIM servers utilise much larger and more complex data sets to be shared by a wider range of users across all AEC disciplines, compared to a general CAD application that often serves a single discipline only.

2.2. AUGMENTED REALITY IN DESIGN COLLABORATION

In building projects, the difficulties in information sharing between different disciplines often result in delays in decision-making as well as errors in project outcomes. This section introduces current AR applications that aim

to improve interdisciplinary design collaboration. Several attempts have been made to address this issue by implementing knowledge integration and sharing between disciplines in AR-based environments. These applications can allow multiple disciplines to contribute and interact with the digital building information in a seamless and intuitive manner during design collaboration. For instance, Wang and Dunston (2008) develop an intuitive mixed reality environment called Mixed Reality-Based Collaborative Virtual Environment (MRCVE) to support the collaboration and design spatial comprehension in collaborative design review sessions for mechanical contracting. The environment can be a face-to-face setting or distributed over network. Wang and Chen (2009) conduct a study investigating how AR can facilitate the collaborative work of multi-disciplinary stakeholders in the context of urban design. The FingARtips project (Buchmann et al., 2004) also applies AR, in which the users can wear head-mounted displays or virtual glasses to view digital information that is overlaid onto physical objects in the real world. However, this application is limited by the number of concurrent users the system could technically support at a given time. The high cost of equipment for individual users also makes the application infeasible to be used by large inter-disciplinary design teams. Furthermore, the tracking of the system is inaccurate, i.e., it is very difficult to have the system thoroughly evaluated for accuracy and precision. Another example of such is a MetaDESK called Tangible Geospace (Ishii and Ullmer, 2006) which is essentially a Tangible User Interface (TUI) system. It has been applied in the field of urban planning. This application aims to support synchronous design collaborations in a face-to-face manner. In this system, several physical objects are used to support designers' tangible interactions with the site. These objects are placed on a translucent holding tray on the metaDESK's surface. During the collaboration process, by placing a miniature model (phicon), such as the Great Dome of the MIT campus onto the MetaDESK, a 2D digital map will appears underneath the MetaDESK bound to the Great Dome miniature at its actual location on the map. Simultaneously, the arm-mounted active lens will display a 3D view of the MIT campus with the Great Dome and its surroundings in perspective. The main function here is for exploring existing designs, the prospects for supporting interdisciplinary collaboration has not been examined.

3. A BIM server as a collaboration platform

A review of 2D collaboration platforms currently used for inter-disciplinary collaboration in the AEC industry and a case study with an existing BIM server have been conducted to identify the technical requirements of a BIM server as a collaboration platform. Identification of these technical features is

important for the assessment of potential integration of AR with BIM.

This section summarises the expected technical requirements and features of a BIM server, and provides the basis for the framework discussed in Section 4. Singh and Gu (2009) categorise the primary technical requirements of a BIM-based collaboration platform as below.

3.1. BIM MODEL MANAGEMENT RELATED REQUIREMENTS

These features and technical requirements are directly related to the storage, operation and maintenance of the BIM model that contains 3D geometries, 2D documents, and other related building information.

3.1.1. Requirements for model management and organisation

- **Model repository.** A BIM server data repository that can be linked to other federated data repositories to increase data capacity and efficiency of the server.
- **Hierarchical model structure.** A BIM model on a server is organised in a hierarchical structure, which should be flexible.
- **Sub-models, and objects with different levels of details.** The BIM server should provide the ability to *map objects with different levels of details*. Users should be able to navigate and switch across different views through simple functions (toolbars) and shortcut keys.
- **Object and model history,** such as ownership and modification records, should be maintained in the data repository.
- **Object property.** It should be possible to *overlay additional object properties* and data. For example, images from as-built structures can be linked with corresponding objects in the original model, and object properties can store related data such as the quality of construction.
- **Public and private model spaces.** Public model is accessible to all users with access rights. Private model could be model in progress, but not ready to be shared with others.
- **GUID.** Globally Unique Identifier (GUID) allows each object to be uniquely identified, preventing duplication.

3.1.2. Requirements for model access and usability features

- **Hierarchical model administration structure.** BIM server administration deals with management and allocation of model access rights, data control and security. BIM sever should allow administrative structures that reflect and support existing organisational practices.
- **Download / upload model.** Different modes of interaction for model download (upload) are possible to include shortcut keys and drag and drop options.
- **Check-in / check-out and version lock.** *Check-in* options should allow addition of new partial model or merging with existing model. Similarly, *check-*

out options should allow download of the complete model or partial models using different modes of interaction. A *check-out with lock* feature should be provided to notify other users that the checked-out data has been locked and deemed not usable. A *version lock* feature should be provided to lock version of the model after sign-off, as a form of archiving.

- **Model viewing options.** Users should be able to *capture and save screen shots, which is a standard functionality provided across CAD packages*.
- **Documentation and reports.** When downloading a part model there should be options to *generate reports* on parametric, linked, and external information for selected objects and other objects in the rest of the model.
- Users should be able to *generate and export PDF* or other document formats.
- **Integration of information from product libraries.** It should be possible to *create a comparison report for alternative product options*.
- Features should be provided to *validate rules* while uploading the files on the BIM server. Users should have the option to switch validation check on and off.

3.1.3. Requirements for user interface (UI)

Other than the standard UI features, the BIM server interface should include: (1) a model tree view position and 3D viewer position; (2) supports for online real-time viewing, printing and mark-ups; (3) the ability to click on an object, and check what sub-sets it belongs to, and (4) the ability to click on an object, and switch from the sub-sets it belongs to for another sub-set. Users should also be able to customise and choose the UI functions.

3.2. DESIGN REVIEW RELATED REQUIREMENTS

These technical requirements and features are specifically related to design review activities, including various functions needed for design visualisation and navigation, as well as team communication and interaction.

Team communication and interaction. Distributed design reviews may require parallel video conferencing, virtual environments, integration of real-time visual feedback from sites and similar interactive media. BIM servers should also provide the ability to capture and store real-time data from online meetings and reviews.

Design visualisation and navigation. Building projects often result in large data files, which reduce the online navigation and viewing efficiencies. Hence, for effective design review across distributed teams, capabilities to create lightweight 3D data are essential. 3D Model viewers supported or provided by BIM servers should have high data compression capabilities while maintaining the visual quality. It will be useful to provide technical features that allow instant, online mark-ups and tags on a shared document or

model being by multiple users during the review.

3.3. DATA SECURITY RELATED REQUIREMENTS

These features and technical requirements are related to network security and the prevention of unauthorised access into the system. In summary, security of data on a BIM server should account for confidentiality, integrity and availability of data.

In addition to these three main requirement categories, Singh and Gu (2009) also list a set of support technical requirements, which are expected to facilitate BIM implementation in a project. However, the support technical requirements are not discussed in this paper because they are not related to visualisation and AR integration.

4. An integration framework for interfacing BIM servers with AR

The technical requirements for a BIM server as discussed in Section 3 highlights the urgent need for a new interface that can utilise the list of the requirements. Among the list of these technical requirements, the core is the enhanced support for inter-disciplinary building data representation, organisation and interaction. We propose the following integration framework for interfacing BIM servers using AR. AR enables a mixed reality design environment that supports both face-to-face and distant collaborations. In an AR environment, building information can be generated and represented as 3D virtual models; the models can then be viewed and interacted virtually, or extracted and inserted into the multi-disciplinary users' views of a real-world scene (i.e. the actual building site). With TUI, AR can also support tangible interactions with digital building information beyond the use of the computer screen, mouse and keyboard, to allow more intuitive interactions such as gestures and body movements that are commonly used in traditional collaboration scenarios. The coupling of BIM and AR can open up potential opportunities for exploring alternative approaches to data representation, organisation and interaction for supporting seamless collaboration in a BIM server.

A BIM server supports multi-disciplinary collaboration by providing a platform for direct integration, storage and exchange of information from all payers involved in a building project. A BIM server is a collaboration platform that maintains a repository of the building information, and supports the viewing, checking, updating and modifying of both the geometric and non-geometric data. The integration framework as shown in Figure 2 highlights the main elements and relationships when interfacing a BIM server using AR.

The first aim of the integration is to support a wide range of activities

occurred during the building project collaboration including the viewing, checking, updating and modifying of building information whenever required, accurately, easily and securely. As shown in Figure 2, the BIM model server therefore will need to satisfy the three sets of technical requirements presented earlier in Section 3 including BIM model management related requirements, design review related requirements, and data security related requirements. The second aim of the integration is to facilitate different levels of collaborations within a building project, through an intuitive interface. As shown in Figure 2, the AR-interfaced BIM server will need to provide a *private space* for intra-disciplinary collaboration where users can interact with specific disciplinary building information. For example, AR-based techniques can be used to foster joint attention to details in 3D models being reviewed by members of distributed teams. The BIM server will also need to provide a *public space* for inter-disciplinary collaboration where users can interact with integrated building information across different disciplines. For example, AR can be used for coordination and integration of onsite construction data with the office-based BIM model for regular update and validation of the construction process.

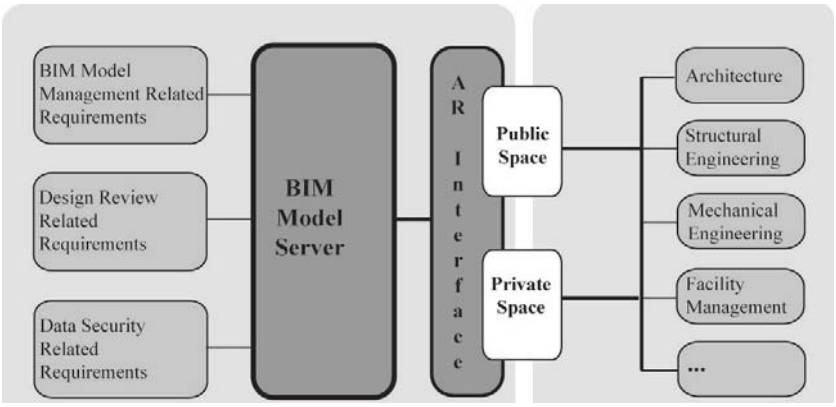

Figure 2. An AR interface for a BIM server.

5. Summary and future works

This paper emphasises the increased significance of realistic, accurate and intuitive visualisation for enhancing BIM-based collaboration across the different design and non-design disciplines in the AEC industry. The paper suggests that AR concepts technologies and techniques can be integrated with a BIM server to enhance visual communication and information exchange. The technical requirements of a BIM server as a collaboration platform are

used as the basis to discuss a framework for AR and BIM integration. Such a framework is proposed (1) to support a wide range of activities that occur during building project collaboration including the accurate, secure and flexible viewing, validating, and modifying of building information, and (2) to facilitate different levels of collaborations within a building project, through an intuitive interface for intra and inter-disciplinary collaboration. The current extension of the project is to (1) detail the framework being developed with a design scenario to further explore different elements and their relationships outlined, and (2) prototype and trial an AR application as a BIM server interface to validate the framework.

References

Bernstein, P. G. and Pittman, J. H.: 2004, Barriers to the adoption of building information modeling in the building industry, *Autodesk building solutions.*

Buchmann, V., Violich, S., Billinghurst, M. and Cockburn, A.: 2004, FingARtips: gesture-based direct manipulation in augmented reality, *Proceedings of the 2nd international conference on computer graphics and interactive techniques*, 212–221.

Ellis B. A.: 2006, Building information modelling: an informational tool for stakeholders.

Fischer, M. and Kunz, J.: 2004, The scope and role of information technology in construction, *Proceedings of JSCE*, **763**, 1–8.

Gu, N., Singh, V., Taylor, C., London, K. and Brankovic, L.: 2008, BIM: expectations and a reality check, *Proceedings of ICCCBEX11 & INCITE 2008*, Tsinghua University, China.

Gu, N., Singh, V.**,** Taylor, C., London, K. and Brankovic, L.: 2009, BIM adoption: expectations across disciplines, *in* Underwood and Isikdag (eds.), *Handbook of research on building information modelling and construction informatics: concepts and technologies*, IGI Publishing.

Haymaker J. M., Kam, C. and Fischer, M.: 2005, *A methodology to plan, communicate and control multidisciplinary design processes*, Construction Informatics Digital Library.

Holzer, D.: 2007, Are you talking to me? Why BIM alone is not the answer, *Proceedings of AASA 2007*, University of Technology, Sydney, Australia.

Howard, R. and Bjork, B.: 2008, Building information modelling: experts' views on standardisation and industry deployment, *Advanced engineering informatics* **22**, 271–280.

Ishii, H. and Ullmer B.: 2006, Tangible bits: towards seamless interfaces between people, bits and atoms, *Proceedings of CHI97 2006*.

Johnson, R. E. and Laepple, E. S.: 2003, Digital innovation and organizational change in design practice, Working Paper, CRS Center, Texas A&M University, USA.

Khemlani, L.: 2007, Top criteria for BIM solutions: AECbytes survey results, *AECbytes*, Special Report.

Singh, V. and Gu, N.: 2009, BIM server, industry needs and technical requirements, *Proceedings of CONVR 2009*, Sydney, Australia, 345–355.

Wang, X. and Dunston, P. S.: 2008, User perspectives on mixed reality tabletop visualization for face-to-face collaborative design review, *Automation in construction*, **17**(4), 399–412.

Wang, X., Gu, N. and Marchant, D.: 2008, An empirical case study on designers' perceptions of augmented reality within an architectural firm, *Journal of information technology in construction*, **13**, 536–552.

Wang, X. and Chen, R.: 2009, A study on collaborative effectiveness of augmented reality potentials in urban design, *International journal of cocreation in design and the arts*, **5**(4), 229–244.

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DEVELOPMENT OF USE FLOW OF 3D CAD / VR SOFTWARE FOR CITIZENS WHO ARE NON-SPECIALISTS IN CITY DESIGN

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Abstract. The purpose of this study is the development of a tool by which citizens who are non-specialists can design a regional revitalisation project. Therefore, a 3D CAD / VR (3-dimensional computer-aided design / virtual reality) combination system was developed by using SketchUP Pro, GIMP, and UC-win / Road. This system has the advantages of low cost and easy operation. The utility of the system was verified as a result of applying the developed prototype system in the Super Science High School program for high school students created by the Ministry of Education, Culture, Sports, Science and Technology, Japan. It has been used for two years, since 2007. In addition, the characteristics of the VR made by the non-specialists were considered.

Keywords. Urban renewal design; participatory planning; 3D CAD; VR; design by non-specialists.

1. Introduction

Finding people who can undertake the necessary work is indispensable for advancing community building using the new public system. The minimum unit in a community and that undertakes the necessary work in the community is the individual. Individuals, regardless of generation, sex, occupation or nationality, are needed to carry out positive activity for the local community

and to take it forward. In the participatory planning era introduced with the new public system, non-specialist citizens need to take not only a passive role but also a positive role. An example of the passive role is that until now, citizens have proposed designs made by specialists such as entrepreneurs, architects or designers. An example of the positive role is that these non-specialist citizens can propose designs they have made themselves.

When citizens work on a regional revitalisation project, they are not often specialists who are well versed in construction, city planning, engineering works, and the information field. Therefore, when the image of the future in the region is studied, techniques that can be intuitively understood are needed. It is thought that a comprehensible mode of expression in three dimensions is effective for this purpose. 3D CAD and VR are considered as potentially useful techniques for this.

In past research, 3D CAD / VR has been proposed as a tool that can be present a comprehensible representation of the design idea to specialists and non-specialists, and which offers interactive functions (Fukuda et al., 2003; Fukuda and Nagahama, 2007; Kaga et al., 2008; Fukuda et al., 2009). However, the results of this process so far have been produced by specialists who belong to universities and private companies that are well versed in VR technology because the price of 3D CAD / VR is fairly expensive compared to software such as MS Office. Moreover, considerable effort and time are necessary to understand the operation of 3D CAD / VR. It is necessary to create an environment in which not only specialists but also non-specialists can produce 3D CAD / VR so that both can produce design ideas.

Therefore, this study aims to develop a design system connecting 3D CAD and VR in which non-specialists, such as ordinary citizens, can make design ideas. The study also verifies the utility of the system developed, and assesses the characteristics of VR content that non-specialists have made. The computer system supporting design creation has already been reported (Lim et al., 2008). However, the users of this system are specialists, and thus are different to the users assumed in the present study. Moreover, a system that uses VR in a virtual environment is proposed as an environment in which the user can cooperatively participate (Lertlakkhanakul et al., 2008). However, the authors do not target VR in a virtual environment, but target 3D CAD / VR that non-specialists can use as a design tool.

In the research, the best software is identified, considering its functionality and the cost. The data interchangeability flow between software is established, and a 3D CAD / VR system that contributes to the purpose is developed. The prototype system was applied to the Super Science High School program (SSH) in the Ministry of Education, Culture, Sports, Science and Technology

(MEXT), Japan. Its effectiveness was confirmed as a result of applying the system. Finally, to understand the characteristic of VR contents that the non-specialists made, they are compared with VR contents made by a specialist, using a photograph.

2. Developed use flow of 3D CAD / VR software

It is thought that there are few chances for non-specialists to use 3D CAD / VR and to engage in regional reproduction design. On the other hand, it is necessary to execute 3D shape modeling by 3D CAD and creation of texture material with image editing software as preprocessing to make the VR that is the final output. Therefore, when the best software is selected for each work flow, it is necessary to consider the interchangeability of software. As a result, characteristics of the software used should be as follows:

- Operation must be easy.
- Interchangeability between software must be high.
- Software should not be expensive.

Based on these conditions, SketchUP Pro (v. 6.4) was used as 3D shape modeling software, GIMP (v. 2.4.6) was used as the texture material making software, and UC-win / Road (Education v. 1.0001) was used as the VR software.

Next, the software interchangeability was verified. As a result, texture mapping is possible in polygons on both sides in SketchUP Pro. Next, a 3D model with texture made with SketchUP Pro was exported in 3ds format, and the data was imported to UC-WIN / Road. At this time, it became clear that the texture was not being displayed on UC-WIN / Road when texture mapping was done on the back side of the polygon on SketchUP Pro. Therefore, texture mapping should be done on the front side of the polygon using the following procedures.

- After the polygon is selected on SketchUP Pro, entity information is displayed by right-clicking.
- In entity information, texture information on the surface is displayed in the left swatch. Moreover, texture information on the back is displayed in the right swatch.
- Texture mapping is done again as displayed in the left swatch when texture information is displayed in the right swatch.

Figure 1 shows the data creation flow with the 3D CAD / VR system that was developed.

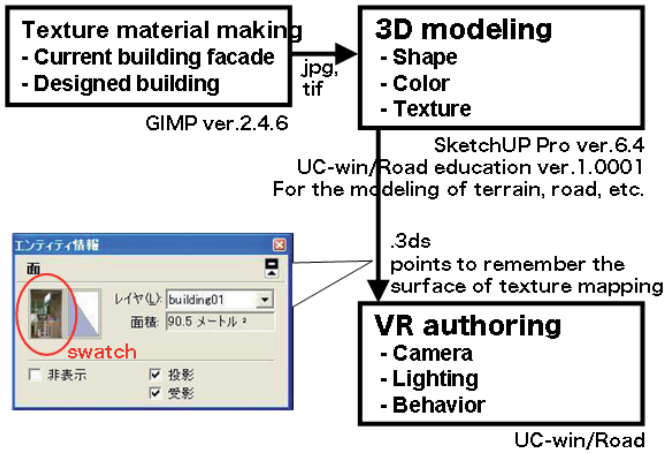

Figure 1. Developed use flow of 3D CAD / VR software.

3. Verification of developed prototype system

3.1. OUTLINE OF CASE STUDY

SSH is a designation awarded by the MEXT to high schools that prioritise science, technology, and mathematics. The program was launched as part of its "Science Literacy Enhancement Initiatives" in 2002. Schools with this status receive increased funding and are encouraged to develop links with universities and other academic institutions. Hyogo Prefectural Kakogawa Higashi High school has been awarded SSH status for five years since 2006. The KAKOGAWA design program applied the developed prototype system in one of the SSH programs in Hyogo Prefectural Kakogawa Higashi High school. This program was executed from October 2007 to February 2009 (Figure 2). Six students participated in this program. The first author is the research adviser. The second author is the teacher in charge. The KAKOGAWA design program was executed by using several PCs. Table 1 shows a PC and the software used.

TABLE 1. PC specification in KAKOGAWA design program.

CPU	Intel(R) Core(tm)2 T5500 1.66GHz
RAM	2.48 GB
VRAM	Intel(R) Calistoga Graphics Controller 128 MB
HDD	40 GB
3D CAD	SketchUP Pro (v. 6.4)
Image edit	GIMP (v. 2.4.6)
VR	UC-win / Road (Education v. 1.0001)

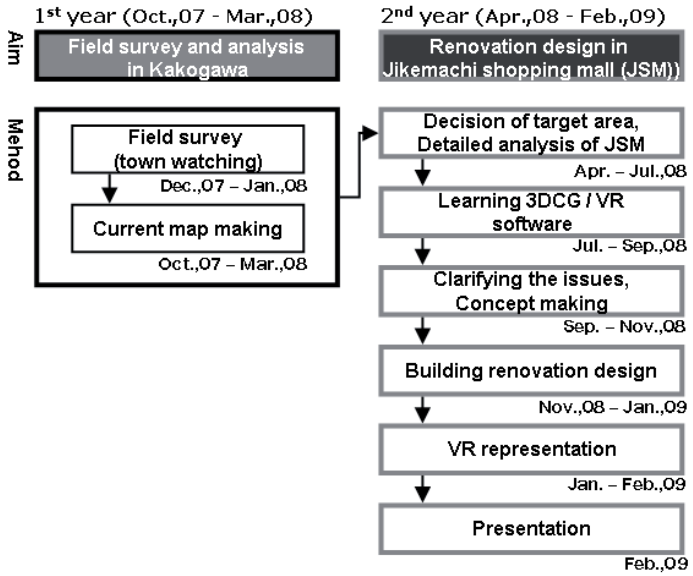

Figure 2. Design process of KAKOGAWA design program.

3.2. KAKOGAWA DESIGN PROGRAM IN THE FIRST YEAR

The KAKOGAWA design program started in October 2007. First, ice breaking was carried out by the six students introducing themselves. Next, field surveys were executed twice, in December 2007 and January 2008, to understand the urban area in Kakogawa City. As a result, the following features were found: 1) completion of elevated railway construction, 2) renewal of central train station in Kakogawa, 3) hollowing of a traditional shopping street located between the station and a high school, and 4) existence of historical construction. These results of the surveys were filled in on a paper map and Google Map, and the current analysis chart of the downtown Kakogawa City area was made. The developed prototype system was not used at this stage.

3.3. KAKOGAWA DESIGN PROGRAM IN THE FINAL FISCAL YEAR

As a result of the examination in the first year, a traditional shopping street located in the downtown area was designed in the final fiscal year (Figure 3 left). This shopping street is experiencing a decline in business, and many stores are closed. Therefore, the project members conceived methods of encouraging citizens to return to this shopping street. First of all, a 1/500 scale map of this shopping street was made. Next, information on the existing building etc. was plotted.

However, when the projects members used 3D CAD / VR technology the final goal was to propose a design for this shopping street. It is impossible to secure much time for 3DCG / VR technical learning in the research program schedule. Additionally, a high specification PC was not available so the lean budget meant an ordinary PC had to be used. Google SketchUP Pro, IMP and UC-win / Road software described in Chapter 2 were used because they satisfied the tight budget conditions and provided the necessary functions for the design. The members learned the operation of each type of software through making a current model of the shopping street (figure 4).

The members continuously enumerated the many problems of the shopping street by the brainstorming method, and classified these according to the KJ method (figure 3 right). Because the members' high school was located near the shopping street, the design concept "Expectations for the shopping street in regard to high school student life" was set. In a six-person group, the project members chose an empty building that existed in the shopping street, and a design to reproduce the building and the shopping street was proposed. Google SketchUP Pro was used to produce the design of individual buildings. Afterwards, the designs were imported to UC-win / Road and these building model data were shown using VR (Figure 5). Finally, a presentation was made three times for high school students and teachers on the study results in February 2009.

Figure 3. Current condition of the shopping mall (left); Sketch UP and UC-win / Road lecture (middle); Design study with project members (right).

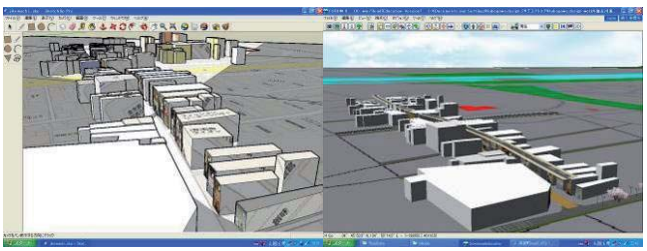

Figure 4. Current model (left: 3DCG, right: VR).

Figure 5. VR screen capture of renewal design.

4. Result

4.1. EVALUATION BY PARTICIPATING MEMBERS

A questionnaire survey on each item of the design process was carried out by the six students who had worked on the KAKOGAWA design. Eight items about the design process were included, namely: “Analyze the present state in Kakogawa City,” “Analyze the present state in the shopping street,” “Acquisition of 3D CAD software,” “Acquisition of VR software,” “Concept examination to solve the problem of the shopping street,” “Building design with 3D CAD software,” “Expression of the shopping street design with the VR software,” and “Presentation of study results.” The members evaluated each item according to four levels: “very easy,” “easy,” “difficult,” and “very difficult.”

The number in the gray circle in figure 6 shows the number of respondents. Moreover, the number beside the black circle shows the mean value by the weighted mean method. The method of calculating the mean value was as follows. “Very easy” was assumed to be one point. “Easy” was assumed to be two points. “Difficult” was assumed to be three points. “Very difficult” was assumed to be four points. In a word, a difficult tendency is shown as the mean value grows.

The lowest the mean value was 2.3 for “Analyze the present state in Kakogawa City” and “Analyze the present state in the shopping street.” Moreover, medians 2.5 were found for two items “Acquisition of 3DCG software” and “Concept plan to solve the problem of the shopping street.” On the other hand, the height of the mean value was 3.7 for “Acquisition of the VR software” and “Expression of the design idea with VR software.” Clearly, the use of VR was rated as “Difficult” while the use of 3D CAD was rated as “Easy.” One of the reasons that VR was considered difficult may be that “The VR software is considerably influenced by the PC specs such as the CPU. Therefore, the performance was bad, and the poor specification PC used with KAKOGAWA design was not easy to use…”

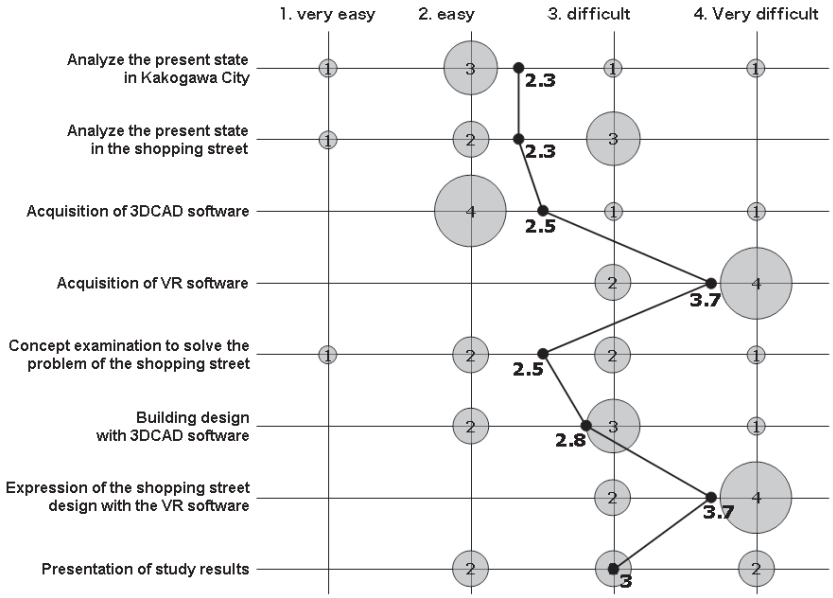

Figure 6. Evaluation by participating members.

4.2. EVALUATION BY CONTENT OF PRODUCTION

The KAKOGAWA design VR that the non-specialists made, VR (other shopping street reproduction projects) that specialists made, and the photograph are compared (figure 7).

