

## **Section I: Digital Design Education**

## “NOT EVERY NEW MONDAY...”

*On using computer-games technology in architectural design education*

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**Abstract.** The application of new media is common practice in architectural offices and complements traditional forms of presentation such as drawings and physical ‘haptic’ models. Other interactive forms of presentation are also already available, for example in the realm of computer gaming, however the transfer and application of game engines to an architectural environment has not yet been explored in any depth. This paper looks at how “new media” can be used as a means of communicating architectonic information without simply emulating an already available traditional means of representation. We discuss the process of learning how “new media” (the computer as a multi media) can be used as a tool for the analysis and reconstruction of architecture. Using Mies van der Rohe’s unrealised project for a brick country house as a basis, a project was devised which communicates valuable design and analysis skills and also allowed us to explore the use of “new media” and to draw conclusions for teaching and research as well as to critically assess the opportunities, limitations and risks involved.

### 1. The Term “New Media”

“New Media” is a catchword that features heavily in numerous publications and programmes. However, what is actually meant by “new media” is not precisely defined, whether in general terms or in the field of architecture; a consistent use or understanding of the term has not been established. While some authors assume that New Media evolved from pre-existing modes of representation, others speak of their genuine novelty (see Luhmann, 1995; Klimsa, 1993).

In the context of this paper we use the term “New Media” to describe (somewhat simplified) the ‘comprehensive computer’, i.e. “a computer that

can serve as a radio, television and video console, that contains a number of media drives, and is connected to the internet” (Seel, 1998). A new media apparatus is a so-called “convergent instrument” that can be used for a number of purposes, e.g. to draw plans, to operate machinery, and also to play games. By new media we mean media, which are technically based on digitalisation, miniaturisation, data compression, network interconnectivity and convergence. For all media, new or old, one can differentiate between perceptive, action-oriented or representational media: language or drawings are, for example, representational media. The “comprehensive computer” is a multi-media device that integrates various media and can therefore bring forth new modes of representation.

## **2. New Media in Architecture**

Architects consume and communicate to a large extent visually through the use of imagery. Using the various tools of traditional media a highly aesthetic and refined culture of (re)presentation has already been developed (Figure 1). Imagery serves as a “bearer of information”, whether in the design process or in ongoing discourse on the history of architecture. Traditionally, a combination of material media such as sketches, descriptive texts, perspective drawings and physical models have been employed (Allen, 1981). By comparison, the use of “new tools” offered by new media, and the specific possibilities made possible by information and communication technologies, breaks new ground.

In the history of architecture, changes in the mode of representation have transformed the ways of communication and analysis. The introduction of perspective and photography are two significant examples. Even today the computer often just copies or adapts “traditional material media”. New modes of expression or representation are explored but used rather reluctantly.



Figure 1. Mies van der Rohe sketching...

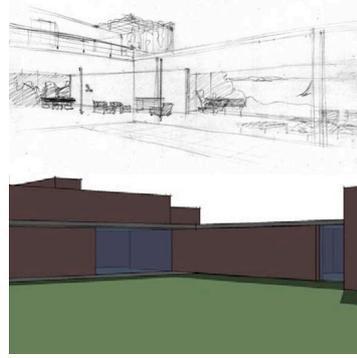


Figure 2. New media in the work process

The choice of a medium and the concomitant acceptance of its limitations to our perception are of fundamental importance. Architecture is more than three-dimensional material space: Likewise, it is also more than just a visual experience, although this is too often forgotten. Most representations of architecture, however, exclude other sensory experiences or create a sensory quality that is specific to the respective medium. As a multi-media device, the computer could help close a gap and bring about new possibilities for presenting and representing architectural ideas. For instance, in interactive systems, spatial relations can be experienced differently: users can immerse themselves in a new perceptive reality by “moving freely” around a virtual model. The use of new media is not just limited to representational purposes; it can also open up new opportunities for analytical investigation. The full range of possibilities in architecture is not yet fully explored.

### 3. New Media in Architectural Education

New Media can inspire and enhance new ways of teaching architecture. In this case we focus on new media as a tool in the work process of an architect (Figure 2). CAD, rendering and animation are already well established tools of modern architectural practice. In most cases, however, they are used as a “digital drawing board” or as “pure” presentation tools. Architectural education should help architects to critically assess and explore the possibilities offered by digital tools over and above ‘digital versions’ of traditional tools – as well as to avoid falling for the many promises made. A sound knowledge of contemporary media applications will serve architecture students in their professional career and they will be able to use them more sensibly and more purposefully.

In order to maintain a competitively high level of education for future architects, it is necessary to engage new media actively and in its specific

contexts. Architecture faculties are facing a series of questions, which should be considered and discussed in design-oriented courses, such as:

- What are the media applications that architecture students should be proficient in at the start of the third millennium – and why?
- How do they differ from previously and currently used media?
- What do they offer in comparison to “traditional” media?
- How can new media be integrated into the design process?
- What do the demands of the media age mean for the profession of architecture?
- How can new media and their tools be taught when the sector is developing so rapidly?

For architectural education this means that the focus should not only be on learning how to use “new media”, but also to critically assess the possibilities offered by applications, to explore new forms of (re)presentation and to define the requirements an architect should expect of such systems. The architect should not need to adapt his or her working method to the program system; the computer or application should be a tool for representing and working with in an architectural context.

#### 4. The Brick Country House

The two drawings of a country house in brick (Figures 3 & 4) date from 1924 and are probably a design for Mies van der Rohe’s own house. The architect followed the idea of a bourgeois residence but formulated it in a radically new way. This project is the last in a series of five projects between 1921 and 1924 including the designs for the skyscraper on the Friedrichstrasse, the glass skyscraper, the concrete office building and the country house in concrete. In retrospect these designs are regarded as a manifesto documenting Mies’ experiments with new materials and construction typologies (Riley, 2001).

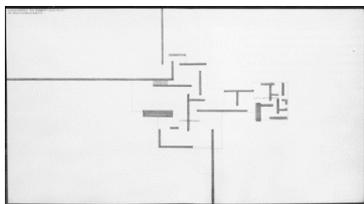


Figure 3. Brick Country House, plan

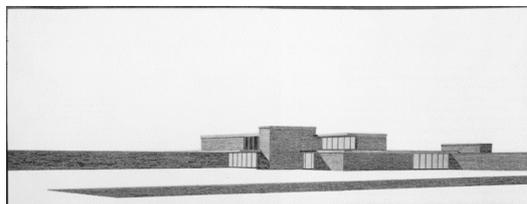


Figure 4. Brick Country House, perspective view

This unbuilt design is generally attributed as being of outstanding importance in Mies van der Rohe's oeuvre: it formulates the open plan and the concept of free-flowing space in a prototypical manner. However, critical acclaim seldom extends beyond this commonplace statement; the brick country house is often characterised as singular and unprecedented. But it is safe to assume that Mies referred to spatial ideas from earlier projects. This hypothesis can be tested through our proposed procedure. The students working on our experimental project chose instead to focus on situations of the brick house that were transferred to subsequent designs and developed further in later projects. They tracked down, as it were, the brick country house in individual elements of later realised projects. To trace developing and changing spatial ideas through design and realisation helps us to explore and understand the design concepts employed by Mies van der Rohe.

Mies' sketches and drawings exhibit a distinctly visual, almost photographic idea of the spaces he envisioned. An analysis shows that he often refers to spatial situations he had created earlier in another design – as he said, one cannot invent a new architecture every Monday...

#### 4.1. ATTEMPTING A PARTIAL RECONSTRUCTION AS A VIRTUAL MODEL

Part of the assignment was to visualise the spatial relations as laid out in Mies' evocative plan. We attempted, as far as possible, to transfer Mies van der Rohe's design for a brick country house to a virtual, digital model. Based on available sources (plans, sketches, photographs) as well as the computer model the students tried to reconstruct key situations in the interior representing the main spatial ideas. The computer-generated model complements the modes of representation employed by Mies van der Rohe and enables us to compare spatial situations.

The photographic reproduction of the lost 1923 drawing could hardly serve as a basis for a precise reconstruction; the 1964/65 re-drawn plan showing brick courses raises even more questions. Therefore, the result of a digital reconstruction can only be one of a series of possible interpretations of the original plan (Figure 5). However a "realisation" of his design was not the intention of the project. Instead the project aimed to explore to what extent spatial concepts could be better understood with the help of a virtual model, as well as to see if one could 'complete', i.e. interpret the rest from Mies' sketches through the knowledge the students had gained of his other projects and his ideals and vision.

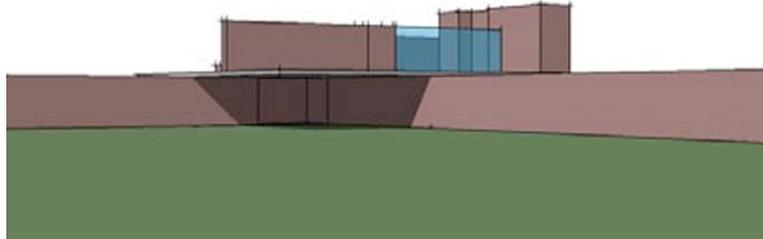
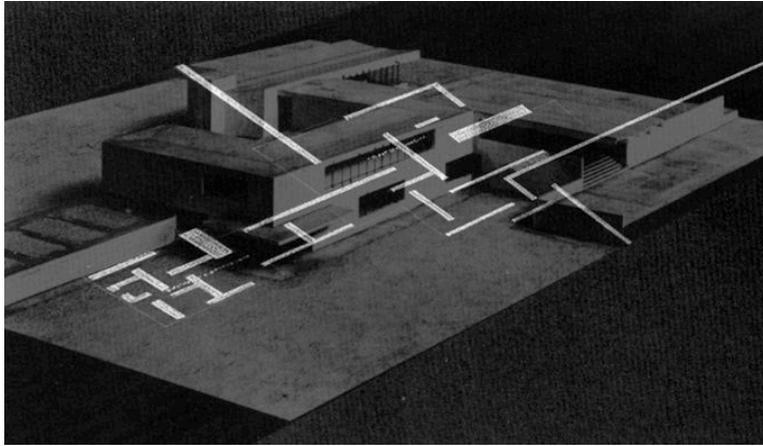


Figure 5. Sketch approximating the reconstruction of the original design

#### 4.2. FROM REPRESENTATION TO ANALYSIS

The use of the computer not just for presentation purposes but also as a tool for analysis was central to our project. We encouraged the students to study the unrealised design and the underlying spatial concept as well as to investigate the possibilities computers may offer for analysis and interpretive reconstruction; the new technologies were to be compared with the traditional repertoire of presentations techniques and judged critically with regard to advantages and disadvantages, the effort involved and added value they offered.

The digitising of available images and modelling in a virtual model provided us with a new fundamentally different representation of the design, and a new starting point for further interpretation. The versatile computer, the same platform which generated the model, could now be used for its interpretation. New possibilities for analysis and interpretation became apparent: a digital image contains information that can be processed in different ways by the computer. It enables us to excerpt particular aspects, to uncover relationships, to discover connections and to compare (Figure 6).



*Figure 6. From rendering to analysis – dynamic superposition of model and plan*

#### 4.3. METHODOLOGY

A reconstruction is a process of successive steps, no matter which media are employed. The aim in this course was a digital reconstruction including a computer-assisted analysis along with an interactive presentation of the results from the preceding stage.

The work process was divided into four distinct stages. These helped to structure the work progress and to schedule additional input: studio work was complemented by lectures on model theory, interactive systems, navigation, and user guidance.

The students were expected to be able to address analytical problems methodically, and have a sound proficiency in the use of traditional tools for architectural representation. The new digital tools were introduced parallel to the initial phase of research and analysis with the aim of comparing working methods with available IT-tools. The emphasis lay not on how to use any particular software application but to assess the suitability and capability of available tools with regard to the task at hand and working method. The series presented here should not be understood as purely sequential; parts of the process often fed back into other phases (Tulodziecki and Herzig, 2004).

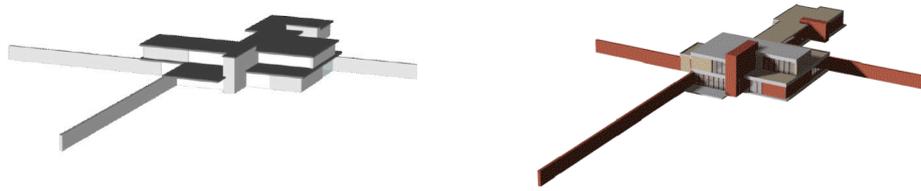


Figure 7. Different digital models

#### 4.3.1. Basic Digital Model

The students were given available material in the form of a plan drawn by Werner Blaser in 1965 and a critique of this plan by Wolf Tegethoff from 1981, from which to generate a basic digital model of the ground floor (Figure 7). Perspective views generated from this model were overlaid with Mies' historic perspective and the digital model was adapted accordingly to match the historic perspective, e.g. the adjustment of room height, and the modelling of the upper storey and the outdoor terrain (Figure 8). Lectures and exercises on CAD and modelling systems accompanied this phase.

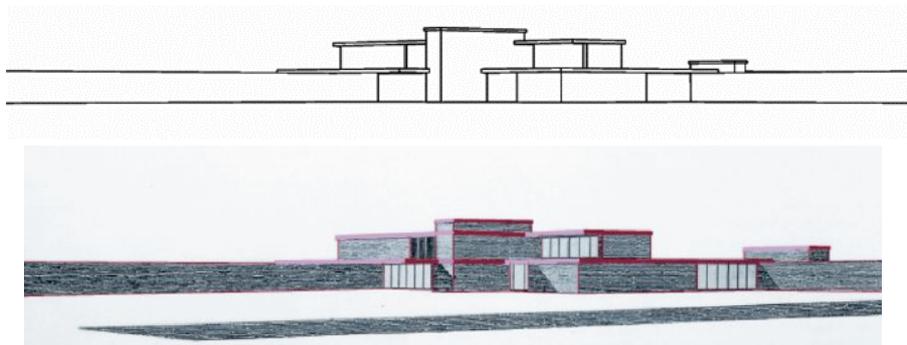


Figure 8. Juxtaposition of digital model and original perspective  
(with additions in red to help determine room heights)

#### 4.3.2. Research

A second phase involved the research and analysis of historic photographs, sketches and drawings of potential reference buildings (Riehl House, Urbig House, Wolf House, Houses Lange and Esters, Barcelona Pavilion and Tugendhat House). Previous reconstructions and analyses were also taken into account. The aim was to improve the students' background knowledge of the work (and motivation) of Mies van der Rohe and to train their

analytical skills in identifying architectonic aspects which could be useful in a comparative analysis.

In this phase the internet served as a source of information. We provided an introduction to image editing techniques as well as OCR software and digitalisation methods for preparing the results of the researched information.

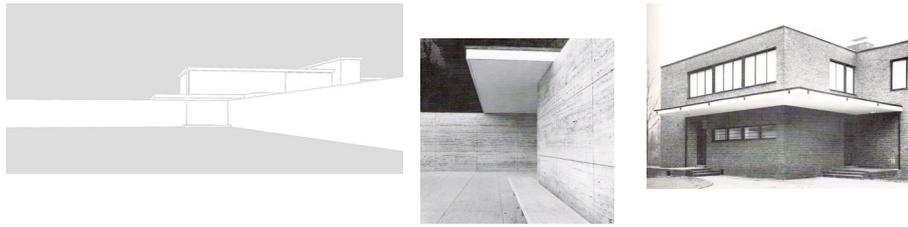


Figure 9. A comparison of entrance situations designed by Mies van der Rohe (left: the reconstructed brick house, centre: Barcelona Pavilion, right: Esters House)

#### 4.3.3. Computer-assisted Analysis

In this phase the students were asked to generate interior perspectives and to overlay or juxtapose them with (edited) historic photographs (Figure 9). Assumptions or postulations made were to be documented and discussed critically.

The phase also introduced students to aspects of image editing and the problem of information visualisation, particularly the question of how to represent vague and inferred information.

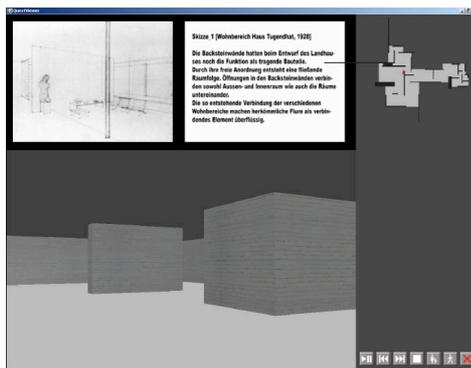


Figure 10. Interactive presentation with Quest3D

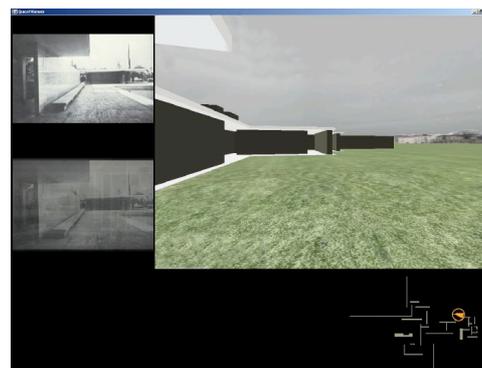


Figure 11. From storyboard to structured programming

#### 4.3.4. *Interactive Presentation*

The final phase involved the preparation and presentation of the results of the analytical work in such a way that both process as well as final result could be clearly communicated (Figure 10).

Techniques borrowed from programming computer games were used to enable one to move around the virtual models. The visualisation and interactions made possible are incredibly varied and limited only by the imagination. They range from the purely visual (3D environments, interactive generation of architectural sections, overlaying with sketches etc.) and the audio-visual (integration of video sequences) to interactive feedback (simulated haptic feedback) where the limits of tangible space are intentionally transgressed.

The phase began with the introduction to a game engine – in this case Quest 3D. In a series of four tutorials the students introduced each other to the basic concepts and programming steps and explored the possibilities of the game engine.

The next step was to write a storyboard, i.e. to develop a strategic concept for the entire presentation (Figure 11). Additional attention was given to questions of interaction, navigation and user interface design. Specific questions could be discussed on the online Quest3D forum.

## 5. Results and Discoveries

The results proved to be as multifaceted as the assignment and the skills required, not only for the students but also for us as teaching staff and for our research interests:

### 5.1. FOR THE STUDENTS

The course helped the students learn to think strategically and how to structure and orient their work process towards the intended result. An added effect of the somewhat demanding learning process has shown them first-hand that there is more involved behind the enticing appeal of new media. They gained an insight and understanding of the structures and principles of CAD and modelling, and hopefully a healthy scepticism of the alluring “everything is possible, now and immediately...” promise of information technology.

In addition to IT-skills, the students also gained a better understanding of architectonic relationships and spatial concepts, which will help them in their future design work. Some of the students developed quite remarkable skills in identifying and reading spatial situations and were able to quickly transfer a found spatial idea to another project and a different context.

During our final presentation one student said that he could not only draw the plan from memory but also sketch views and vistas from within the plan. The experimentation and analysis of different media and modes of representation offered during the assignment helped him to improve his ability to link plan and perspective with one another and to develop a complex understanding of varying spatial situations. By the end of the course they had established an intimate relationship with the brick house and were able to intuitively navigate through the virtual country house, to point out and to explain reference situations.

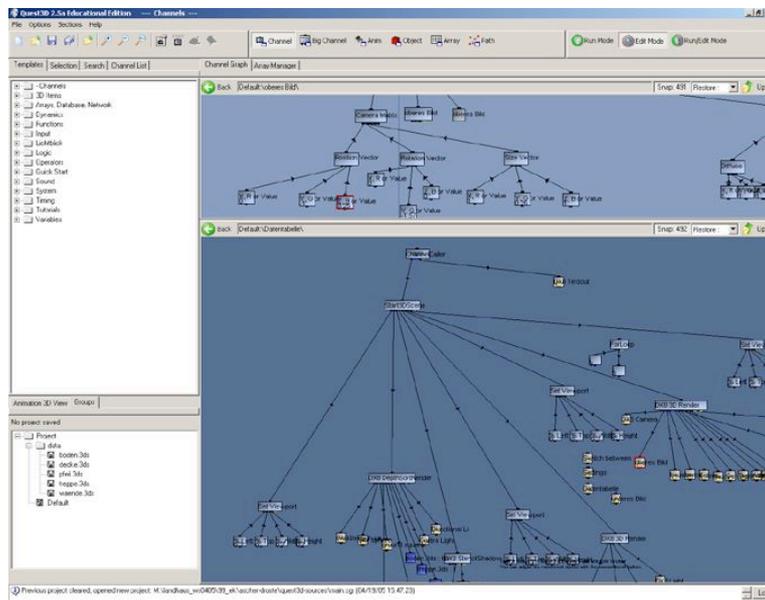


Figure 12. Quest3D main user interface

## 5.2. FOR THE TEACHING STAFF

With this assignment we were able to school design skills in a way that we may not have achieved through a traditional design project. We were also able to better address those students with less sensibility and awareness of design and conceptual issues. To a certain degree, these students are also those who are particularly enthusiastic about technology and therefore least critical in their approach to using them.

The project also demonstrated that the same skills as those required for design projects are also necessary for working with new media: conceptual clarity and a determination to subject oneself to the weary process of relating results to initial intentions over and over again.

We also became aware that many students were overwhelmed by the wide range of possibilities (particularly with regard to Quest3D) and the

process of learning simultaneously. As a result, not all possibilities were understood and used productively or appropriately. Here too Mies’ dictum of “less is more” proved to be a valuable lesson.

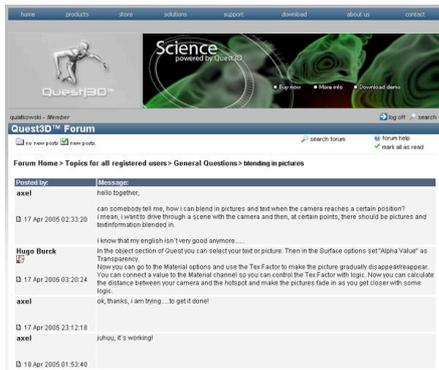


Figure 13. Quest3D Forum – individual web-based learning

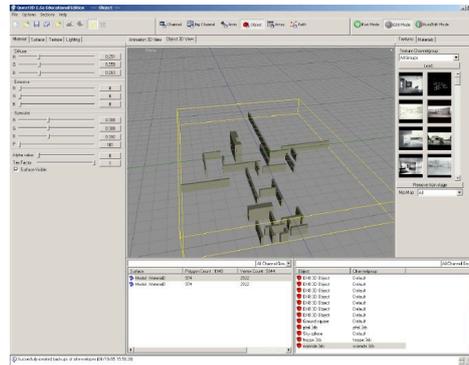


Figure 14. Complex menu in Quest3D

### 5.3. IMPLICATIONS FOR RESEARCH

The project is a further example of the versatility and potential offered by new media for architecture. It also shows that many of the tools are extremely complex and the sheer variety of possibilities is distracting or proves to be unmanageable for those less skilled in using information technology (Figures 13 & 14). Future research must focus on ways of simplifying the available software and to adapt it to the needs of architects.

New media, especially interactive systems, can also offer valuable tools for analysis, for which there is no real equivalent in conventional practice; they add a further dimension in communicating architectural concepts to the professional community as well as to a wider public.

In addition to technical aspects, research will also need to more closely examine the question of representation (abstraction versus photorealism), the visualisation of information (e.g. non-visible, non-geometric information and ‘approximations’) as well as the user interface in order to make full use of the potential offered by such technologies for architectural design.

## 6. Outlook – Opportunities, Limitations and Risks

Rapid technological developments enhance the possibilities of architectural representation. Today one can achieve more than merely static visuals or predetermined camera flights; the combination of common techniques of

reconstruction can result in completely new modes of presentation. Over and above the obvious possibilities of showing variations, creating atmospheres or animated scenes, it is also possible to illustrate relationships or sequences in time. Interdependencies and correlations can be revealed to the observer that would not otherwise be immediately apparent. This applies not only to architectural education or professional discourse but also to the public discussion on architecture and the built environment.

The wide range of options offered by the variety of different media is almost innumerable and consequently difficult to comprehend. Each of the different media available has certain advantages and disadvantages, and these are best assessed with reference to the needs of the specific project. This brings with it the need to focus, a restriction and concentration of the possibilities, i.e. to do not what is possible, but what is necessary.

We aim to continue the project described here, but to devise more directed assignments, with less room for diversion, and with a better knowledge of the tools at our disposal.

To complement the currently used hardware, we are also looking to explore the use of other technologies such as auto-stereoscopic displays and ARcave installations (ARcave is a research project at the Bauhaus-University Weimar, with the aim of creating immersive cave-like environments with the help of AR projection techniques on surrounding surfaces, Bimber, 2005). The aim is to assess the possibilities offered by “real” 3D modes of output and to compare these with the “normal” 2D output of the computer screen.

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## **THE SIGNIFICANT ROLE OF AN ELECTRONIC GALLERY TO THE EDUCATION EXPERIENCE AND LEARNING ENVIRONMENT**

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**Abstract.** Multimedia has brought new paradigms to education where users are able to use the technology to create compelling content that truly represents a new archetype in media experience. According to Burger (1995), the synergy of digital media is becoming a way of life where new paradigms for interactive audio-visual experiences of all communicative arts to date are mandatory. It potentially mixes technology and disciplines of architecture and art. Students can learn on their own pace and they can be tested in a non-linear way while interactivity allows the curious to easily explore related topics and concepts. Fundamental assumptions, theories and practices of conventional design paradigm are constantly being challenged by digital technology and this is the current scenario in architecture and art and design schools globally. Thus schools are enhancing the methods and improvising the technology of imparting knowledge to be in consistent with recent findings and knowledge. To be able to cater the use of digital media and information technology on architectural and art design education, four criteria are required, which are; the SPACE and place to accommodate the educational activities, the TOOLS that assist imparting of knowledge, the CONTENT of syllabus and information and the acceptance and culture of the receiving end users and HUMAN PERCEPTION. There is a need for the research of realization and activating the architectural space that has been equipped with multimedia tools and upgraded with recent technology to facilitate and support the community of learners and users. Spaces are now more interactive, multi functional, flexible and intelligent to suit the trend of computing in normal everyday life of the education sector, business and management, art and leisure, corporate and technological area. While the new concept of computing in education is still in the earlier phase, the conventional analogue paradigm still dominates the architectural design discourse which acts as a barrier to the development of digital designs and architectural

education. A suitable approach is in need to bridge the gap between what theory has been explored and the practice of knowledge. A digital support environment with intelligent design and planning tools is envisioned to bridge the gap and to cater for the current scenario.

## **1. Introduction**

It is with the issue of a paradigm shift in education that suggests research on a new approach and methodology to present the existing content of knowledge. This exploration intends to make a study of the Electronic Gallery or e-Gallery of Faculty of Creative Multimedia, Multimedia University on how the gallery as a versatile hybrid container can act as a digital support environment for the art and architectural design course. The main objective is to seek whether the envisioned gallery as an intelligent space is able to cater for an educative environment exclusive for the benefits of the students and staff of the design faculty. The gallery is chosen as it is seen to have a great potential for a multiuse of space and function for various activities and for the credibility of being able to attract visitors with its basic function of public collective space. Students need a space that is well equipped for their educational activities apart from their classroom teaching. To what extent, what kind of digitally supported space and to what level of interactivity and flexibility of the space required by the learners would be the ultimate research objective.

Are university galleries capable of holding opportunities for end users of education and are they being fully explored to serve multiple functions? Do they become a place of necessity or communal node to the design faculty? Does it have the potential to provide content and display such as interactivity, installation, navigation, games and audio and visual that can interest students and staff to make it a learning hub that is easily accessible. Can users use it as a platform and vehicle in acquiring knowledge and to hold various functions such as demonstrations, exhibitions, performances, discussions, classes, critique sessions, installations, archiving and others where they can benefit from a change of classroom teaching.

According to Lawson (2001) space is needed for a change of mood, to establish relationship, to separate activities, to suggest appropriate behavior and creates settings.

## **2. e-Gallery**

A museum is a non-profit making, permanent institution in the service of society and of its development, and open to the public, which acquires, conserves, researches, communicates and exhibits for purpose of study,

education and enjoyment. Material evidence of man and his environment. (International Council of Museums (ICOM) 1974)

Galleries, museums and collective nodes are highly suitable for the exploration of space as defined by <http://dictionary.reference.com>, the meaning of space is an extent or expanse of a surface or three-dimensional area and an area provided for a particular purpose.

### 3. Objectives of e-Gallery

- i. To promote a new media as a medium for creative expression.
- ii. To enhance the teaching and learning environment.
- iii. To set up a new media showcase and R&D unit .
- iv. To showcase the best of student's works of the Faculty of Creative Multimedia.
- v. To act as a digital support environment for the art and architectural design course.
- vi. As an intelligent space is able to cater for an educative environment exclusive for the benefits of the students and staff of the design faculty.
- vii. As a great potential for a multiuse of space and function for various activities and for the credibility of being able to attract visitors with its basic function of public collective space.
- viii. As a communal node to the design faculty where digital archiving and art projects databases area centered.
- ix. To provide content and display such as interactivity, installation, navigation, games and audio and visual that can interest students and staff to make it a learning hub that is easily accessible.
- x. As a platform and vehicle in acquiring knowledge and to hold various functions such as demonstrations, exhibitions, performances, discussions, classes, critique sessions, installations, archiving and others. (<http://www.mmu.edu.my/~mmcampus/web/home.html>: Jan 2002).

Also included are seasonal showcase of a group or one-man show and workshops, demonstrations, presentations and drawing sessions. Basically it

is used for almost any event due to its flexible quality. Figure 1 shows the plan of e-gallery and Figure 2 shows the interior view of e-gallery from the entrance as presented in Sarji, Hussain & Eshaq (2002).

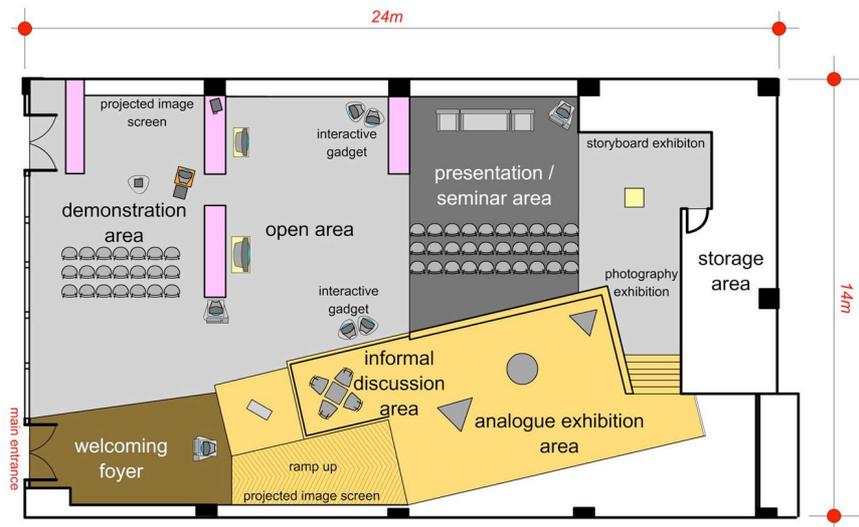


Figure 1. Plan of e-Gallery



Figure 2. Interior view of e-Gallery from the entrance

#### 4. Five Study Areas

The five main areas of concern are the General Factors, Space and Utilization, Content of Gallery, Multimedia Tools Usage and Human Interaction.

General Factors' issues cover aspects on general gallery organization such as accessibility, opening hours, peak periods, types of visitors and

reason of visits, external service to other branches and links to other educational, cultural or social institutions, staff structure which includes the director and management team: keeper, curator, chief administrator, museum specialists, commercial staff, technical staff, administrative, security and ancillary staff. While works and maintenance area include Building Maintenance of fabric/structure, lighting and plumbing, Environmental Equipment and Controls such as heating, humidity, air pollution and security systems, and Gallery and Exhibit Maintenance of the décor, display, graphics, audio-visual, information technology and mechanics. (Matthews 1991)

Gallery Space and Utilization according to Matthews (1991), are spaces that should adhere to different functions such as for collection, public spaces, administrative areas and ancillary space. For each of the space we need to analyse the nature of activity, relationship to other spaces/functions, types, size and number of collection items to be exhibited and stored away, number of users and staffs to be accommodated, special requirements such as surveillance and information technology, equipment, furniture and fittings, environmental services and controls such as lighting, heating, humidity, air pollution and acoustics and extra provision for flexibility.

Content of Gallery depends on the concept and purpose of the gallery, gallery space and accommodative aspects, density of display/storage, open or controlled access, special display, storage problems and availability of content either analogue or virtual, flexibility to accommodate different types of exhibition, adaptability of space to alternative usage and appropriate exhibition tools.

Multimedia Tools Usage is vital in any field of study which requires a representational medium, a surface on which ideas can be recorded. This is not only vital for communication with others but is also important for further evaluation and development.

Human Interaction is on the appearance and behavior of persons communicating and increasing attention is being given to the influence of nonhuman factors on human transactions as well.

## **5. Methodology**

All Survey Questions and Interviews are based on the five main areas mentioned.

- i. 4 groups from students and staff of the faculty, the professional practitioners, school children and general visitors were

investigated. They were brought in separately during allocated duration of time, left to explore the gallery and examined through method of observation and answered questionnaires.

- ii. Further interviews were conducted with people related to the gallery as well as students and staff of the faculty to determine issues, problems and suggestions.
- iii. An experiment on a controlled group consisting of Foundation Year students were brought in. They were tested according to their actual studio activities on one of the selected projects of Design Fundamental subject. A comparison chart is tabulated that records students' participation, output, advantages and benefits, problems and arising matters that occur when a class is conducted outside of their classroom.