4.2.1. Accuracy of expression

There is a blank between the arcade and the building when the KAKOGAWA design VR is observed. Moreover, there is a big blank also between the building and the road. Such a blank is not seen in the VR produced by the specialist or in the current photograph. Thus, a difference was seen in the accuracy of the reproduction of a current shopping street.

4.2.2. Content of expression

There is an assumption that the area was quiet because a signboard set up in the shopping street was not shown in the KAKOGAWA design VR. In the VR and the current photograph that the specialist made, there is a lively impression because the signboard is shown. Thus, a difference was seen in the content showing the current shopping street.

Figure 7. Comparison of VR made by non-specialists (left), current photograph (middle) and VR made by specialists (right).

5. Conclusion and future work

The purpose of the present study was development of a tool by which non-specialist citizens can design a regional reproduction. Therefore, 3D CAD / VR flow was developed by using SketchUP Pro, GIMP, and UC-win / Road. The utility of the system was verified as a result of applying a prototype system that was developed using the KAKOGAWA design program intended for high school students. In addition, the characteristics of the VR that the non-specialists had made were considered. The result of the present study is as follows.

- A 3D CAD / VR system that non-specialist citizens could use was developed by combining 3D CAD software with VR software etc. at low cost. This succeeded in solving the problem of data interchangeability between software.
- The citizens made a regional reproduction design by using the VR system that was developed, and were able to present their study results.
- The participating members felt that the operation of VR was difficult though the operation of 3D CAD was easy as a result of using the authors' developed use flow. One of the reasons why the operation of VR was difficult was the poor VR performance caused by the basic computer specifications.
- The points on which the accuracy of the expression and the content of the expression were different from reality were confirmed with the VR made by non-specialists. When the non-specialist VR was used, various differences with reality were noted.

Future works are described as follows. The system was verified in the present study for the small number people of six people. Moreover, these six people were young people of high school age – a generation who are usually competent at operating computers. The system will be verified for citizens of various ages and occupations, and a larger number of subjects will be used in the future.

Acknowledgements

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References

Fukuda, T., Nagahama, R., Kaga, A., Oh, S. and Sasada, T.: 2003, Collaboration support system for city plans or community designs based on VR / CG technology, *International journal of architectural computing*, **4**(1), 461–469.

Fukuda, T. and Nagahama, R.: 2007, Consideration of historical city area activation design study method by VR use: case study on Matsue City, *DACH2007, the 2007 international conference on digital applications in cultural heritage*, 177–190.

Fukuda, T., Kaga, A., Izumi, H. and Terashima, T.: 2009, Citizen participatory design method using VR and a blog as a media in the process, *International journal of architectural computing*, **7**(2), 217–233.

Kaga, A., Matsunaga, Y., Sakai, K. and Fukuda, T.: 2008, Construction of a design support system for a public space design in which citizens participate, *Proceedings of the 13th international conference on computer-aided architectural design research in Asia*, 426–432.

Lertlakkhanakul, J., Lee, S. Y. and Choi, J. W.: 2008, A study of the effects of placeness on collaborative virtual workplace, *Proceedings of the 13th international conference on computer-aided architectural design research in Asia*, 572–578.

Lim, S., Prats, M., Chase, S. and Garner, S.: 2008, Sketching in design formalising a transformational process, *Proceedings of the 13th international conference on computer-aided architectural design research in Asia*, 472–478.

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A SYSTEM FOR FORM FOSTERING

Parametric modeling of responsive forms in mixed reality

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Abstract. This paper investigates the integration of mixed reality with parametric modeling. This supports the concept of Form Fostering, which goes beyond the traditional form finding. Form Fostering takes sensory input from the physical world to inform a parametric model. We will present a prototype of the system that we have developed, which includes the use of a Wii Remote, an Arduino processing board, servo actuators and a camera as haptic input and interaction devices for Form Fostering. The potential benefits of designing in mixed reality are significant since designers can get real-time feedback from both the physical context and from changing physical design constraints represented by virtual parametric relationships. In order to leverage seamless interaction and activity between the physical and the virtual world, it is invaluable to consider sensing as an input for design.

Keywords. Parametric modeling; mixed reality; responsive architecture; responsive form; physical interaction; form fostering.

1. Introduction

The adoption of ubiquitous computing and sensory technology into interactive and responsive architectural design changes the ways in which we think about architecture, how we describe architecture and how we design architecture. The advances in ubiquitous computing and growth of computational power have driven the notion of the mixed reality, which is the spectrum between physical reality and virtual reality, as illustrated in Figure 1 (Milgram and Kishino, 1994).

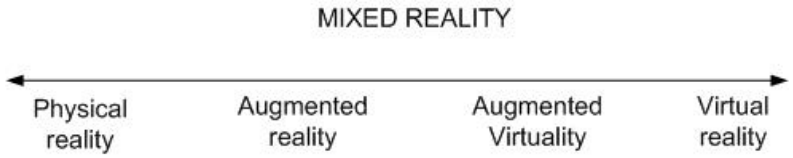

Figure 1. Milgram's virtuality continuum (Milgram and Kishino, 1994).

In augmented reality, users are interacting with physical objects, whereas in augmented virtuality, users are interacting with the virtual environment, yet the respective virtual and physical objects are displayed seamlessly (Hughes et al., 2005). The scope of interactivity and mixed reality modeling in this paper lies between the two augmentations, with the focus on parametric design for the purpose of Form Fostering.

3D architectural computer models in virtual space are generally highly malleable in parametric software like Digital Project (Dassault Systèmes CATIA), Generative Components (Bentley Microstation) or Grasshopper (McNeel Rhinoceros). The methods and tools for designing, prototyping and calibration of architecture in the mixed reality are missing from current practice and research. Given the flexible modeling power of existing parametric modeling software and inherent parametric thinking in design, there is a potential in extending these tools and techniques to allow for a more continuous process in generating architecture. The methods and tools for design in the mixed reality described in this paper are built upon existing parametric software capabilities. To our knowledge, the research and practice of modeling and simulating (responsive) architecture in a mixed-reality parametric design environment is largely non-existent.

This paper is organized as follows. Section 2 presents the related work in responsive architecture and design interfaces. Section 3 introduces the notion of Form Fostering. Section 4 presents Form Fostering experiments using Wii Remote and Arduino. Section 5 concludes the paper and presents proposals for further work.

2. Related work: responsive architecture and design interfaces

The ubiquity of bits and atoms in the mixed reality has created a great span of new frontiers for architectural design (Massachusetts Institute of Technology, 2008). Since the introduction of "kinetic architecture" in 1970 by Zuk and Clark (1970), there are various terms that have been used to connote the ability of architecture, space, structure, or building to respond to stimuli from users or the environment by means of changes in shape, organization, content or appearance. Some of these responses are more complex than others, can include feedbacks and are adaptive.

The cybernetician Gordon Pask has suggested an architectural system that is involved in a continual conversation with the users and the environment. In 1978, Pask's key collaborators, Cedric Price and John Frazer, conceptualized the Generator project, known as the first concept for an intelligent building (Frazer, 1995). Adaptive architecture has only physically materialized in the last decade. Built examples are the Aegis Hyposurface project (SIAL, 2006) by dECOi that is an interactive metal surface that responds with shape changes to multiple inputs simultaneously. Kas Oosterhuis (ONL) developed the Muscle interactive pavilion (Oosterhuis and Biloria, 2008) that responds to environmental stimuli and theoretically to other similar pavilions. The Digital Water Pavilion, designed by the Carlo Ratti (carlorattiassociati) and the MIT Senseable City Lab, encompasses an interactive and responsive water façade in Zaragoza, Spain (Massachusetts Institute of Technology, 2008). In these examples of responsive architecture, physical changes to the building occur in real-time and are driven by physical events, physical variations in the environment, or physical interaction between the architecture and the users.

As an interface to assist product design, the Augmented Foam was created (Lee and Park, 2005) as Lee and Park pointed out the need for physical and tangible interaction with 3D CAD models. The Luminous Planning table by MIT Media Lab and School of Architecture and Planning was developed for urban simulation (Ben-Joseph et al., 2001). The integration between the physical building models and the digital drawing, plans and models allows real-time simulation of sun, wind, and shade being projected on the physical models sitting on the table. The building models can be moved or rotated to generate real-time feedback of the impact of the variations. However, the physical-digital integration is not feeding into parametric design software, therefore the modification of the model is limited to changing the location and orientation of the buildings. The Tangible User Interface (TUI) by MIT Media Lab was designed to interact with Geographic Information Systems (GIS) data and parameters (Ratti et al., 2004). The TUI table is largely used for supporting landscape design as interaction with physical objects or markers are

augmented on the visualized digital terrain. This work has reported the potential for 3D free-form modeling, integration of physical and digital modeling, and the need for incorporating real-time actuated feedback on modeling in the virtual and the physical environment as future work. The work also does not mention the integration with parametric modeling software for adaptive architecture design.

3. Form fostering

Form Fostering challenges the traditional approach of informing a virtual model purely with virtual 'knowledge'. It seeks to measure data in the physical world and 'capture' relations and interactions that exist in the physical world (physical parameters) in a larger model that is not only virtual. The architectural design models therefore become mixed: partly virtual and partly physical.

Figure 2 depicts a scenario of associations between parameters in a model following the Form Fostering approach. A parameter can be associated with another virtual parameter and informed by virtual events. A parameter can also be linked with the physical environment and receives input from sensor or haptic devices. A parameter can also be static or constrained if it is informed for example by a static object in the built environment. This can be useful if an existing building or an already built part of the building is to be included in the model. This allows for design to take place in the mixed reality. Also, because the model will exist in various stages of the mixed reality, both the early stages of design (mainly virtual) and the final stages of construction (mainly physical) can be captured in the same model. In responsive architecture the relations between the building and the environment remain dynamic, even when the construction process has finished: the parametric model has materialized.

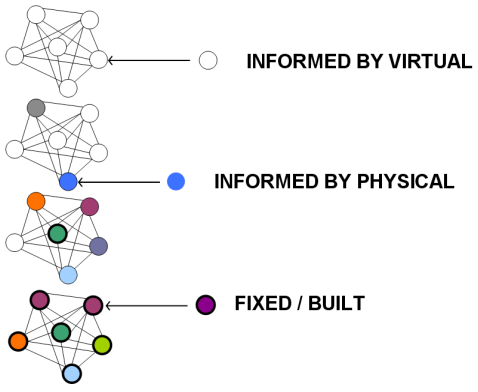

Figure 2. Parametric associations in form fostering.

Form Fostering requires interfaces for the mixed reality, both to interact with users as with the environment. The dynamic feedback loop is facilitated through informing the virtual models with changes in the physical world as well as informing the physical objects with changes in the virtual world. Real-time updates in the model can be managed in Form Fostering since designers can now use sensors, which stream data from the physical environment, as input to drive the parametric variations in the model.

4. Form fostering system prototyping experiments

The experiments described in this paper use Bentley Generative Components (GC) to build the parametric model. GC software is based on Bentley Microstation and allows users to define objects in Microstation through a different interface. Users can add additional features and functions by coding, compiling and adding Dynamic Link Library (DLL) as plug-ins to GC. Through GC, parametric relations can be defined between objects in Microstation. Complex models can be produced in this way as the relations can also be based on script or code.

We present two types of Form Fostering experiments. The first one is using a Nintendo Wii Remote (Wiimote). And the second one is using an Arduino processing board, a servo actuator and a camera. Both experiments are developed only in four days using low-cost materials. In comparison to the high-cost and complex TUI and ClayTools system, the tools developed in our experiment are much more economical.

4.1. THE WII REMOTE EXPERIMENT

A Wii Remote (Wiimote) is the revolutionary hand held motion detection sensor and controller for Nintendo Wii. The main components of a Wiimote are a 3-axis-accelerometer, an infrared emitter, and a Bluetooth interface. A Wiimote can be used to communicate with any computing device that has Bluetooth interface. Given its internal features, low cost, and the release of the open source for Wiimote development, in C#.NET (Peek, 2007) and Java (WiiRemoteJ, 2008), Wiimote has become a state-of-the-art wireless sensor device. Infrared tracking and augmented reality applications with Wiimote have been developed (Lee, 2008). However, none has actually incorporated the use of Wiimote to interact with parametric modeling for design. We first developed a Rhino plug-in that utilizes Wiimote to draw curves in 3D space. The successful experiment with Rhino 3D motivated the Form Fostering experiment of the Wiimote interacting with GC.

In the first experiment, the Wiimote is staged as an input for the virtual model. We have developed a custom C# function in GC that allows a Wiimote to interact with the GC environment using Wiimote's sensory information such as acceleration, up/down/left/right and button press/actions. The approach chosen was to input directly to the core of GC, thus various functions such as modifying nodes and changing the camera position in a virtual space were possible.

In the experiment depicted in Figure 3a, the parametric model set up in GC includes a random number of points scattered across random positions in space and a cube that acts as a selector of points that are located within its boundaries. As the Wiimote is moved, the cube's position updates and the cube moves and resizes accordingly. The points selected by the cube are updated whenever the cube moves.

In the next experiment (Figure 3b), a Wiimote is used to control the dynamic parametric surface. Whenever the Wiimote moves, the surface reforms itself dynamically based on the position of the Wiimote controller point located under the surface. This experiment has an unlimited number of real-world analogies to the creation of a responsive surface or façade. If other sensors such as light, temperature or wind sensors can be linked to such a surface, it would be useful to simulate a surface that can respond, adapt, and reform itself to suit the changing environment (e.g. a roof that extends its eaves on a hot sunny day, or a wall that curves itself when someone sits in a windy non-enclosed space).

In the experiment depicted in Figure 3c, a Wiimote is used to draw a BsplineCurve. Although the mouse is the most usable tool to interact with any 3D CAD programs, it is essentially a 2D interaction tool and is a difficult tool to use for 3D sketching in CAD (Lawson, 2004). Given the unrestricted movement of the Wiimote in the physical space and its ability not only to feed x, y, z positions in space (using infra-red emitter and tracker), but also to stream gravity acceleration data as the Wiimote is moved, it has the potential to be a tool complementary to the mouse for 3D sketching.

The experiment shown in Figure 4a demonstrates the use of the Wiimote as a camera view controller. The parametric model in GC contains a sphere object. The Wiimote is connected to a GC camera object that is linked with a controller point traveling on a sphere and gives a snapshot of the model from the camera point of view. The camera views the surface from a certain direction and angle from the sphere and can take snapshots of the view.

The parametric model in the following experiment (Figure 4b) has a direction vector as the parameter interfacing with the Wiimote's x, y and z gravity acceleration movement. The movement of the Wiimote in a certain direction

updates the position of the axis (direction vector) of the object and causes the object to move along the same direction as the Wiimote.

The last experiment (Figure 4c) demonstrates the use of the Wiimote buttons (up/down/left/right/A/B) as a "remote control" to dynamically move components across the grid points in the model or to magnify or shrink the selected object in the model 'on-the-fly'. For example, pressing 'B' button enlarges the GC parameterized component associated with the Wiimote.

4.2. THE EYE

The second experiment uses a different protocol. It allows for both input into GC and output from GC. The experiment setup was a simple relation between a physical model and a virtual representation of an eye. The virtual model mimics the physical model and vice versa, therefore allowing for calibration and for trans-reality feedback loops.

The physical model of the eye was a little robot that consists of a (web) camera and two servo motors. The orientation of one servo motor allows the camera to rotate along a vertical axis, and the other allows for movement along a horizontal axis. The servos rotate 180 degrees. The view of the camera could therefore cover roughly half a sphere like the eye of a chameleon (figure 5).

The two servos are controlled using an Arduino controller board. Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software (Arduino, 2009). Arduino controller boards connect to other hardware and have a chip that can be programmed and then

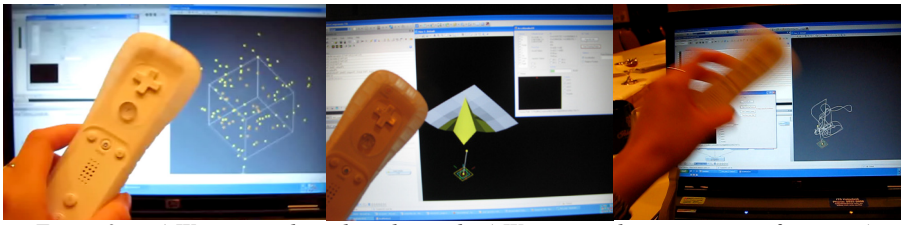

Figure 3. a: A Wiimote and a cube selector. b: A Wiimote and parametric surfaces. c: A Wiimote for 3D sketching.

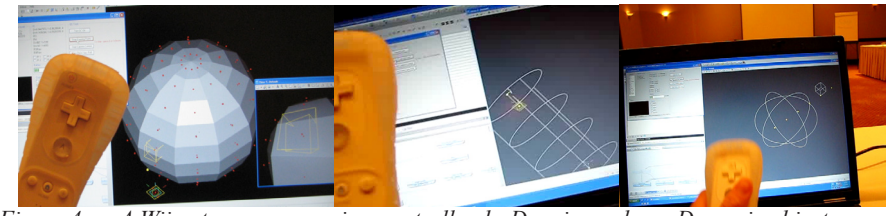

Figure 4. a: A Wiimote as camera view controller. b: Dancing pole. c: Dynamic object mover, magnifier or shrinkage controller.

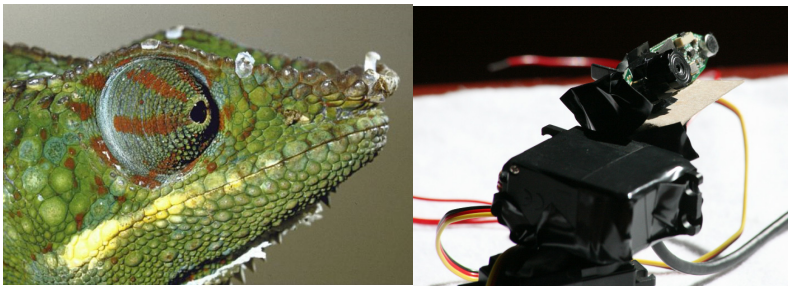

Figure 5. The Physical Sensor and Actuator of the Eye

run in a stand-alone mode. The board can also stay connected to a USB port of a computer and communicate through a serial protocol. The controller board was programmed to wait for a signal on the serial port. If the signal comes in the right format, the signal is decoded and the two servos are instructed to rotate to a defined angle.

The webcam was also connected to a computer. Open-source software (openFrameworks, 2009) was used and adapted to control the webcam and compare consecutive frames. Areas in the image that are different from the previous are marked. Therefore the software can tell that firstly there is motion in the image, and secondly where in the image that motion takes place. The software was adapted to send data to the serial port in a format that Arduino could interpret. The largest area of motion in the picture indicated the point of interest and the software would make the camera point towards that point of interest. When the camera moves however, consecutive images look completely different. Therefore a delay was added between instructions, and it was found that motion tracking of a single object along an evenly coloured background worked best. With the integration of openCV (OpenCV, 2009) for face recognition and tracking, the background image is ignored and the performance of the motion tracking is improved.

The virtual model is a sphere in GC with a dish-like solid to represent the iris and the pupil (figure 6). The size of the eyeball was kept fixed, but the rotation of the eye was based on two graph variables for a rotation along a vertical axis and rotation along a horizontal axis. The size of the pupil was controllable through another graph variable.

There were two directions of communication: the GC output mode and the GC input mode.

In the GC output mode the eyeball was controlled in GC using the sliders alongside the graph variables. A function was written in C# that would create a communication channel with the serial port. On a change of one of the variables in GC, this would send data over that channel. The data in turn would be

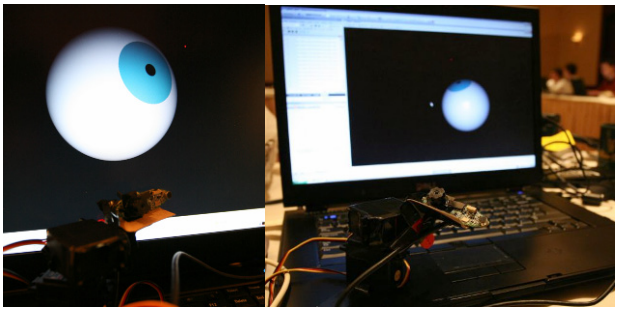

Figure 6. The Virtual Eye Interacting with the Physical Eye

interpreted by Arduino and rotate the camera. A window on the screen would display the live video stream of the camera.

For the GC input mode use was made of a web server that runs as a plug-in in GC. The web server when started waits for http requests of a specified form. This way the values of graph variables can be changed for example. The camera position was changed by moving objects that the camera would track. Based on the instructions sent to the camera, the software also sends http requests to the local web server. The graph variables would be updated and the graphic display in GC updates accordingly. The size of the pupil was driven by the size of the movement blob in the video stream.

5. Conclusion and future work

The system prototypes for experiments with form fostering validate the hypothesis of the potential of parametric modeling software as a simulation bench for responsive architecture design. When integrated with sensors, actuators, or any haptic devices, an early-stage design of responsive architecture can now be simulated. Design variations in the virtual model can be generated by parametric changes from the physical environment and vice versa. Although responsive architecture may drive this research, it is envisaged that the outcomes are more broadly usable in parametric design.

The experiments showed practical issues that need resolving such as delays in the system that complicate direct feedback. Also, with increasing complexity of interactions, the response of the parametric software would decrease. For a more generic approach and development of this field, a unified method for communication between various parts of software and hardware would be beneficial. This would allow flexibility so that “input,” “output,” and “process” can be openly defined by the designers themselves. This work is in progress and envisaged to be an open-source platform for educational and research purposes.

Other work will focus on the continuity of the responsive design through virtual and physical stages and includes experiments on capturing social and environmental parameters. Experiments in the near future are envisaged with the integration of thermal, light, humidity sensors and weather stations as well as data from social networking websites to influence variations in the parametric model. An investigation of tools and techniques is also taking place to inform the system with building performance and energy analysis.

References

Arduino: 2009, *Arduino, HomePage,* available from: http://www.arduino.cc/ (accessed 9 November 2009).

Ben-Joseph, E., Ishii, H., Underkoffler, J., Piper, B. and Yeung, L.: 2001, Urban simulation and the luminous planning table: bridging the gap between the digital and the tangible, *Journal of planning education and research,* **21**, 195–202.

Frazer, J.: 1995, *An evolutionary architecture,* Architectural Association Publications, London.

Hughes, C. E., Stapleton, C. B., Hughes, D. E. and Smith, E.: 2005, Mixed reality in education, entertainment and training: an interdisciplinary approach, *IEEE computer graphics and applications,* **26**(6), 24–30.

Lawson, B.: 2004, *What designers know,* Architectural Press, Elsevier, Oxford.

Lee, J. C.: 2008, Hacking the Nintendo Wii remote, *IEEE pervasive computing,* **7**(3), 39–45.

Lee, W. and Park, J.: 2005, Augmented foam: a tangible augmented reality for product design, *Proceedings of the 4th IEEE / ACM international symposium on mixed and augmented reality,* IEEE Computer Society, Vienna.

Massachusetts Institute of Technology: 2008, Digital water pavilion makes a splash in Spain, *ScienceDaily,* http://www.sciencedaily.com/releases/2008/06/080617115237.htm.

Milgram, P. and Kishino, F.: 1994, Taxonomy of mixed reality visual displays, *IEICE transactions on information systems,* E77-D, 12, 1321–1329.

Oosterhuis, K. and Biloria, N.: 2008, Interactions with proactive architectural spaces: the muscle projects, *Communications of the ACM,* **51**(6), 70–78.

OpenCV: 2009, *OpenCV wiki,* Available from: http://opencv.willowgarage.com/wiki/ (accessed 9 November 2009).

openFrameworks: 2009, *openFrameworks*, Available from: http://www.openframeworks.cc/ (accessed 9 November 2009).

Peek, B.: 2007, *Managed library for Nintendo's Wiimote,* Available from: http://blogs.msdn.com/coding4fun/archive/2007/03-/14/1879033.aspx (accessed).

Ratti, C., Wang, Y., Ishii, H., Piper, B. and Frenchman, D.: 2004, Tangible user interfaces (TUIs): a novel paradigm for GIS, *Transactions in GIS,* **8**(4), 407–421.

SIAL: 2006, *Aegis hyposurface*, Available from: http://www.sial.rmit.edu.au/Projects/Aegis_Hyposurface.php (accessed 4 November 2009).

Zuk, W. and Clark, R. H.: 1970, *Kinetic architecture,* Van Nostrand Reinhold, New York.

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Invited commentary

THE NEXT REVOLUTION: DIGITAL BUILDING KITS

Materialising designs with digital fabrication

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Abstract. Novice designers are gaining increased access to CAD tools for design computing and digital fabrication that were once exclusively used by expert designers. As evidenced by the rise in manufacturing incubation facilities, novices can prototype their ideas in ways similar to expert designers. Also available for novice designers are online rendering consultants, online manufacturing and online ecommerce as a way to distribute and sell products. Discussed here are the reasons for this emergence, complications when using design and digital fabrication as a standard mode of production and new focus for experts.

Keywords. Digital fabrication; sustainable design.

1. Introduction

A recent article in *Wired Magazine* entitled "The next Industrial Revolution" should be cause for concern for most people in design and manufacturing fields (Anderson, 2010). Fear of a revolution in manufacturing and design should follow the same concerns we once had over jobs and communication during the internet revolution. The fear is with good reason; so far the internet has shaken the foundation of news organisations and the traditional keepers of information. The United States has seen extermination of many local and international newspapers. Society now trusts information generated by non-expert sources (blogs) as much as they do expert sources. In many design fields, in particular architecture, the internet has given rise to drafting and rendering industries that generate images and construction documents overnight.

The article in *Wired* should soon rock the foundation of any product maker because it illustrates the ease with which ordinary people can invent, prototype and manufacture their own goods. Novice inventors do not need sophisticated software, large factories, high powered computers, high-tech design courses or instructors. Weekend designers are motivated by the availability of computer controlled machines, free CAD tools and more importantly value of ideas as real products traded through online ecommerce.

The focus of this paper is not on new high-powered robotics, gadgets that separate DNA strands or explain the latest technology around faster computers. Instead it describes the phenomenon of human invention with manufacturing machines. It is about sharing design ideas and methods of making with product kits. It highlights automobiles; however with a bit of online probing one can find that small aircraft, hobby boats and small structures are ever more being sold as kits that everyday people can assemble and enjoy. In many cases novice designers are inventing, designing with free CAD tools, emailing a file to online prototyping companies, fabricating and selling their own products. The websites such as alibaba.com and Maker Faires are visited by do-it-yourself product makers who digitally design and customise their own products. Everyday people can manufacture one or multiple copies of the same product with ease from designed kits or sell their own kit for manufacture by other novices.

In spite of the ease of fabrication there are rules and constraints that guide all digitally manufactured products. These rules are based on traditional design constraints such as form, function and appearance. They also must consider machine constraints such as CAD/CAM tooling, the limits of component casting and assembly. The rules for self generated design follow rules similar to all do-it-yourself (DIY) products, and include:

- Design and manufacturing is limited by machines, modeling tools and materials.
- Simple tools such as hammers and screw drivers are best for products sold as kits.
- Good products are designed for replication in contrast to one off products.
- Flat pack for ease of transportation.

2. Fab Labs

Facilitating this movement are open CAD / database software and open prototyping labs for public access. Professional labs such as TechShop in San Francisco provide digital tools for physical creative play and learning. Alternatively community based workshops are also growing; one in particular was founded at MIT defined as Fab Labs. They are small-scale workshops with

an array of computer controlled tools that cover several different scales and various materials, with the aim to make "almost anything." Fab Labs started as the brain child of Media Lab Professor Neil Gershenfeld in early 2002 (Gershenfeld, 2005). They are equipped with the same computer-controlled machines found in design schools such as laser cutters and large CNC machines. They also come with machines that allow for micro-level milling as a way to build circuit boards with programmable chips for second generation internet accessibility. With a Fab Lab, household lights can be programmed with internet IP addresses making them smart and accessible from afar. It is possible to Fab a building from a Fab Lab outfit with furniture and finishes. In theory, a Fab Lab can be used to manufacture a Fab Lab. For houses, Fab Labs can be used to manufacture furniture, electrical devices such as phones, ovens and someday solar panels. Fab Labs can be a sustainable response in natural disaster sites if Fab Labs are equipped with their own power source (solar power). It could be an addition to the western model of response that ships products to disaster sites in the form of finished products. Alternatively a Fab Lab can support manufacturing of finished goods on the battle field or disaster sites from raw goods. Sustainable relief plans may be enabled by employing local labor for manufacturing and product assembly.