## 6. Findings

TABLE 1. Tabulation on e-Gallery's space and function, aid of tools, content and users.

Space	Function	Activity	Multimedia Tools	Content	Human Interaction
Foyer	Welcoming Area Over Flow Area	Introduction	Computer Kiosk	Faculty Introduction 5 Majoring Information www	Human and Machine
Main Exhibition Area	Exhibition Official Reception Seasonal or Main Exhibition Multi Functional	Exhibition Reception Multi Function	Computer Video Projector Audio Visual	Current Exhibition or Function	Human and Machine Human and Human
Analog Exhibition Area	Analog Art Works Sculpture Painting	Exhibition Archiving		Student and Staff's Art Works	Human and Art Works Human and Human

Presentation Area	Presentation on the Related Function	Presentation Discussion Area	Computer LCD Screen Projector	Faculty Introduction 5 Majoring Information www Related Function	Human and Human Human and Tools
Discussion Area	Informal Discussion Mini Class	Discussion			Human and  Human
Demo Area	Demo	Demo Presentation	Computer Projector Screen	Demo Information	Human & Tools Human and Human
Temporary Display Area	Temporary Seasonal	Exhibition	Computer	Temporary Works	Human and Machine Human and Human
Digital Interactive Area	Exhibition	Exhibition Surfing Information Games	Computer Touch Screen	Archiving	Human & Tools

TABLE 2. Comparison between the Existing Classroom Teaching and e-Gallery as an Additional Education Aid

No.	Stages of Design	Space	Activity	Existing System
1	Project Briefing	Discussion Area	Short Briefing and Discussion	One way Briefing System at the Lecture Theatre
2	Brainstorming	Outdoor gallery Foyer	First Ideation Discussion include ideas and sketches	Done at the Studio Space
3	Design Stage	Discussion Area	Exploration of ideas using multimedia equipments	Done at the Studio Space for manual analogue drawings
4	Critique and Presentation Session	Presentation Area	Students present their work	Done at the Studio Space where the design process takes place Same area usage
5	Exhibition	Analogue and Digital Gallery Space	Exhibition include Analogue Exhibition, Digital Interactive Exhibition, Installation, Audio & Visual Presentation	Exhibition at Studio Space Same area usage
6	Archiving	Digital Archiving	Interactive Digital Archiving Database	None

TABLE 3.

Subject: Design Fundamental Level: Alpha Foundation Year

Number of Students: 30 Number of Lecturers: 1

Duration: 1 semester of 3 months Venue: e-Gallery

No.	Stages of Design	Existing Problem at Design Studio	Solution at e-Gallery
1	Project Briefing	No communication	A smaller space for interaction Better visuals
2	Brainstorming	Loose Space No Facilities	Controlled area Fresh space for Ideation
3	Design Stage	Suitable only for Analogue Drawings	Suitable only for Digital Drawings
4	Critique and Presentation Session	No definite space allocated for pinning up works or digital presentation Loose space and lost of concentration	Well allocated space for analogue and digital presentation Presenter and examiner can concentrate better
5	Exhibition	No allocated space for proper analogue and digital exhibition Temporary exhibition only because of limited space	Proper Exhibition for Analogue and especially Digital Exhibition with proper curators, tools and space area
6	Archiving	No tools for storage	Minimum space as archiving is done digitally. Multimedia tools needed Fast database search.

The experiment was done on a controlled group of Design Fundamental class. This subject is taught at Alpha Foundation level which is in the first year of their Degree course in Multimedia University. They are taught Basic Design Elements, Colour Theory and Introduction to 3Dimensional Character Design. Their projects are analogue art works with the aid of computer tools to assist in their some of their design projects. Sketching, painting, drawing, photography and production are their end products while discussion, critiques sessions and presentations are carried out throughout their semester as a way of communication. As tabulated, it is seen that the gallery acts as an enhancer or additional aid to the existing system. Conventional Design Studio is essential to the design education and the gallery succeeds in filling in void spaces with its credibility of a digitally supported space where multimedia tools and adequate content in a comfortable and secure space would present a hybrid space for students. Exhibition and Digital Archiving can be done at the e-Gallery where conventional studio does not allow for such activities. With these additional commotions, the gallery is able to pose as a one stop centre for design activities and multi functions at the same time as well as a centre for digital information and archive.

## 7. Conclusion

Understanding the future for digital design reorientation in theoretical and practice has provoked the research on searching further for a vehicle to cater for the progressive education of the multimedia age. Creative ideas to enhance the learning environment will provide students a better setting for the deliverance and experiential organization design students are associated with. As acclaimed by Mitchell (2002), a given space, through electronic intelligence and functionality, will not only be more responsive and efficient, it will also be programmable for wider range of activities.

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# ADAPTING DIGITAL TECHNOLOGIES TO ARCHITECTURAL EDUCATION NEEDS

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**Abstract.** Adapting digital technologies to architecture school settings is a topic of universal interest. Properly construed, adapting digital technologies to architectural education emanates from philosophical underpinnings. For architectural programs, the scientific-artistic attribute notion can be a powerful reference for mapping program mission, goals, and curriculum. A program plan developed with scientific-artistic attributes of performance in mind can tap on the use of digital media from the perspective that the media has scientific-artistic characteristics itself. Implementation of digital technologies adaptation can be challenged, among other things, by scarcity in resources. This paper focuses on the role of digital equipment resources in adaptation. A case in point is the use of digital technologies at the Architecture and Environmental Design Studies (Arch/EDS) Program of Bowling Green State University. The study considered the utilization by the third and fourth year design studio students of the digital resources at the Center for Applied Technology, a College based, but University wide serving unit. The objective of the study was to build up a theoretical understanding of the adaptation problem and come up with strategy guidelines for adapting digital media resources to architectural education. A survey of students and interviews with the Center's personnel were methods used to collect data. The study has placed the adaptation problem in a philosophical context, turned out a set of theoretical generalizations about digital utilization, and suggested strategy adaptive guidelines. Beyond facilitating adaptation specific to the Arch/EDS Program, the results of the study are bound to affect digital adaptation in a general sense.

## 1. Introduction

Digital technologies have been introduced into architecture education probably in ways as diverse as the number of schools that considered them.

Although some hold that hand drawing will preserve its place in future (Basa and Senyap 2005, p. 269), the digital lure continues to fuel the debate worldwide on the rationale and strategies for adapting digital technologies to architecture school settings. Ehn (1998) advocated instilling in students the spirit of exploration, learning, and incorporation of new digital technologies. Kurlansky (1998) went further to stress the value for students to explore the impact of different digital tools on their thinking and communication processes. The result is a bewildering gamut of experiments, models, and "adjusted" thoughts on the subject applied with varying degrees of success. On one end, we find schools with modest thought and resources given to digital technologies, perhaps in the form of a few computer units confined to drafting applications; on the other end, we find schools with eminent planning and resources dedicated to digital design studio with top-of-the-line applications.

Self-assessment of the place of any school of architecture in the digital world is presumed. All schools are to face the challenge of closing the gap between their digital needs and available resources. Acquiring resources helps close the gap; however, the manner in which the resources are used is equally important. A case in point is the use of digital technologies at the Architecture and Environmental Design Studies (Arch/EDS) Program, a unit of the College of Technology at Bowling Green State University. Students in the Program are required to complete two computer applications courses, one is mechanically oriented and the other is architecturally based. An elective course in computer modeling and visualization in architecture is also available. This study does not address such courses in particular; rather, it turns our attention to the availability of a set of digital technologies, such as powerful scanners and printers, for design project presentation purposes and the way these instruments have so far been used to support students' project presentation materials.

A space reallocation in the College of Technology three years ago resulted in moving the upper level design studios of the Arch/EDS Program to the ground floor of another building on campus and also in moving the Center for Applied Technology, a College entity, to an adjacent space on the same floor (Figure 1). The reallocation was based on the expanding space needs of the College rather than on the working relationship between the Arch/EDS Program and the Center.



*Figure 1.* Comprehensive view of the Center's space and equipment

However, architecture students in the third year and fourth year studios operating in the new space have been exploring and gradually tapping into the Center's digital capacities in laser cutting, prototype modeling, printing, and scanning primarily to produce design project outcomes in the form of presentation boards and physical models. Available to the public at large, the Center services provide: a) laser cutting and engraving of a variety of boards and materials using 2D image files or line drawings, b) rapid prototype physical modeling generated from 3D programs, c) large format inkjet printing up to 72" width on a variety of materials, and d) high resolution scanning for originals up to 36"x48".

Driven to realize its own growth objectives, the Center's personnel has lent a hand to students on an individual, ad hoc basis. The students' growing aptitude for using digital tools, on the one hand, and the Center's incessant updating of digital technologies, on the other, has begun to reveal insufficiencies in the mode of service. For one, it is no longer viable for the Center to continue operating on a sporadic, uneven assistance mode to students. Secondly, students' access to the service only partially taps the full potential of the available technologies. In the midst, the architecture faculty members have tended to keep at bay, more of passive, but restless, observers—trying to grasp the situation.

There is a growing understanding among all parties, especially the faculty, that an opportunity exists to bring the architectural curriculum in general, and the upper design studios in particular, into a more harmonious and productive relationship with the Center's digital resources. Out of this understanding, the objectives for this study were set as follow:

- To place digital adaptation problem in a philosophical context
- To examine the Center for Applied Technology's digital technologies and their capabilities
- To review the manner in which the technologies have been used by architecture students
- To develop theoretical basis and strategy guidelines for adapting digital technologies to architectural education needs

Besides our own observation on the utilization of the Center's digital technologies, we had conducted a survey for the third and the fourth year students as a source of data for the study. Further, we had conducted interviews with the Center's leading personnel. It is to be noted that all figure images in this study were courteously provided by the Center for Applied Technology. Further, the Center provides online information on its digital equipment (The Center for Applied Technology 2005).

## **2. Philosophical Context of the Adaptation Problem**

Properly construed, adapting digital technologies to architectural education emanates from philosophical underpinnings. The belief that digital methods are efficient and supportive of creative endeavours has long been established. What remains unclear is the question of how to tap on digital media to support academic objectives. In this regard, the ever-changing, more enabling nature of the media poses difficulties. The core challenge, however, lies in formulating strategies and charting modalities for taking advantage of the media. Consummating such strategies and modalities springs, in one outlook, from diversity of tools, and subsequently from versatility of use, of the digital media and computational methods: prescriptive and predictive on one end; discretionary and creative, on the other.

Curricular needs, in substantive and methodological learning terms, can be contemplated through the all familiar "scientific-artistic" spectrum notion. Curricular schemes with "appropriate" measures of scientific (prescriptive and predictive) and artistic (discretionary and creative) components vary widely. For example, while physics is bluntly scientific in content, it can be taught with degrees of creativity. On the other hand, while painting is creative in intent, it can be taught with some degree of systemic guidance. Turning to architecture as a discipline of learning, we find more of a scientific-artistic balance in its makeup, substantively and methodologically.

For architectural programs, the scientific-artistic notion can be a powerful reference for mapping program mission, goals, curriculum, down to individual course assignment—with a concomitant impact on program assessment. A program plan developed with scientific-artistic attributes of performance in mind can tap on the use of digital media from the perspective that the media has scientific-artistic characteristics itself. Stated otherwise, adapting digital technologies to architectural education needs can take place within the framework of the proposed scientific-artistic model.

To succinctly illustrate the use of the model in an architectural curriculum, two common, but pivotal, areas of design studio activities are

considered: generating design and representing design. How do these two areas fair on the scientific-artistic scale? Which area hangs closer to one end of the spectrum or the other? Each area pondered separately, which aspect—of several—for the area is more prescriptive? Which aspects are more creative? Which digital tools are appropriate to use for enhancing the orientation (prescriptive or creative) of the element in question? The depth and breadth of the analysis are, of course matters defined by the concerned faculty.

Implementation of digital technologies adaptation can be challenged, among other things, by scarcity in resources and expertise. This paper focuses on digital resources, and in this framework, on the use of digital production equipment by the third and the fourth year design studio students of architecture at Bowling Green State University.

### **3. The Center's Digital Technologies and Their Capabilities**

The digitally based functions that the Center administers are introduced below through the equipment name and type, equipment capabilities, and the operational context. Observations on the students' access and use of each function are also made.

#### **3.1. LASER CUTTING AND ENGRAVING**

The M-300 Laser by the Universal Laser Systems is the main piece of equipment that supports the cutting and engraving function (Figure 2). The machine is controlled from a computer work station using Corel Draw, a software provided by the system supplier. Other software, with varied capabilities, can be used. The machine handles a variety of materials including wood, art board, brass, and glass with some variations in effectiveness. The 24"x12" size of this machine's bed limits the subject boards to be cut or engraved up to this size.

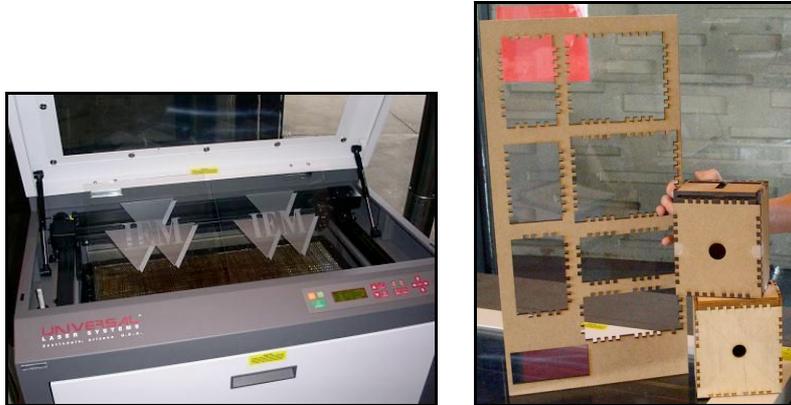


Figure 2. The laser cutting and engraving machine (left) and cut products (right)

Students have access to the M-300 Laser system from 8:00 am to 5:00pm during the five working days of the week. Because of the popularity of this device, its use is regulated by a signup list, for one-hour blocks of access per request. Architecture students so far make the bulk of the clientele, and because of the unit organizational relationship, these students are given priority of service. Students in the nearby School of Art are becoming more and more active users as they continue to discover the potential of the machine.

Making the M-300 Laser system available for use is not without difficulties to both the students and the Center's personnel. Curious to explore the system and driven by an interest in taking advantage of its capabilities, first-time students soon realize difficulties in developing an operational facility with the machine. The Center's personnel provide guidance to student users as their time permits. However, because of inadequate staffing, such guidance is meager at best, and, accordingly, the students are left to their own devices to achieve their learning aims.

### 3.2. RAPID PROTOTYPE PHYSICAL MODELING

The Model 2402 Rapid Prototyping Printer by Z Corporation (Figure 3) builds up physical models through printing (adding) thin layers of plaster powder or starch material. The machine uses the software Z Print; the software reads CAD or other 3D files in the Stereo Lithography Text Language (STL) format and sends them to the printer. Somewhat demanding in preparation, operation (printing), and cleaning, the machine produces rather limited model sizes, confined to 8"x8"x12" envelope. A model of this size runs into hundreds of dollars in cost, a reason why the machine use by student is rare. As modeling and prototyping is becoming an

approach for architectural design in which stages between conceptualization and construction tend to collapse (Mandour, 2004), the excessive utilization costs of the rapid prototype machine has a depriving effect on learning new skills. However, the machine 3D modeling capabilities is attracting users from other units of the university, such as the School of Art's Sculpture Program and the Department of Chemistry, especially for projects that have funding. A promising technique for architecture, rapid prototype modeling found it's way in critical applications such as fabricating the mould for artificial bioactive bones (Chen et al. 2004, p. 327). Kieran and Timberlake (2004) lamented architects for using computers mainly in 2D drafting and 3D rendering instead of developing solid modeling capacity through such systems as rapid prototyping.



*Figure 3.* The rapid prototype modeling machine (left) and a product model (right)

### 3.3. LARGE FORMAT INKJET PRINTING

The HP 5000 is the main and the mostly used printer in the Center. Usually operated by staff, it prints up to 72" width on a variety of materials. Because of the versatility of the materials that can be used for printing (vinyl, fabrics, fine art paper, etc.), this equipment is more utilized by the fine arts students than any other student group, including architectural students. Other smaller printers with specialized use also in operation at the Center including Colorspan Mach 12 and Series XII and Mimaki JV4 and TX-1600.



*Figure 4.* The large format inkjet printing machine

#### 3.4. HIGH RESOLUTION SCANNING

The Cruse CS 155 ST is a well known scanner of the Center. It is capable of scanning 36x48 inch images in one operation. The CREO Eversmart Supreme, another scanner, has a scanning area of 12x17 inch. These scanners have been helpful for architectural students who want their large drawings scanned before reducing them to a portfolio format.