3. Computation for physical production

After two decades of investment into design tools for computer visualisation, a grand challenge for The Next Revolution is definition of new models of computation that support design for physical production. Challenges relate computing systems that transform ideas as 3D models into descriptions for machine manufacturing, material compliance and assembly (Sass, 2005). Palladio used mathematics to describe best design and construction techniques for masons when translating his 2D plans and elevations to 3D masonry details (Palladio, 1965). His rules could be used to successfully reconstruct moldings in 3D, structurally support all loads in 3D and subdivide geometry for best methods to assemble brick and stone components. In Palladio's villa designs, wall construction required the top floor to be one brick less thick than walls on the first floor. He also wrote that walls at the basement should be twice the thickness of walls at the first floor. He had codified masonry composition as rules based on his own experience as a mason. His system of construction procedures expressed in text and drawings used to guide the fabrication of his villas.

3.1. COMPUTING BUILDING ELEMENTS

Materialising is a rule-based system with procedures that enables physical production from 3D shapes in CAD with CAD/CAM machining. Materialisation is a mathematical process of shape decomposition resulting in 2D interlocking component shapes from 3D models. The aim of the system is support for manufacture of 3D models with 2D CAD/CAM tools and common sheet goods. As a set of computational functions, materialising follows similar methods of manufacturing found in layered manufacturing or rapid prototyping (Dolenc, 1994). As a building system comprised of components, materialising follows assembly goals found in integral attachment design (Messler, 2007). Functions start by subdivision of 3D shapes into surface parts for small artifacts. For larger artifacts functions are used to subdivide the exterior of the shape and a second set of functions generate internal layers of a typical thickness. Secondary functions subdivide exterior sections and sliced layers into smaller parts based on material machine stock sizes. Assembly functions add features to the ends of each subdivided part to join components. The end product of a materialised 3D shape are components as 2D geometries ready for CAD/CAM manufacturing and hand assembly.

3.2. MESOSTRUCTURES

Software for rapid prototyping machinery has similar outcomes focused on building artifacts as a series of assembled objects. Research in this field has focused on discovery of efficient functions for slicing shapes in CAD into layers for manufacturing. New research explores ways to generate geometry as internal meshing or structuring defined as mesostructures tailored for a specific performance (Chen, 2008) as opposed to layers. In one example, Yong considers application of these mesostructures for finished manufacturing of cushions designed to vary in areas of firmness and softness. His method builds foam pads with micro-structures as a way of varying foam density. A mesostructure is non-uniform sectioning thorough a 3D file as a way to generate tool paths for layering of material. Yong's computation allows for manufacturing of non-solid objects manufactured with rapid prototyped machines, the artifact is composed of an open web structure and an external solid surface.

3.3. MATERIALISING A SHAPE

Materialising a shape is generation of geometry for manufacturing in layers along three axes opposed to horizontal only sectioning found in rapid prototyping software. The desired physical size of the final artifact determines the number of functions needed to decompose an initial shape and the degree to

which each function can be automated. For example, a function that copies all sides of a three-dimensional shape from 3D to 2D for laser cutting can be an automated function. In contrast, once each side is drawn as a 2D shape, sorting thousands of parts for material efficiency may be best implemented as a non-automated function. For a very tall structure manufactured components at the foundation should be manufactured first, components at the top of the structure should be manufactured last.

3.4. SIZE MATTERS

The size and material thickness of the finished artifact determine the investment computation. For example, manufacturing of a very large artifact requires three to five core functions along with many sub-functions in order to transform a 3D shape to 2D cut patterns. Subdivision and organisation of the 2D cut patterns are guided by *rules of construction.*

Materialising an artifact the physical size of sports balls is computation and digital fabrication with physically thin material. The first function set organises the subdivision of outer shape into panels developed prior to the computation. The second set of functions is aimed at adding features to previously subdivided geometries for assembly. These features aid physical assembly between components after CAD/CAM manufacturing. Characterisation and generation of features in CAD are designed for connectivity between parts with assemblies sustained by friction. The third set of functions creates 2D shapes from the 3D model. Fourth is sorting and packing of 2D shapes within the boundary of a sheet.

Materialising large artifacts such as buildings where an internal structure is required a similar set of functions are used to decompose the surface first, followed by creation of internal structure. Three core sets of functions are employed; the first decomposes the exterior surface into components, second generates an internal structure and the last set of functions integrates the surface and internal structure. Both sets of functions are determined separately, later integrated with functions that create features for connection between surface and structure. For building structures materialising three-dimensional shape(s) provides a virtual skeleton for design and integration of other systems such as plumbing, electrical and energy.

3.5. CONSTRUCTION RULES

Layered manufacturing software generates surfaces from a 3D model as horizontal sections for manufacture one layer at a time. The software assumes physical manufacturing and assembly parameters as part of the subdivision

process. *Materialisation* generates manufacturing and assembly data as part of the subdivision and object creation process. *Construction rules* are imposed constraints that limit subdivisions and guide the generation of geometry based on the material and machining and assembly limits (Sass, 2007). For larger structures non-automated steps allow for calculation and planning for manufacturing and assembly efficiency. For example, structural testing and materials ordering can be challenged during the subdivision process. Areas of material under high stress loads can be fabricated of high strength plastic or steel, while parts under low stress can be fabricated of recycled material. Also a systematic approach to the design integrated assemblies is possible. Integral assembly design is commonly found in the plastics industries in the design of snap-fit assemblies (Genc et al., 1998). Limits in assemblies between components and assembly mechanisms can be designed as part of the generative process.

Materialising a design as a computational process is used to prepare a CAD model for manufacturing of 2D components, key aspects of the process are described below:

- 2D machine-compliant shapes are generated for manufacturing from 3D models.
- Functions can be automated and non-automated.
- Construction rules set limits for generative functions and component composition.
- Functions generate components as surfaces for the artifact and components as internal structure.
- Integration functions assure a relationship between the surface and structure.
- Each component includes an assembly feature that relates to adjacent components.
- Shaping of components and component assemblies is based on rules from a construction grammar.

4. Sustainable design production

Novice involvement in production of manufactured buildings is possible by materialised geometry directly from 3D design model files. This process of making small and large products offers some hope for real development of local economies by situating design and production in one place. Situated production benefits developing nations and sites of natural disaster which require permanent product production rapidly. In many cases non-western societies cannot support large building factories (prefab) and importation of building materials such as dimensioned lumber or shaped steel. Needed is a flexible design and production system as a way to introduce new design possibilities

and ways to think about non-western product development.

In response to new methods of construction, not all countries will have or need access to westernised construction systems. Digital fabrication machinery is small, portable and simple to run. Digital fabrication and materialisation functions provide access to a production system supporting ongoing interest in regional or individualised design and fabrication. The benefits are worldwide sustained production at a low startup cost. Socially sustainable design solutions make better use of local labour and knowledge.

Materialised design data also allows for physical construction with few tools. Rapid assembly is possible by inclusion of designed building assemblies into the manufacture of each component. Structural safety is also assured by enabling virtual testing with algorithms for finite element analysis of components. Typical methods to evaluate a building's structural stability require that components are designed for efficiency first, after which more material is added to the component to increase its strength for safety. Over-structuring compensates for the communication gap and material variability between the design model, the shop and field conditions. This gap in communication has been solved in automobile and aerospace engineering from CAD/CAM machining with advanced CAD tool applications such as finite element analysis. Materialising a design is an efficient process for production; the question continues to be tool development.

5. Physically integrated components and systems

For western societies this New Revolution in production and design exploration supports sustainable design practices for novices. It will also empower partnership with design and engineering schools for development and innovation of new building components for experts. We have seen great promise with building information systems (BIM) providing a platform for designers, engineers and builders to integrate their intentions. Effective computing (materialising), flexible manufacturing (direct manufacturing) and new forms of communication are critical for the following emerging fields.

- Materialising systems for whole building models for all materials from steel to wood and concrete.
- Integrated energy solutions into BIM models: solar panelling, wind and geothermal.
- Analysis modeling: assured relationship between structural loading, seismic, 4D and 3D BIM modelling for higher levels of fidelity.

Materialisation of the building structure and integration of associated engineering fields will offer pathways to challenge building performance during

the design process. Emphasis is placed on computing of the actual objects in construction in contrast to representations or intentions on screen.

7. Next generation building kits

Production of houses as e-commerce products has been promised for many decades. Architects have posted drawings and CAD models online for others to view and purchase. Alternatively materialising and BIM modelling demonstrate the potential of buildings as a kit of parts that could result in a well thought-out product. Home kits can be high quality products delivered as a collection of snap-fit components that once assembled result in an integrated product. The flexibility of digital fabrication can empower localised designs and localised manufacturing.

The idea of housing kits has been available since 1902 from Sears and Roebuck, to the Lustron House and the General Panel Company started by Walter Gropius and Konrad Waschmann. Currently there are panelised, dome and green home kits also available online. Companies that make these houses claim their systems to be easy and simple to build. A related question is: if they are so simple, why have house kits not contributed to the worldwide need for affordable homes? Why have home kits not had the same impact on society as cell phones have on communication? Is it too expensive to ship house kits, assemble with few tools, or generate a variety of building styles or manage the costs?

There is a number of home kit providers online who offer standard home products as kits that include most of the elements needed to build a house. A current example of a conventional building kit is the Katrina Cottage offered by Lowes Home Stores intended for sale as a kit of parts. Unlike a digital set of components, it sells a materials list for contractors and tradesmen to follow along with a set of drawings. The owner is required to hire an architect, specialised labour, with specialised tools and purchase space. Such home building kits require many service workers from various trades and consultants: plumbers, electricians and carpenters.

An important comparison can be made between building kits with car and aeroplane kits that are also sold online. These kits are made for assembly by hand with few tools. The benefit of the kit is that reduced labour lowers the cost of the end product. Such automobile and aerospace kits are integrated product kits for assembly of complex systems including brakes and engine to electrical and mechanical systems. Another advantage is that kit producers offer a variety of styles; car kits range from low-grade sports car kits to a Hummer car kit.

A materialised building kit could arrive as a complete product of parts, ready for assembly with a few basic tools. Structure and building skin could be manufactured of interlocking parts. Mechanical systems as a series of flexible conduits and pipes and electrical lines as solid state with snap together tracks and lines are possible. Lighting, plumbing fixtures and kitchens can be integrated products as well as easy to assemble with few tools. Most important is involvement of the kit owner at all levels from plumbing to painting.

Building a house from a kit of materialised components could simplify home delivery for worldwide access. With this we also have to face the fact that complexity remains in design and rethinking home delivery with digital tools. Manufacturing can be simplified with Fab Labs and flexible building systems. Required are redesign and refocus on integration and manufacturing of complete and finished homes that also include new energy systems such as solar and geothermal systems. In the end the next revolution implies integration of systems mixed with manufacturing as a way to produce products for general consumers to build as well as experts.

References

Anderson, C.: 2010, Atoms are the new bits, *Wired magazine*, February.

Gershenfeld, N.: 2005, *FAB, the coming revolution on your desktop: from personal computers to personal fabrication*, Basic Books.

Palladio A.: 1965, *The four books on architecture*, translation by Isaac Ware in 1738, Dover Publications, New York.

Messler, R.: 2006, *Integral mechanical attachment: a resurgence of the oldest method of joining*, Butterworth-Heinemann, Burlington, Mass.

Chen, Y.: 2008, Computer-aided product design with performance-tailored mesostructures, *Computer-aided design and applications*, **5**(1–4), 565–576.

Dolenc, A., and Makela, I.: 1994, Slicing procedures for layered manufacturing techniques, *Computer-aided design*, **26**(2), February.

Sass, L.: 2007, A physical design grammar: A production system for layered manufacturing machines, *Automation in construction*, **17**(6), 691–704.

Genc, S., Messler R., and G., Gabriele: 1998, A systematic approach to integral snap-fit attachment design, *Research in engineering design*, **10**(2), 84–93.

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MATERIAL FEEDBACK IN DIGITAL DESIGN TOOLS

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Abstract. How do design tools feedback material behaviour to the designer? Digital design tools in use by designers today provide a rich environment for design of form but offer little feedback of the material that ultimately realise that form. This lack of materialism limits the value of the design tool and the exploration of the design space where material behaviour can provide important feedback. This work examines the modes and value of material feedback in design using systems engineering principles, illustrates the challenge with current tools and explores a prototype simulative interface. It approaches the problem from a new perspective of simulating physical manipulation and experiment rather than existing CAD paradigms.

Keywords. Interactive design tools; material simulation.

1. Introduction

1.1. BACKGROUND

In the modern era, architecting and building have become two separate endeavours, separated by a chasm between an architect's vision and the practicality of building within resource constraints. This chasm is an artificial separation that requires time and effort to bridge and introduces risk, error and waste. Despite some historical opposition of this separation by critics like Ruskin and others, the movement has distanced designers from the material used to realise designs.

Digital tools are slowly bridging this chasm with technology, changing the nature and business of designing and building. This is not simply an evolution in the efficiency of building, but a change in the way designs are realised. The changes ripple all the way back to how designers work in the design tools and how those tools can inform design. To understand this change, we

must examine the nature of the chasm and the relationship of the tools to the designer.

1.2. PROBLEM DEFINITION

For this work, I am concerned about the nature of the feedback of material behaviour to the designer. There is a primitive direct saliency when designing directly with the material as an artist or craftsperson would. The material behaviour has a direct channel of feedback to the designer and the moves and gestures that are made are intimate with the material. As we look at designing within the currently available digital toolset, there is a lack of this informative intimacy with the material that limits the design space that can be explored, even with digital rapid prototyping tools. The distance from the material often leads to arduous post design rationalisation.

1.3. OBJECTIVES AND METHOD

This work investigates the use of feedback of material behaviour to designers during the design process by decomposing the structure of these feedback channels and evaluating the value of this communication. Methods of data flow diagrams and systems engineering principles, I approach this by examining prior research, applying analysis techniques, extrapolating historical developments in this framework and exploring a prototype interface for material responsive extension to current tools.

2. Background

2.1. FEEDBACK IN THE DESIGN PROCESS

Design involves a cycle of generation of possible solutions to a problem, perhaps ill-defined, through pursuit, testing and refinement of solutions. Feedback from possible solutions provides validation of the explored space at many levels and may redefine the problem itself. In this pursuit the designer has many tools available to them including their own experience, physical analogy, imagination, prototyping and, increasingly, digital tools. What is common among all of these tools is the feedback the tool provides to the designer that they can use to refine the solution or spark new design paths.

Feedback loops are well supported by studies of designers through observation (Fricke, 1993; Cross and Dorst, 1998) and through theoretical models of designing (Oxman, 2006). These studies have found a common set of activities in the design process which involve a feedback loop of analysis, synthesis and evaluation. Often the way these paths of feedback have been realised is in

separate processes with separate tools supporting them.

2.2. MATERIAL KNOWLEGE IN FEEDBACK LOOPS

While material knowledge is needed for the rationalisation of designs, some target material performance may be considered early in the design stage. Cross (Cross and Dorst, 1994) and Akin (Akin and Lin, 1996) have observed, in controlled design cognition studies, that the quality of design may be correlated to the frequency of non-exclusive modal shifts between drawing, examining and thinking (analogous to synthesis, evaluation and analysis) during exploration of conceptual design. This suggests that tools engaged during this time of creative rapid shifting of strategies have a large effect the quality of the design solution. Information flow in this phase includes internal knowledge and external feedback from the design tool including material behaviour. Friction to information flow between the designer and tools will negatively impact the design solution or increase the effort to refine the design.

While not every design process may be informed or dependent on material behaviour, there is evidence that material feedback loops have an important value to designers for both rationalisation and design exploration. This includes design in which material behaviour is used only as an analogy for the final form. In the analysis I examine why reducing the material feedback loop has value and look for clues as to the next logical steps in the development of the tools.

3. Exploration: material feedback loops

3.1. CLOSING THE LOOP

By examining actual feedback loops in the designing process, we can understand the nature and value of the information passed back to the designer. If we ignore, for the moment, the implicit knowledge of the material by the designer, which functions as a short cut in the design process, we can diagram the feedback loop of the naïve designer in a simple mode of designing with a separate builder without prototyping (figure 1).

This case requires the designer to hand off indirect design documents to a separate maker who implements the design into a physical instance and returns the information about constraints to the maker indirectly. This is a costly and long process which reduces the quality of information back to the designer and ultimately limits the material sensitivity of the designer to observation of full scale implementation. It is evident why the “expert” designer’s material knowledge is valuable in producing feasible / adept designs rather than rely on indirect feedback in a longer loop.

The tradition of prototyping has reduced this loop for visual, mechanical and material feedback. The history and pedagogy of prototyping in design is well documented. The effect of prototyping is to reduced the total length of the loop and bring the feedback closer to the designer. If the act of prototyping is used as a design tool directly by the designer, the activity is approaching the immediate modal shifting feedback that has been shown to have high value to the design process. This direct manipulation of the material in 'playing' with the prototype changes the mode of design thinking.

Rapid prototyping directly from digital designs such as laser cutting, CNC-machining or 3D-printing further reduce the time to gain feedback and increase the iterations that a designer can achieve with the same amount of effort. The value of the prototype depends on the accuracy of modeling the actual scale behavior.

This indicates a historical trend of cost reduction (or ease of iteration) and increasing accuracy and value of the feedback (figure 2).

Other information flow diagrams were used to understand various modes of designing, prototyping and materialisation including novel approaches of design in the physical realm with digitisation in the manner of Geary (Shelden, 2002). The scope of this research did not allow further quantitative measures of loop length in resource cost or time and this is left for a future area of investigation.

3.2. DIGITAL MATERIAL FEEDBACK

The next logical progression in closing the feedback loop is to allow digital simulation of the material behavior. This reduces the feedback loop to near direct manipulation of the material, albeit without tangibility. If we examine

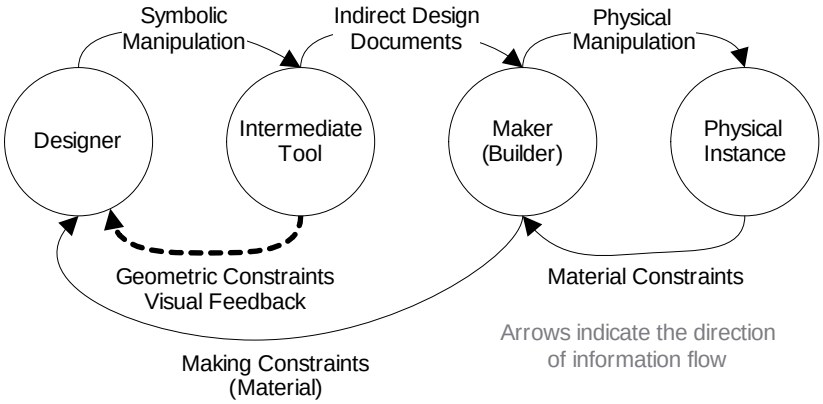

Figure 1. Design feedback loop, separate builder, no prototyping.

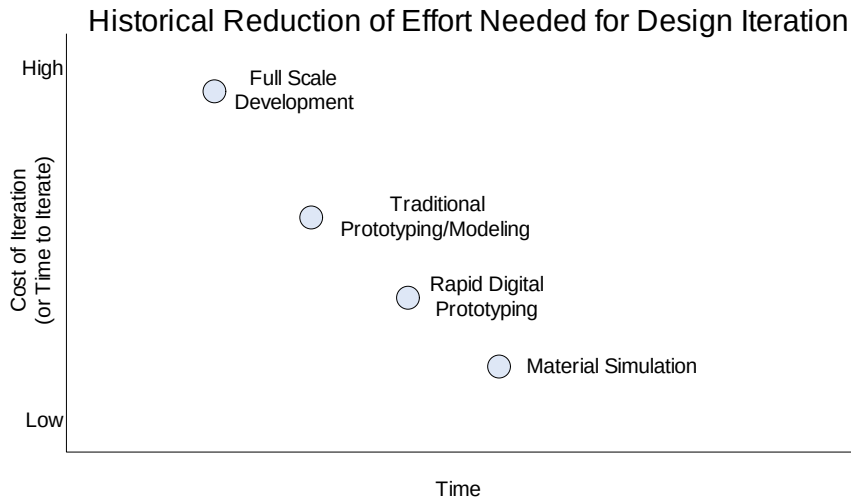

Figure 2. Historical reduction of effort needed for design iteration.

the flow of information (see figure 1), the flow from the intermediate tool back to the designer (figure 1 dashed line) is the most immediate and powerful. This step has already been incorporated into digital design tools for visualisation with the increasing fidelity of rendering engines expanding the space of visual exploration. Just as visualisation has become more advanced as computing power has improved, simulation of basic homogeneous and mildly heterogeneous material behaviors is now possible.

3.3. DESIGN TOOLS PARADIGMS

Design tools have been developed, regardless of the underlying geometry representation, for providing manipulation of abstract primitive shapes without regard for material at the time of design. This has lead to the paradigm of basic build up of geometric operations that only have an indirect analogy to the physical action of manipulating real material (see example above). This disconnection between design tool operations and the physical operations to materialise the design pushes the implementation and knowledge of material specific behaviors to other tools and experts away from the designer. This is just a new manifestation of the design loop shown above.

Other explorations into projecting material behavior into a digital simulative tool (Oxman and Rosenberg, 2007) have explored problem with non-interactive scripted simulation of complex behaviors. The simulative and generative solutions are largely purpose-scripted. Based on historical progression in other software user interface maturations this does not represent a sustainable and flexible design tool solution.

How could digital design tools evolve to allow manipulation of simulative material?

4. Exploration: tools solution

4.1. ILLUSTRATING THE PROBLEM: THE "SIMPLE" RIBBON

As an illustration into the limitations of the current toolsets for designers, a "simple" ribbon shape was chosen. This shape is very simple to calculate physically. It is a simple band folded and joined at right angles and the material defines the shape (figure 3). Attempts and failure to reproduce this shape in representative digital tools (Bentley Generative Components, AutoCAD, Digital Project and Rhino) illustrates the lack of tools to deal with even simple material behaviours.

The conclusion of this exploration was that the tools available for digital design were poor in exploring even a simple physically defined figure without geometric derivation and scripting to reproduce the physical behavior.

A tool was developed in the Processing environment to simulate the material behavior rather than rely on the built in primitives of existing tools. This tool was developed from the general physics of elastic material behavior, calibration against physical material and simulating both the twisting and gluing used to make the ribbon physically. The simulated ribbon recreated the geometry found in the paper ribbon as well as other similar designs and was able to illustrate simple limits to material elasticity. This tool, however, still lacks an interactive design experience.

4.2. EXTANT MATERIALLY RESPONSIVE TOOLS

Tools that offer simulative interactive environments are emerging, but are not

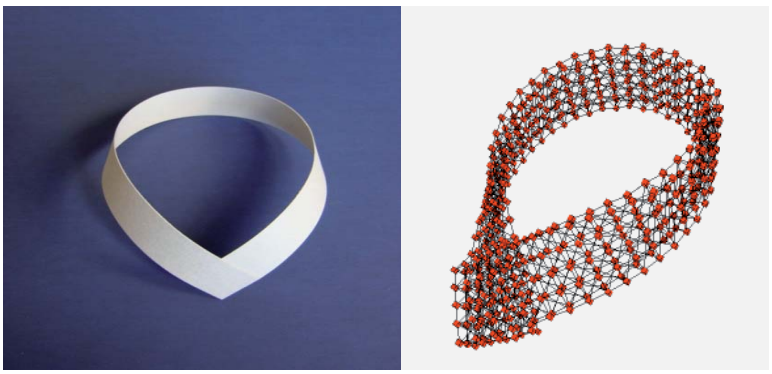

Figure 3. Physical artifact and simulative model of "simple" ribbon.

yet used in the architectural design field. Blender (www.blender.org) is one of the best examples; it used to build virtual objects with behavioural attributes for the entertainment industry. A sculpture mode allows the designer to sculpt in gestures very similar to physical manipulation. This tool is aimed at virtual production but using it as a design tool for physical artefacts is intriguing.

Other tools simulate more macro physics behaviour, typical of this class of software is Crayon Physics (www.crayonphysics.com). Of note with this tool is the design interface which behaves like traditional sketch pad. Tools in this class are just beginning to be commercialised. Autodesk Inventor is focused on mechanical design through simulation.

Commercial design tools are still largely manipulating abstract geometric and post design simulation and not material simulations at design time. These are largely object based rather than process or assembly.

4.3. DESIGN TOOL DEVELOPMENT

Current traditional design tools such as AutoCAD, Bentley, Rhino, Digital Project and others support primitives operations but lack operations for simulating material behaviour such as bending or stretching. The ribbon exploration above illustrates whole class of design alternatives which involve bending or twisting that are unavailable to a designer using one of these tools.

We can show how these features would be added to traditional tools, although the feasibility of retrofitting current software with a whole new type of object behaviour and simulation may not be possible. We illustrate the simulative design environment with mock ups of additional features in the Rhino environment.

This is not proposing to replace other more accurate simulation of material or other attributes by more specialised software but to provide feedback to the designer similar to the strong material feedback of physical modelling in as an extension of the tools in use today by designers.

We can illustrate this by following a scenario with well understood sheet material to show simulated manipulation. The material could be wood or paper or other material manipulated in the elastic zone of deformation. In an expanded tool, malleability, nonlinear and asymmetric elasticity curves could also be modelled.

4.4. DESIGN TOOLS FEATURES TO SUPPORT MATERIAL BEHAVIOR

Creating the object involves specifying the material properties using extensions of the existing object attributes. Objects can be manipulated with traditional tools for cutting, splitting, Boolean solid operations and mesh editing

that affects the physical boundaries of the object without regard for materiality. This is standard functionality of existing tools.

An object can be ‘relaxed’ into the default state and ‘glued’ to a plane (figure 4). The concept of ‘gluing’ is adopted from the physical world and closely follows the actual operations that you would use to construct the object. The relaxed state of an object might be one of curvature or even an intermediate state of construction and a malleable object may have the relaxed state change with the application of forces.

The act of gluing the object fixes these points in relation to some other object, in this case the world UCS. In this mock-up, the yellow 2D arrows indicate the ‘glued’ fixed patch that is attached. This patch of gluing could be any shape, but here it is rectangular. In more sophisticated environments gluing could have yield strength.

Springs can be assigned to points on the surface, edges or to whole planes and the object responds the same way a physical material would behave. Springs have force and direction. The direction could be normal to the plane

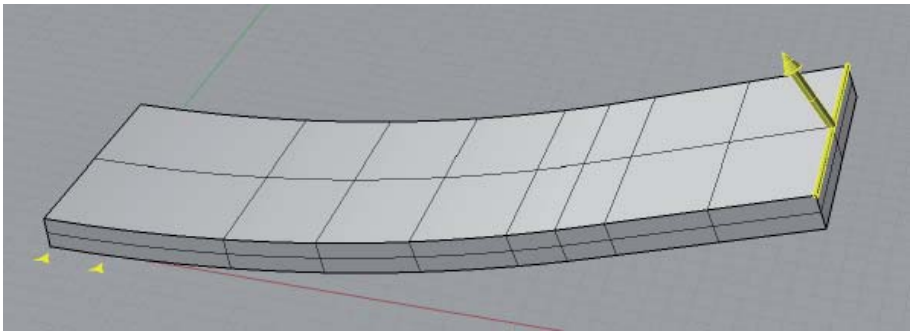

Figure 4. Plank anchored and force applied to an edge.

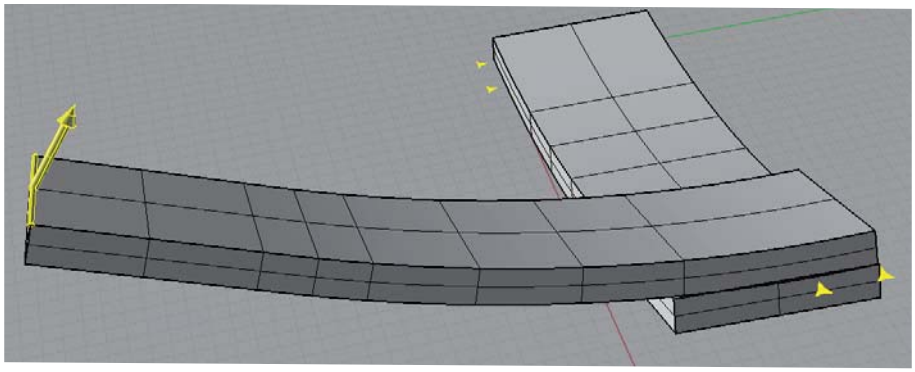

Figure 5. Two planks glued together (lower plank has twist from torque).

or pointing at some other point, either fixed or on another object. The designer should be able to attach a spring to a dynamic point and experiment with the material behaviour in real time (a spring anchored in a dynamic point).

The failure mode of real material is very complex, but the object should indicate the limits of elastic deformation. It should be clear to the designers that they are approaching or past the limits of deformation. The object can be redefined with different material and the object will respond to that change given the force and gluing that had occurred.

Objects should allow interference with other objects and they should be able to exert pressure just as solid objects should be expected to behave. Chains of operations should be supported, so gluing one plank to another, should behave properly (figure 5). Note that the end of the first plank is twisted in relation to the other end, truly simulating the torque placed via the force of the second plank.

Note that the assembly sequence and the operations involved mirror the actual assembly process although perhaps not always linearly.

While there is more that could be implemented, the three features described here: Interference, Bending and Gluing could create a robust environment for materially responsive design.

5. Conclusion

5.1. SUMMARY

With the increasing fidelity of simulative environments, the capability is emerging from purely technical assembly and engineering digital environments into environments that mimic physical manipulation of material. This advance will provide the designer with an environment that allows form finding and / or early materialisation of abstract form through feedback that has been shown in this paper to have value to the entire macro process.

5.2. FUTURE DEVELOPMENTS

I believe that we are on the cusp of design tools transitioning from the purely abstract basic object manipulation to more immersive simulation environments where the designer can explore the mechanics, material behaviour, fabrication constraints, assembly and visualisation directly in the design tool in near real-time. Many trends point to this future including the progress in understanding design as a process, the advancement of digital rationalisation and the availability of enabling computing power. Change in the business of architecting has also increased the designer’s interest and responsibility in rationalisation and delivery of designs. Pressure from firms leveraging (and

struggling with) these technologies is driving development of more advanced simulative integrated software. These tools will expand the designer's ability to explore the design space while producing designs that are more easily rationalised and responsive to the material properties.

5.3. CONCLUSIONS

This research has produced several conclusions: Material feedback in design tools has strong theoretical support including that early rationalisation / materialisation has implicit value to the downstream process after conceptual design, both in design quality and project economy. There is a historical progression of tighter material feedback loops driven by value to the design process which would indicate that simulative tools continue that trend. Most commercial design tools only weakly support material simulation and it is possible to build tools that effectively simulate the behaviour of material within constraints. Having digital simulative environments opens new areas for design exploration and material use.

References

Akin, Ö., and Lin, C.: 1996, Design protocol data and novel design decisions *in* N. Cross, H. Christiaans and K. Dorst (eds.), *Analysing design activity*, Wiley, Chichester, (35–64).

Cross, N. : 2007, *The designerly way of thinking*, Birkhäuser Verlag London Ltd, London.

Cross, N., and Dorst, K.: 1998, Co-evolution of problem and solution spaces in creative design: observations from empirical study, *Computational models of creative design IV.*

Cross, N., H., C., and Dorst, K.: 1994, Design expertise among student designers, *Journal of art and design education*, **13**(1), 39–56.

Fricke, G.:1993, Empirical investigations of succesful approaches when dealing with differently precised design problems, *International conference on engineering design ICED93*, Heurista, Zurich.

Mitchell, W. J., and McCullough, M.: 1997, *Digital design media*, John Wiley & Sons, New York.

Oxman, N., and Rosenberg, J. L.: 2007, Material performance-based design computation, *Proceedings of the 12th international conference on computer aided architectural design research in Asia*, Nanjing (China), 5–11.

Oxman, R.: 2008, Performance-based design: current practices and research issues, *International journal of architectural computing*, **6**(1), 1–17.

Oxman, R.: 2006, Theory and design in the first digital age, *Design Studies*, **27**, 229–265.

Schön, D.: 1983, *The reflective practitioner*, Ashgate Publishing Limited, London.

Shelden, D. R.: 2002, Digital surface representation and the constructibility of Gehry's architecture, MIT thesis.

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BIO-SHELL (BIODEGRADABLE VACUUM-FORMED MODULARISED SHELTER)

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Abstract. This paper demonstrates how digitally fabricated vacuum-formed components can provide a new type of efficient construction applicable to architecture. Vacuum forming has the advantage of rapid mass-production capability of 3D curved forms. Recent digital fabrication technologies, such as 3D CAD and CNC machining, have dramatically reduced the cost and time for making the mould. In combination with biodegradable plastic, such as PLA (poly lactic acid) made of biopolymer, it could open up new type of sustainable construction system, which is applicable for temporal disaster housings or exhibition booths.

Keywords. Digital fabrication; biodegradable; vacuum forming; finite element; lightweight structure.

1. Introduction

The importance of material-efficient construction is significantly increasing due to recent growing concern for a worldwide shortage of natural resources and rising material costs (*The Economist*, 2007). Most of temporal structures are material-efficient and lightweight as they often require quicker construction. The material-efficiency ensures not only savings in material consumption but also reduces transportation energy.

There are mainly three types of temporal construction systems. Firstly, tensile structure, such as tent, has proven as one of the most material-efficient structures in human history. However, it often sacrifices efficiency of usable space and adaptability due to required continuous membrane forces (figure1a). Secondly, frame and panel structure which is almost ubiquitous in contemporary environment, and provides highly efficient space and adaptabil-

ity although it is less lightweight than the tensile structure (figure1b). Thirdly, surface structure such as thin-shell dome is both space and material-efficient, however, few have been constructed recently due to difficulty in its fabrication process and costly 3D formwork (figure1c).

Recent rise of digital fabrication technologies, such as computer-aided design and manufacturing (CAD-CAM) have dramatically reduced the cost and time for making complex 3D mould. Finite element (FE) method can simulate structures prior to construction. The advanced digital technologies suggest that we reconsider use of surface structure as reasonable material-efficient construction method. Such temporal constructions are also often required to be collapsible and efficiently stacked while not in use. Because of shorter building life cycles, issue of construction waste becomes more significant than in permanent constructions.

Figure 1. Lightweight structural type:. (a) tensile, (b) frame and panel, (c) surface.

This paper aims to demonstrate how advanced digitally assisted design and fabrication processes can create temporal lightweight surface structures which provide efficient usable space and adaptability with various configurations yet reduce amount of construction waste after its use. First an overview of the bio-shell will be presented, followed by its structural geometry, FE analysis, digital fabrication and assembly testing. The paper concludes with comparative analysis with precedents.

2. Biodegradable vacuum-formed modularised shell (bio-shell)

The bio-shell is a lightweight shelter for sustainable construction made of biodegradable plastics. Each component is rapidly vacuum-formed with digitally fabricated 3D curved moulds in order to increase its structural stiffness instantly. It is ideal for temporal constructions which need to be cleared swiftly after its use without burdening the environment.

In 2007, the first author conceptualized the bio-shell in Hong Kong through a series of field researches on fabrication processes and materials in Pearl River Delta in China, named the world factory. The concept was awarded at the international architecture competition, Self-Sufficient Housing, in Barcelona. Since then several prototypes under the same concept are developed.

This paper introduces the latest and the most material-efficient structural prototype among the past and current explorations.

We take a multidisciplinary approach which includes the following four steps: 1) Structural geometry, 2) FE analysis, 3) Digital fabrication and vacuum forming, and 4) Assembly and joinery testing. These steps are repeated until we reach an optimized design. Constant feedbacks are made to the master 3D modeling data generated by Rhinoceros, NURBS modeling software that are then reflected to the all steps simultaneously.

2.1. SURFACE STRUCTURE GEOMETRY

2.1.1. Structural design concept

Four major principles of modular shell structural geometry are employed. Firstly, the overall configuration should be almost cubic like geometry in order to maximise usable space and adaptability. Secondly, the wall and roof panel geometry may consist of hyperbolic paraboloid (HP) shell in order to achieve material-efficient structure. The balance between usable space and structural efficiency should define the aspect ratio, namely the proportion of length and height of HP shell. The higher the aspect ratio, the thicker the wall panel, which means stronger structure but fewer usable space. Thirdly, those HP shell wall / roof panels should be smoothly connected with each other to transfer forces efficiently from roof to wall, or vice versa. Finally, the HP shell wall / roof panels should be articulated into repetitive smaller scale components due to producible size of vacuum-forming process.

Combining all those principles, we develop the HP shell-cube structure (figure2). The whole structure resembles the shape of a cube while its surfaces are of HP shell (figure2a). The ribs, which are inevitable residual parts of vacuum forming process, are corrugated and innovatively configured so that they serve both as the joint between the modular components and the bracing system for the overall HP shell-cube structure (figure2c). It can be self-supported without the need of additional bracing system. The Surface-frame, which is a corrugated single curvature shell surface, achieves the force transfer between the roof and walls (figure 2b).

2.1.2. Hyperbolic paraboloid shell theory

The HP is a double curvature thin shell structure that is capable of having a large span with a great bearing capacity, mathematically expressed as:

$$2y = (x^2/c^2) - (z^2/d^2) \quad (1)$$

where c and d are constants. Under a constant projected load p over the surface,

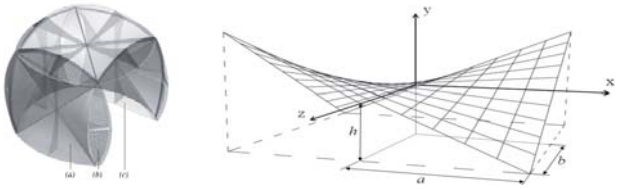

Figure 2 (left). A sample HP shell-cube structure, which is a hybrid of (a) HP shell; (b) Surface-frame; (c) Rib structure. Figure 3 (right). Hyperbolic paraboloid.

$$N_{xz} = -(ab/2h)p = -kp \quad (2)$$

it is customary to assume the axial forces are zero in HP, and the shear forces are:

In the case where $a = b$, the aspect ratio a/h plays a pivotal role in the load-carrying capacity of HP (figure 3).

2.2. FINITE ELEMENT SIMULATION

The FE modelling utilises the geometric models built in Rhinoceros by importing them into Patran which generates FE models which adopt eight-node shell. Uniform pressure loads are applied onto the weaker wall. Figure 4a shows the FE meshes and loads for a typical model in the current study. The FE analyses are performed in the general-purpose FE software Abaqus, which include both geometric and material nonlinearity.

The interactions between the surfaces of ribs and between the ribs and the bolts / washers are very difficult to model numerically. The simplified FE models assume that the whole structure is fully continuous as if it is fabricated as one piece in a fabrication mould. To offset the overestimation of the structural performance as a result of the above simplification, the thickness of the ribs is reduced by half which would lead to reduced bending stiffness of the ribs and hence conservatism for the overall structure.

The identification of the appropriate thickness and aspect ratio for the HP-Shell-Cube structure is aided by FE analyses. Table 1 compares the effect of thickness. All the models are of the same aspect ratio $a/h = 2.8$. The strengths of the models with 2 mm thickness are not satisfactory. The analysis for the model with 3 sidewalls does not proceed as the capacity of the model with corner top panel removed is under 200 Pa which is already unacceptable. When the thickness is increased from 2 mm to 3 mm, the capacities of the respective models all increase by a significant amount. All of them can resist a wind pressure of at least 1000 Pa.

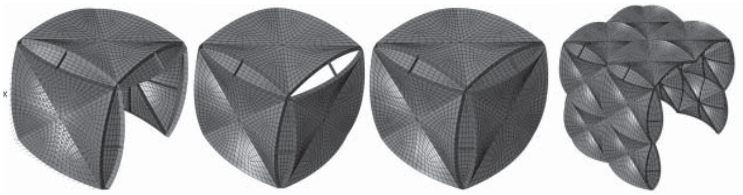

Figure 4. Sample mesh for a HP-Shell-Cube. (a) single module, 3 sidewall + roof (with entrance); (b) single module with corner top panel removed (ventilated); (c) single module, full model; (d) multiple modules, 3 sidewall + roof (with entrance).

The choice between single module and multiple module models is influenced by two competing factors: performance (load-carrying capacity) and cost. With the same overall dimensions and aspect ratio, multiple modules models give lower wind load resistance but they are cheaper than single module models because the size of moulds required for multiple modules is about one quarter. Given the same overall model size and modular component size, the model with lower aspect ratio a/h can resist a larger wind load. Table 2 summarises the load-carrying capacity for different configurations. The goal is to choose a cost-effective structure. While the load-carrying capacity of single module model with aspect ratio 1:4 and multiple modules model with aspect ratio of 1:2.8 are about the same, the multiple module option is cheaper.

The stress contours of two different configurations are presented in figure 5. The regions under almost zero stress are indicated in blue, while the regions under higher stresses are indicated in red and gray. For illustration purpose, any region having a stress above 5 MPa is indicated in gray. All the highly

Table 1. Wind load resistance for different thickness (aspect ratio a/h = 2.8)

Thickness PLA(mm)		Full model	Corner top panel removed (ventilated)	3 sidewall + roof (with Entrance)
2	Load (%)	32	14	-
	Load (Pa)	410	174	-
3	Load (%)	100	89	81
	Load (Pa)	1280	1135	1040

Table 2. Wind load resistance of different configurations (model size: 3m × 3m × 3m).

Configuration (aspect ratio *a/h*)	**Load resistance (Pa)**
Single Module (4)	470
Single Module (2.8)	1040
Multiple Module (2.8)	480

stressed regions are along the lines that connect modular components and surface frames. This common stress pattern suggests that the structural design details for the connections/joints are very important.

2.3. DIGITAL FABRICATION TESTING

The master 3D data generated by Rhinoceros is saved as STL format, and then pre-processed for CNC routing in Cut 3D (Vectric) CAM software for the route pass generation. Frogmill (Streamline Automation) CNC router is used for the subtractive rapid prototyping process (figure 6a).

Due to relatively low temperatures and pressures employed in vacuum forming, medium-density fibreboard (MDF) is selected for the mould prototype. It is economical and has fine homogeneous grains suitable for detailed shape. For mass production, more durable aluminium powder-filled epoxy or polyurethane mould is necessary (Gruenwald, 1998). It takes about 8 hours to complete the CNC routing process for 400 × 400 mm 1:5 scale moulds (Fig. 6b). As the mould making takes time, it is critical to reduce the types of mould. By mass-customisation, only 2 types of mould with minor variations of each, with and without corner pieces are fabricated.

2.4. VACUUM-FORMING TESTING

Vacuum forming has advantage in rapid mass-production of complex 3-D forms. It can deform a thin sheet of plastic to increase its stiffness instantly (figure 7). Vacuum forming is mainly used for making industrial products such as bathtubs, disposable cups and other packaging components. The shape of

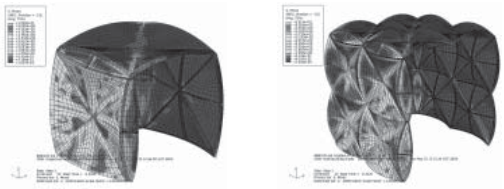

Figure 5. Stress contour (a) single module, a/h = 4 at wind load 470 Pa; (b) multiple modules, a/h = 2.8 at wind load 480 Pa.

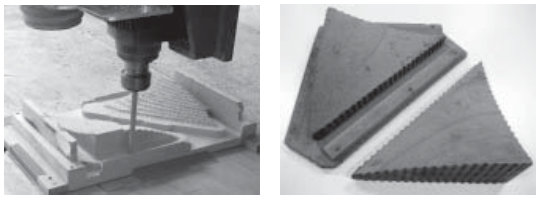

Figure 6. (a) CNC milling of the moulds; (b) Moulds for Vacuum-forming.

mould is restricted by technical constraints associated with vacuum forming process; for instance, at least 3 to 6 % outward taper all around the periphery is recommended for successful mass production (Gruenwald, 1998). Higher and deeper moulds also require thicker plastic sheets, which then result in an increased difficulty of removing the mould and trimming the periphery after moulding. Other thermo-forming methods, such as drape forming could also make 3-D form relatively easily, but it is not suitable for detailed mould, such as with corrugated periphery. Splay moulding could fabricate with much stronger materials, such as fibre-reinforced plastics, but it takes far longer period than vacuum forming.

Figure 7. Vacuum forming process with MDF mould fabricated by CNC routing.

2.4.1. Selection of thermoplastics

Four types of plastics are tested for comparison: PC (polycarbonate), PS (polystyrene), PVC (polyvinyl chloride) and PLA (poly lactic acid, biodegradable plastic).

PC is stiff and seems ideal for architectural use. But it has difficulty in stretching to trace detailed moulds and also to trim the periphery after moulding. Of the four, PS is the most stretchable. Traceability to a complex mould is exceptional. However, it becomes too brittle after cooling down. Therefore it is not suitable when component strength is required to resist repeated bending and stretching action as is the case for a shell. PVC is the one most balanced between stiffness and flexibility. It follows shapes of mould tightly with relatively lower heating temperature. After cooling, it still maintains flexibility, thus it can be removed from moulds easily. PVC components can also resist frequent bending and stretching actions, and it is also easy to trim. PLA is a kind of biodegradable plastic made of biopolymer. It may degrade into soil above 60°C with certain humidity and microorganism. Its material property is in between PS and PVC, which has enough traceability for complex mould but becomes relatively brittle after thermoforming. For the above reasons, we select PVC as the initial material for structural testing to optimise the geometry and fabrication processes, while we target PLA for final prototypes, in prospect that the properties of PLA would be improved for external architectural use in near future.

2.4.2. Vacuum forming stretch testing

By vacuum forming process, materials are stretched and the thickness will be deflected. The higher the mould is, the thinner the sheet thickness becomes. We estimate the deflected thickness by using square grid lined sheets. After vacuum forming, the deformation of the square grid lines indicates how the sheet is stretched, both in direction and dimensions (figures 8a, b). The vertical surfaces stretch most up to 200%, which implies that the thickness become about a half. We identify the most critical stress concentration regions (those in red to grey colours) in the FE analysis stress contour (figures 5a, b), then to make sure that those points maintain the required thickness of 3mm.

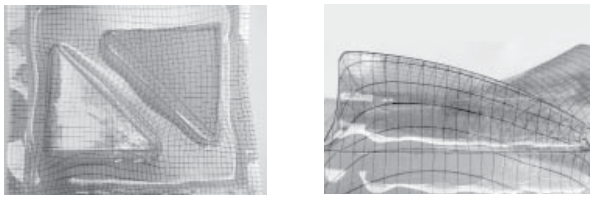

Figure 8. (a) Vacuum form stretch testing with 10 mm square grid sheet; (b) Vertical surfaces stretch up to 200 %, while its thickness becomes a half inversely.

2.5. ASSEMBLY TESTING

The bio-shell assembly process requires both structural continuity of HP shell components and quick assembly / disassembly. Clipping joints seem to be too weak to ensure the structural continuity, while gluing and welding connections are not suitable for dismantling purpose. Mechanical joints, such as bolting, would be the most appropriate to ensure the both. The drawback is relatively longer time required for jointing. The corrugated surface joints are applied all along component peripheries, which increase the structural continuity by frictions while minimizing bolting to where critically necessary. The central circular joints, which tighten up 8 triangular HP-Shell components also play critical role to enhance structural continuity with just 1 bolt (figure 9b). Those vacuum formed components are identical thus easily stacked compactly for transportation (figure 9a).

3. Conclusion

Table 3 summarises comparisons between the bio-shell and 3 other lightweight shelter types. The tent has the lightest weight / volume (kg/m^3) ratio, which

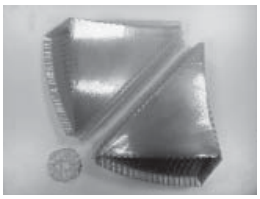
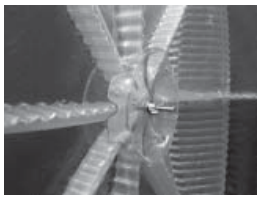

Figure 9. (a) Stacked components for one wall panel. (b) Corrugated surface-joint and Centre joint.

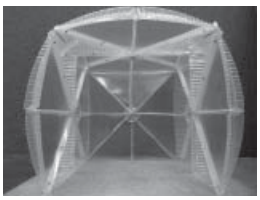

Figure 10 (left). Completed 1:5 structural model.
Figure 11 (right). Multiple module application as refugee shelter. Organic heat insulation (straw, etc.) is to be sandwiched between double layers of vacuum-formed components. Sand-bags on site will weigh down foundation thus no anchoring required.

is approximately 1/100 of the container, while its space efficiency and adaptability are low. On the other hand, the container has merit on space efficiency and quick assembly by prefabrication. The dome has second lowest weight / volume ratio; however it takes 160–200 man-hours for on-site assembly.

The bio-shell prototype provides not only lower weight / volume ratio close to the dome but also adaptability by modular design and efficient space usage by cube like shape. Its cost / area ratio is not particularly further effective compared to the container and the dome, which are already low-cost shelters. However, it can provide higher transportation efficiency by stacking identical components compactly. In addition, it can be biodegraded after its use without burdening the environment.

While our current investigation mainly focuses on structural aspect, it needs to be also weatherproofed to be fully functional shelter. The J-shape joinery as a part of vacuum-formed components may integrate gutter into structural bracing without additional parts. For thermal insulation, double-layered roof/ wall with infill may reduce heat gains (figure 11) or to control translucency of PLA with colour pigment. Further research is needed to optimise PLA for structural / external use, to control conditions and durations of biodegrading process and to minimise potential structural creeping of the plastic. But this requires further collaboration with material scientists.

(US provisional patent application under serial no. 61/299,502.)

TABLE 3. Lightweight shelters comparison.

Shelter Type	Weight/ Volume (kg/m^3)	Cost/ Area (US$/ m^2)	Man-hours (on-site)	Trans-portef-fici-ency	Adapta-bility	Space effici-ency	Others
Bio-Shell [(a)] (PLA, 3mm)	**6.29** [(e)]	**641**	16	High	High	High	Bio-degra-dable
Tent [(b)] (Fig. 1a)	1.15 [(e)]	51.3	2-4	High	Low	Low	Short term use
Con-tainer [(c)] (Fig. 1b)	102.4	627	Nil	Middle	Middle	High	Prefab-ricated
Dome [(d)] (Fig. 1c)	6.92 [(e)]	750	160-200	Low	High	Middle	Insulated

(a) Estimated from 1:5 scaled model. Subject to be verified with 1:1 prototype; (b) Northstar X4, The Coleman Company Inc.; (c) 8ft Long Container, S. Jones Container Services Ltd.; (d) Dome House Type 7700, International Dome house Co. Ltd.; (e) Weight does not include floor systems.

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References

Gruenwald, P. E.: 1998, *Thermoforming: a plastics processing guide*, Technomic Publishing.
The Economist: 2007, Material World, 18.10.2007.

B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010,* 575–584. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

FIBRE COMPOSITE SYSTEMS

Stress as growth promoting agent

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Abstract. The main intention of this paper is to propose a theoretical framework for an integrated design methodology which incorporates natural morhogenetic principles for the realisation of fibre composite structures. Stress, in these processes, becomes the driving force of shape modification and fibre articulation, while the material thresholds become a driver of generative evolution. The inferences and results of such an approach will be looked into using a case study of a composite monocoque shell bridge design.

1. Introduction

The methodology proposed lies at the intersection of material science, biomimetics and computation; it involves the implementation of digital and physical form-finding methods and analytical tools leading to structural systems able to be fabricated by computer numerically controlled machines. It focuses on the integration of form, material, structure and program into multi-performative composite systems of different scales, able to satisfy several possibly contradicting objectives. Form, generation, and behaviour are treated as inseparable factors, one influencing the other; form is being developed by anticipating a range of behavioural patterns which in turn affects the original form.

This design system is built up by the strengths inherent in both generative modelling and multi-performance analysis, being inspired by biological systems and the way they develop under load, distribute and organise material by responding to internal factors and environmental conditions. This mechanism of adaptation allows every load-bearing natural construction to "adhere to a uniform stress distribution" and to achieve an optimal design "of high reliability and minimum consumption of material and energy" which enables

them to survive the competition of natural selection (Mattheck, 2005). This leads to a seamless and gradient differentiation of material distribution, porosity, degrees of transparency and varying mechanical properties, generated by the same constituents.

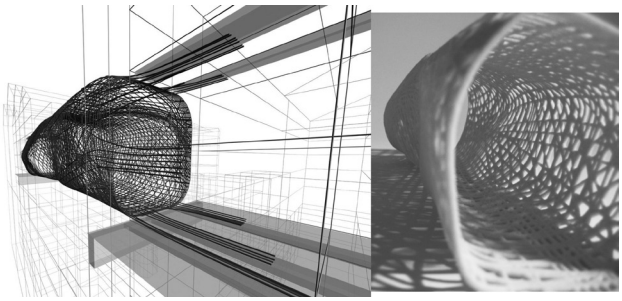

Figure 1. Digital and physical model of the monocoque shell bridge.

1.1. MATTER AND ENERGY RELATION

The matter–energy relationship is another factor that drives the theory and methodology of this research. Evolutionary processes entail intensive processes where structures emerge out of intricate relationships, alliances and aggregations of matter. Natural intensive systems adopt a transient intrinsic organisation which affects and at the same time is affected by the host environment. In nature therefore, form is being derived through this intricate relationship of matter and force, and through the self-organisation of the material system in search of equilibrium.

There are several examples in the history of architecture and engineering that deal with the feedback relationship between matter and energy in search of load-bearing capacity, for example P. L. Nervi, A. Gaudi, F. Otto and H. Isler among others, but of particular interest here is the establishment of an open feedback loop which deals with multiple attractors of influence, able to encompass more than the structural factor.

This research works towards an ‘embodied physiology’ as seen in biological organisms, which deal simultaneously with structure, form and performance through one material solution which is constantly in dynamic exchange with the environment. According to Scott Turner (2007, 27), the conception of embodied physiology is “the modern conception of homeostasis” whose “core idea is the steadiness of the environment within the body regulated by homeostatic agents” (devices that regulate environments).

2. Composites: natural and artificial

The selection of the material system is closely related to the process of embodied physiology, in the sense that fibre composites, both natural and artificial, can behave in multiple ways by varying mechanical properties along the same system. This is achieved by depositing material locally where it is required and in the orientation that is needed according to the emerging behavioral pattern in interaction to its complex contextual environment. The major mechanism involved in this process is called *adaptive growth;* "an intelligent survival strategy that enables biological structures, to adapt flexibly their original optimum designs," to transient changes in environmental conditions (Mattheck, 2005).

One consequence of slow adaptive movements that fibre architectures express is the generation of a significant range of varying modulus structures by the combination of only two components; matrix and fibres. The same collagen fibres are used in low-modulus; highly extensible structures such as blood vessels, intermediate-modulus tissues such as tendons and high modulus rigid materials such as bone (Jeronimidis, 2004).

The same anisotropic and heterogeneous attributes can be met in the composites' artificial equivalents, although their potential has not yet been fully exploited, especially in the field of architecture. The intention is to incorporate the thresholds stemming from long fibre composites along with the evolutionary mechanisms taken from natural systems into a methodology of adaptive growth. In order to achieve this, the material properties and manufacturing technique play a crucial role as they pose new constraints and potentials.

3. Fibre placement technology

The construction equivalent, which gets closer to the biological paradigm, is the numerically controlled fibre-placement technology (Langley, 1999; Lee and Suh, 2006), which is normally reserved for aerospace or sailing applications (3DL technology). This technique is developed as a combination of filament winding and automated tape laying, hence overcoming some of their limitations that relied on the limited complexity of surfaces, restricted freedom of fibre position and orientation as well as the ease of repeatability.

Each laminate is made by combining layers with various fibre orientations, material properties, or thickness. Its innovation lies mostly in the fact that fibres can be laid up curvilinearly, extending the customisation of the design and its response to prescribed loading conditions and programmatic requirements. By allowing the stiffness to vary from one point to another, this manufacturing technique is an advancement of the classical 'stacking sequence'

method because it opens the possibility for a gradient material distribution, leading to an energy and resource-saving construction similar to biological systems.

Although fibre placement technology is a relatively new fabrication processes, it has potential to be used in an architectural context in which structure, cladding, and ambient qualities can be perceived as different aspects of the same system integrated into one process.