*Figure 5.* High resolution scanning machine

#### **4. Assessing Students' Access and Utilization of Digital Technologies: the Survey**

The interface of students' needs with the Center's resources generated modalities for accessing and using available digital technologies. To assess in more certainty the access and utilization of the resources by students, a survey questionnaire was the basic instrument employed. The discussion below includes descriptions of the attributes and questions of the survey instrument and a comparative analysis of resource utilization by both classes.

##### 4.1. SURVEY ATTRIBUTES AND QUESTIONS

A survey questionnaire was the basic instrument for assessing the use of digital technologies by students. The questionnaire contained ten questions revolving around attributes deemed relevant to the characterization of the use of technologies. The opening question addressed the student standing, junior or senior. The final question invited student open-ended comments on any matter relating to the digital technologies. The eight intervening questions addressed the following attributes:

1. Frequency of access and utilization of the four main equipment (four questions)
2. The source through which the student had learned the use of two pieces of the equipment (selected based on an assumed most heavily used equipment; two questions)
3. The level of importance that the student attach to the use of the technologies for increasing his or her technical skills (one question)
4. The nature of cost that the student ascribes to using one particular piece of equipment (selected based on the assumed high cost of this piece use; other equipment costs were not considered because either they are, up to now, free of charge for architectural students (Laser Cutter) or because the cost is too prohibitive to begin with that hardly any contemplates using it (Rapid Prototype); one question)

##### 4.2. COMPARATIVE ANALYSIS OF UTILIZATION: THIRD YEAR VERSUS FOURTH YEAR

Handling survey attributes individually, students' responses on access and utilization have been summarily compared and comments were made on the comparison.

## 1. Frequency of access and utilization of the four main equipment

<i>Third Year</i>	<i>Fourth Year</i>
30% indicated "a Lot," "Some," or "Rarely." 70% indicated "None."	62% of participants indicated "A Lot" or "Some"

Comment: The extensive utilization by fourth year students and modest utilization by third year students reflects the effect of student opportunity and maturity on utilization.

## 2. The source through which the student had learned the use of two pieces of the equipment

<i>Third Year</i>	<i>Fourth Year</i>
Regarding Laser Cutter: 40% of participants responded. 81% (9 responses) indicated "Peer Student" and 19% (2 responses) indicated "Faculty." Regarding Rapid Prototype machine: 4% of participants responded (1 response) indicating "Supervisor at CAT."	Regarding Laser Cutter: 100% of participant responded. 77% indicated "Peer Student"; and 23% indicated "Supervisor at CAT" and "Faculty" combined. Regarding Rapid Prototype machine: 40% of participants responded. 22% of responses indicated "Peer Student"; 33% indicated "Supervisor at CAT"; 44% indicated "Faculty".

Comment: The extensive responses by fourth year students and modest responses by third year students reflects the effect of student opportunity and maturity on utilization. The third year's lower responses indicate no learning had occurred relating to the operation of this machine. For both groups, "Peer Student" is the definite source of learning. The complexity of the Rapid Prototype machine made it more handy to be utilized by fourth year student, and hardly by third year students.

## 3. The level of importance that the student attach to the use of the technologies for increasing his or her technical skills

<i>Third Year</i>	<i>Fourth Year</i>
65% indicated "Very Important"; (23%) indicated "somewhat important".	81% indicated "Very Important"; 19% indicated "Somewhat Important"

Comment: There is a clear appreciation for the importance of digital technologies by both groups, although this is stronger in case of the fourth year students.

#### 4. The nature of cost that the student attribute to using the Large Format Ink Jet Printer

<i>Third Year</i>	<i>Fourth Year</i>
66% of participants responded. 66% of respondents indicated “Too Much”; 34% indicated “Reasonable” or “Fair”	36% indicated “Too Much”; 36% indicated “Reasonable”; 28% indicated “Fair” and “Very Affordable” combined

Comment: The third year students’ lower responses reflect their unfamiliarity or non-experience in using the machine. The third year perception of cost is skewed in the “Too much” level; the fourth year perception of cost is much more even, and can be more reliable.

### 5. Theoretical Generalizations and Strategic Directions

Our direct observations of the Center’s resource utilization, understanding of the survey results, and quest for a congruent digital integration into architectural education led us to some theoretical generalizations and strategy guidelines for the utilization of production digital resources in particular, and the digital technologies in general. The theoretical generalizations provide a background for the strategy guidelines.

#### 5.1. THEORETICAL GENERALIZATIONS

The theoretical generalizations are associated with faculty, students, and the supporting unit (the Center), and explained below in the context of the Center’s digital resource utilization.

##### *5.1.1 Faculty is the Source of Digital Utilization*

Being a response to studio project assignments, all the student work that flows into CAT is, to a great degree, influenced by instructors’ expectations of the final, representation products. Such expectations gear students to use the digital resources excessively or lightly. As a way of example, project presentation requirements may allow manual drafting, with no digital production; plotting on a standard CAD plotter; or modeling by a sophisticated prototype printing machine. The implication for the level of digital utilization in the three cases is widely different.

Faculty members’ role in taking advantage of digital production tools is an extension of their individual and collective responsibility towards their programs. Digital utilization in design studios permeates for pre-production (drafting and design) tasks and is becoming so for design outcome production tasks as well. The ideal service of the faculty of any unit to the

curriculum they are entrusted with is to collectively give a serious scrutiny of the abounding digital opportunities and to chart strategies for filtering in the opportunities that further curricular objectives. Guided by strategic bearing, individual instructors will be in a better position to anticipate the digital needs in their studio. In absence of a collective outlook, individual instructors remain to navigate their way regarding how to put the available digital resources in service of their studios and classes. It is still a responsibility each has to reckon with.

#### *5.1.2. Students Are a Measure and an Instrument for Digital Change*

At the receiving end in the instructional milieu, students are prompted to action by the nature of studio assignments. They proceed to capitalize on whatever digital resources are available despite the fact that they are left to their own devices in inadequately supported digital settings. Inundated to begin with by a myriad of academic and non-academic trepidations, students grow more and more concerned about having to deal with such inadequately supported settings.

The survey questionnaire we have administered to the 49 third and fourth year studio students was—particularly through the responses to the open comments question—instrumental in measuring digital service inadequacies (or adequacies) in the eye of students. The students focused on three areas of concern: a) availability and accessibility of the technologies, b) orientation and training on the technologies, and c) affordability of the services. Primarily centered on time, the availability concerns were voiced through suggestions for 24 hour accessibility, extended hours, or weekend hours. Some comments reflected pressing desire for shrinking the three day normal order service, especially for the large format printing. Some other comments focused on the need for larger size bed for the laser cutting machine or adding another machine. It is of notice that a number of responses suggested adding CAD plotting machines (to the two already exist on other premises) although the questionnaire was meant to measure the digital technologies utilization at the Center's grounds. All in all, many more responses were received from fourth year students compared with third year students, which reflect the first group's longer experience in the utilization of digital equipment.

The other two areas of concern were less emphasized. The area pertaining to orientation and training on the technologies was marked by suggestions for training sessions, more knowledgeable staff, and information explaining the use of machines. These suggestions came primarily from junior students, which reflect this group's limited experience in using the digital equipment. The area pertaining to affordability of services was marked by suggestions for reducing costs to students.

The students direct involvement with digital equipment makes them not only a measure for digital resource adequacy (or inadequacy), but also an instrument for digital utilization improvement. This is possible in their capacity as peer “teachers”. A clear majority of our survey respondents in both student groups indicated “Peer Student” as the source of learning. The role of student as a learning facilitator is not necessarily uncommon in reflective architectural environments, but here it is marked in its effectiveness.

### *5.1.3. Digital Centers Have Curatorial Function*

For university supporting units, like the Center for Applied Technology, client service is a part of the unit’s mission. The unit’s staff would seek student users’ satisfaction through running efficient, safe, and financially viable operations. The interviews completed with the Center’s leading staff in connection with this investigation established that the Center’s concerns are, in many ways, parallel to those of students, but of course from the unit’s perspective. Having a regular working day hours, the Center regulates the access and utilization of most popular machines, such as the laser cutter, through a signup list for specific time slots. Receiving repetitive questions and providing repetitive help to individual students, the Center’s staff is very much aware of the need for a training program, and actually has plans to offer student training workshops. Aware of the unwieldy manuals for the machines that are directly accessible to students, the Center issued a few user’s guiding sheets. The price structure for different services is well defined, with a graduated scale for student, university personnel, and external clients.

## 5.2 STRATEGY GUIDELINES

Developing strategies for adapting digital technologies to architectural education needs is an ambitious, but a tedious objective. Tediousness stems from not only the difficulty in determining the needs, but also from the changing nature of such needs. With this understanding, the utilization of the Center’s current digital technologies by students seems too specific a topic of investigation in its contextual and temporal references. Developing utilization strategies with assumed unchanging nature of the technologies (types, number, etc.) and fixed needs of student users will work just for a short while. On the other hand, developing strategies with assumed changes in the technologies and users’ needs will work much longer. Developing strategies for technology utilization will best be considered under the following guidelines:

- Considering architectural education thought on integrating digital media.

- Expecting erratic digital change.
- Recognizing the interests and collaborations of faculty, students, and the digital unit personnel.
- Building in flexibility in planning and scheduling.
- Adopting digital planning and assessment on a cyclic basis.
- Conducting on-going digital training program.

The training program, in particular, could incorporate topical workshops, on-line tutorials, and a mentor program. The latter could benefit from the relationships of the parties involved in the digital game to have: unit staff mentor students or faculty, faculty mentor students or faculty, and students mentor students.

## 6. Conclusions

This study dealt with a specific context of digital technologies utilization involving 49 third and fourth year architectural design students, the Center for Applied Technology resources, and the faculty. The study has sufficiently identified and described the Center's resources, the manner in which the technologies have been used by architecture students, and the challenges to students and the Center's staff. Prompted to meet such challenges, the study looked into adapting digital technologies to architectural education in a general sense. For the adaptation, it was necessary first to place the adaptation problem within a philosophical context and propose a set of theoretical generalizations about digital utilization which served as a foundation for more specific discussion on strategy guidelines for digital utilization.

The results of this study will contribute to the adaptation of digital technologies to architectural education in a number ways. Facilitating adaptation specific to the Arch/EDS Program, the results will, more importantly, cast light on possible strategies for effecting digital adaptation in a general sense—anywhere. Further, the results provide a precedent for augmenting strategy guidelines on the assumption that a holistic, long range plan for integrating digital tools in architecture studio is appropriate.

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## **EVOLUTION OR REVOLUTION: IS DIGITAL CONCEPTUAL DESIGN THE WAY FORWARD FOR ARCHITECTS?**

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**Abstract.** This research investigates architectural conceptual design and discusses its recent historical, philosophical and theoretical development within the overall architectural design process and attempts to establish an objective definition more tuned to current thinking and advancement in technology. It also evaluates the various traditional and information technology (IT) tools available to the designer and establishes their relationship to the conceptual design process in order to identify if any of these tools, in particular the IT tools, have a role to play in the practice and the enhancement of the conceptual design process.

A survey of Scottish practicing architects (small to medium size practices) was undertaken to validate the results of the investigation. The results seem to suggest that IT tools are not essential to the conceptual design process but that they are very well capable of enhancing the creativity and speed of some aspects of it. They also suggest the existence of an inherent resistance amongst Architects / designers to utilising these tools in conceptual design.

It is, furthermore, identified that if practitioners were to encompass new working practices and acquire new skills, IT tools could also provide powerful new modes of communication with the client. A correlation between the size of the practice and the degree of exposure and experience of IT tools was also established.

To test some of the above findings, a design studio experiment was undertaken where half of the students adopted digital tools, utilising SketchUp software and digital sketchpads, whilst the others adopted traditional tools for the conceptual design part of their projects. No attempt was made to gauge the quality of the actual designs produced.

The results indicate that the SketchUp group rated their conceptual design experience higher in terms of efficiency, flexibility and communication. The control group, who had dominantly adopted traditional freehand sketching, were impressed by the outcome from

the SketchUp group. All student who answered the questionnaire, both SketchUp and control groups, said they would consider adopting some form of 3D sketching in the future.

## **1. Introduction**

The use of information technology (IT) as a design tool is one of the most contentious issues in Architecture today; questions such as “How is the use of the computer going to influence our creativity or problem solving capability?” (BERTOL, 1997) and “Are architects embracing the full potential of IT design tools?” need to be addressed. When architects began automating their offices in the 1980’s they substituted word processors for typewriters, and computer aided drawing for drafting pens (LAISERIN, 20001). The use of IT in the project production design stage is now well established in that as long ago as 1996 an estimated 90% of architectural design offices had some sort of computer aided drawing (CAD) system in use (O’HALLORHAN et al. 1996). CAD is now all-pervasive in this field, the associated benefits of efficiency and cost reduction now being reaped by all.

IT has generally been adopted in architectural offices for repetitive high volume tasks that contained no creative design element (DAY, 1997). However IT offers a greater range of tools to the architect than just CAD (UDDIN, 1999). Tools such as image editing suites, digital sketching and composition, 3D modelling and rendering, animations and much more are readily available for use off the shelf. This paper sets out to evaluate if these tools are of any relevance to architects in terms of conceptual design

## **2. What is Design?**

Even the word design itself is open to interpretation in architectural circles (LAWSON, 1997) in that it can be interpreted as meaning the design process itself as well as the finished product of the design process. For the purposes of this paper the definition “design process” is being adopted.

Some architects are of the opinion that “design” is a creative art, similar to sculpture, painting and music, in that they are creating something new for people to experience. LAWSON (1997) seems to confirm this as he states that “design is not some mystical ability, but a skill which must be learned and practised” whilst BIJL (1989) is of a similar opinion in that he states “design is an activity which lies between calculated reason and magic”.

Other architects believe that design is not only the result of a specified routine but that good design comes from inspiration. This seems to infer that

good design is arrived at as a result of chance. COHEN (1993) disagrees as he adopts a Thomas Edison quotation that good design, like genius, "is one percent inspiration and ninety-nine percent perspiration". He goes on to identify that most designers will take a small idea and work with it until it is manageable. This he says describes the design process.

BEAKLEY et al (1973) warn against confusing style with good design. A design might contain no amount of good style but if it does not satisfy the essential functions of the brief then it cannot be considered a good design. Indeed they introduce the concept that style is just the modern equivalent of marketing.

LAWSON (1997) believes that "there is no infallibly correct design process" and there are many and diverse opinions as to what constitute the design. However most architects would agree with SANDERS (1996) that the design process is an iterative one where schemes are identified, explored, measured, revised and enhanced until a solution is identified. This is confirmed by TAYLOR (1992) who describes design as the reverse of analysis by expounding that design begins with no specification only a brief from which proposals must be created and a specification derived. It is this cyclic process, which he believes, leads to the description of design being synthesis. Design can therefore be described in general terms as being a cyclic creative process.

### **3. Nature of Architectural Design**

Design of buildings is only one of a number of design processes, which lead to the making of some artefact. Architectural design has been acknowledged for thousands of years, Vitruvius treatise is a clear proof, because of the complexity of Architecture and its symbolic values- higher content, its impact on peoples lives and the physical environment as a whole.

It can be safely said that architectural design, meaning the design process as defined above, has been undergoing extensive appraisals and redefinitions at least since the late 19th century. The contributions of architects such as Le Corbusier as illustrated in "Towards a New Architecture", Frank Lloyd Wright and architectural groupings such as the International Congress of Modern Architecture are well established. It is the intention in this section to briefly examine the thinking that has recently emerged on what is architectural design.

BRAWNE (1992) draws an analogy between Karl Popper's model of theory construction and design: P1 TS EE P2. P1 stands for problem, TS (TS1.... TSn) stands for tentative solutions, EE error elimination and P2 for newly formulated problem. In this model, architectural design develops through a series of criticism where a particular set of answers is seen to be failing in some way- formally, socially, technically. Then those aspects seen

as the dominant failings are identified and alternative suggestions are first made then tentative answers provided, usually by going through the process of a model shift; and these in turn are elaborated and criticised. Arguably this summarises what happens at the conceptual stage of design and surely the dominant method of teaching in architectural schools- repeated criticism and problem solving. The attitudes of the architect, cultural, psychological... and how they are assessed is an issue that arises given its influence on the design.

BROADBENT (1988) on the other hand splits the design process into 2 components: the quantifiable and the non-quantifiable. The former may use a range of techniques that have become available to the architect from ergonomics, operational research, system analysis, computer applications that offer powerful tools for decision-making. The latter, however, relates to more subjective matters of imagery, values, identity and sense of place, which are not fully understood by human sciences and therefore architectural design cannot be fully automated i.e. subjected to any objective model. Add also the historical and cultural elements without which the continuity of architecture and peoples' associations with it would be seriously fractured. Clearly the view here is that the non-quantifiable, often referred to as form, remains within the realm of artistic creativity.

BRAWNE (1992) argues that form and technical matters are so closely intertwined together in design that it would be hard to approach them separately. The emphasis on form stems from the belief that it is more obvious, more easily understood and more visible and therefore more easily related to every day experience.

SANDERS (1996) view is that the design process is an iterative one where schemes are identified, explored, measured, revised and enhanced until a solution is identified is one that agrees most with the model derived from Popper's. Considering the TS and EE in the sequence, computer tools offer a tremendous potential not only of stimulating the design in the widest sense but also to assist the design process in the widest range of problem solving and error elimination during the design and development stage.

Traditional design tools available to the architect take the form of drawings (sketches, orthographics, pictorial views and rendered scenes) and 3D physical models (exploratory or communicational). Sketch drawings and sketch models are utilised to explore ideas and arrive at the concept which forms the basis of the design- they may be considered as very useful for generating ideas but poor communication tools especially to the non trained eye. Orthographic views and pictorial views are used to communicate the design and form an integral part of the language of architecture. They are an effective means of ensuring design intentions are understood.

Historically these tools have not changed much and ensured an established means of communication between architects and to a lesser extent their clients. One may claim that traditional tools are strong for the development of ideas but weak for the presentation of these ideas. IT tools potentially

offer a wide range of alternative solutions to the architect for the generation and communication of ideas provided the gap of understanding and adopting, or even accepting new languages can be bridged.

#### **4. Evaluation of IT Tools to Support the Conceptual Design Process**

It is generally accepted that the starting point of conceptual design is the evaluation of the client's brief and thereafter the exploration of ideas to satisfy those requirements via the application of intelligence, experience and creativity. Tools adopted for these tasks must allow the designer to record and develop ideas. Information technology provides a number of tools that may be suitable for adoption; these include digital sketching, formal drawing via computer aided drawing (CAD) software, parametric CAD, 3D modelling, drawing rendering, image photorealism and virtual reality. Some of these tools are capable of complimenting the traditional design process whilst others provide entirely new tools and thereby new techniques. CROSER (2001) identifies that the adoption of new IT tools could be detrimental to the generation of new ideas as they will necessitate learning new skills and that if the designer does not fully understand his/her tools then the design will inevitably suffer.

It is important at the conceptual design stage to be able to create quick sketch drawings to aid the process of design development. BERTOL (1997) believes that computer aided design is a misnomer because of its infrequent employment in the conceptual design process, whilst SNYDER (1998) comments that CAD tools are geared more towards accurate construction drawing than rough sketching. CAD therefore does not seem to be able to support the requirement for a digital sketch tool and most design practices refute the idea that IT could replace hand sketching with many believing that CAD should be redefined as computer aided drafting. There is however a number of IT tools available that can be employed to create quick sketch drawings, these are painting and image processing software, digital palettes and sketch based CAD tools.

A hand drawn sketch cannot be easily scaled up edited or converted into a formal drawing, however a digital sketch can be comparatively easily manipulated and converted. Most CAD software enables the importing, re-scaling and tracing of digital sketches. Indeed many designers commonly convert their hand drawn sketches into digital sketches by scanning then into image processing software application where the benefits of easy manipulation can be obtained. Adobe PhotoShop is the most commonly used painting/image manipulation software tool employed by designers. GOIRDIAN (2001) comments that PhotoShop, in its current version, has vector drawing capabilities that may more easily enable the incorporation of digital sketches into CAD drawings. Sullivan (1999) identifies that hand held computers are becoming more popular and that these tools are capable

of supporting hand drawn sketching via the use of a stylus directly onto the computer screen and thereby more closely mimic the traditional hand sketching process.

Another requirement of the conceptual design stage is the need to produce formal orthographic and pictorial views of the “design” for communication and information transfer purposes. In many design offices the task of producing these formal drawings is seen as being a “technical skill” and is commonly performed by technicians working from the hand drawn sketches provided by the designer. Consequently it could be argued that since this is not a tool employed directly by the designer that it is therefore technically not a design tool. Few would however argue that formal drawings, 2D and 3D, did not form part of the conceptual design process. The conceptual design of some but not all projects may also make use of three-dimensional modelling. Traditionally physical three dimensional scale models are made of the whole or parts of the conceptual design so that the designer can gain a real feeling for the scale and proportions, space and light relationships of the design (MORGAN et al, 1995). These physical models, usually made of wood or foam, are expensive and very time consuming to create can be easily damaged and are not easily portable. The use of three-dimensional digital models is not dissimilar in concept. Three-dimensional 3D modelling can take many forms e.g. solid, wire frame or surface modelling. These various techniques have evolved and developed as IT and CAD have themselves developed and are closely related to the functionality and power of the computer systems upon which they were made to operate. As IT has become more powerful and affordable the more powerful and affordable the modelling techniques have become to the architectural designer. Digital solid modelling is a boon as it allows rapid movement of virtual solid objects on a computer screen (MORGAN et al, 1995). Once a model is created, pictorial views can be generated in a much simpler way than traditional methods. Instead of creating tools which will aid the design process, the design process is changed to suit the IT tools available (CROSER, 2002). Further 3D modelling has the advantage of allowing the model to be viewed more realistically from more natural viewpoints than a physical model allows as these are often unnatural and are not how the final building will be seen. Three-dimensional 3D modelling can be taken a step further by rendering the model. Various techniques can be employed that can be described as rendering (UDDIN, 1999). All attempt to make the line model appear more realistic. This is normally performed at the conceptual design stage to communicate design intentions in a photo realistic fashion. Adding detail to computer models is an effective way of increasing photorealism (Fleming, 1998). By combining the visualisations produced from 3D modelling with real life photographic images photo-montages can be created placing photorealistic images of a conceptual design into their real world environment (SANDER, 1996) and helps to visualise the design as it will appear when the building is completed. Alternatively photo-

rendered three-dimensional images can be created from the model and then “painted” adopting image painting/editing software to create sketch quality images that may fit in better with the design portfolio (UDDIN, 1999). All of the foregoing IT tools compliment the traditional design process. However IT is also capable of providing access to new tools and techniques that may be useful to leverage the conceptual design. These include parametric CAD systems, three dimensional model animation and virtual reality.

The concept of parametric CAD is that a single model is made of the building from which all drawings and visualisations can be generated. The first feature of a true parametric CAD program is object orientation, which enables the designer to work not with mere lines, but with virtual objects (O’HALLORHAN & SPOHRER, 1996). Using objects rather than lines gives a far greater degree of control than a standard CAD program (Morgan et al., 1995). Parametric CAD enables three-dimensional models to be easily and quickly created from a library of parametric objects. Using object orientation is a good way to describe the architectural world as it is made up of real-life components which can be represented as model objects in the view of WEI (1998), EARNSHAW, JONES & VINCE (1997) AND SANDERS (1996). The single model concept has advantages over the traditional CAD drafting approach, for as the model is being created so are the basis of the orthographic drawings and also the rendered visualisations thereby saving time and effort. Another tool, which is not available with the adoption of traditional techniques, is architectural animation. The reason for animating a design is to add even more realism than is possible with photorealistic still images and to further enhance the visualisation of the design concept. Motion will give the illusion of life to a design (SANDERS, 1996).

Animations vary in complexity, from a simple moving viewpoint to a scene with moving people and objects and can include walkthroughs, sun-studies and fly-arounds. These are normally generated from the same digital models as the static visualisations. An animated viewpoint leads the viewer to believe that there is nothing to hide, rather than seeing the design from a viewpoint chosen by the designer. This can be a very impressive thing for a client to see, and can “sell” the concept to him in a way no static representation could (KERLOW, 2000). SPILLER (2001) has an alternative view considering animation unnecessary and detracting from the communication of the design philosophy whilst FEAR (2001) considers architectural animation a gimmick which has the ability to impress with style, but not with substance.

Virtual Reality (Desktop VR) is another new tool provided by IT. This is closely allied to architectural animation but can be used to create real-time animation of an architectural scene. The intention is to create a viewing experience as if it were a real world scene (WOOLEY, 1993). ROWE (2001) envisages that desktop VR could be used at the design stage in the same way as a traditional sketch model. Immersive VR has however been criticised as

being a poor communication tool and Rowe points out that immersion prevents collaborative interaction of simple communication such as pointing out and discussing aspects of a design.

### **5. How Could IT Tools Enhance Conceptual Design?**

The preceding literature review suggests that IT tools are available to support and possibly enhance the traditional conceptual design techniques of sketching, formal drawing and modelling and that it provides new tools and techniques in the form of parametric CAD, architectural animation and DESKTOP VR. It was further identified that the IT tools were not seen as being essential in the development of the conceptual design but were likely to lead to efficiency gains especially in terms of speed. It also identified that whereas the traditional tools were strong in developing ideas IT tools were strong in communication of the concepts developed and also in terms of the quality of the presentation materials.

To validate and test these findings a survey was carried out of practitioners. A total of 291 questionnaires were sent and 45 (out of a total of 69 returns) valid responses were considered. To guarantee reliability, architectural firms with only one staff member were deliberately omitted. Of the 45 firms surveyed, 15 were very small (up to 3 staff), 15 small (4 to 7 staff), 7 medium (8 to 12 staff) and 8 large (more than 12 staff). A distinct correlation between the size of the firm and the type of work undertaken was evident in the response. The small and very small firms worked predominantly upon housing projects and secondly commercial projects. Medium sized firms had a more or less equal spread of workload over housing, commercial and industrial commissions. The very large firms were predominantly occupied with commercial projects and secondly with housing commissions.

It was anticipated that practitioners' views would be influenced by their exposure to and experience of IT tools and the survey reviewed what experience respondents had of the various tools. All but one of the respondents had experience of at least one of the IT tools identified. In many instances a range of tools had been experienced although in the case of the very small firms the experience had in many instances been limited to 2D CAD drawings replacement. It was noticeable that as the size of the firm increased the exposure to CAD decreased. Modelling with laser CNC cutting tools was the least utilised tool of all with only one respondent claiming to have used them. In the case of the very small firms' digital pictures, 3D modelling and rendered images were the most adopted tools after CAD. A similar picture of use was evident in the small firms excepting that they also made use of animation. Large and medium sized firm returned very similar results excepting that CAD was much less predominant and that digital pictures was the tool with most exposure. Interestingly none of the large

firms had any experience of laser and CNC modelling as may have been expected.

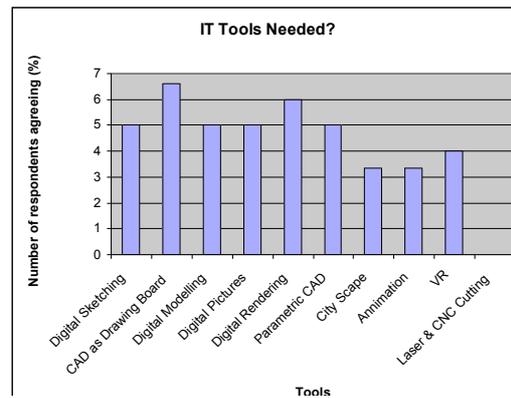


Figure 1. IT tools needed

The tool CAD as drawing board replacement being needed in conceptual design was a view held strongest amongst the small and very small firms as was the need for 3D modelling. The one respondent who had experience of Laser and CNC modelling did not think it necessary as a conceptual design tool. The priority of IT tools for conceptual design are, in terms of the feedback from respondents, CAD and then rendered images, then the following which were all seen to be equally important, Digital sketching, 3D modelling Digital pictures and parametric CAD.

### 5.1 TOOLS VIZ. CREATIVITY

The literature review had identified hand sketching as being the ultimate tool associated with creativity. All firms irrespective of size clearly favoured this tool as their creative tool of choice. Very small, small and medium sized firms identified pictorial views as a very poor second tool of choice. Large firms on the other hand identified physical modelling as their second tool of choice and there was evidence here of a broader range of tools being employed. Very small firms least preferred hand rendering; small and medium sized firms orthographic projections and large firms identified digital photographs as the least creative tool. Hand sketching is unquestionably the creative tool of choice with small variations in the use of other tools being identified and correlated to the size of the firm. The results of the literature review were validated and confirmed.

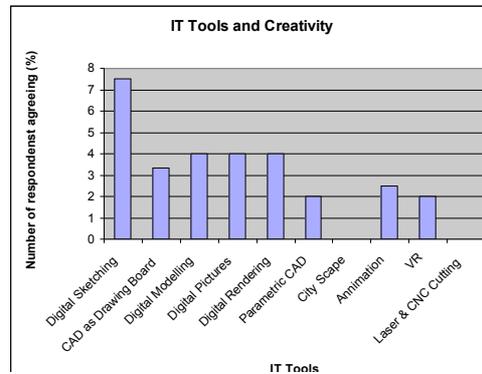


Figure 2. IT Tools and Creativity

There was some agreement amongst respondents that IT tools were not creative. However, some very small firms identified CAD as the most creative tool, small firms digital sketching and medium sized firms 3D modelling. Large firms did not identify that any of the tools were particularly creative. The mixed responses may be due in the case of large firms to the fact that apart from the initial conceptual ideas, design is delegated to others. In smaller firms, architects do most of the production work themselves. The literature review also identified that IT tools are perceived as not creative.

## 5.2 TOOLS VIZ. COMMUNICATION

The literature review identified that formal drawings are primarily a presentation tool for showing design evolution progress or a completed design concept in a universally understood format and that they are sometimes used to convey scale and proportions of a design idea. The literature review also identified that hand rendering was necessary at the conceptual design stage for exploring ideas of colour and also to communicate these to the client. The survey established that very small firms favoured hand sketching whilst all of the others chose physical modelling as their tool of choice. Large firms equally favoured physical modelling and hand sketching. The literature review had identified that physical modelling was a helpful tool for communication of the design but that it was not essential and that constructing models was expensive and time consuming. Very small firms second tool of choice was pictorial views whilst that of small and medium sized firms was hand sketching. Least favoured by all without exception was orthographic projections. A greater variance of opinion was evident here with hand sketching being less dominant and once again a correlation to size of firm and range of tools used was evident. The survey largely contradicted the findings of the literature review and further

established that hand sketching was a commonly adopted communication tool.

None of the respondents identified any of the IT tools as being particularly good in respect of communication; this contradicted the findings of the literature review which had identified this as strength of the IT tools. Very small firms thought CAD the strongest tool; small firms also favoured CAD as well as DESKTOP VR and medium sized firms' favoured animation and 3D modelling. Large firms did not identify that any of the tools were particularly good at communication.

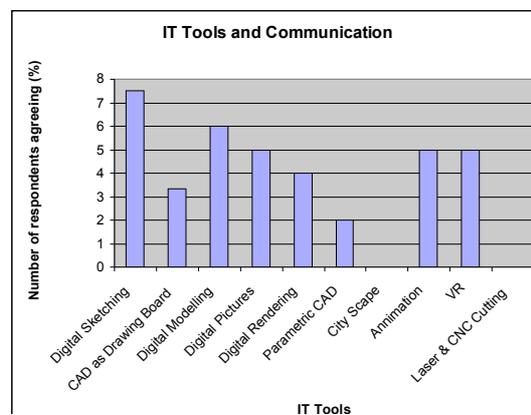


Figure 3. IT Tools and Communication

### 5.3 TOOLS VIZ. EFFICIENCY

The literature review identified that hand sketching was a highly efficient tool followed by orthographic views. The survey revealed a wide and disparate range of views although all clearly favoured hand sketching in terms of efficiency. Very small firms tool of second choice was orthographic projections as it was for large firms. It should be noted however that as many respondents from large firms identified orthographic projections as their least favoured tool as did their tool of second choice. Orthographic projection was also the least favoured tool of choice identified by small firms. Very small firms identified physical models and photography as their least favoured tools in respect of efficiency. Photography was also identified by large firms as being their least favoured tool. Medium sized firms gave a conflicting range of views other than clearly identifying hand sketching as their tool of choice. Hand sketching was clearly the tool of choice for all which substantiated the findings of the literature review.

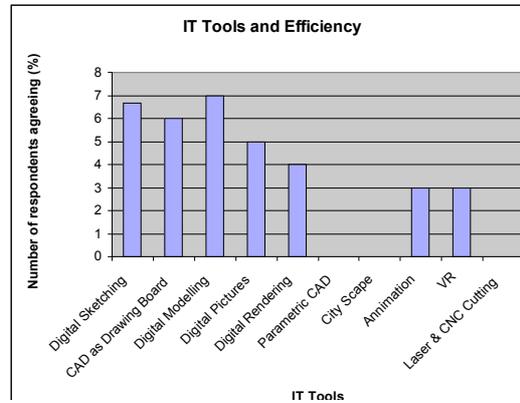


Figure 4. IT Tools and Efficiency

CAD and 3D modelling were identified by very small and small firms as being the most efficient of the IT tools. Small firms also identified digital pictures as being efficient. Medium and large sized firms both identified 3D modelling as being the most efficient of the IT tools. These results suggest that there is consensus amongst most respondents on the efficiency of IT tools, a fact also identified by the literature review.