3.1. EXPERIMENTS ON THIN COMPOSITE PLATES

Trying to understand the impact of curvilinear lay-up on the behaviour of a material system, a series of physical experiments were carried out which dealt with the fibre articulation on thin composite plates and their impact on structural performance. The main variables that changed in each of the experiments were fibre directionality and fibre density. The results revealed that stiffness is enhanced when fibres are aligned to the principal stress direction because the material system is capable of counteracting the applied forces.

4. Biomechanical Adaptive Growth

In order to understand and exploit the complex articulation, along with the structural and performative capacities of natural systems, the field of biomimetics plays a critical role. The design methodology which is described later in this text draws much from the research methods conducted by the biologist Claus Mattheck.

Mattheck (1998) has made an extensive study on natural composites and created three different but complementary computational methods to simulate biological adaptive growth. These processes aim at a biomechanical optimisation of shape through the interaction of system-intrinsic material characteristics and external stimuli of environmental forces.

The first method, named soft kill option (SKO) follows “the same construction principle that nature employs to promote growth” (Mattheck, 1998). Building material is removed or decreased from the less stressed areas and re-deposited in the highly stressed ones. The second method, computer-aided optimisation (CAO), takes as a given that biological shaping is consistent with a single design rule: the axiom of uniform stress. Stress and temperature distribution are used to control the simulated growth by altering locally the shape in search of uniform stress distribution. The third method, called computer-aided internal optimisation (CAIO), optimises the performance of fibre-composite materials by aligning the fibre distribution with the force flow, mimicking this way the optimum fibre direction of biological components. It has been

proved that the force-flow lines are free of shear stress, leading to an increase in maximum load capacity.

4.1. DIGITAL EXPERIMENT: FIBRE CHAIR

The principles of the SKO and CAIO method described before, are being used in the design methodology of one case study. This is the fibre-composite interpretation of the Panton chair.

Fibres are articulated according to the principal normal stresses while their density is defined by the material distribution analysis. To do this we conduct finite element analysis on principal stresses and on 'topology optimisation.' According to the first analysis, splines are generated by connecting points that indicate stress peaks in the direction of the stress vectors. According to the second analysis, fibre density increases in high stress areas as the material distribution analysis indicates (figure 2).

However, instead of eliminating material, the graph of the analysis is interpreted as a gradient material distribution. Fibre density increases at the most vulnerable areas without disturbing the continuity of the structure, while the patterns that emerge cause a higher degree of redundancy within the structure. An evaluation of the system having as objective functions the weight and structural capacity, would illustrate whether fibre continuity enhances the performance of the chair or not.

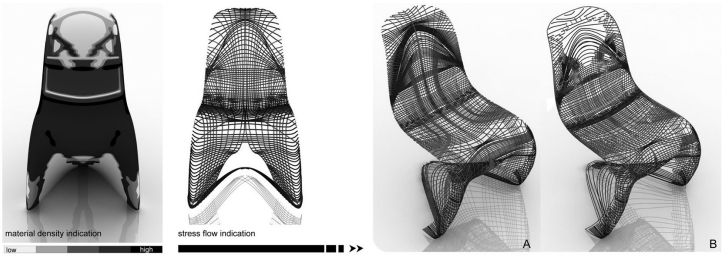

Figure 2. The two interpretation of a fibre composite Panton chair.

5. Digital morphogenesis and associative modelling

By bringing together certain aspects deriving from the aforementioned references, an integral design framework is being formulated. Thus, the specified material and geometric behaviour along with manufacturing restrictions as well as the underlying principles of natural adaptive mechanisms become the generative drivers embedded in an associative computational model. This set-up allows the breeding of a variation of designs which all comply with a set of generative principles within a given range of constraints.

A crucial constituent of the morphogenetic process are the embedded anal-

ysis mechanisms which set the fitness criteria related to structural, environmental, and ergonomic constraints and reveal the system's behavioural tendencies. The iterative evaluation process is an operative element which acts as a decision making tool in search of coherent configurations within the range of versatile parameters and rules.

The aim is not to produce a single optimal solution that fulfils a particular task, but rather to come up with a range of solutions able to fulfil varying and sometimes conflicting objectives. This idea necessitates a shift from single optimisation to multi-performative generation.

5.1. DESIGN STRATEGY

The information gathered through research and experimentation is inspiring a design methodology for the generation of stress-driven composite systems.

A design brief is being formulated with the intention of creating a fibre-reinforced composite shell that bridges two existing buildings at a span of 10 metres. The site is located at the internal courtyard of the Architectural Association School of Architecture and will function both as a passage between the buildings which are now isolated and as a space of temporary exhibitions. The objectives of the systems are not limited to its load-bearing capacities, structural behaviour and weight reduction as is common with composite structures, but also for fulfilment of the programmatic requirements and internal ambient conditions integrating simultaneously the manufacturing constraints of the numerically controlled fibre placement.

The design method follows a homeostatic process of morphogenesis aiming at a system growth stimulated by mechanically adaptive mechanisms as observed in natural systems. The modern conception of homeostasis, which is physiology's core idea, is the steadiness of the internal environment of a body. It refers to the way the components of the system interact with each other and organise by adaptively responding to their contextual conditions. The connective tissue is a distinctive example of such a process; it acts as a dynamic living system which is continually being remodelled to the end of regulating tension in the fibres, by homeostatic agents called fibroblasts (Turner, 2007, 37-43).

The computational framework consists of two main elements. The associative module sets a range of parameters that operate within certain limitations defined by the intrinsic characteristics of the material system, its ergonomic requirements and performative potentials, while the second element of evaluation manages the analysis and sets the 'fitness criteria.'

Three main mechanisms are being implemented, each one dealing with different levels of hierarchy, varying from the local to the global domain of

the system. The three main mechanisms termed shape, fibre-path and porosity generation, work simultaneously and in association, controlled by a constellation of points that act as homeostatic agents and morphological units.

5.1.1. Global shape mechanism

The first set of rules are concerned with the simulation of the setting and the allocation of the spatial components. The system is composed by a random distribution of control points along a cylindrical bounding area which implies the area of intervention. The points are associated through the application of a Delaunay mesh with certain spatial constraints that keep the interstitial area free of intersections. Each of the point-nodes is classified with different loading conditions according to their initial position within the coordinate system.

The resulting structure is evaluated through a finite element analysis which for a given set of materials, density and elasticity, produces a value for the objective function, which in this case, is stress and strain levelling.

The nodes that indicate the lowest values of stress and displacement operate as attractors for the neighbouring nodes and prompt the self-organisation of the system in search of equilibrium. The algorithm repeats according to values obtained each time by stress analysis, until a constant stress state on the surface is achieved, according to the axiom of uniform stress (figure 3).

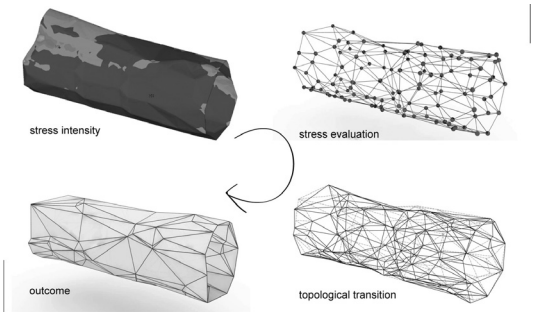

Figure 3. Shape evolution: from stress analysis to topological transformation.

5.1.2. Fibre path mechanism

The fibre path generation process takes place concurrently with the global shape configuration, but the nodes that act as the morphogenesis cells in this process are the ones that indicate the highest stress values. Those nodes become the source points of fibre paths, and restructure their environment to regulate tension, by releasing fibres along the direction of the quantitatively largest principal stresses (figure 4).

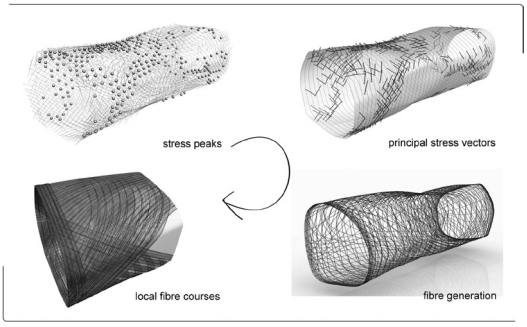

Figure 4. Generation process of fibre paths.

This arrangement increases the maximum load capacity by minimising shear and transverse stresses between the fibres (Mattheck, 2005). Therefore, the pattern that emerges out of the arrangement of the fibre courses, in anticipation of the loading conditions, comprises the force-record of the structure.

Both in the shape and in the fibre generation processes, the nodes work as receptors for detecting local stress peaks triggering a homeostatic growth process; they constitute repeated modules of identical structure, whose function alters depending on their position and role within the system.

The splines generated though this process, represent the reference paths which is the curve traversed by the centre of the applicator head of the tow-placement machine during the fabrication of a single course. Therefore, each spline is the central tow of a course that consists of up to 30 single long fibres and has a width of about 10cm (figure 5).

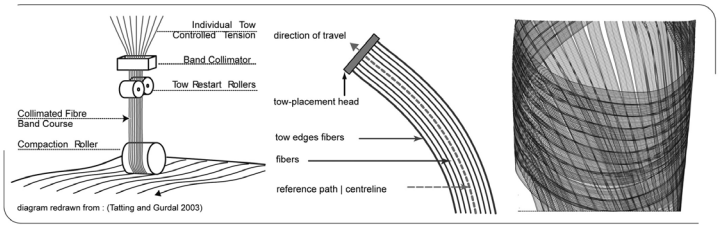

Figure 5. Fibre placement process.

5.1.3. Porosity mechanism

The third mechanism is responsible for generation of porosity as an additional property of the system to modulate internal environmental conditions of the structure with creation of small apertures along the surface.

Specification of the optimal position of apertures derives from further analyses. Material distribution analysis shows the areas with the least stress concentration, where material can be reduced. Fibre volume fraction analysis

favours solutions with low fibre density which facilitates the creation of voids. Solar exposure analysis measures the distribution and availability of incident solar radiation on the model and prevailing winds. And CFD analysis displays the best possible areas to accommodate ventilation and avoid strong currents and water penetration (figure 6).

This process results in the local alteration of fibre directionality in such a way that the continuity of stress flowing in the fibres will not be disrupted when they approach the voids; they do not terminate abruptly at the edge of the holes but follow contours around them.

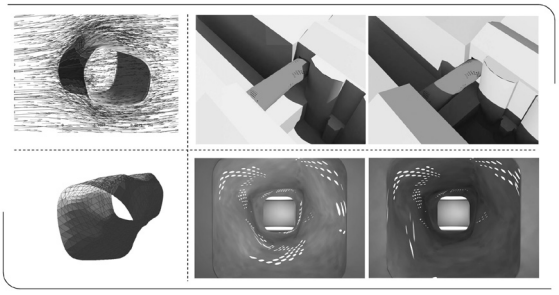

Figure 6. CFD and lighting analysis of structure.

5.1.4. Fabrication

The dimensions of the bridge allows it to be fabricated as a one-piece component that can be extracted from a dismountable mould, transported to site, and craned into place. First the mould has to be milled into separate pieces with the use of CNC machines that can be easily interconnected and dismantled to extract the shell. Thereafter, the process of fibre lay-up is going to take place by using the fibre placement technology. A small physical prototype was fabricated by following the same procedure while replacing the numerically controlled method by hand-lay-up due to lack of resources (figure 7).

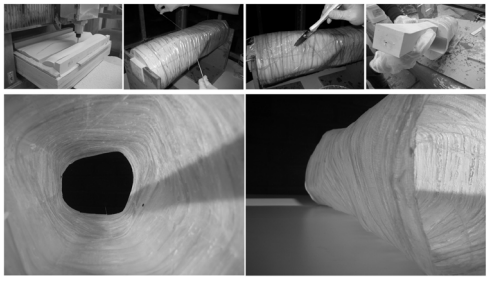

Figure 7. Physical prototype with hand lay-up placement of fibres.

6. Observations

The above research sets a new combination of concepts and methodologies in order to come up with a coherent system whose overall shape, materialisation and manufacturing logics are interrelated. Material behaviour does not conform to a fixed geometry but is implicated in the generation process and at the final outcome as it interacts with its environmental inputs. The selection of the fibre placement technology facilitates in the integration of the structural elements which otherwise would be separated into individual systems.

A further aim of this work is the fabrication of a mockup by computer numerically controlled machines which would necessitate the re-evaluation and elaboration of the computational design methodology and verify the validation of the design process from conception to materialisation. It is a major challenge to set-up a computational system that will incorporate the different variables and will establish a feedback loop with the ever-changing inputs of each evaluation stage. The creation of such an open system will promote the development of a coherent design framework aiming at the generation of systems of adaptive growth.

Acknowledgements

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References

Beukers, A., and Van Hinte E.: 2005, *Flying lightness: promises for structural elegance,* 010 Publishers, Rotterdam.

Jeronimidis, G.: 2004, Biodynamics, *in* M. Hensel, A. Menges and M. Weinstock (eds.), *Emergence: morphogenetic design strategies,* AD Wiley, London, 90–95.

Langley, P. T.: 1999, Finite element modeling of tow-placed variable-stiffness composite laminates, M.S. Thesis, Virginia Polytechnic Institute and State University, Available from: <http://scholar.lib.vt.edu/theses/available/etd-060799-143312/unrestricted/etdpl.pdf> (accessed 7 November 2009).

Lee, D. G. and Suh, N. P.: 2006, *Axiomatic design and fabrication of composite structures: applications in robots, machine tools, and automobiles,* Oxford University Press, New York.

Mattheck, C.: 1998, *Design in nature: learning from trees,* Springer Verlag, Berlin.

Mattheck, C.: 2005, *Biomechanics and structural optimization,* Karlsruhe: Forschungszentrum Karlsruhe Institute for Material Research, available from: http://www.fzk.de/fzk/idcplg?IdcService=FZK&node=0849&lang=en (accessed 17 July 2008).

Turner, S.: 2007, *The tinkerer's accomplice,* Harvard University Press, Cambridge, Mass.

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SIMPLY COMPLEX

A case study of construction-driven design using computational methods

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Abstract. This paper explores how fabrication-based criteria can be integrated into design processes through computational methods. Based on the ongoing project of the Library of the Bao'an Cultural Complex in Shenzhen, China (referred as 'the Library' in this paper hereafter), this paper discusses the process of the rationalisation of an intuitive architectural form and its subsequent tiling design based on the adaptation to the conventional fabrication techniques of the building façade industry in China. These objectives are followed by the establishment of robust computational systems of automation that provide a concrete basis for the visualisation, the development of envelope details, and the generation of the list of component data for fabrication. This integrative approach is markedly different from a more conventional one, in which computational systems serve as a priori solutions to unconstraint design sketches.

Keywords. Fabrication criteria; rationalisation; computation workflow.

1. Background

At the competition stage, the architect had a vision of developing the architectural form of the three buildings, namely the Library, the Youth Palace and the Performance Centre, along the central green axis of Bao'an Central District, Shenzhen. Ruled surfaces defined as a surface formed by moving a straight line along a directrix curve (Pottmann et. al., 2007), each of which was formed by a straight line and a planar curve, were adopted as the form generator for all the three buildings. The Library discussed in this paper is the first building to be constructed.

2. Approach to the architectural geometry and envelope

The volume of the Library is defined by two curvilinear façades that bulge in and out along the north–south axis of the building, and an undulating open roof feature that splits in the middle to allow natural light penetration.

A double-façade system is adopted at the outset of the design development to isolate the shading screen from the glass envelope enclosure. This is a critical move that allows more freedom for the exploration of an open grid system for the fabric-like shading screen, which is less demanding in the developing of fabrication details compared to the inner enclosure system that calls for more sophisticated details to perform the function of waterproofing, thermal & acoustic insulation. The property of the design surface of the façade is therefore extremely critical for the design exploration and the subsequent fabrication of the outer open grid shading skin and the inner glass enclosure.

This paper focuses on the following three exercises that facilitate the tender drawing documentation and eventually the future fabrication:

1. Rationalisation of the design surface of the envelope;
2. Design exploration of the open grid shading screen configuration with respect to the design surface; and
3. Application of the planar glass panel onto the design surface and the subsequent development of curtain wall details.

The above exercises, together with the export of data through automation scripts that follows, produce the façade setting-out information for the entire curtain wall tender drawing package.

2.1. WORK FLOW

The workflow of the three aforesaid explorations can be summarised in the following flowchart (fig. 1). The input of fabrication criteria is based on the advice from the façade consultant and the discussion with façade fabrication.

3. Rationalisation of the design surface

3.1. ESTABLISHING CRITERIA: DESIGN SURFACE

In order to discretise curvilinear surfaces by means of façade components, i.e. by transferring a continual surface into discrete parts (Pottmann et. al., 2007), a design surface (Peters, 2007) is used as a basis for which anchoring points (or setting-out points) of these components are located. Therefore, in the case of the Smithsonian Courtyard Enclosure by Foster + Partners, where a rationalised freeform surface is used as a design surface for the populating enclosure components (Peters, 2007), the beams that support the shell are dis-

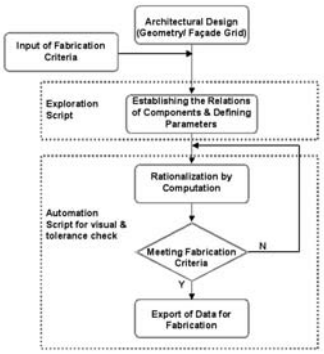

Figure 1. Workflow: criteria-to-computational systems

cretised as straight members aligned to the curvature of the design surface. That, and the setting out techniques required, may be deemed difficult for local contractors to follow.

From the point of fabrication, it would be much easier if all these setting-out points lie on the primary structure of the façade system, i.e., the mullions, and in terms of structural efficiency, it makes more sense if these structures are linear elements (the shortest span) that can be populated along the slab edge with equal spacing to ensure the span of the secondary components is well within an acceptable range.

3.2. OPTING FOR RULED SURFACES

It has been clear since the competition phase of the project that the team would opt for ruled surfaces as design surfaces for the facades and the roof. At that stage, however, no rules were established regarding the direction of the generatrices. This, as the team later discovered could be problematic for aligning straight mullions across the surface – either they would not be parallel with each other, in which case the glass units in the inner façade would become irregular quadrilateral infills, or, if parallel, equidistant curves are projected onto the surface and used as reference curves for mullions, the mullions would become segmented or curved members. Neither of the outcomes is pertinent to the design intent, nor are they economical for fabrication.

Therefore, the design surface needed to be fine-tuned: the generatrix, which rotates to form the bulges, is forced to be on a plane that is always perpendicular to the direction of the straight directrix (fig. 2). More specifically, in order to control how far the façade bulges out, the second directrix of the ruled surface is formed by connecting line-arc segments. Through controlling the chord length of the line-arc segments the bulging distance can be systematically controlled.

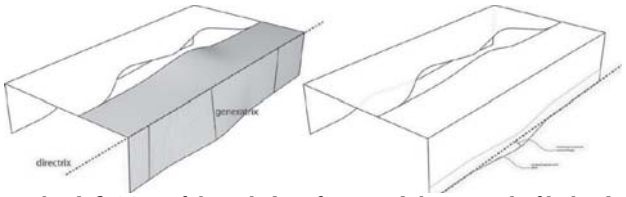

Figure 2. The definition of the ruled surfaces and the control of bulged surface.

The advantage of using ruled surfaces as design surfaces is that since the surface curves only in one direction, it is possible to align structural members (mullions in this case) along the direction of the straight generatrix, at a fixed spacing along the straight directrix. In addition, the distance between each façade component along a mullion can be obtained from simply dividing the length of the mullion into equal parts. In other words, a simple 2D grid, within which all points can be obtained through simple derivation, can be intuitively applied by the contractor.

4. Design exploration of the open grid shading screen

4.1. ESTABLISHING CRITERIA: LINEAR COMPONENTS

While the straight generatrices of the design surface are adopted as primary structural support, the shading fins, which run diagonally across the design surface, would either be curvilinear or segmented should they align with the design surface to form a weaving pattern. From the fabrication point of view, these segmented shading fins can take up different profiles to form a gradation pattern efficiently if all these profiles can be formed by folding the material instead of producing by extrusion through dies (fig. 3).

4.2. EXPLORATION SCRIPT FOR DESIGN EXPLORATION

This process of design investigations was facilitated by a series of ‘Exploration Scripts’ coded in Rhinoscript – a VBscript-based language used on Rhinoceros 4.0, a 3D NURBS modelling software. Exploiting its object-oriented properties the Exploration Scripts are built in a ‘skeleton-modules’ format.

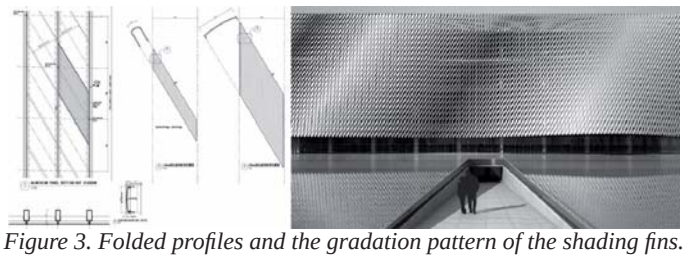

Figure 3. Folded profiles and the gradation pattern of the shading fins.

The structure of the exploration scripts look like this in pseudo-code form:

```
SKELETON{
    INPUT: design surface, top directrix, bottom directrix, generatrix
    VARIABLES: horizontal spacing between mullions, vertical
    spacing between facade components
    1. CREATE orthogonal grid
    2. TRANSLATE orthogonal into diagonal grid
    3. CALL mullion generation [to create mullions]
    4. CALL façade component generation [to populate diagonal fins
    between mullions]
}
END SKELETON
MODULE mullion generation
MODULE façade components generation
```

While the 'Skeleton' creates an orthogonal grid on the design surface and translates it into other grid systems (diagonal, hexagonal etc.), the 'modules' create the façade components at each node of the grid. The script was deliberately built flexible enough to visualise design decisions quickly. Furthermore, local parameters set for each module can be varied to create visual options for further design decisions (fig. 4 left).

It is worth-noting that with the 'skeleton-module' structure not only was the team able to visualise local parameters change quickly, but global parameters (such as the form of each façade component) as well. The 'mullion generation' module and the 'façade component generation' module, which generate diagonal fins between mullions, can be easily replaced with, say, a 'diagrid' module (fig. 4 right) using the same grid created in the 'Skeleton'.

4.3. DIGITAL MOCK-UP: FROM EXPLORATION SCRIPT TO AUTOMATION SCRIPT

Although the Automation Scripts are very similar to the Exploration Scripts in terms of their operations, the Automation Scripts are geared towards producing accurate digital mock-ups for construction cross checking and therefore need to be more robust in terms of parametric definitions. Like the

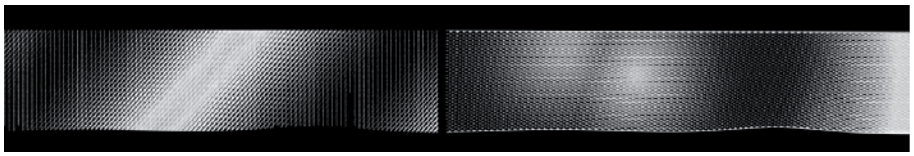

Figure 4. Design exploration of facade grid.

Exploration Scripts, the Automation Script partakes of a similar 'skeleton-module' structure:

```
SKELETON{
    INPUT: design surface, top directrix, bottom directrix, generatrix
    VARIABLES: horizontal spacing between mullions, vertical
    spacing between facade components
    CREATE orthogonal grid from horizontal and vertical spacing
    TRANSLATE orthogonal grid into diagonal grid
    CALL MODULE mullion generation [to create mullions]
    CALL façade components generation [to populate diagonal fins
    between mullions]
    CALL data export [to export components data for construction
    drawings]
}
END SKELETON
MODULE mullion generation
MODULE façade component generation
MODULE data export
```

The difference between the Exploration Scripts and the Automation Scripts can be best illustrated by the generation of gradation patterns on the façade. The gradation patterns are generated by varying the width of the fins along the same diagonal (dubbed 'bands') by a certain increment / decrement. In the Exploration Scripts, the increment / decrement Δ is expressed as:

Wmax : the maximum width of the fins, 500mm in this case
Wmin : the maximum width of the fins, 140mm in this case
Dmax : Distance between the maximum band and the setting out point
Dmin : Distance between the minimum band and the setting out point
S : the spacing between each mullion, which is 600mm in this case
Δ: increment width between adjacent bands

$$\Delta = (Wmax - Wmin) / ((Dmax - Dmin) / S)$$

While this simple formula alone can generate the gradation patterns needed for design explorations (e.g. moving Dmax and Dmin to different locations), the Δs at different points of the façade are almost bound to be irregular numbers. To eliminate these irregularities, Automation Scripts pin down the exact location of Dmax and Dmin (as multiples of S) and the increment (as either 10mm or 15mm).

5. Application of planar glass panel onto design surface

5.1. ESTABLISHING CRITERIA: PLANAR GLASS ON DESIGN SURFACE

The importance of maintaining a planar surface is crucial as curved double glazed unit would be extremely costly to produce in China. The adoption of a planar panel to tile up curved surface would mean at least one of the four vertices of a glass unit would pop out from the design surface. This would require special detailing in the mullion and transom design that can accommodate the variance of such vertex offset. Based on the functional requirement of the façade grid, the maximum offset is obtained through computation model and such data is adopted as the tolerance allowance in the mullion and transom design. It is worth mentioning that the planar glass panel is mounted on a non-planar frame. The deviations between the planar glass and the non-planar frame are to be covered by thermal break material on outside and aluminium covers on inside.

5.2. DIGITAL MOCK-UP AND AUTOMATION SCRIPT

A digital mock-up for the glass unit layout is used to visualise the deviation between the glass unit and the design surface (fig. 5), as well as to generate data that is exported as Geometry Method Statement.

The Automation Script in this case is written in Grasshopper, a plug-in for Rhinoceros that provides an interface for creating real-time parametric models. This Automation Script also exploits the object-oriented property of the language and therefore also partakes of a ‘skeleton-module’ structure:

SKELETON {
INPUT: design surface
VARIABLES: floor height, number of floors, mullion spacing
1. CREATE sectional curves across the design surface at specified floor heights on planes that are parallel to the WorldXY Plane

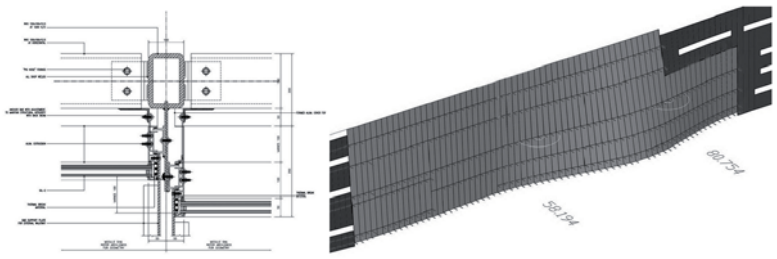

Figure 5. Deviation between glass unit and the design surface, and the corresponding mullion design to absorb the vertex offset.

```
    2. CONVERT sectional curves into connected segments at the
    specified mullion spacing
    3. CALL MODULE mullion generation [to create mullions]
    4. CALL glass unit generation
    5. CALL data export [to export deviation between glass surface and
    design surface for construction drawings]
}
END SKELETON

MODULE mullion generation
MODULE planar glass unit generation {
    INPUT: connected segments created from sectional curves
    VARIABLE:
    1. CREATE glass edge by connecting corresponding points on the
    connected segments
    2. CREATE, from the end points of a mullion (Pt A, Pt B) and the
    upper end point of the next mullion (Pt C), the plane on which the
    glass panel lies.
    3. PROJECT, along Y direction, the lower end point of the next
    mullion onto the plane on which the glass panel lies to create Pt D
    4. REGISTER the distance between the lower end point of the next
    mullion and Pt D. This would be the deviation (D) between the
    design surface and each planar glass surface.
    5. CREATE a planar surface using Pt A, Pt B, Pt C and Pt D as
    corner points. This planar surface would be the outer surface of a
    glass unit.
}
END MODULE
MODULE data export
```

6. Export of data for tender drawing documentation and fabrication

After crosschecking the design against the digital mock-up, it is crucial that the construction data, mostly issued as drawings to the local contractors, is accurately addressed in a format that is easy to follow. The team issued a set of Geometry Method Statement - a term used by Foster + Partners to describe "[a] set of rules and relationships that, if followed correctly, result in the determination of all the necessary set-out information for the project" (Peters, 2007). In the case of the Library, four sets of these Geometry Method Statements are issued to describe the setting out of all the components for the façade:

1. Mullion Setting (fig. 6): This set of data contains the ID number, angle of rotation along the straight directrix and length of each mullion. It establishes a

grid on the façade on which the façade contractors can identify every diagonal fin and derive its exact location with respect to the mullions.