#### 5.4 TOOLS VIZ. FLEXIBILITY

The survey identified that hand sketching was the very clearly the tool of choice of all in this respect yet the literature review had identified this technique as being inflexible. Very small firms identified orthographic projections and pictorial views as their tools of second choice. Orthographic projections were also identified by small firms as their tool of second choice whilst hand rendering was the tool of second choice of large firms. Conversely orthographic projections were identified by small and large firms as their least favoured tool. Whilst very small firms identified physical modelling as their least favoured tool. Medium sized firms, other than identifying hand sketching as their tool of choice, returned a disparate and contradictory set of results. The survey contradicted the findings of the literature review by identifying hand sketching as being the most flexible traditional tool instead of orthographic projections.

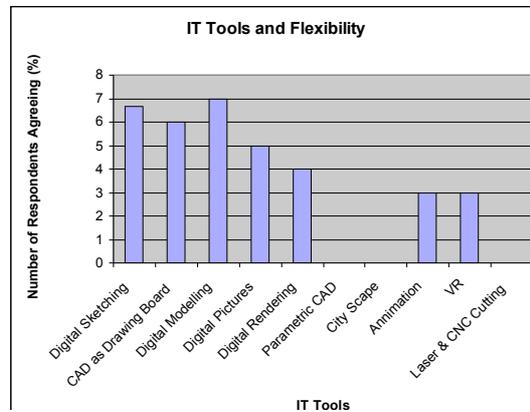


Figure 5. IT Tools and Flexibility

None of the respondents considered the IT tools to be particularly flexible, this was an unexpected result given that the literature review identified that this was one of the IT tools strengths. Very small and small firms identified CAD as the most flexible. Small firms also identified digital sketching as being flexible. Medium and large sized firms identified 3D modelling as being the most flexible.

### 5.5 TOOLS VIZ. ACCURACY

The literature review had not identified accuracy as being a characteristic associated with conceptual design. This measure produced the widest range of views in the survey of all the questions asked in relation to the traditional tools. Hand sketching was the tool of choice of very small and small firms but less dominantly so for the other measures assessed. Medium sized firms favoured physical modelling and large firms' orthographic projections. Least favoured by very small and small firms was hand rendering and medium sized firms identified pictorial view as being the least accurate tool. Large firms least preferred photography. None of the respondents commented that accuracy was not a characteristic of conceptual design which contradicted the literature review.

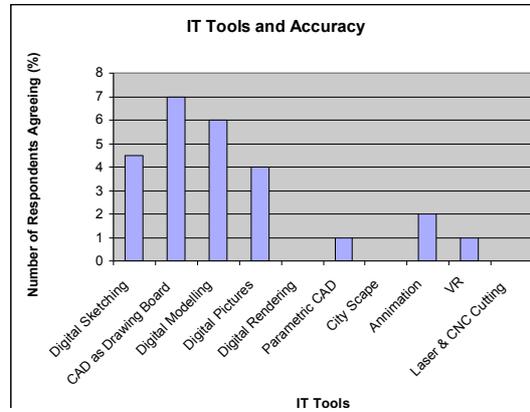


Figure 6. IT Tools and Accuracy

None of the respondents considered the IT tools to be strong in terms of accuracy. All, with the exception of medium sized firms, favoured CAD in this respect. Medium sized firms identified 3D modelling as being the most accurate as did large firms after CAD.

## 7. Studio Experiment

To pilot test some of the findings of this investigation, namely attitudes and working practices of designers, a design studio experiment was undertaken. Half of the students adopted SketchUp (a sketching application not CAD based and very easy to master) and digital sketchpads whilst the others adopted traditional techniques. The experiment was set to measure the following within a teaching environment of years 2 and 3:

- validity of digital sketching as a design tool
- speed: do digital sketching tools speed up the conceptual design process
- communication: do digital sketching tools enhance the communication of design ideas both to the designer and client
- could digital sketch pads be a substitute for or a compliment to pen and paper.

Students were instructed to keep a log of the number and duration of digital sketching iterations carried out. They were all subsequently surveyed to see what benefits or disadvantages had resulted from the experiment.

## 8. Studio Experiment Findings

Given the pilot nature of this experiment and not testing practising architects / designers, the findings can only be viewed as indicative. The results were that the SketchUp group rated the software higher in terms of efficiency, flexibility and communication. The control group, who had adopted traditional freehand sketching, was obviously impressed by what they saw from the SketchUp group too - everyone who answered the questionnaire, both SketchUp and control groups, said they would consider adopting SketchUp in the future. About half of the control group felt they had been disadvantaged by not using SketchUp.

Unfortunately only one of the SketchUp group had used the digital sketchpad. The others cited access problems, we only had five pads, and difficulty in mastering a technique which they felt was unnatural compared to freehand sketching. The one user however thought it useful and had employed it with both SketchUp and Photoshop.

## 6. Conclusions

Although conceptual design is capable of being defined by practitioners in many different ways all agree that it is an iterative creative process that involves the identification and evaluation of different design solutions to satisfy the Clients brief. The essential requirements of the process are flexibility, visualisation, communication and speed.

Free hand sketching is without doubt the traditional tool of choice of the conceptual designer as unanimously confirmed by all respondents. A slight variation in choice of tools was then evident according to the size of firm and also with the type of work undertaken.

Small and very small firms rated hand rendering and photography as their second most preferred tools of choice. Medium sized firms favoured pictorial views, hand rendering, physical modelling and digital photography as their second tool of choice, as did large firms although they equally also chose orthographic projections as a second tool of choice. The data seems to suggest that the size of firm has an influence upon the traditional tools utilised by practitioners upon conceptual design as does the type of commission undertaken, although all use hand sketching extensively.

Exposure to and experience of IT tools is a key factor to their adoption in the workplace. There was evidence that the larger the firm and the greater the diversity of the workload away from housing the greater the experience of IT tools became. The latter finding confirms a similar study of architectural practices in the US (KALISPERIS 1994). The data also revealed that the more complex the IT tool, e.g. DESKTOP VR, CNC, and Parametric CAD, the less exposure there was to them. There was general

agreement upon the lack of flexibility of the IT tools; this was surprising as this had been identified as one of their strengths. Conversely there was agreement as to the efficiency of the IT tools. All but one of the respondents had experience of some of the IT tools identified and many had experience of more than one which suggests that practitioners are now experimenting with these tools.

The data also revealed that most had experience of 2D CAD drawings replacement where CAD was not being utilised to its full potential and further that no attempt had been made to change work practices in the adoption of this new tool. Rendered images and 2D CAD drawings replacement were the IT tools most utilised in conceptual design. It was surprising, however, given the superiority of hand sketching that digital sketching did not prove more popular. Users of digital sketching rated it highly in terms of creativity, communication, efficiency and flexibility.

IT tools are clearly not essential to the conceptual design process but are, when utilised appropriately, capable of supporting and enhancing existing working practices. For this to happen, attitudes and working practices amongst conceptual designers may need to change and adapt to these new tools to take advantage of the potential benefits. This may necessitate supplementary material and training resources. KALISPERIS (1994) states in this respect:

Continuing education should be offered for practicing architects so that they could become familiar with possibilities presented by incorporating computers into the design process and not simply utilising them as drafting tools.

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## A COLLABORATIVE DIGITAL DESIGN WORKSHOP

*An ANN-based paradigm approach*

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**Abstract.** This paper relies on observation and analysis an internationally digital design exchange activity, “The FCU & Bartlett School of Architecture, university college London (UCL) digital architecture workshop” to propose an educational model based on the artificial neural network (ANN). We expect that the results of this work can lead to the establishment of a scoring mechanism that can "adapt" to the difficulty of assigned problems and assess students' progress. An international technological exchange workshop based on the theme of digital design is helpful to attain an accelerated heightening in the quality and experience of education. This is going to be an educational trend and increasingly prevalent in the future. A successful educational curriculum in digital design relies on a concerted effort amongst curriculum framework, learning activities, and course content. While, an internationally exchange digital design workshop is different from traditional "semester-based" units of curriculums. The short-term educational models are required high degrees interaction and collaboration. On the other hand, artificial neural network system that is context aware in ill-defined and complex environments is highly adaptive. It can extract, interpret and use the context information and adapt its functions to obtain an optimal correspondence between “context change” and “desired goal” efficiently. Therefore, an ANN-based pedagogical mechanism is able to encourage students to select relatively difficult design problems and promote more design originality, interaction and collaboration.

## 1. Background and Objective

Since the introduction of the computer-aided design and the application of internet technologies, CAAD pedagogical paradigms have shifted to the design-oriented teaching, which have to not only satisfy the inheritance of computer technology but also streamline the design thinking, (CHEN, 2004). The educational environment of architectural design has been changed and evolved. Electronic design workshops (MCCULLOUGH, 1900); virtual design studios (BRADFORD, 1994); and collaborative design workshops, (CHIU, 2001) have subsequently emerged, and they set a foundation for digital design learning. However, excessive emphasis on the application of digital utility technology is not entirely beneficial to the creativity in design, therefore, in the ACADIA '98 international conference, the “digital design studio” was its theme, (SEEBOHM, 1998). The domain is expanding, and pedagogy shifts from technology-driven, toward methodology-driven.

The nature of pedagogy is to strive for a well-functioning "adaptive" system. While there should be positive, flexible interaction between the content of instruction and the quality and quantity of learning within such a system, design instruction is full of inherent indeterminacy and complexity. Thereby, whether do achievements of a design workshop, a special case derived from digital design studio, truly reflects students' progress especially under such a short-term teaching and learning? It becomes absolutely indispensable to know how to operate, evaluate, understand, construct and analyze a design workshop.

Based on literature review, this paper proposes certain hypothesis, and relies on experimental education, actual research, and participant observation. Expected results include: (1) reflective analysis on computer-assisted design educational models, (2) establishment of theoretical framework, (3) operation of digital design and records of its physical fabrication process (4) assessments of differences between theory and reality, (5) conclusions and suggestions.

## 2. Theory and Method

Can Students' level be proved upgraded within extreme short-term learning? Artificial intelligence experts in the field of design have proposed a long series of "cognitive models" attempting to explain designers' design behavior. Additionally, “Cognition Models” can serve as reference to teaching framework, platform for pedagogical research or tool for developing computer-aided-design. A design cycle may be regarded as”

process of delivering information to solve the problems”, (NEWELL, 1957), it requires to be decomposed into distinctive steps and well-defined plan that the “Decision tree” will not stretch out without limits. Therefore, the process to modify a problem shall be involved in “Decision-making circle” (ASIMOW, 1962). However, the aforesaid models that base on “Rule-based Algorithm” have congenital limitation and are applied to well-defined problems solely, whereas most of the design addresses Ill-Define problems (ROWE, 1987). Creative design is usually expelled by normal rules. Artificial neural network, which is good at addressing ill-defined and non-structured problems, has scientific algorithm and evaluation index. It thus provides better solutions to develop “Design Cognition” and therefore, promote “Design learning”.

http://www.arch.fcu.edu.tw

**2005**  
**逢甲建築暨倫大bartlett雷數位設計展**  
**Archi, FCU & Bartlett, UCL Digital Architecture Exhibitions**

2005/03/02 (三) 18:00 - 19:00 2005逢甲建築暨倫大bartlett雷數位設計展及數位設計展覽開幕式暨茶會 逢甲大學忠勤樓五樓中庭  
Start of *marcosandurjon Archi FCU workshop* and opening of *marcosandurjon exhibition*

2005/03/02 (三) 19:00 - 20:30 專題演講：倫大bartlett雷馬可士與馬力安之實驗性數位建築創作 逢甲大學忠勤樓八樓804 演講廳  
Public lecture *marcosandurjon experiment*, Marcos Cruz back to back with Marjan Colleitt

2005/03/03 (四) - 03/09 (三) 倫大bartlett雷Marcos & Parjan的互動合作數位建築 逢甲大學忠勤樓五樓505展覽室  
10:00-17:00/ Close on Sunday *marcosandurjon and archi to bartlett digital architecture exhibition*

2005/03/11 (五) 18:00 - 19:00 逢甲建築暨倫大bartlett雷數位建築教學成果展覽開幕式暨茶會 逢甲大學人恩大樓一樓穿堂  
Opening of *marcosandurjon Archi FCU workshop exhibition*

2005/03/12 (六) - 03/18 (五) 逢甲建築暨倫大bartlett雷數位建築教學成果展 逢甲大學人恩大樓一樓穿堂  
10:00-17:00/ Close on Sunday *marcosandurjon Archi FCU workshop exhibition*

主辦單位Organized by: 逢甲大學建築學院及人文社會學院  
協辦單位Co-organized by: 逢甲大學圖書館、人文社會學院展覽中心  
協辦單位Co-organized by: 逢甲大學美術系數位建築設計中心、資訊處、國際處、公關處、大覺大學機械與自動化工程學系、國立交通大學建築研究所  
贊助單位Sponsored by: 行政院國家科學委員會、逢甲大學建築學院中庭展示會、財團法人數位建築設計展覽會、聯群設計有限公司(聯群建築設計)、綠島彩色印刷

Figure 1. Poster, (copy from FCU.)

The research is to observe an internationally collaborative digital design workshop – The Archi, FCU & Bartlett, UCL, digital architecture workshop (SHU, 2005), (Figure 1). We propose a neural network model operating in a virtual environment and conforming to circumstances in accordance with the workshop's instructional framework, features, and requirements. We then validate and revise the ANN-based instructional model via on-site observation and participation in the instructional process. The ANN-based framework shall represent design process and evaluation index in virtual environment through simulation of Neural-Solution software and can obtain from learning the predictability that is based on induction and inference, (Figure 2).

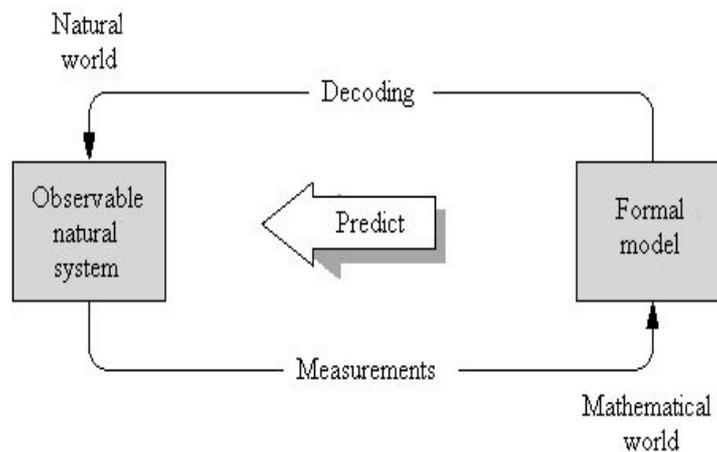


Figure 2. Nature system and formal models, (PRINCIPE, 2000)

### 3. Process and Result

#### 3.1 FCU & BARTLETT, AND UCL DIGITAL ARCHITECTURE WORKSHOP

International design workshops give students or academics an opportunity to share ideas and achieve progress in design learning. The Archi, FCU & Bartlett, UCL, digital architecture workshop invited Marcos Cruz and Mariano Colletti, the lecturers of Bartlett School of Architecture, University College London, to give an eight-day teaching demonstration of digital design in Taiwan. In spite of the short length of this activity it elicited exceptionally high expectations. The workshop required students to produce works and fast converge toward a certain level learning result. It also

emphasized students' collaboration. During the eight-day curriculum (0302~0309/ 2005), they attempted to "individually express their own works", and then, to "compile them into an architecture", which was not only a technical "content-aware smart entity" (MARI, 2000) but also a feasibility of visual and dynamic "zoomorphic form" (HUGH, 2004). The curriculum was divided into 3 phases. During Phase I, The 26 qualified and selected students and they were to individually develop the feasibilities by two groups: inhabit wall and sp-line animal. During Phase II, after critique (Figure 3), the students' creations were classified by attributes into 6 elements (including architecture structure and facility installation) such as external wall, internal wall, canopy, furniture, sensor and cable as well as animation. And, following was to "integrate" those elements. During Phase III, the integrated design did not stay in virtual space but proceeds cutting of substantive materials (timber, metal and so on) by Computer Numerical Control (CNC) machines. And accompanying with draft-models and animations, recording design process, the cut or bended parts were assembled for review and exhibition in order to display instructional results, (CHEN, 2005), (Figure 4).



*Figure 3. critique*

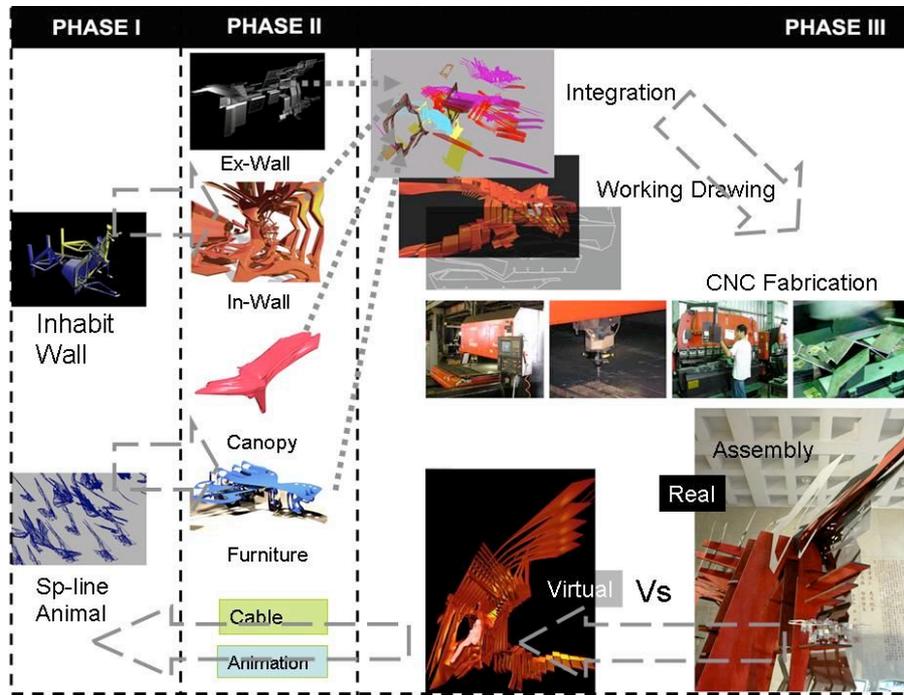


Figure 4. Flowchart of the Archi, FCU & Bartlett, and UCL digital architecture workshop

### 3.2 CONSTRUCT NEURAL NETWORK MAP SITUATION MODEL

An artificial neural network uses computer to simulate organism's nerve network. Network algorithm is executed by parallel and distributive units—neurons and their connections (synapses). It is good at synchronizing process of multiple data and its output values may be approximate to desired output values through adjusting synaptic weights of neurons. Therefore, there is no need to make any prior assumptions about the relationship between the input data and output value when sufficient cases are provided. This “adaptive” algorithm is especially appropriate to judge non-structured decision-making. It is able to learn, recall, induce and deduce from the input environmental information, (CHANG, 2004). Basically, design of neural network depends on following principles. Firstly, the network architecture is decided by the complexity of events to be processed. The contents of which includes deciding quantity and layers' number of neurons, back-propagation or feedback mode. Secondly, supervised or un-supervised learning is judged by whether desired output values exist in learning process. Finally, selecting suitable learning algorithm according to characteristics of problems to be processed (GIROSI, 1995). We have built up a neural network to simulate

teaching process according to characteristics of digital design workshop. The network was constructed according to the following steps:

### 3.2.1 .Decide network model:

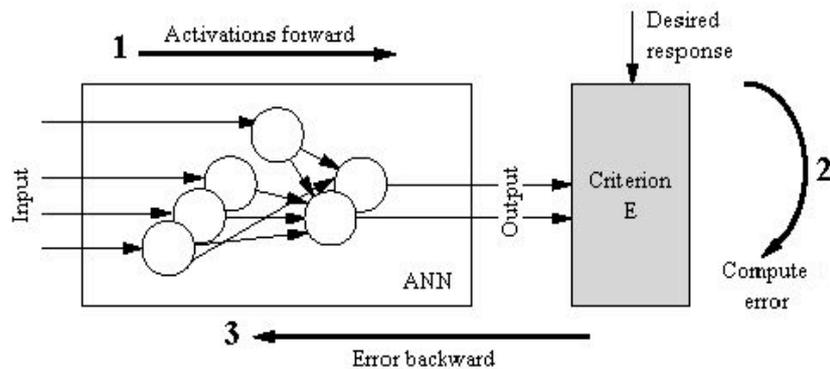


Figure 6. Chaining of operations in the back propagation algorithm (PRINCIPE, 2000)

In order to obtain a certain quantity of teaching achievements within a short period, parallel process of designs shall be adopted at initial stage. In consideration to limited budget for entity construction and endeavor for students' collaboration, the better strategy is to classify different elements from numerous teaching results and, select them thereof to integrate a design creation, process construction drawings and construction accordingly. Input end shall be multi-dimensional vector, output end unitary-dimensional vector. Network framework (architecture) is presented by “multi-layer perceptron, (MLP.), plus back-propagation, (BP), network” (Figure 6).

### 3.2.2 Determination of learning attributes:

We adopted "supervised" learning for fast convergence. Supervised learning means that the network weights are adjusted in accordance with the "teacher's" desired value. Adjustment on weights shall be performed until difference (error) between output and desired values less than certain “threshold value”.

### 3.2.3 Select algorithm:

Selecting “Least-Mean Square algorithm, LMS” is the most common use according to characteristics of reinforcement (back-propagation) network architecture and attributes of “supervised” learning. It looks for “Mean-Square-Error, MSE” (3), by adjusting weight value  $\Delta w_{ji}$ , (4), according to “steepest decent”. MSE is also named as “Cost Function”, which is index of error between “output value  $y_k$ ”, (1), and “desired value  $d_k$ ” of neuron.,

(3), Whereas rate of “adjusting weights”, (5), is named as “learning rate  $\eta$ ”. The  $\eta$  value affects rate and stability of learning. Important functions, (4), and equation of “Least-Mean Square algorithm, LMS” are per followings, (HAYKIN, 1999).

- In the network, input value of number j neuron in the  $n^{\text{th}}$  layer is Non-linear function of neuron in the  $(n-1)^{\text{th}}$  layer, “output value” of the  $(n-1)^{\text{th}}$  layer □

$$Y_j^n = f(\text{net}_j^n) \tag{1}$$

- “summation function” of the  $(n-1)^{\text{th}}$  layer □

$$\text{net}_j^n = \sum_i w_{ji}^n y_i^{n-1} - b_j^n \tag{2}$$

- “mean-square error function” :

$$E = \left(\frac{1}{2}\right) \sum_K (d_k - y_k)^2 \tag{3}$$

- “weight adjusting value” □

$$\Delta w_{ji} = \eta \frac{\partial E}{\partial w_{ji}} \tag{4}$$

- “adjusted weight value” □

$$w_{ji}(p) = w_{ji}(p-1) + \Delta w_{ji} \tag{5}$$

### 3.3 ENCODING DATA AND NEURAL NETWORK TESTING

TABLE 1 En-code data

Inhabit Wall	11	12	13	14	15	16	17	18	19
Sp-line Wall	21	22	23	24	25	26	27	28	29

We had to encode the data in order to perform simulation and verification using the neural network software, “Neuro-Solutions”. During phase I of design workshop, students were grouped into two: inhabit wall and sp-line

animal. Teachers select 9 works from each group. They were encoded: Prefix “1” represented inhabit wall group (i.e. 11, 12, 13 etc.), and prefix ”2” represented sp-line animal group (i.e. 21, 22, 23 etc.), (Table 1).

### 3.3.1 To select train and test data set:

During Phase II, students carefully selected every time 4 from above 18 works to play such architecture elements as external wall, internal wall, canopy and furniture that affect the “style” and, assembled those elements to a whole creation. Assembled works are displayed in sequential order and noted down individual code of those four elements for open review and critique. The aforesaid 4 codes shall become “input end” of train data and scores gained by assembled creations become “desired value”. As shown in the table that the winner work 3 is composed of 25, 14, 22, 19, scored 90 (Table 2). Additionally, it was required to group data in two: one was “train set” (Table 3), the other was “Test set” (Table 4).

TABLE 2. Work No.3 is composed of (25, 14, 22, 19), scored= 90

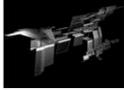
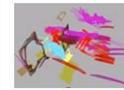
No.3	25 	14 	22 	19 	90 
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TABLE 3. Train set

Works	INPUT				Desire
	Ex-wall	In-wall	Canopy	Furniture	Score
No.1	21	13	16	29	85
No.2	14	17	25	27	60
No.3	25	14	22	19	90
No.4	17	23	28	12	80
No.5	15	16	29	27	70
No.6	11	14	17	22	65
No.7	23	26	15	18	75
No.8	22	23	27	13	50
No.9	19	15	29	21	40

TABLE 4. Test set

Works	INPUT				Desire	
	Ex-wall	In-wall	Canopy	Furniture	Score	
No.11		24	13	15	28	85
No.12		17	17	25	27	65
No.13		22	16	24	19	85
No.14		15	23	28	15	80
No.15		16	16	29	27	60
No.16		12	14	17	22	75
No.17		23	26	19	18	70
No.18		22	23	27	13	55
No.19		19	15	29	21	45

3.3.2 Training

We manipulated “Neuro-Solutions” software as train simulation, firstly we selected multi-layer back-propagation networks, And then to proceed the followings in sequence: to input train data, to select LMS algorithm, to select activation function, to adjust learning rate and set “threshold” of MSE between output scores and target output scores (Figure 7), (Table 5), It stopped at 325 epochs when “Mean-Square-Error, (MSE)”= 0.001 and learning curve approached to stability.

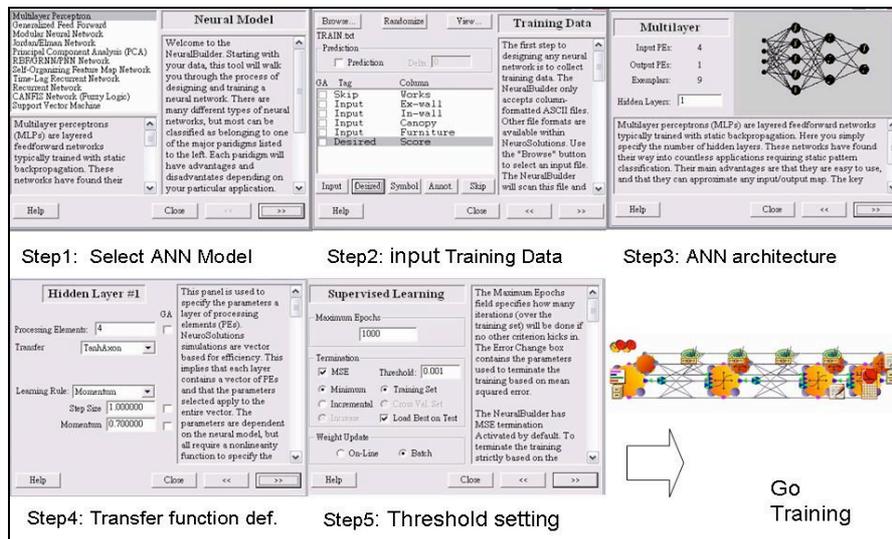
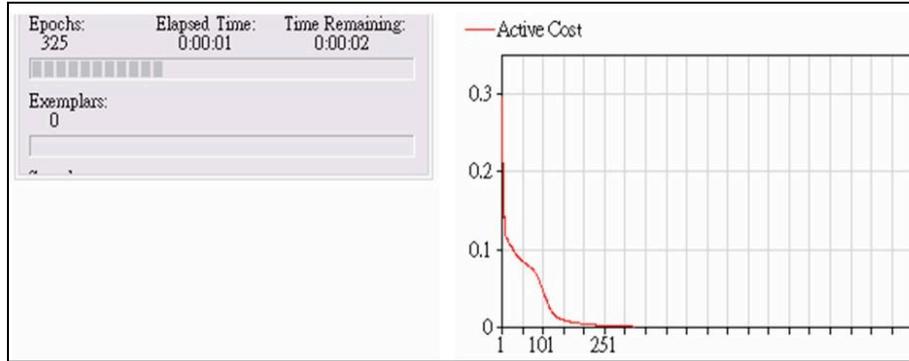


Figure 7. Training process flowchart for Neuro-Solutions software

TABLE 5. Train 325 epochs, until MSE is 0.001



### 3.3.3 Result

Output values of “train set” will be very close to desired scores if the network training is completed. It represents that the system has capabilities of induce and deduce. Therefore, the new output value should be close to desired scores while using “test set” to confirm training results. In fact, although their currents map each other approximately yet there sometimes existed large differences between values. We can deduce that means value inferred by network is higher than what students actually obtain if output value is higher than desired score, and therefore, there existed space for students to progress. Vice versa, students’ level have exceeded over the value inferred by network (Works’ No. 12; 13; 17), (Table 6).

TABLE 6. Test Results: Output scores Vs. Desired scores

Des Score		Out Score
85.000000000000		88.319859615666
65.000000000000	<b>No.12</b>	45.168132695852
85.000000000000	<b>No.13</b>	65.766580971638
80.000000000000		81.797989389942
60.000000000000		62.493419070371
75.000000000000		70.543502629333
70.000000000000	<b>No.17</b>	51.843671816590
55.000000000000		49.089979819925
45.000000000000		42.481135774854

In accordance with these observations, student achievements under this instructional framework are influenced by two main types of factors, one of which being the students' talent and effort, the other being the difficulty of integrating the selected architectural elements. The former is implicit and difficult to measure, while the latter is explicit. Design results can be obtained and expressed as the output value of a neural network. This output value can serve as a standard of the difficulty of integrating architectural elements. In addition, the difference between the output score of the neural network's "machine calculations" and the desired score obtained by "human cognition" provides a yardstick for determining whether a student is making progress. Therefore, it is worth noting that these findings indicate that design learning is not a totally goal-oriented process. Design learning can be considered a process of dynamically adjusting weights to achieve corresponding "desired value."

#### **4. Conclusions and Suggestions**

The success of the Archi, FCU & Bartlett digital architecture workshop was to highlight skillful control of design procedure that presented context relation through input data mapping output results. ANN-based architecture allowed close and intensive collaboration among teachers and students to fast converge toward high quality design results. The educational model in design learning was different from traditional ones that restricted input conditions with rigid specifications; design results were required to meet the rules set under constrains. Therefore, it became time consuming to induce process; and the design focuses were usually too dispersed to be converged by inexperienced designers. The demonstration in this digital design workshop was though very short but design results are highly recognized. Exhibitions were held March 12 –18, 2005 at "Ren-Yan" exhibition Hall, Fen Chia University; (Figure 8), from September 9, 2005, at Hamburg Culture Policy Research Institute, Germany, and then, at The Bartlett department of Architecture, University of London, UK afterwards. Not only that, this research represented design process through manipulating neural network algorithm. The differences between network "output value" and "desired score" proved that the teaching program promoted students' progress substantially.

In addition, several neural network algorithms have been developed to meet different problems. However, are those theories suitable to support the other cases of design education? Or are they able to be adopted to construct computer design-aided system? For example, it may be more appropriate to adopt "dynamic" "Time-Delay Neural Network" if the evaluation of a design

work is influenced by the evaluation of the previous work. Or it is possible to construct computer design-aided system by adopting genetic algorithm and adopt its crossover and mutation functions to sort out poor architecture elements at an early stage to ensure design quality and generate design creativity. We believe that, in the field of design, neural networks should not be used exclusively in design education, but also in the development of computer-aided design systems.



Figure 8. Installation and exhibition at “Ren-Yan” exhibition Hall, Fen Chia University

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## **Section II: Computer Applications and Future Architecture**

## DESIGN INFORMATICS

*A case based investigation into parametric design, scripting and CNC based manufacturing techniques*

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**Abstract.** The research paper exemplifies a novel information integrated design technique developed at ONL (Oosterhuis and Lenard), Netherlands, specifically appropriated for manifesting complex geometric forms. The ‘informed design technique’, apart from being highly instrumental in conceptualizing and generating the geometric component constituting architectural form in a parametric manner, is also efficiently utilized for precise computer aided manufacturing and construction of the speculated form. Geometric complexities inherent in contemporary architectural constructs and the time spent in appropriation of such topologies, fueled the ‘informed design’ approach, which caters to issues of timely construction, precision oriented design and production (visual and material) and parametric modeling attuned to budgetary fluctuations. This design-research approach has been tested and deployed by ONL, for conceiving ‘the Acoustic Barrier’ project, Utrecht Leidsche Rijn in the Netherlands and is treated as a generic case for exemplifying the ‘informed design’ technique in this research paper.

The design methodology encourages visualizing architectural substantiations from a systems perspective and envisages upon a rule based adaptive systems approach involving extrapolation of contextual dynamics/ground data in terms of logical ‘rules’. These rules/conditionalities form the basis for spawning parametric logistics to be mapped upon geometric counterparts exemplifying the conception. The simulated parametric relations bind dimensional aspects (length, width, height etc.) of the geometric construct in a

relational manner, eventually culminating in a 3D spatial envelope. This evolved envelope is subsequently intersected with a 'parametric spatio-constructive grid', creating specific intersecting points between the two. A pattern of points attained from this intersection: 'the point cloud' serves as a generic information field concerning highly specific coordinates, parameters and values for each individual point/constructive node it embodies. The relations between these points are directly linked with precise displacements of structural profiles and related scaling factors of cladding materials. Parallel to this object oriented modeling approach, a detailed database (soft/information component) is also maintained to administer the relations between the obtained points. To be able to derive constructible structural and cladding components from the point cloud configuration customized Scripts (combination of Lisp and Max scripts) process the point cloud database. The programmed script-routines, iteratively run calculations to generate steel-wire frames, steel lattice-structure and cladding panels along with their dimensions and execution drawing data. Optimization-routines are also programmed to make rectifications and small adjustments in the calculated data. This precise information is further communicated with CNC milling machines to manifest complex sectional profiles formulating the construct thus enabling timely and effective construction of the conceptualized form.