2. Panel Matrix (fig. 7) This table allows the façade contractor to locate all diagonal fins on a façade and their respective widths. Since the location of Dmax, Dmin, and the increment width between adjacent bands, this table was used to govern the behavior of the automation script.
3. Plan Setting-out (fig. 6). This set of data, exported from the Automation Script allows the main contractor (responsible for the construction of the concrete slab) to locate points at which mullions are anchored to the concrete slab.

7. Conclusion

The case presented in this paper shows that for complex architectural surfaces, computation could serve as an instrument for integrating fabrication and setting out criteria into the design process such that these surfaces can be built from components fabricated and executed by facade contractors. In the case of the Library, computation is deemed useful in rationalising design surfaces into ruled surfaces with parallel generatrices on which façade components are populated. Doing so would allow mullions to be kept straight and undistorted as they conveniently follow the rotating generatrices. Upon

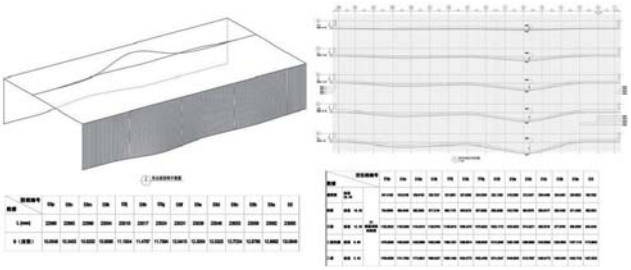

Figure 6. Mullion schedule and plan setting-out schedule.

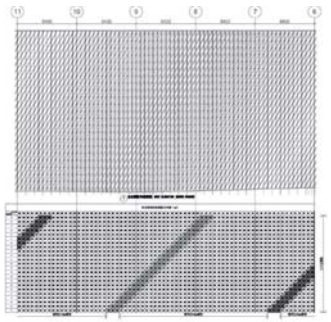

Figure 7. Shading fins with the corresponding width plotted on facade grid.

establishing fabrication criteria, well-structured computational tools can be used to generate design options quickly by either changing local variables, or changing global variables by replacing modules in a 'skeleton-module' script. Finally, automation scripts can be used to generate digital mock-ups for cross checking and exporting large quantity of fabrication and setting out data in batches for tender drawings.

Exporting data into a system of readable drawings is, in this case, a particularly important operation as it translates abstract geometrical intents into a system of readable drawings for contractors to follow. Given that construction drawings and diagrams are still the prevailing medium of communication among builders in China, this ability to translate would be the key to successful execution of construction.

Acknowledgements

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References

Peters, B.:2007, The Smithsonian Courtyard Enclosure: a case-study of digital design processes, *Expanding bodies: art, cities, environment, proceedings of the 27th annual conference of the Association for computer-aided design in architecture,* Halifax, Nova Scotia, 74–83.

Pottmann, H., Asperl, A., Hofer, M. and Kilian, A.: 2007, *Architectural geometry,* Exton, PA, Bentley Institute Press.

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PRELIMINARY TECTONIC PHENOMENA OF DIVERSIFIED ARCHITECTURAL SPATIAL FORMS IN DIGITAL AGE

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Abstract. The research on tectonics in the architectural field began from the middle of nineteenth century and in recent twenty years digital technology gradually developed and permeated through the field of architecture. Liu and Lim (2006, 2009) integrated classic and digital tectonic factors a present framework of new tectonics. However, the previous studies related to the tectonics in this digital age were only on architectural cases that use a great deal of digital media. The research wants to know what and how the tectonic factors affect the different spatial forms of modern architecture and focused on a case study of the diversified spatial forms, orthogonal, folding and curving. The results show the classic tectonic thinking is imperative until now. It is critical to prove the significance of adding the new digital tectonic factors in digital age.

Keywords. Digital and classic tectonics; spatial form; digital media.

1. Introduction

1.1. NEW TECTONICS: CLASSIC AND DIGITAL TECTONIC THINKING

The research on tectonics in the architectural field began from the middle of nineteenth century (Botticher, 1843; Semper, 1951; Sekler, 1965; Gregotti, 1983; Frascari, 1984; Vallhonrat, 1988; Frampton, 1990; 1995). They proposed many tectonic observations and then gradually established the theory of classic tectonics today. Liu and Lim (2006, 2009) integrated the previous

viewpoints with the seven classic tectonic factors, including joint, detail, material, object, structure, construction, and interaction.

In recent twenty years, digital technology gradually permeated through the field of architecture. The digital procedure implying the process of architectural design and construction was exactly different from the way of traditional architectural thinking (Mitchell, 1998; Cache, 2002; Spuybroek, 2003; Cook, 2004; Leach, 2004; Fang and Zhou, 2007; Vanggaard and Pontoppidan, 2007; Deplazes, 2008). The development of digital free-form is the most obvious aspect of digital techniques (Imperiale, 2000; De Luca and Nardini, 2002; Ham, 2003).

Therefore, the application of digital media opened a new page for the development of the free-form architecture. A new spatial form of digital architecture was emerging (Mitchell, 1998; Pongratz and Perbellini, 2000). According to the previous views, Liu and Lim (2006, 2009) thought classic tectonic theory could not totally cover digital design and construction with the seven tectonic classic factors in the digital architectural age and afterwards presented the four additional digital factors, motion, information, generation, and fabrication. The eleven of classic and digital tectonic factors came into being a present framework of new tectonics.

1.2. THE RELATIONSHIP OF ARCHITECTURAL SPATIAL FORMS AND TECTONICS

Architectural theories evolved time after time and tectonics theories also followed them. Building technique was not a tool for solving the problem of form, but was just the source for considering architectural spatial form (Giedion, 1967). To view the architectural history, the discussion of the architectural progress always followed the revolution of technologies. The technique at that time could directly reflect the presentation of architectural structure and even change the spatial form of architecture (Wachsmann, 1959; Giedion, 1967). The spatial form of architecture was regarded as an extended result of the structure and construction. When the process of architectural production underwent changes, then changes in the form of architecture followed (Gao, 2004). In other words, the spatial form of architecture reflected a series of fabrication process (Gregotti, 1983; Frascari, 1984). Architecture spatial form should be studied and examined through tectonics, forming an inseparable bond between architectonics and tectonics (Semper, 1952; Frampton, 1995).

We found that the novel spatial form which was created from some historic stage of architecture never disappears in the later age, but revives into an innovative form as a result of the new techniques, new materials and new building

methods. The progress of architectural design thinking is from 2D drafts to 3D models, from straight lines to free-from curve. In this time, the diversified spatial forms of architecture are deeply affected by the digital age in the 21st century. Architecture of nowadays shows every kinds of spatial forms.

2. Problem and objective

However, the previous studies about the tectonics in this digital age almost only selected the architectural cases that usded a great deal of digital media to be the research subjects. It was not adequate to reflect today's diversified spatial forms and discuss them in accordance with the classification.

Therefore, this paper is base on Liu and Lim's (2006) framework of new tectonics, eleven new tectonic factors (joint, detail, material, object, structure, construction, interaction, motion, information, generation, fabrication), to be the analytical basis. The authors want to know what and how the tectonic factors affect the different spatial forms of modern architecture. The objective of this paper is to indicate the tectonic phenomena of the different spatial forms and the orientation of the tectonic factor in the diversified special forms.

3. Methodology and steps

In order to reach the objective, the research focused on a case study of the diversified spatial forms of architecture in the 21st century and integrated several phenomena of the above factors on the different spatial forms.

The case study selected the real architectural case of NEXT-GENE as the subject, which was a group design for a residential site in Taipei County in 2007. The NEXT-GENE project invited 20 noted architectural teams to this international contemporary architecture forum and exposition. They had to design one house on the site. The characteristics of this case were that the 20 architects collectively designed in the same site, for the same program, but from different countries. The analysis data included design concept, diagrams, sketches, drawings, renderings, and physical models.

These works of 20 architectural forms could be classified into three kinds of spatial forms, orthogonal, folding and curving spatial forms, according to the previous style of designers and this design presentation. The definition of orthogonal forms (O) was that all walls are 2D plane and it is vertical between all walls and the roof. The definition of folding (F) was that all walls are 2D plane, but with more than two adjacent walls are *not* vertical. The definition of curving (C) was that more than one wall are 3D curve.

In order to definitely distinguish into the three of the spatial forms and avoid confusing the results of the following analysis, the authors selected only

three works of each spatial form from the 20 buildings. The selections had to completely match the above definitions.

This study analysed nine cases of table 1 based on the eleven new tectonic factors of Liu and Lim (2006, 2009). Figure 1 is the analysis framework.

Table 1. The selected cases from 20 houses of NEXT-GENE project.

Spatial Form	Case [No.]	Project Name	Designer	Country
O	Case [1]	FlexiVilla	Toshiko Mori	USA
	Case [2]	Floating Courtyard	Ray Chen	Taiwan
	Case [3]	Triptych House	Yungho Chang	USA
F	Case [4]	Ridge House	Hailim Suh	Korea
	Case [5]	Latent Dragon	Irving Huang	Taiwan
	Case [6]	Radix House	Shu-Chang Kung	Taiwan
C	Case [7]	Architecture Farm	Akihisa Hirata	Japan
	Case [8]	Calligraphic House	Yu-Tung Liu	Taiwan
	Case [9]	Symbiotic Villa	Zaha Hadid	UK

4. Case study

The 11 new tectonic factors were proposed by Liu and Lim (2006, 2009). For their definitions, please refer to Liu and Lim's (2009) publication of *New tectonics: classic and digital design thinking in Feidad Award.*

However, owning to the special demands of housing program, all of the 20 cases did not generally consider the "information" factor. Therefore, the research did not take "information" into account temporarily and would

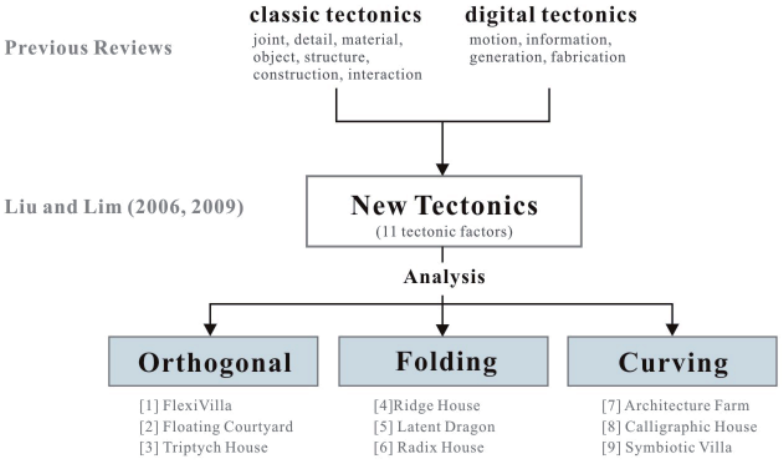

Figure 1. Analysis framework.

proceed to the discussion in the future. The following was going to analyse the remainders of ten tectonic factors.

4.1. JOINT

In the orthogonal forms, joints mainly figured on the skin for the additional requirements beyond the architectural form, including the ornament of minor structure, the special effect of light, and the assembly of mobile joints as figure 2a, 2b. Joints were a kind of expression. There were not directly related to the whole spatial form.

In the folding forms, there were two kinds of purposes in regard to the presentation of spatial forms. First was for the additional requirements attached to skin similar to the orthogonal ones (figure 2c). Second was for the connection between two segments of the whole, which usually hided behind the skin to present the whole form as the curving ones (figure 2d).

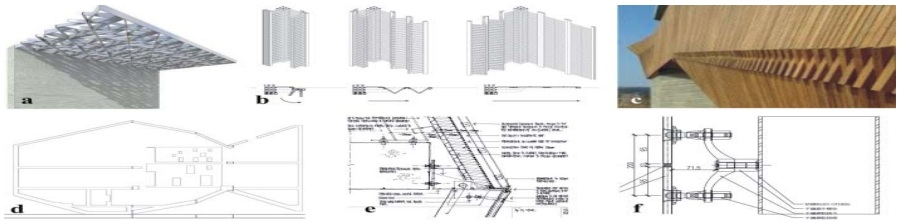

Figure 2. a. case[1], b. case[3], c. case[4], d. case[6], e. case[8], and f. case[9] of joint.

In the curving forms, they were assembled by several units, so the joint design came from the free-form curve, which were usually hided behind the skin in order to present the whole form as figure 2e, 2f.

4.2. DETAIL

In the orthogonal forms, details mainly appeared in the architectural skin. Amount of repeated units followed a rule and recombined together and then produced a weaving, complicated pattern as figure 2a. Therefore, the presentation of this form expressed the enriched and detailed texture, and then created an open space and produced magical lighting effects.

In the folding forms, there were two different kinds based on the expression of spatial forms. One stressed the decoration of architectural skin in order to create detailed skin and lighting effects as the orthogonal ones. The other purely stressed the connection of function. Details were hided behind the skin as the curving ones.

In the curving forms, details only possessed of the functional meanings. They derived from the spatial form. Details usually came up between a frame-

work and skin and were wrapped in the architecture.

4.3. MATERIAL

In the orthogonal forms, it emphasised to use some specific materials for the presentation of detailed skin. Designers particularly mentioned what kinds of materials were used in the external skin as figure 3a, 3b. The multiple collection of colours was an important feature for design expression.

In the folding forms, designers used single material to unify the style in the part of the folding form. They also specially addressed it to be the main materials in the concept design stage. However, in the part of the vertical and horizontal form, more materials were used for function as figure 3c.

In the curving forms, designers stressed simplicity of material and used less than three kinds. There was no steam on the curving skin and it only used only one kind of material. Structural materials were the exhibition materials showing on the external skin. The enclosure system usually used transparent glass to make the form purer.

4.4. OBJECT

In the orthogonal forms, some classic architectural elements of the explicit door, window, beam, column, floor, and wall, assembled around the building form. Space functions were clearly separated into interior and exterior by the geometric module objects. Objects in this form emphasised the object combination system of function demands.

In the folding forms, parts of classic objects were still recognised clearly such as the door, window, etc. However, the objects of external ones were less distinct than internal. The relationship between ceilings and walls disappeared and then integrated into a new “skin object” as figure 3d.

In the curving forms, the classic objects disappeared and were hard to identify because of the free-form curve. They came into being a whole object system, which was composed of many irregular customised objects for the design form as figure 3e, 3f.

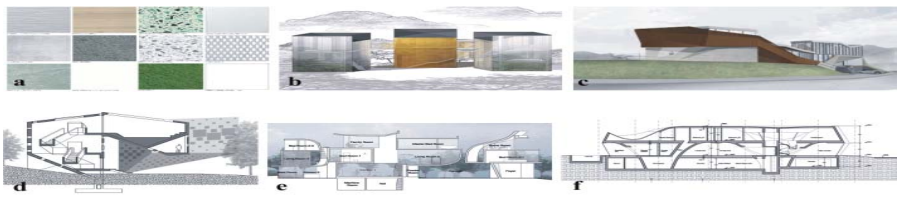

Figure 3. a. case[1], b. case[2], and c. case[5] of material; d. case[6], e. case[7], and f. case[9] of object.

4.5. STRUCTURE

In the orthogonal forms, there were most vertical and horizontal structural systems of beam-columns. The transmitting direction of force was vertical. The main structural system was reinforced concrete or steel structure as the frame of design form and attached to an ornamental skin structure.

In the folding forms, they still adopted the structural system of beam-columns, but the distribution of beams and columns was irregular in order to be closer to the site condition. Because of folding walls, there were other transmitting directions of force besides vertical.

In the curving forms, the form of structure had to be regarded as the building appearance. They usually developed with a steel framework of 3D curve or a whole cast of camber. The transmitting direction of system of force followed the building form.

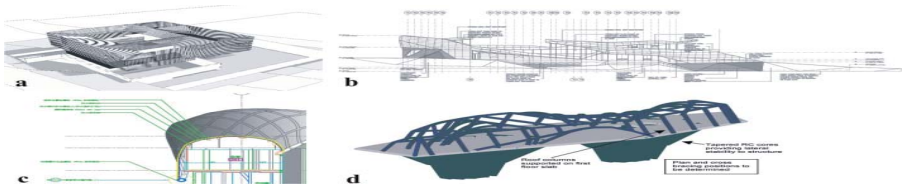

Figure 4. a. case[2], b. case[4], c. case[8], and d. case[9] of constructions.

4.6. CONSTRUCTION

In the orthogonal forms, construction was according to the orthogonal structure. The procedure of construction should be prioritised from the main structure to the attached skin. The order was usually bottom-up as figure 4a.

In the folding forms, the part of vertical and horizontal form was built of reinforced concrete in the site (as the orthogonal forms). The part of inclined plane needed to precast customised units in the plant and transport to the site to fabricate (as the curving forms). See figure 4b.

In the curving forms, they usually adopted the customised construction. The form was cut into segments, made in a plant, and transported to the site to fabricate as figure 4c, 4d.

4.7. INTERACTION

In the orthogonal forms, owing to that forms usually followed functions, they tended to create a partly-open courtyard. People did not directly contact with surroundings. The building created multi-level spatial perception and emphasised the interaction with people.

In the folding forms, there were two characteristics of the expression of spatial form. More than two building complexes created the inner space and added the levels of interaction with people and surroundings (as the orthogonal ones). The other expression is that forms followed topographies. Architecture interacted with site and people with direct contact with surroundings (as the curving ones).

In the curving forms, they emphasised form would be apart from topography. People in the building were just like in nature. They stressed the interaction with architecture and site. Therefore, the relationship between people and the surroundings became natural.

4.8. MOTION

In the orthogonal forms, the motion mainly presented in the process of function units such as stacks of volume, pull of partition, and fold of object. Finally it showed the suite space form based on the function.

In the folding forms, the purpose of motion was for the pursuit of esthetics and the condition of the site. They started from the move, twist, stack, or deformation of regular units and then displayed irregular folding forms in the end.

In the curving forms, motion came from the dynamic deformed process of a simple form. It was to fit the condition of the site and the pursuit of esthetics.

4.9. GENERATION

In the orthogonal forms, generation created inextricable 2D patterns which were used on the design of details and saved time and costs as figure 5a, 5b.

In the folding forms, there was less tectonic thinking of generation in the design process. Only case [6] was for the product of inextricable 2D patterns that was the same as the orthogonal ones.

In the curving forms, there were two kinds of form generation. One was the process from single to multiple of unit forms. The other was deformed by the free-form itself.

4.10. FABRICATION

In the orthogonal forms, fabrication was used on the detailed parts, such as small components on the details of the complex skin. It usually displayed with 2D plane and used the laser cutting and CNC machine to replace the artificial efforts. The advantages were cost saving and accuracy promotion.

In the folding forms, fabrication was used on the folded plates for the convenience and accuracy of construction. At first, the folded plates had to be

flatten a plane surface, and then precast conveniently in the plant for the final fabrication.

In the curving forms, fabrication proceeded to the precasting way. There were many modes of output, such as flattening, lofting, cutting, assigning, and assembling using the CAD/CAM tools. See figure 5c, 5d.

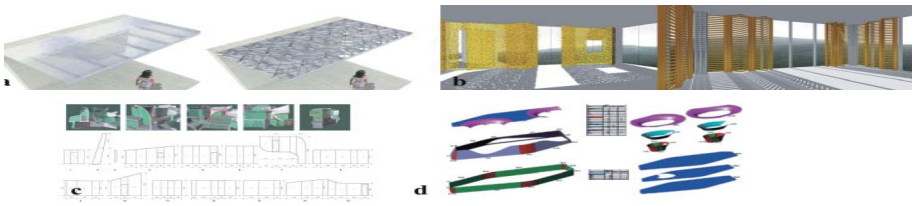

Figure 5. a. case[3] and b. case[6] of generation;c. case[7] and d. case[9] of fabrication.

5. Conclusion

The research finds that the seven classic factors all emerge in the three spatial forms of nine cases. The result shows the classic tectonic thinking is imperative until now. However, there is not an obvious discrepancy in the degrees of the three kinds of spatial forms dependent on the digital tectonic factors. It is critical to prove the significance of adding the new digital tectonic factors from Liu and Lim (2006) in digital age. Not only do the generally-known curving spatial forms greatly consider the digital tectonics, but also every kind of spatial forms emerges the phenomena of digital thinking.

For the further discussion, it is the difference of tectonic thinking among the orthogonal, folding and curving spatial forms in the case study. In the classic tectonic factors, the tectonic thinking of folding forms almost has the thinking as the orthogonal and curving. However, the digital factors are not clear. The tectonic thinking of folding forms usually tends to be the orthogonal or curving. Moreover, the thinking of the orthogonal form stresses on the regulation of function and the details of skin. The thinking of the curving forms stresses on the presentation of architectural forms and the interaction with the surroundings.

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References

Botticher, K.: 1852, *The tectonics of the Hellenes*, Postdam.
Cache, B.: 2002, Gottfried Semper: stereotomy, biology and geometry, *Architectural design*, 72: 28–33.
Cook, M.: 2004, Digital tectonics: historical perspective – future prospect, *in* N. Leach et al. (eds.), *Digital tectonics*, Wiley-Academy, Chichester, 40–49.
De Luca, F. and Nardini, M.: 2002, *Behind the scene: avant-garde techniques in contemporary design*, Birkhäuser, Basel.
Deplazes, A. (ed.): 2008, *Constructing architecture: materials, processes, structures*, Birkhäuser, Basel.
Fang, L. and Zhou, Q.; 2007, Digital tectonics in shape finding of spatial structures, *CAADRIA 2007*, 543–548.
Frampton, K.: 1990, Rappel à l'ordre: the case for the tectonic, *Architectural design*, **60**, 19–25.
Frampton, K.: 1995, *Studies in tectonic culture*, MIT Press, Cambridge, Mass.
Frascari, M.: 1984, Tell-the-tale detail, *in* K. Nesbitt (ed.), *Theorizing a new agenda for architecture: an anthology of architecture theory 1965–1995*, Princeton Architectural Press, New York, 498–515.
Gao, W. P.: 2004 Tectonics? A case study for digital free-form architecture, *Proceedings of CAADRIA 2004*, Yonsei University Press, Seoul, 519–534.
Giedion, S.: 1967, *Space, time and architecture: the growth of a new tradition*, fifth revised, enlarged edition, Cambridge, Massachusetts.
Gregotti, V.: 1983, The exercise of detailing, *in* K Nesbitt (ed.), *Theorizing a new agenda for architecture: an anthology of architecture theory 1965–1995*, Princeton Architectural Press, New York, 494–497.
Ham, J. J.: 2003, The computer as a tectonic design tool: comparisons between virtual and actual construction, *21th eCAADe*, Austria, 265–268.
Imperiale, A.: 2000, *New flatness: surface tension in digital architecture*, Birkhäuser, Basel.
Leach, N., Turnbull, D. and Williams, C. (eds.): 2004, *Digital tectonics*, Wiley, London.
Liu, Y. T. and Lim, C. K.: 2009, *New tectonics: classic and digital design thinking in Feidad award*, Birkhäuser, Berlin.
Liu, Y. T. and Lim, C. K.: 2006, New tectonics: a preliminary framework involving classic and digital thinking, *Design studies*, **27**, 267–307.
Mitchell, W. J.: 1998, Antitectonics: the poetics of virtuality, *in* J. Beckmann (ed.), *The virtual dimension: architecture, representation and crash culture*, Princeton Architectural Press, New York, 205–217.
Pongratz, C. and Perbellini M. R.: 2000, *Natural born CAADesigners: young American architects*, Birkhäuser, Basel.
Sekler, E. F.: 1965, Structure, construction, tectonics, *in* G. Kepes (ed.), *Structure in art and in science*, George Braziller, New York, 89–95.
Semper, G.: 1951, *The four elements of architecture and other writings*, Cambridge University Press, New York.
Spuybroek, L.: 2003, Textile tectonics, *in* B. Tschumi and I. Cheng (eds.), *The state of architecture at the beginning of the 21st century*, Monacelli, New York 102–103.
Vallhonrat, C.: 1988, Tectonics considered: between the presence and the absence of artifice *Perspecta*, **24**, 122–135.
Vanggaard, O. and Pontoppidan, E.: 2007, Digital tectonics, *Tectonics making meaning conference*, Eindhoven University of Technology.
Wachsmann, K.: 1959, *Wendepunk im Bauen*, Ott Krauskoph Verlag.

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THE INTERDEPENDENCE OF LINEAR AND CIRCULAR CAUSALITY IN CAAD RESEARCH

A unified model

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Abstract. This paper discusses the relationship between linear and circular conceptions of causality and questions the common mutually-exclusive bivalent logic applied in distinguishing them. It argues that (circular) conversation *and* (linear) control both have their place in the design process. This calls for open minds and a reconsideration of value systems in CAAD practice and research, without which CAAD remains the futile attempt to deploy techniques developed to identify and enforce linear causation for the benefit of a practice that depends upon circular causality.

Keywords. Control; technique; novelty; predictability; surprise.

1. Background: Dual polarities and mutual arising

Chances are that your education and your thinking are influenced to some degree by Aristotelian logic, including the "principle of the excluded middle" (lat.: *tertium non datur*) according to which two opposites (A and not-A) can never both be true. This notion suggests that one can only be either right or wrong, that one can only either win or lose, and that a bit can only either be 0 or 1. This notion is an excellent foundation for performing reductionist science by using the kind of logic that is commonly performed today[1], not only on digital computers, but also by modern minds, which, after all, thought up the digital computer. Downton (2004) warns design researchers explicitly of dual oppositions as figments of the mind that are enforced by language. From the perspective of the Aristotelian tradition of thought, however, alter-

native notions of reasoning can seem bizarrely misguided and irrational. For example the Hindu notion that each thing implies, and must in time become, its opposite (represented by the goddess Bagalamukhi) can appear outlandish to Western observers. This notion that every A necessarily implies and brings about not-A can be further traced within Buddhism (Macy, 1992) and in the Taoist tradition where it is expressed in the Taijitu symbol (☯). Indeed, in much of Asian thought, the holistic notion of interdependence of any thing with anything else, including its perceived opposite, is deeply engrained – albeit rapidly disappearing with the influx of the globalising modern thinking of the Western world, whose reasoning is largely based on the drawing of dual, mutually-exclusive distinctions (yes/no, true/false, good/evil etc.). Accepting the co-existence and possible joint validity of A and not-A implies the acceptance of possible circular interaction, interdependence and gradients and spectra between them. While this, as I argue here, offers some advantages, it is perceived as a threat to conventional linear logic. In order to protect the basis from which they operate, scientists tend to avoid interdependencies in their theories and models, even when they admit the relevance of interdependencies to the phenomena they describe and model (for example Minsky, 1986, p. 48).

The emphases on reductionism, linear logic and linear causality on the one hand and on holism, circular logic and circular causality on the other hand mirrors the ideological rift between the two strands of our field's dual heritage in the sciences and the creative arts (Kvan, 2004). Despite the CAAD field's positioning at the junction of science, technology and the arts, remarkably, the subjects of causality and logic have not yet received much attention in our discourse. We have, be it for convenience or out of ignorance, acquired the bulk of our philosophical foundation from natural science and with the logic embodied in the digital technology we use. As a consequence, we tend to straightjacket design-related phenomena into conventional scientific and machine logic, where the development of alternative kinds of reasoning and machine logic that do justice to designing should be developed or considered. Moreover, circular causality and logic as well as holistic thinking, as mentioned above, are fundamental to important Asian traditions of thought (Nisbett, 2005, pp. 173ff.), which I believe makes the reflection I am proposing here particularly relevant in the Asian computer-aided design research context.

2. Relevance to CAAD (research)

Two key principles that are essential ingredients of models of designing but incompatible with common notions of logic and causality are interdependence and self-contradiction. Before I describe the essential role of circularity in

designing, I will illustrate the pertinence of these principles to our field using some concrete examples.

I was once at a design school where administrative structures were rudimentary and funding was scarce. There was a lab with outdated, barely adequate computers. Students maintained the lab and used it to teach each other as well as local professionals, generating a modest income for small system upgrades here and there. The lab was the site of constant activity and exchanges about possibilities and desires, driven by questions usually formulated around the phrase "what if we could...?" The creative misuse of digital tools was a routine. Many of the students learned how to program computers and went on to use this skill creatively. Resulting projects and learning were often impressive (though they usually remained unpublished). Later, I was at a design school that was administratively mature. Its various committees presided over generous funds. There were several computer labs with dedicated technicians and annual upgrades of all hardware and software. There were also some pieces of expensive advanced computer equipment that had been purchased to maintain the flow of research funds even though nobody was capable of or interested in using them. Students attended, and very often dreaded, scheduled computer lab classes covering text book exercises. Hardly any of the students learned how to program computers or ever used them in unexpected ways.

This juxtaposition not only casts a liberating light on the utilitarian quest for bigger and faster tools. The first school's gain of opportunity in its lack of opportunity, and the second school's loss of opportunity in its gain of opportunity also illustrate unavoidable dilemmas: Upsides come with downsides and downsides come with upsides. There is loss in gain and there is gain in loss[2].

Virtually everybody desires and appreciates positive surprise and dreads prolonged absence of stimulating unpredictability. At the same time, everyone appreciates a predictable supply of necessities and waking up in the morning with their heart still beating reliably. The desires for reliable predictability and for surprising unpredictability are seemingly at odds with one another. These two mutually contradictory desires are not only present in practically every individual. They are also present in the deployment of strictly controlled technology (and methodology) in support of (and to investigate) the generation of surprising novelty.

This apparent contradiction dissolves when we embrace stability *and* change and when we accept that stability leads to change and change leads to (dynamic) stability. This resolves the perceived incompatibility of scientific rigour and design thinking. We hence need to explore the question of how the two go together and whether there is an operational compass to navigate the

spectrum between designerly production of change and scientific description, prediction and control of stability.

Conventional logic advocates

"either A *or* not-A"

I advocate acknowledging

"A *and* not-A"

Using conventional logic, the difference between both can be mistaken as

either "either A or not-A" *or* "A and not-A"

while I regard it as

"either A or not-A" *and* "A and not-A".

I regard the design process as a conversation (circular interaction) between a self and an other (Glanville, 2007): "I sketch this because of something I saw in my previous sketch, which I drew because of something in my preceding sketch etc." Or: "I say this because of what you said because of what I said etc." The self/other distinction must not be taken as a literal or reference to necessarily two persons. The number two is chosen since it is the smallest possible group and because attention in encounters is usually focused on one other. The line of distinction between self and other does not have to coincide with physical boundaries of the participants since groups can act as one and individuals can be split. The minimum requirement for novelty generation is the ability of self to multiply the set of conceptions with which (s)he enters into a conversation with an other (who may reside inside self).

3. Causality

CAAD research investigates (scientifically) what already is, while seeking to determine (designerly) what shall be. While this positions the concept of causality as a central issue in our field, it is however not yet much discussed. I understand causality as an observer's way of describing the connection of events, which that observer recognises as connected. In this view, it does not exist independently of an observer's mind. It is a useful phantom that is constructed to establish descriptive and predictive powers. Linear causality ("A affects B") is the causality of the reliably predictable and of the known. Circular causality ("A affects B, B affects A"; or simply: "A affects A") is the causality of the surprisingly unpredictable and of coming to know something new. Both ways of conceptualising causality can co-exist and complement one another: Linear causality, the emphasis of which I have grown tired of because

within my field of experience it is grossly overemphasised, offers suitable ways of describing processes of exploitation, instruction, dominance and technique that offer static and conclusive results. Circular causality, to which I am sympathetic because it is neglected and because it delights me, offers suitable ways of describing perpetual processes of mutuality, interaction, interdependence, designing, researching and learning.

I propose that the CAAD (research) field's current focus on linear thinking and logic should be balanced by paying greater attention to circular relationships. For this purpose, the following section introduces a new model that integrates the reliably predictable and the surprisingly unpredictable and their underlying linear and circular conceptions of causality. It shows that these two conceptions of causality can be thought of as occupying the same logical space, being positioned at different locations of the same conceptual spectrum, along which each of them offers specific benefits and penalties when applied to different kinds of concerns.

The need for orientation in this logical space poses a navigational challenge that brings us back to the Hindu goddess Bagalamukhi whose role as the pivot between dual polarities allows us to master them just as a compass allows us to navigate unknown territory. This is the purpose of the model presented below.

4. Development of the Model

We start by drawing a distinction between an A and a B – for example (your) *self* and (someone) *other* (see Glanville, 1990). This gives us the essential ingredients for modelling encounters: A minimal set of entities between which causal relations can be observed (even if A and B may be considered identical. For example: 'I the tired' can make 'me the eager' take a break.). Note that the mentioned observing can be done by participant-observer A or B within the encounter of interest or by an observer C from outside the encounter of interest. Further note that C's observation forms another encounter[3] – possibly leading into a potentially recursive, but soon boring cascade.

To develop this model, we may choose a simple approach: We consider the set of possible encounters between *A*s and *B*s (see left of figure 1 below), ignoring self-observation of A and B and contenting ourselves with considering linear causality only. We assume the position of the outside observer C similarly to the idealized *locus observandi* assumed by scientific experimenters. Now, two possible linearly-causal scenarios can be observed in the encounter, each one being a mirror image of the other: A dominating B (A>B) or B dominating A (B>A) as illustrated on the right of figure 1.

A: “Do as I say! Otherwise [some threat]”
B: “Your wish is my command!”

or

B: “Do as I say! Otherwise [some threat]”
A: “Your wish is my command!”

To A and B, the insiders of the observed encounter, there is no symmetry at all. (One)*self* is either dominant or dominated, which makes a great subjective difference. We, C, find ourselves outside the encounter, empathetic with A or B or maybe both. We cannot help but draw a second distinction besides the distinction between A and B: that between A dominating B and B dominating A. These correspond (for A and B immediately or via C’s empathy) to *self* dominating *other* and *other* dominating *self*.

Figure 1. Set of all possible encounters of As and Bs (left). Encounters in which A dominates B and encounters in which B dominates A, distinguished by a line (right).

Distinction-drawing is widely perceived as helpful. The ability to distinguish between friend and enemy, for example, is not only a prerequisite for naming them as such – it can be vital for survival. But where lines of distinction are drawn too coarsely and where the named deserves a chance to get another name (a good way of eliminating an enemy is to make friends with her), it comes at a price. Thus, distinction drawing facilitates both conven ience and violence. Consider any distinction of the “black or white” type. For as long as we focus on the most obvious instances, the conveniences gained from drawing the distinction appear to outweigh the penalties. Further away from the most obvious instances, gradients appear: spectra on either side of the line of distinction. There is an infinite variety of ways and degrees of being somewhere between “black” and “white”. Towards the one side of the distinction appear *A*s that are more and more like *B*s while *B*s that are more and more like *A*s appear to the other side. These gradients also appear in the case of the distinction between A dominating B and B dominating A.

Gradually, the perceived unidirectional dominance between A and B can decrease, the more A and B meet ‘at eye level’[4]. There are two ways of getting there: Inside the encounter, A and B can take less dominating and less dominated attitudes respectively by negotiating the terms of their interaction. Inside

and outside the encounter, (self-)observers A, B and C can assess domination (linear causation) across varying observational scopes, to allow larger portions of the encounter to enter the observation and a more balanced picture to appear, provided A and B take turns in affecting each other. The more balanced the encounter is perceived to be, the less unidirectional dominance is apparent and the more of a conversation appears. Balance is found towards the far left as well as to the far right from the initial line of distinction shown in figure 2. Thus, both sides can be joined to form a continuous gradient from one side of the distinction line to the other. The right of figure 2 shows the initially distinguished gradients joined, in what I call (due to its overall shape) the Q-model[5].

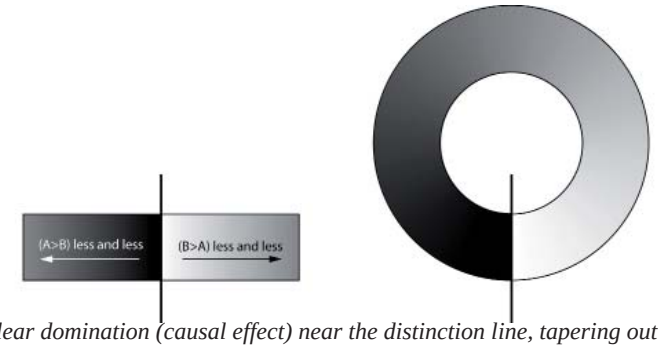

Figure 2. Clear domination (causal effect) near the distinction line, tapering out further away from the distinction line (left) and joined Q-model (right).

This is a more general and unified model of possible encounters that offers, I believe, a more viable alternative to commonly encountered polar distinctions such as those between "black" and "white", as well as between encounters of possible power relations in encounters of *A*s and *B*s. That which is represented by the medium-grey area at the top of the model is in many cases of particular value (Glanville, 2000). Usually, however it is ignored since it undermines the Aristotelian mutually-exclusive drawing of distinctions, thereby posing a threat to conventional rational logic. With this unified alternative on offer, the choice we have is between either compartmentalising human experience for the benefit of a pure logic and expanding conventional logic for a better fit with human experience.

The annotations in figure 3 show how the conversational, circular causality located at the top of the model relates to the out-of-control (Glanville 2000) divergent (Guilford, 1967) generation of variety (Ashby, 1956; Rittel, 1972, p. 395) required to generate novelty whereas the dominant, linear causality located at the bottom relates to the in-control convergent reduction of variety required to accomplish intentions, both of which are essential to designing

(these are usually associated with the early and the later design stages respectively). The polar connectedness and interdependence or linear and circular causality shown in the annotated Q-model in figure 3 bears a strong conceptual resemblance to the Polarity Management Framework proposed by Johnson (1992). This framework shows the polar interdependence of (supposedly) contradicting opposites such as the ones between individual effort and team effort, stress and tranquility or between capitalism and socialism. Figure 4 shows an application of this framework to circular and linear causality. The poles are located to the far left and to the far right and their respective upsides and downsides are marked above and below on either side.

Johnson explains that an exclusive emphasis on the upside of either pole will lead to its downside, and thus to a gravitational pull towards the upside of the opposite pole

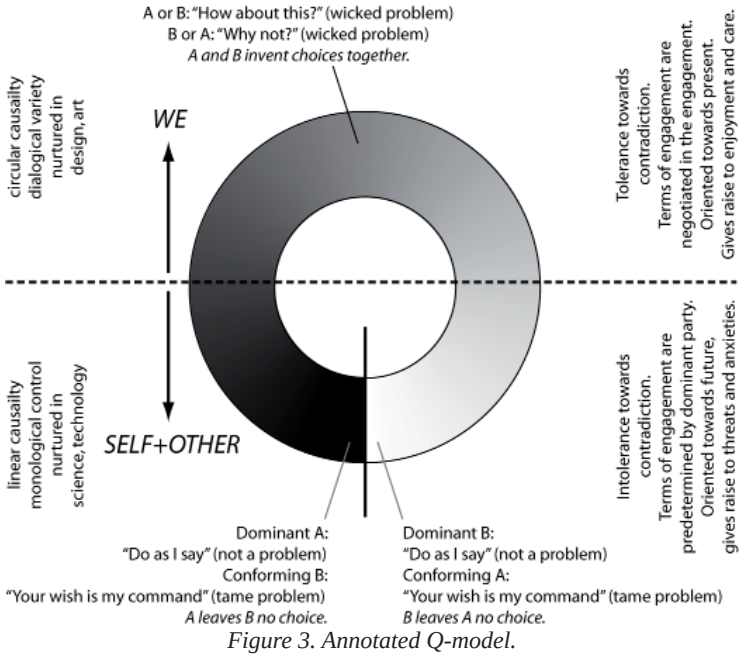

Figure 3. Annotated Q-model.

and so on, generating a lying figure-8 shape trajectory. The best way to navigate this space is by staying in motion, harnessing the upsides and minimizing the impact of the downsides as much as possible.

5. Implications for CAAD research

> Always choosing one side of the coin, instead of simply choosing the coin itself (Williams, 1998, p. 82).

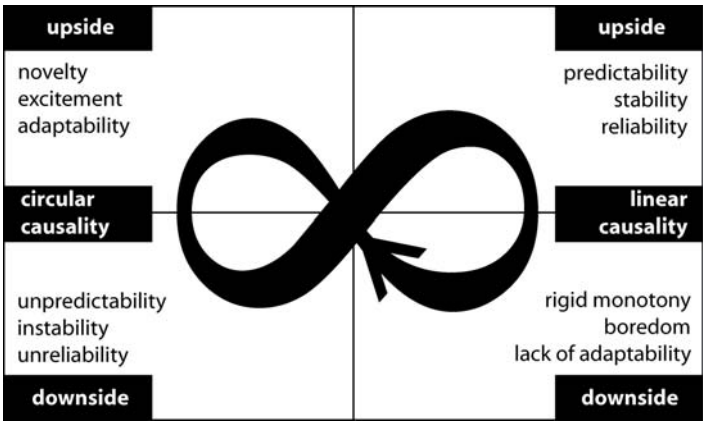

Figure 4. The polar distinction between linear and circular causality according to the Polarity Management framework (Johnson, 1992).

Acknowledging linear causality and logic and ignoring circular causality and logic (in CAAD and beyond) is like deciding that inhaling is right and exhaling is wrong. A view of either one of them by itself without the other is ultimately incomplete. In this paper I show that both views of causality can be thought of as occupying the same conceptual space. This space must be navigated wisely if the potentials and limitations of our means are to match the challenges of our ends.

In its current state, much of CAAD, and neo-positivist scientific research in support of it, are preoccupied with the deployment of techniques developed to detect and to enforce linear causation (at the bottom of the Q-model and on the right side of the Polarity Management model shown in figure 4 above) in a misguided effort to support a practice that depends upon circular causality (at the top of Q-model and on the left side of the Polarity Management model shown in fig. 5 above). The futility of this agenda has been recognised before, in particular with the demise of the design methods movement (Cross, 1984, pp. 309-316). The Q-model presented in this paper offers metrics by which the upsides and downsides of linear and circular causality can be named and weighed so that the gradual space between these polar opposites can be navigated from the perspective of those inside design conversations. The perspective assumed with the Q-model differs from the third-person perspective from which upsides and downsides are positioned objectively in the Polarity Management model. It acknowledges that within design conversations upsides and downsides are subjectively negotiable. Similarly to the Polarity Management framework, the Q-model shows that the path towards harnessing upsides can lead across stretches of sometimes severe downsides. Proficient navigation

of the presented conceptual space within which linear and circular causality co-exists corresponds, in my opinion, to Heinz von Foerster's (1973) *Ethical Imperative*: "Act always so as to increase the number of choices."

Acknowledgements

I gratefully acknowledge the feedback and support from Anand Bhatt as well as from Ranulph Glanville and Timothy Jachna of the American Society for Cybernetics.

Endnotes

1 Syllogistic, subject-predicate and similar straightened-out structures of reasoning.
2 This is why trying to set up "games" in which there is winning without losing is as futile as trying to break a magnet to obtain only a south pole (see Watts, 1975, 18–36). And thus, Western "modern lifestyle," now global, wreaks havoc.
3 The explicit acknowledgment of this relationship is the difference between first-order and second-order cybernetics.
4 Rittel speaks of "conspiracy," "symmetry of ignorance" in Cross (1984), p. 325.
5 Circular conversational causality happens at the top of the Q-model, linear control at the bottom. The interdependence of circular and linear encounters in designing is expressed in the overall ring-shape of the model.

References

Ashby, W. R.: 1956, *An introduction to cybernetics*, Chapman and Hall, London.
Cross, N. (ed.): 1984, Developments in design methods, John Wiley and Sons, Chichester.
Downton, P.: 2004, *Design research*, RMIT University Press, Melbourne.
Fischer, T.: 2009, Reassessing rigour, re-cycling research, *in* T.-W. Chang et al. (eds.), *Proc. 14th CAADRIA Conf.*, Dept. of Digital Media Design, NYUST, Taiwan, 791–794.
Glanville, R.: 1990, The self and the other: the purpose of distinction, *in* R. Trappl (ed.), *Cybernetics and systems '90*, World Scientific, Singapore.
Glanville, R.: 2000, The value of being unmanageable: variety and creativity in cyberspace, *in* H. Eichmann et al. (eds.), *Netzwerke*, Falter Verlag, Vienna.
Glanville, R.: 2007, Grounding difference, *in* A. Müller and K.H. Müller (eds), *An unfinished revolution?* Edition Echoraum, Vienna, 361–406.
Guilford, J. P.: 1967, *The nature of human intelligence*, McGraw-Hill, New York.
Johnson, B.: 1992, *Polarity management*, HRD Press, Amherst.
Kvan, T.: 2004, The dual heritage of CAAD research, *IJAC*, **1**(2), pp. 11–17.
Macy, J.: 1991, *Mutual causality in Buddhism and general syst. theory*, SUNYP, Albany.
Minsky, M. L.: 1986, *The society of mind*, Simon and Schuster, New York.
Nisbett, R. E.: 2005, *The geography of thought*, Nicholas Brealey Publishing, London.
Rittel, H.: 1972, On the planning crisis: systems analysis of the 'first and second generations,' *Bedrifts Økonomen*, **8**, 390–396 .
Rittel, H. and Webber, M.: 1973, Dilemmas in a general theory of planning, *Policy sciences*, **4**, 155–169.
von Foerster, H.: 1973, On constructing a reality, *in* F. E. Preiser (ed.), *Environmental design research*, **2**, Hutchinson & Ross, Stroudberg, Dowden, 35–46.
Watts, A.: 1975, *Tao: the watercourse way*, Pantheon Books, New York.
Williams, T.: 1998, *Otherland volume two: River of Blue Fire*, Orbit, London.

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QUANTUM ARCHITECTURE

An indeterministic and interactive computational design system

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Abstract. The evolution of computational design technique from mere substitution of hand drawing to customised design algorithms exhibiting a certain degree of intelligence, naturally opens up a new research frontier that studies the relationship between designers and customized design algorithms. Most of current customised architecture design algorithm adopts a deterministic paradigm to raise their design questions, that is to say, given the explicit rules and parameters, only one solution is allowed at each discrete computation step. Due to this deterministic nature, an intuitive and efficient communication between design algorithm and designer is hard to achieve, as there is almost no space for designer to step into the running generative process. This lack of progressive communication channels and the inefficiency of translating perceptual judgment into computer language directly results in the unconscious rejection of non-parameterisable design factors like intuition, aesthetic judgment and associational reasoning that are essential to any design activity. This paper introduces the quantum design paradigm as alternative computation paradigm for constructing an interactive and intuitive design system. An algorithm prototype, probability field, will be introduced to illustrate the logic and possible application of the proposed quantum design paradigm.

Keywords. Quantum design paradigm; intuition; algorithm prototype; interactivity; probability field.

1. Interactive design computation

The evolution of computational design technique from mere substitution of hand drawing to customised design algorithms exhibiting a certain degree of intelligence, naturally opens up a new research frontier that studies the

relationship between designers and customised design algorithms. As shown in figure 1, this relationship can be mapped as a rigid master/slave model which is deeply rooted in the early day's 'batch' mechanism. This relationship can however be set up as an interactive[1] process, for which designer not only program the design algorithm, but also actively communicate with design algorithm to bring in a set of non-parameterisable design factors, such as intuition, aesthetics judgment and associational reasoning[2] that are essential to any design activity.

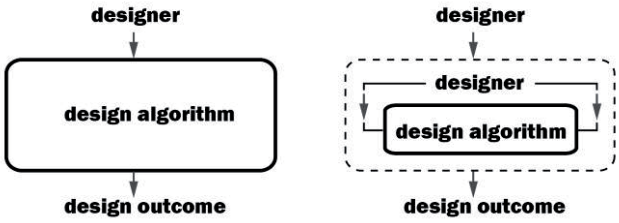

Figure 1. Designer and design algorithm relationship.

This inquiry into the conversational designer/design algorithm relationship has profound impact on the design of a new kind of design algorithm which challenges the binary nature of current design computation philosophy. This paper presents the probability field algorithm prototype[3] as one possible way to construct such an indeterministic and interactive design computation system. A brief examination on the limitation of deterministic algorithm structure will be provided at first to reveal the necessity for introducing an indeterministic and interactive design paradigm namely the quantum design paradigm.

2. The limitation of deterministic algorithm structure

According to Wikipedia, as for mathematic and computing, *an algorithm is defined as a sequence of finite instructions. It is formally a type of effective method in which a list of well-defined instructions for completing a task will, when given an initial state, proceed through a well-defined series of successive states, eventually terminating in an end-state.*

In light of this definition, most of current customised architecture design algorithms are constructed as a series of computation instructions that are organised by a predefined structure, while the transition between different instructions are rigidly regulated by *if, then* logic. For such algorithms, given explicit rules and parameters, only one solution is allowed at each discrete computation step, i.e., the computation question is always formulated to expect only one rational answer. This algorithm structure may work independently with strictly defined design problem solving and optimisation, but due

to its deterministic nature, an intuitive and efficient communication between design algorithm and designer is very hard to achieve, as there is almost no space left for the designer to step into the running computation process, and no reason for the independent design algorithms to provide feedback to the designer except for an error print. This lack of communication and the inefficiency of translating perceptual judgment into computer language directly results in the unconscious rejection of non-parameterisable design factors and reduces the customised algorithm to mere design problem solving machine instead of a design partner to its full potential.

This deterministic algorithm structure may very well be addressed to the Newtonian philosophy that advocates the clockwork paradigm while minimising human impact to preserve the rigor of the perfect machine. In order to open up the design computation process to personalised design considerations from designer, it becomes important to search for an alternative computational design paradigm for novel conceptual framework and methodology.

3. Quantum design paradigm

Many, if not all, of our computation methods are actually originated from scientific observation and abstraction of physical reality, e.g., genetic algorithm, neural network, fractal geometry and swarm logic. Quantum theory, as the most successful explanation of the particle world, has not only triggered tremendous technical improvement but also an emerging scientific worldview: Quantum paradigm. Quantum paradigm advocates an interactive relationship between human being and their physical environment, thus put into question the deterministic worldview as stated by Newtonian physic. Its implications in different social and technical aspects are profound. In order to better discuss the relevance of quantum paradigm to design computation system setup, a brief introduction to quantum paradigm in general will be necessary.

3.1. A BRIEF INTRODUCTION ON QUANTUM PARADIGM

Quantum paradigm is constructed by a set of correlated philosophical reflections on the nature of the universe and our relation to it. As stated by the Wave-particle duality[4] and Heisenberg uncertainty principle, the observed reality is a statistical representation of a relative reality that has its uncertain principle derived from the irreducible fuzziness of its basic building blocks, particles. As for quantum paradigm; nothing can be said for certain about a physical system other than a probability wave function that can only be described with statistics. While any attempt to probe the configuration of a quantum system will definitely collapse its wave function. This is to say that the very act of

observation is actually an interaction between the observer and observed system that not only yields a reading of the current configuration but also reconfigures the system itself. Thus the objective belief of an absolute and deterministic reality is put into question, and replaced with a relative reality that potentially includes consciousness as a part of it.

Besides the concept of absolute reality, the principle of locality has also been violated by quantum theory. Derived from Eisenstein's relativity theory, the principle of locality states that physical processes occurring at one place should have no immediate effect on the elements of reality at another location. As proven by a series of experiments, the opposite of this principle is apparently well demonstrated. The violation of the principle of locality promotes new ideas of understanding the universe with more than 3 dimensions which were further developed into many-world interpretations and the super string theory that, among many others, are both very important explanations of the quantum reality.

3.2. KEY CONCEPTS FROM QUANTUM DESIGN PARADIGM

The study on quantum design paradigm yields a set of interrelated concepts for setting up such an interactive computation system. This paper will discuss two key concepts that have been tested with the probability field algorithm prototype.

3.2.1. Probabilistic description method

For quantum physics, probability is a definable indeterministic function based on the assumption of the system's elements. Due to the internal fuzziness and correlated event potentiality of any quantum system, it becomes necessary to introduce a probabilistic description method to depict the state of tendency for a quantum system with incomplete information. An illustration of the probabilistic description method can be found in figure 2, which is a sequence in increasing time after the launch of two wave packets in a weak random potential landscape that is outlined by dark high potential barriers. In this artwork, instead of a definite indication of the exact position in time, the colour temperature of the 2D space represents the possibility for the electrons to be at that particular spot at a particular point of time,

By introducing the concept of computational probability and probabilistic description method into computation system setup, we have the tool to construct and communicate with an indeterminisitic system built with multiple possible configurations. Thus, on top of the classical description vocabulary composed of position, velocity and other affirmative object properties, we

could add one more dimension to describe the system potentiality. This naturally legitimates open-ended computational design questions with a set of simultaneously rational solutions.

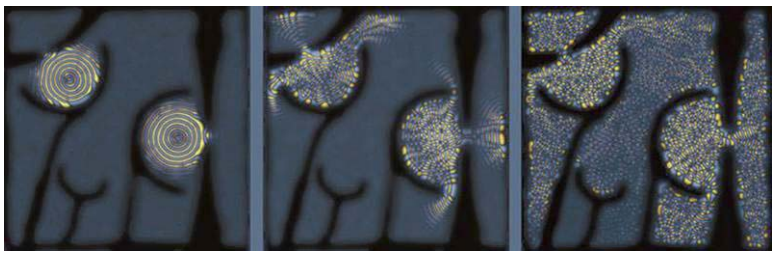

Figure 2. Resonator Triptych by Eric J. Heller (2004).

3.2.2. Non-local information sharing

In quantum physics, the violence of locality has been accepted as a given fact of particle universe. As for the computational design system setup, the concept of non-local information sharing indicates a condition that information within a computation system can be communicated and shared remotely. This leads to a new attitude towards the bottom-up computation system, for which local connectivity won't be the obstacle for direct communication of certain kind of information that are necessary to be grasped by the whole community of actors. This understanding naturally paves the way for introducing global constant as a common design constraint, which is currently treated as a taboo in the field of complex adaptive system research, while actually can be crucial for certain architecture design scenario that requires particular overall system summation to be constant, e.g., the general construction cost and overall construction area should be controllable to ensure realistic design proposals.

4. Probability field algorithm prototype

The probability field algorithm prototype is based on the synthesis of non-local information sharing concept and probabilistic description method. Its algorithmic principles can be summarised as following:

- The probability field is constructed with homogeneous, non sub-divisible units, which are identifiable by unique states.
- The units from different states have different impact on their neighbor units, measured by the intensity of its influence field.
- Unless sufficient local and global information is obtained, a single unit is always in a quantum state, which is a collection of all possible states. For these elements, a probabilistic ranking between all possible states can be calculated and communicated.

- The order of the probabilistic ranking can be altered by the designer to introduce personal design considerations.
- The global criteria must be always fulfilled by means of automatic system examination and update mechanism.

4.1. PROBABILITY FIELD ALGORITHM STRUCTURE

The probability field algorithm structure is constructed by grafting the reasoning tree structure on top of a bottom up computation grid, as shown in figure 3. Global constant parameter is also introduced as an overall computation criterion to regulate the evolution of system solution space.

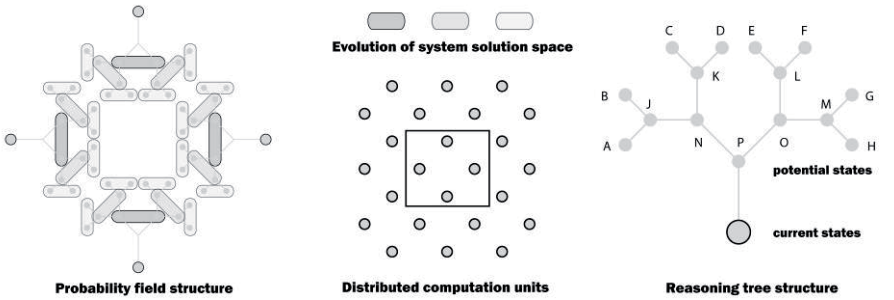

Figure 3. Reasoning tree structure and bottom up system.

The reasoning tree structure allows multiple computational solutions to be simultaneously rational at each decision making node. Similar to the traditional branching design decision making process, the reasoning tree structure here also allows the interactive design system to jump back to a previous decision making node to choose another path while keeping the reasoning trajectory before that node untouched. The bottom up computation grid provides a set of distributed computation units to handle massive design information. By manipulating node state of the reasoning tree structure of each distributed computation unit, designer can affect the computational decision making process on the basic computation unite level.

As shown in figure 4, the evolvement of the probability field algorithm prototype is triggered by the interaction between the human designer and the design algorithm. At each computation step, the design algorithm will examine the general system condition and suggest a list of rational states that the designer can assign to the particular computation unit that is of concern for this step. All of these rational states will be further evaluated on their different level of recommendation according to the built-in evaluation criteria, while the result of this evaluation will be presented to the designer as visual feed back, as indicated by the gradient colour in this diagram.

The human designer is free to choose any rational states that are allowed but not best recommended by the algorithm to manifest his/her particular design consideration that overweighs the generated ranking. Thus the evolution of this computation design process will no longer be confined to predefined mathematical formulas, but open to personalised aesthetic and intuitive judgment from human designers. General checking will be carried out automatically after each decision making step, for any unit, if there is a conflict[5] between its current state and its local condition, the system will automatically fix it and update the entire system accordingly.

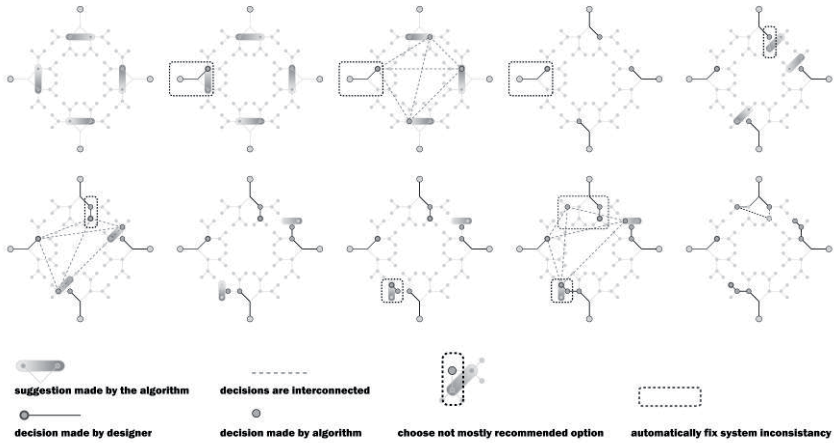

Figure 4. Computation system evolution.

4.2. MINESWEEPER DESIGN GAME

The probability field algorithm prototype has been implemented with an interactive design system, the minesweeper design game, figure 5. This design game reverses the mine discovering process of the classic minesweeper game into a design process that requires the designer to define the location of mine cells by assigning local connectivity figures to the undetermined cells within a definite 2D matrix. By assigning a local connectivity figure N to any undetermined cell, say with 8 neighbors, the designer is actually telling the algorithm that there will be N mine cells located beside this particular cell, thus the local probability parameter for all adjacent cells to be a mine cell will increase by N/8 according to this newly registered information. There is also a global constant of the total amount of mine cells, which introduces a global probability parameter for each undetermined cell. The overall probability parameters will be constantly updated after each new design decision and visualised with the gradient color to inform the designer about current system condition.

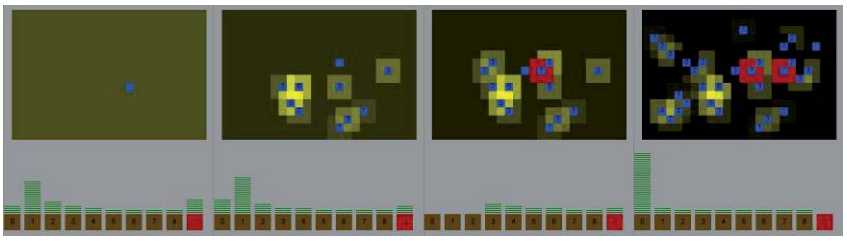

Figure 5. Screen shots from Minesweeper design game.

For any undetermined cell picked by the designer, the minesweeper design algorithm will suggest a list of ranked possible figures that can be assigned to this cell. The action of assigning one particular figure will trigger a checking process through out the entire matrix, which will locate and fix any system inconsistency. Thus, this design algorithm actually acts more like a supportive design partner who not only provides suggestions, but also makes necessary corrections on designer's decisions.

4.3. APPLICATION SKETCH

The logic of probability field algorithm can be applied in various design scenarios that involve both massive computation and personalised design judgment. As for complex design task, different design considerations can be mapped onto different probability field layers and added up together later to reduce scripting complexity. As in the urban development game sketch, figure 6, the probability field table A controls the amount of extrusion of individual units, while table B distorts the control grid surface.

The surface population tool sketch, figure 7, aims at integrating parametric modeling, building performance evaluation and personalised selection within one interactive design computation procedure. Realtime data exchange between different software platforms is being developed at this moment to

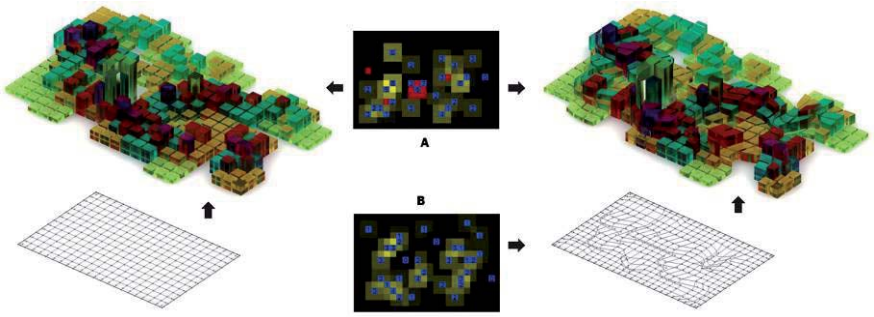

Figure 6. Urban development game.

update the originally iterative design-evaluation-selection workflow with a new progressive workflow that incorporates different design considerations all at the same time.

Figure 7. Surface population tool.

5. Conclusion

Quantum design paradigm, as discussed in this paper, provides novel concepts and methods for setting up an indeterministic and interactive design computation system. The switching mentality of creating design algorithm as design partner instead of design tool, naturally requires design algorithms to handle computation questions with multiple rational solutions. The selection of the 'best' solution in this case involves both the objective evaluation carried out by design algorithm and subjective evaluation derived from the sensibility of designer. Operate in a progressive manner, as discussed in the surface population tool sketch, these two types of evaluation are not separated as independent functions, but constantly negotiating with each other to balance different design impetus and promote the general evolution of design.

Although promising potentials can be clearly envisioned, the research on designer/design algorithm interaction and probability filed algorithm prototype also exposed a great need for the support from a branch of parallel research. Some of the expected research may come from the design cognitive point of view about how human designer adapts his/her design habit to the interactive design environment, some from the computer science point of view about how to make algorithm smarter to understand, remember and even predict the design preferences of different designers, some may also come from the interface design point of view about how to balance the level of representational complexity from both sides to facilitate efficient communication. All of these interdependent research trends could be very well concluded under the general research direction of interactive design computation, which

could be a new challenging and promising frontier for the current exploration of digital architecture.

Endnotes

1 As for this paper, interactive refers to a circled communication process that involves mutual understanding and unexpected stimulation, which should be carefully distinguished from the concept of reactive. A rigourous terminology for conversation, interaction, environment and participation can be found from Gordon Pask's conversation theory.

2 Oppose to causal reasoning which has been commonly deployed by computer programming, associational reasoning refers to the faculty of human mind to bridge one idea with another in consciousness, if they were associated by principles like similarity, contiguity and contrast.

3 Algorithm prototype refers to an abstract machine exhibiting particular computation structure and logic, e.g., cellular automata and genetic algorithm. It mainly concerns with typological computation principle and is open to further specific implementation.

4 Wave–particle duality is the concept that all matter and energy exhibits both wave-like and particle-like properties. A central concept of quantum mechanics, duality addresses the inadequacy of classical concepts like "particle" and "wave" in fully describing the behaviour of small-scale objects. http://en.wikipedia.org/wiki/Wave-particle_duality

5 As concrete prediction on designer's future decision is impossible, the conflict between current rational suggestion and certain possible future system states is inevitable. Instead of making the effort to model an over-simplified decision making strategy of designer, this research adopts the checking function to achieve maximum robustness and tolerance that are essential to human-machine interaction.

References

Heller, E. J.: 2004, Quantum resonances, <http://www.ericjhellergallery.com/index.pl?page=image;iid=84> (accessed 31 August 2009).

Ayssar, A: 2002, *Quantum city*, Architectural Press, Oxford.

Ford, K. W.: 2005, *The quantum world: quantum physics for everyone*, Harvard University Press, Cambridge, Mass.

Ruairi, G.: 2008, Conversational environments revisited, *Cybernetics and systems research 2008*, Graz, Austria.

Wikipedia: Algorithm, <http://en.wikipedia.org/wiki/Algorithm> (accessed 11 November 2009).

Kas, O.: 2007, *ONLogic*, Images Publishing, Mulgrave, Australia.

Haque, U.: 2007, Distinguishing concepts: lexicons of interactive art and architecture, *in* L. Bullivant (ed.), *Architectural design: 4dsocial: interactive design environments*, Wiley-Academy, London, England, **77**(4): 80–88.

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OPEN ARCHITECTURAL DESIGN

An approach to managing complexity and uncertainty in an open design process

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Abstract. By open exchange of ideas and artifacts and non apriori hierarchical processes, Open Strategies enable a better usage of distributed resources, and the release of more creative potential. Applying these Open Strategies to the architectural design process, is goal of our project. The technical basis for our research is FREAC, a software framework developed in-house which provides a collaboration space for co-operation between different users and tools. This framework is designed not just for exchanging the outcome of the design process but also for opening up the design process itself and making it more transparent. Such highly open and distributed design processes, however, also present new problems and uncertainties which need to be taken into account in order to reach successful design outcomes. As a result proposals for the management of such processes need to be developed that facilitate collaborative work but do not unnecessarily constrain the inherent complexity of the design process. The actor-network theory, and other different management concepts, provides a theoretical underpinning for our approach. The project is a collaboration between the fields of computer science in architecture and media management.

Keywords. Collaboration; open design process; actor-network theory; software framework.

1. Introduction

Contemporary architectural design and planning brings new challenges to the design process: internationalisation, digitisation, increased differentiation between disciplines as well as spatially and temporally distributed working methods. Effective coordination between different participants plays an important role in fulfilling the complex requirements of today's building constructions and to achieve high-quality results. Although the architectural design and planning process is now almost completely digital, computer-aided spatially distributed collaboration and the associated use of distributed expertise in the key phases of design have still be implemented successfully. While current developments in building information modelling are centred around the integrative aspects of a common model, they focus primarily on effective data exchange and maintain a strict division of roles. Although the exchange of data is being conducted at a faster rate than ever before, the working process is still dominated by a linear and sequential pattern. Mistakes made in such "a priori" hierarchically organised processes are hard to correct. In addition, rigid structures hinder the emergence of creative processes and innovation.

The potential of digital technology lies not only in the acceleration of already established working methods, but also enables them to be restructured entirely. A good example of how structures are changing across many fields is the emergence of open development methods, e.g. open source initiatives in computer science (Raymond, 2001) or collective intelligence or swarm intelligence in economics (Levy, 1997). These make it possible to access and exploit decentralised skills more effectively. "Open" thereby designates the free exchange of information, licenses, ideas, data and artefacts. How this exchange is designed varies from case to case. Initial approaches to applying such open strategies to the process of designing are evident, for example, in "Wikitecture" (Chase et al., 2008), the urban planning project "divercity" (Köngs et al., 2000) as well as in product design (www.theoscarproject.org). All these projects, however, lack suitable management strategy approaches for successfully facilitating a genuinely open process. Typical problems include issues of quality assurance and motivation, the enabling of coherent action, the mapping and storage of information and knowledge, and effective communication between designers.

Our goal is the development of techniques and methods to enable spatially distributed design processes based on such open strategies in the field

of architecture. A key challenge of the project is to avoid hindering the creative process of designing in digital environments, in other words to create "enabling spaces". At the same time, it addresses approaches to coordinating processes occurring within these "spaces" without constraining their inherent complexity. In the following we introduce a theoretical and technical foundation that provides insights into how and with what mechanisms such open design processes can be controlled.

2. FREAC as a framework for collaborative architectural design in digital networks

The practice of designing typically deals with non-operational problems. For the most part, actions in this process take place simultaneously at different levels of abstraction and scale. Architectural design is therefore not innately suited to a sequential chain of fixed stages but is instead characterised by simultaneity, plurality and the mutual production of interconnected information. Everyone involved informs the result by contributing ideas and skills (fig.1). To exploit such networked expertise as accessibly as possible, a space needs to be created on a technical level that facilitates the act of contributing. For several years we have been developing tools based on our in-house experimental programming platform FREAC (Framework for Enhancing Research in Architectural Design and Communication). This platform provides a flexible data structure for the integration and linking of digital tools. It allows an open exchange and transfer between different actors and provides a flexible technical framework for different research projects. The main aspects of this framework are as follows:

2.1. SEAMLESS COUPLING OF HETEROGENEOUS TOOLS

Almost all collaborative design projects face the problem of having to develop interfaces between different tools. As a result, many projects are limited to an asynchronous exchange of data over the net in the form of web platforms, etc. These "interruptions" reinforce a phase-oriented working method and thus interfere with the flow of the creative design process. To facilitate networking as an open process, it is vital that the barriers between tools are kept as low as possible. Rather than using one complicated universal program, it should be possible to create and use many small, easy-to-use tools that can be seamlessly interconnected and combined as required. The FREAC platform uses a TCP client–server principle to effect communication between these tools. When changes are made to the digital model all clients linked with the server are automatically informed and can synchronise their local models. The resulting

seamless coupling of different tools means that every tool can immediately "see" how other tools have affected the model and can build directly on the changes made. It also allows different tools, methods and technologies to be brought into direct relationship with one another, for example to seamlessly integrate freehand sketching (Schneider and Petzold, 2009). The resulting content is therefore always linked to each other in one or the other semantic form, creating networks of design tools and artefacts (see fig. 2).

2.2. CONNECTING USERS (SEAMLESSLY)

Communication within spatially distributed design processes is always mediated – by the digital tools as well as the content and artefacts created with them. These are stored on a server which all parties are able to access in real time using different tools. The seamless technical interlinking of digital tools and their users enables them to circulate freely and without barriers in the network. Modifications can occur both asynchronously and synchronously at any time creating a smooth transition between individual and group editing and facilitating the dynamic formation of networks (flexible group sizes) of human actors.

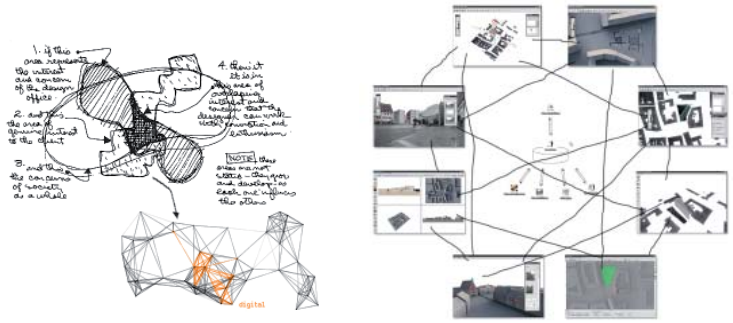

Figure 1 (left): Designing a network: digital tools as part of the design networks [sketch collage of Charles Eames (1969) and its own graphic]. Figure 2 (right): Via FREAC all (connected) tools are interlinked and form a complex network of heterogeneous data / content (video online at: http://vimeo.com/8591465).

2.3. STORING PROCESSES (AUTOMATIC)

The FREAC server can handle all kinds of data. Each item of data receives a reference detailing when it was created, with which client and by which user. Each reference can be called up, combined with others and interpreted selectively. To avoid unnecessary data load, the model only changes within the transactions, i.e. only the changes are saved, not the whole model. The aim is the emergence of an ordered structure that obviates the need to structure the data manually.

The technical framework is a basis for the creation and use of (design) tools and creates an open communication space for collaborative design projects. In the following, the theoretical foundation (from a management perspective) for capturing, analysing and evaluating designing in open networks is discussed.

3. The actor-network theory as a framework theory for an open architectural design model

The creation of technical networks is simultaneously the creation of social and organisational contexts and spaces of action. To coordinate complex processes in such technical and social networks (different tools, content, users), it is crucial to make visible the processes taking place. The actor-network theory (ANT) is used to describe these multiple interactions between the actors in their necessary complexity. Decisive here is the acceptance of complexity, as a complex open design network is able to respond more innovatively and flexibly to changes and gives rise to creative synergies. The actors play a key role in the ANT. They represent entities that freely interact within a network and behave in different ways. Their "capabilities lie in how they are able to affect other actors, how they change, transform or produce them" (Belliger and Krieger, 2006). A special aspect of the actors lies in the assumption that there is a coexistence or symmetry of human and non-human actors, who mutually ascribe one another action (Belliger and Krieger, 2006). As such, in the process of a specific "open architectural design-project" (e.g., an open competition), there are heterogeneous human and non-human actors that act differently within the network and influence one another mutually.

Besides the architect, expert planners and developers, one can also regard design tools, environmental conditions, laws, norms and institutions as contributing actors in the design process. While their differences are not denied, the construction of networks helps to uncover their differences and their available capacities and influence. Overall, the resulting design can no longer be seen as the work of a single actor, but as the product of input from all the actors contributing to the network, regardless of their importance or size. Although the network gradually stabilises over time, it can be understood as an open network: it is open to ongoing change produced by the participating actors, as well as any new actors that enter the process, and as such is in a state of permanent flux.

The relationships between these actors influence the entire design process and a permanent navigation, mediation and translation takes place between these heterogeneous components in the network (fig. 2). At a technical (digital) level it is therefore important that the different demands, ideas, restrictions, rules, designers and tools can be integrated in a suitable manner to guarantee

effective translation processes and foster the emergence of networks. A specific architectural design project which runs on FREAC as a digital platform can be seen as an actor-network. Thereby different people can contribute by making models, sketches, but also by sharing knowledge about architectural references or experiences with specific situations. But also tools (which are developed in different research projects based on FREAC) contribute by calculating or simulating different aspects, or by searching relevant content from internet databases (such as Panoramio, GoogleMaps, nextroom.at, etc.). Such tools in turn can influence decisions of human actors and trigger communication processes.

4. Accepting and managing uncertainty and complexity in an open design process

Open development methods, such as those suggested here for the creative design process make it possible to effectively use and process decentralised skills and competencies. At the same time, however, it is more difficult and challenging to keep it under control. Together with the emerging complexity, different sources of uncertainties appear. They evoke questions for effective coordination. Bruno Latour addresses in conjunction with the actor-network theory five sources of uncertainty in order to highlight the discrepancies between the sociology of the social and the sociology of associations (Latour, 2007). Below, four of these sources are used to address the most important uncertainties, which have to be considered in an open design process in more detail. The first uncertainty insists in “the nature of groups.” He describes the fact that in a network there is an ongoing relocation of actors who leave their traces, which can be analyzed (Latour, 2007). According to that a network is not preexisting, but always has to be assembled anew as an association. At this point, the design process manifests itself as an open network in which many actors and with it many ideas and skills can flow in. It is a fluid and permanent evolving network, which has no stable structure. The second source of uncertainty is concerned with the nature of actions and includes that human activity is not transparent, but a conglomeration of many surprising sources which have to be revealed to finally make statements about who is acting (Latour, 2007). Accordingly, one never knows who is actually acting. If individual actions in the design process are difficult to identify, it is also difficult to coordinate and motivate these actors. The third source of uncertainty – the nature of objects – describes that different threads of action mix together arbitrarily, therefore they often not purely consist of human-to-human or object-to-object relations (Latour, 2007). Without objects / artefacts architectural design processes would be unthinkable. Digital tools have an impact on the perception

and the actions of the designers and the entire design process, so that they should be taken into account for the purpose of an effective management. The fourth source of uncertainty – the nature of the facts – Latour stresses that an object of study should always be understood as a controversial and not as an indisputable fact. In architectural design processes, we are always dealing with unfinished, incomplete and vague constructions of reality. Thus there is a permanent need for interpretation, which in turn depends on the experience and knowledge of the actors involved.

The identified uncertainties, which occur in the proposed open design process, raise up questions about the coordination or management of the heterogeneous elements of a network. Unlike in traditional approaches including principal-agent theory or the hierarchical management process of planning, organisation and control, it is not enough to search moments of indeterminacy in only one other subject or in a linear and hierarchial process (Schreyögg, 2003). So how can one coordinate processes that take place in constantly evolving networks in which it is hard to draw conclusions about who is actually acting, where the influence of non-actors must be considered and artifacts are negotiated, which are interpreted individually by all the actors?

5. Coordinating open design networks

In our project FREAC, as the digital platform provides the space for an open design process. Based on the identified uncertainties in the following possible solutions are outlined how these can be coordinated in a virtual design environment.

5.1. GROUP DYNAMICS

In open design network is characterised by instability and constant change. The coherency of actions and the consistency of the results therefore appear vague because, unlike previous approaches, they do not take place within a fixed structure. The ongoing changes to networks with no predetermined structure are triggered by the free, creative and networked actions of different actors. Human and non-human actors contribute to each other, initiating translation and network-formation processes, changing them, expanding or limiting them. FREAC allows recording these different stages of development in a process-oriented way. With the collected information, including the intermediate steps and links that were necessary for their creation, navigation techniques can be developed that make permanent changes understandable and thus “coordinateable”. Actors can not and must not understand all the complex processes of change and integrate them into their local activities.

They select only the relevant change processes and accordingly adapt them for their actions. Their changes are automatically stored and in turn available for other actors and their adjustment processes.

5.2. TRANSCRIPTION OF ACTIONS

The scope for actors in an open design network is much larger than in a linear design process. However, assigning actions to actors is more difficult and may lead to motivation as well as quality problems. A decreased level of direct external regulation must therefore be compensated for by increased self-control. In addition to a policy of seeing and being seen, the digital tools in FREAC can be used for storing and reading evaluations and feedback. Beyond that, monitoring occurs not only directly but also, and more importantly, indirectly through networked action. As anyone is able to partner with another actor, actors need to react flexibly to one another, continually adjusting their actions and their designs to each other. Monitoring, control and by implication also feedback is therefore already an aspect of the open design process itself. Each actor stands in the centre of observation and is himself an observer of all the others involved. Observation is not limited solely to other human actors, but can also be undertaken by digital evaluation and simulation tools. Feedback from other actors allows the actor to adapt flexibly to the expectations of their environment. As in an open and complex network one is not able to immediately identify who does what at a particular moment in time, open design networks can potentially be seen as a permanent space and stimulus for self-reflection (Bröckling, 2007). Through the seamless linkage of actors and the permanent and automatic saving of changes in the design process, a technical basis is created for such self-reflection and self-optimisation processes. The seamless coupling of actors establishes a 360-degree field of vision, which makes it possible for actors to continuously monitor, evaluate and compare. By recording changes in the design process, it is possible to trace actions to a specific tool, user, point in time and their relations.

5.3. THE ROLE OF THE OBJECTS

Digital tools and other non-human actors such as norms and laws have a significant impact on the overall process, as well as on human action and human perception. Here we need to consider the affect of individual tools and the impact of their limited functionality and action-space in the design process. The use of a tool of any kind sets up a temporary ‘world,’ which is limited or defined by the scope of the respective tool (its functionality) and its compatibility with other ‘worlds’ (which in turn are the product of other tools). For

example, while using a volumetric modelling tool, one can design volumetric models and is therefore restricted to this view. Since the process of designing occurs in parallel at many levels of abstraction and scale, one needs to be able to switch between tools and the functionality they provide according to the respective situation. In the case of digital tools, a crucial aspect is therefore the ease with which one can switch – the smoothness of transition – from one tool to the next. In FREAC heterogeneous tools (sketches, models, drawings, simulations) coexist within the same design space and one is not so tightly focused on one tool (and its scope), but can move freely between different 'worlds'. The tools do, however, leave recognisable traces which can therefore be tracked and analysed.

5.4. OPEN PROCESSES AS A PERMANENT CONSTRUCTION

When designing, constructs are constantly being negotiated and exchanged which need interpretation. In digital design processes greater importance is therefore accorded to the transparency and stability of knowledge and information resources than in linear hierarchical design processes. Human actors must accordingly possess the competence to interpret the structures and develop this ability constantly. In addition, they must be able to work and learn independently without direct instruction. Non-human actors, such as digital artefacts should serve as so-called "boundary-objects", which can constitute and maintain a connection between the different worlds of knowledge (Rossler, 2008). For this, they need to convey a sufficient degree of common shared meanings. Such objects need to be plastic enough to be adaptable to the local needs of different groups while remaining robust enough to retain a common identity across different situations. In this respect, we are concerned with the descriptive mapping, storage, transfer and use of knowledge and information. However, it is difficult to coordinate a network of completely heterogeneous components, since the interpretation of the different content itself is problematic. This is due not least to the fact that their construction and interpretation depends on the specific knowledge of the respective individuals and is as a consequence highly subjective. Likewise, in many cases different tools are not directly comparable, and even artefacts created with the same tools can transport entirely different meanings, intentions, etc. Of course, ambiguity of meaning on the one hand and the specificity of the individual actors on the other can represent a creative potential that does not necessarily need conclusive clarification. In the technical implementation, it is therefore necessary to establish connections – boundary objects – between different virtual artefacts. These different pieces of information or artefacts must have some kind of semantic relationship to one another (e.g., a sketch belongs to a model from

a particular viewpoint, authored by XYZ). Using this information, navigation structures can be derived which enable one to represent contextual links. Thus it becomes possible to browse between different states of artefacts, to derive and record intentions and so on.

6. Conclusion / outlook

The paper introduces Open Architectural Design as an experimental approach to collaborative design, and reflects it from a media-managment perspective. At the outset we discussed the concept of "open" as denoting the free exchange of ideas and artefacts, much in the same way that open source projects make their source data freely accessible. Using the technical framework FREAC presented in this paper, we extend this definition to open up the design process itself. In this way, it is possible to facilitate the networking of actions by many different actors. However, even complex systems require efficient coordination mechanisms to keep the network under control, without – and this is the biggest challenge – limiting its degree of openness. The extent to which creative processes can actually be opened up, and whether this has added value for the quality of the results needs to be explored further. This paper has discussed a theoretical framework to assist in the conception of digital tools. In future work we will create communication and coordination prototypes using FREAC, in order to extend "action spaces" and manage them sensibly. Additional problems and issues relating to the management of these action-spaces can then be evaluated empirically.

References

Belliger, A. and Krieger, D. J.: 2006, *ANThology. Ein einführendes Handbuch zur Akteur-Netzwerk-Theorie*, Transcript, Bielefeld.

Bröckling, U.: 2007, *Das unternehmerische Selbst. Soziologie einer Subjektivierungsform.* Frankfurt am Main.

Chase, S. Schultz, R. and Brouchoud, J.: 2008, Gather round the wiki-tree, *Architecture in computro: proceedings of 26th eCAADe conference*, Antwerpen, 809–816.

Königs, U. Heineman, I. C., and Schmidt, C.: 2000, *in* I. F. G. Ulm (ed.), *Strategischer Raum-Urbanität im 21. Jahrhundert*, Frankfurt am Main, 1–18.

Latour, B.: 2007, *Eine neue Soziologie für eine neue Gesellschaft: Einführung in die Akteur-Netzwerk-Theorie*, Suhrkamp, Frankfurt am Main.

Lévy, P.: 1997, *Die kollektive Intelligenz: Eine Anthropologie des Cyberspace.* Mannheim.

Malik, F.: 1994, *Management-Perspektiven: Wirtschaft und Gesellschaft, Strategie, Management und Ausbildung*, Paul Haupt, Bern.

Raymond, E. S.: 2001, *The cathedral and the bazaar: musings on Linux and Open Source by an accidental revolutionary*, O'Reilly.

Roßler G.:2008, Kleine Galerie neuer Dingbegriffe: Hybriden, Quasi-Objekte, Grenzobjekte, epistemische Dinge, *in* G. Kneer, M. Schroer, and E. Schüttpelz (eds.), Bruno Latours Kollektive, Frankfurt am Main, 76–107.

Perry, C. and Hight, C.: 2006, Collective intelligence in design, *AD architectural design*, **76**(4), John Wiley & Sons, Columbia.

Schneider, S. and Petzold, F.: 2009, Digital and analog: seamlessly integrating freehand designing in a virtual design environment, *Proceedings of 9th EAEA*, forthcoming, Cottbus.

Schreyögg, G.: 2003, Prinzipal-Agenten-Beziehungen in Organisationen, G. Schryögg, *Organisation*, 4th ed., Wiesbaden.

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