### **1. ONL and the Notion of Multi-disciplinarity**

ONL, a multidisciplinary office directed by Prof.ir. Kas Oosterhuis and visual artist Ilona Lenard performs as a design-research body driven by contemporary Information communication technologies, focusing upon issues of collaborative design in a media (digital and electronic) augmented spatial environment. The notion of visualizing a context embedded design solution, at ONL is conceived through building a generic connectivity between geometric styled-prototypes (spawned by existent spatial scenarios) articulated with parametric relations and a corresponding data base (influencing parameters: speed of traffic etc) of their contextual settings. Such inclinations allow one to simulate emergent spatial behaviors through real time data exchange and a networked nature of the architectural grammar constituting corresponding physical prototypes. ONL, in order to manifest such an agenda, embodies a synergistic merger of the expertise offered by architects, visual artists, web designers and programmers, who work together and join forces, practicing the fusion of art, architecture and technique on a digital platform. The notion of fusing information (context driven data scapes): soft component with the physical materiality of architecture: hard component to generate a co-evolving spatiality drives the design-research ideology at ONL. The research paper describes a design strategy: the

‘informed design’ exemplifying this synergistic merger (of art and science) for the case of the ‘Acoustic Barrier’ project (Figure 1) developed at ONL.



Figure 1. The Acoustic barrier project (with the Cockpit/Hessing showroom): ONL

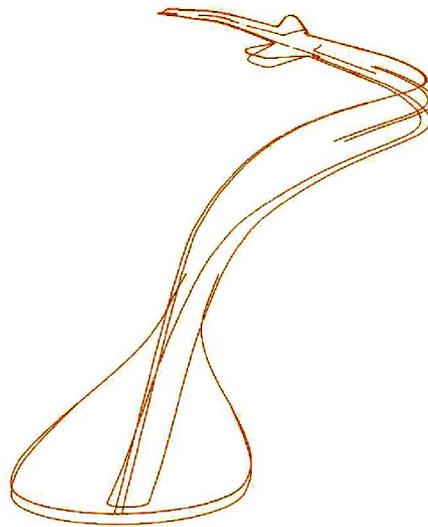
## 2. Form Finding

ONL in its attempt to decipher ‘form’ delves into diverse processes of utilizing digital to analogue means of mapping contextual dynamics onto generic geometrical compositions. The stylization process ranges from hand drawn curvilinear geometry, which is eventually digitized and parameterized, to sophisticated digital simulation based generative geometry to tactile conceptual prototypes (physical), which through a process of reverse engineering are translated into the digital realm. A relatively intuitive approximation of sets of curves, surfaces and masses is hence formulated as the conceptual root at this stage. The notion of developing a generic connectivity between the real and the virtual is employed over these conceptual prototypes by computational means. These computational means range from developing inherent connectivity of geometric conceptions with database structures, visualizing initial sketches as continuous curves and surfaces (NURBS), developing generic relations between geometric components by means of parametric design and deploying self developed scripts focusing upon extraction of digital data required for direct file to factory processes.

For the purpose of this research paper, we will specifically concentrate on the Acoustic barrier project and will subsequently elaborate upon the design development and form finding phase deployed in visualizing the projects complex curvilinear, almost reptilian form.

### 3. The Acoustic Barrier: Parametric Set-Up (Conceptual Resolution)

The project based in Utrecht Leidsche Rijn in the Netherlands aims to combine a 1.5 km long acoustic barrier with an industrial building (the cockpit/Hessing showroom) of 5000m<sup>2</sup>. The conceptual underpinning for the project is laid by means of articulating sets of NURBS curves, suggestive of a relation between height, width and the length of the barrier. These curves are stretched along the 1.5 km stretch of the highway and form the above-mentioned spatial guideline for the project (Figure 2)

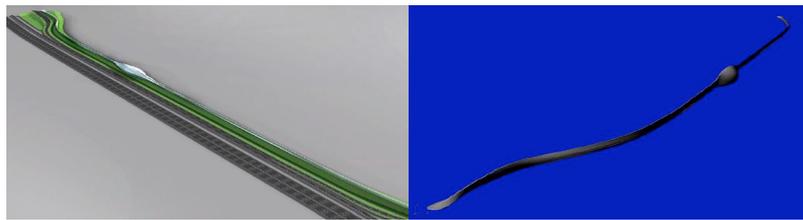


*Figure 2.* Set of related curves defining the topology of the Acoustic Barrier

Subsequently, the deployment of computational logic to the abstract sets of curves is contextually derived with respect to the speed/flow of passing traffic. The swarm of cars streaming at a speed of 120 km/h along the acoustic barrier site lays the rationale for deriving parametric rules, specifically linked with developing generic geometric relations between the NURBS curves. This relational set up is specifically defined (in this case) owing to the manner in which the form of the acoustic barrier will be seen by the commuting mass. A relational rule that satisfies issues of scale, surface-continuity and smoothness (non-distracting) of the construct conditions the aspects of styling, visual perception and form generation. The barrier, a “one mile building” seen from the perspective of the highway,

(considering the above mentioned criteria) derives its curvilinear form from the basis of a context driven rule: the length of the built volume of the Cockpit emerging from the acoustic barrier will be 10 times more than its height.

This parametric relation regulates the linear form of the barrier to generate transversal sections, which are smoothly transformed from concave towards convex faceted surfaces with occasionally emerging sharp longitudinal folds. This parametric relation once set, and mapped onto the sets of curves yields a relatively smooth curvilinear surface with an equally smooth transient bulge, which houses the cockpit/Hessing showroom space (Figure 3). This ‘informed geometry’, which creates the three-dimensional skin for the acoustic barrier not only operates as a ‘form generator’ but also proves to be a ‘form regenerator’, owing to the geometrically relational (parametric) dependence of the generic curves. Any parametric alteration made to the curves, consequently leads to a regeneration/re-appropriation of form in accordance with the context based, basic rule (which induces the relation between the dimensional aspects of the 3d form) hence reflecting a new, yet controlled spatial configuration.



*Figure 3.* Set of related curves with the parametric relation mapped onto them resulting in the bulging topology

### 3.1 Parametric Set Up (Finer Resolution: The Point Cloud)

In order to derive a finer degree of control over the obtained (conceptual) three-dimensional form (from the network of curves), a ‘parametric structural grid’, which obtains its dimensional logic from an optimal construction, oriented perspective (e.g. dimensions of glass panels) is mapped onto the surface of the conceptual construct. This intersection results in the extraction of a distinct series of nodes/points, collectively called the ‘point cloud’ (Figure 4).

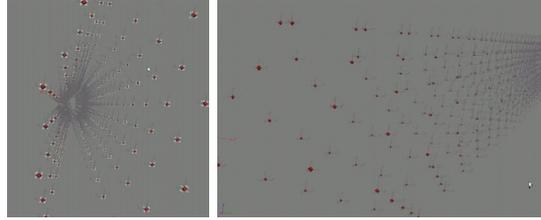


Figure 4. Point cloud generated from the conceptual 3D envelope

The point-cloud represents a parametric set-up: it describes the volume by points and establishes spatial relationships between them: by serving as a generic information field concerning highly specific coordinates, parameters and values for each individual point/constructive node it embodies. The sound barrier contains approximately 7000-point objects, whose relations are administrated in a database. These relations are directly linked with precise displacements of structural profiles and related scaling factors of cladding materials. This linkage is further extracted from the point cloud body by running specialized ‘Scripts’ developed at ONL. These will be explained in detail in the next section (1.4).

Apart from creating a precision oriented geometric configuration, working with parametric models also creates an excellent communication space for the stakeholders in the building design process and enables one to discuss varied dimensions composing the quality of the proposed space. Such an approach also releases the design process to collaborative engineering opportunities during the execution phase of the project and hence creates an open framework for generating meaningful interactions between clients and users.

#### 4. Generative and (Re) Generative Design by Scripting

The “point-cloud” is a crucial model fostering generation and [re] generation of all point-data, parameters and the relations between the points (constructive nodes). However, in order to develop a constructive spatial structure and to manufacture the glazing and cladding material for the acoustic barrier, a novel application was programmed. (Scripting and programming refer to the process of writing a simple program in a utility language to orchestrate behavior. It consists of a set of coded instructions that enables the computer, to perform a desired sequence of operations). This application, programmed in diverse scripting languages [MAX-script, Auto Lisp] connects to a database system developed for handling all point-data and their relations.

The developed scripts operate on a simple rule: all points should look at and analyze their neighbors (in terms of co-ordinates and proximity). Such a rule-based interaction is akin to the notion of Flocks: Flocking behavior and Boids, as stated by Craig Reynolds. Boids, replicated in the case of the digital model by points/constructive nodes, are active members of a flock, calculating their position in real-time in relation to each other. Each Boid, locally, extends the principle incorporated by Flocking mechanisms of computing a limited set of simple rules, towards scripting the Point cloud behavior. This behavior of localized and limited computational performance by parts of an entire system, bring about complex reactions at a holistic level. These simple sets of rules, can be interpreted as the behavior producing genes of the nodes (junctions in the prototype) and these behaviors in-turn, are directly related with the formal articulation of the prototype: a bottom up approach directly inducing top down performance determination.

The programmed script-routines, based on such flocking principles, when applied on the point-cloud iteratively run all the calculations to update:

- Steel-wire frames with its databases
- Steel-lattice-structure including all the execution drawings
- Dimensions and Execution drawings of glass plates.

The scripting computational component operates at three levels, each component embedding within it a series of iterative operations. Exemplification of the three scripting levels in relation with their operational performance is as follows:

#### 4.1 SCRIPT 01

**Basic operation:** Loads the Rhino generated .DWG files containing the point clouds > Makes a single mesh out of them > Offsets this mesh by the r brace value (radius of the braces conceived by the glass manufacturer that will be used for the assembly of the glass plates) > Creates a series of spheres cantered to the vertices of this mesh that represent a second point-cloud to be used exclusively for the glass plates

Script 01: Overview of Input parameters:

```
global fmin=01
global fmax=44
global rbrace=61
global threshold=250
allthepoints=#()
allcount=0
```

The script operates at two levels to perform the basic operation > Data administration phase and Mesh generation phase.

- Data administration phase: the operation involves a methodological extraction of data from the body of the point-cloud at three sub-levels namely
  - o Defining 'f min and f max values' (the range of segments to iteratively generate the requested data) and hence subscribing a dimensional aspect for limiting the administration process to a given length.
  - o Logistically naming and re-naming of the points (to be administered) in the point cloud
  - o Formulating an Array wise database of the points (based on X, Y, Z co-ordinate orientation)
- Mesh generation phase: after the data administration phase, the script generates a mesh, where each face in the mesh embodies a face of a glass plate including the Scaling of the glass plate.
  - o Scaling for the glass plates is defined by the 'r brace value' (radius of braces/scaling distance for fixing the glass plates: provided by the glass manufacturer). This value re-defines the distance parameter in the initial point-cloud configuration
  - o Projection of a re-configured point-cloud version > point-cloud + alternated displaced points normal wise aligned towards the orientation of the point (with neighboring points) is initiated through a scripted iterative process.
  - o A possibility for adjusting the Threshold value for searching for points can also be adjusted at this stage.

#### 4.2 SCRIPT 02

The second Script based operation is responsible for segmentation of the entire point-cloud body into bays of 9.33 m. This generation of segments dissects the barrier into three bays with 118 points each (Figure 5, a) and derives its logic from the sequence in which the foundations for the construct have to be laid. This basic dissection of the volume apart from being appropriate for Physical construction also proves to be beneficial in terms of CPU usage and data handling and hence tends to be much more efficient in the long run. Each segment contains a group of points and its corresponding mesh. The meshes in turn describe the glass plates and the amount of displacement needed by the extracted glass plates in between adjoining segments.

#### 4.3 SCRIPT 03

**Basic operation:** Builds the axis of the steel profiles that form the structure  
> Projects the planar surfaces generated between the points, defining shape and position of the glass panels.

The third script operates at two levels > Generating steel construction (Figure 6) elements and Generating Glass plate elements (Figure 5, b)

- The script geometrically generates steel construction elements in a wire-frame mode and exports the file in a specified protocol format for the production process (to be communicated to steel cutting machines). This protocol, set up by ONL and Meijers Staalbouw (the steel manufacturing company), presents the obtained data-file in several layers, colors and named elements. The layers are set up for different purposes, for example, describing the steel-profiles in a hierarchical fashion: horizontals, tubes, diagonal profiles scaled or non scaled, highway side elements, industry side elements, etc.
- Besides the steel sections, the generation of glass plates also happens in a similar manner but these are eventually flattened down on an X, Y plane for control and visual judgment purposes and to enable one to check the script wise generation of data.
- This geometrically generated data for the glass plates is further exported, arrayed, logically named and positioned in a complex Excel data sheet, which is directly utilized by the glass manufacturer for precision based production purposes.
- This sheet is also used for further data manipulation, like optimization or correction routines.

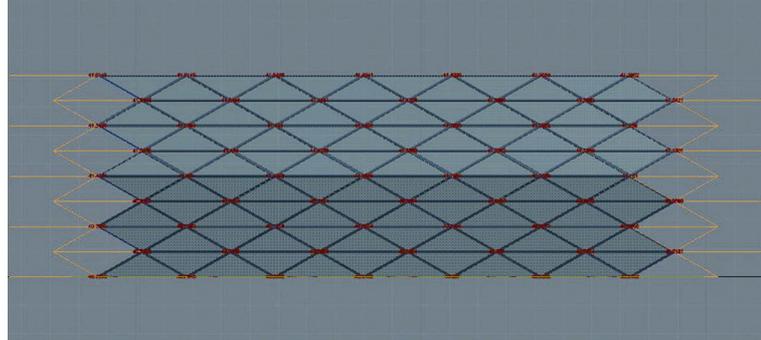


Figure 5, a. 3d wire frame model displaying a segment of the acoustic barrier and the relations between the points in the point-cloud

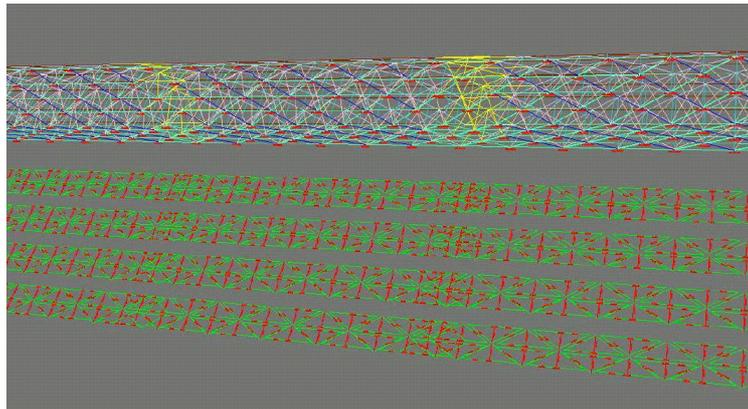


Figure 5, b. 3d wire frame model displaying a segment of the acoustic barrier and the administration of all unique glass plates [generated by script]

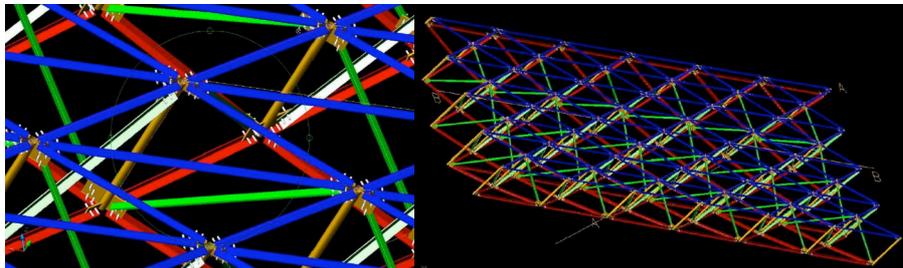


Figure 6. 3d model displaying a construction node [= point in point cloud] of the acoustic barrier and the steel profiles, steel plates and welded joints [generated by script]

#### 4.4 SCRIPT OPERATION OVERVIEW

The three scripts combined together present a methodological approach towards efficient translation of conceptual form to precise geometric and information rich entity. This sequential translation after offsetting the Rhino based point cloud (through script 1) through scripting can be listed in the following manner:

- Reading one after the other the .max files with the double point clouds
- Drawing 3d splines representing the axis of the steel profiles (structural) and the contours of the glass plates
- Unwrapping the glass surface and placing it on a horizontal plane as separate triangulated elements
- Naming each element with quotations
- Assigning Layer numbers to each element according to the sequence of construction
- Saving these elements (according to the specified protocol) in separate files segment after segment:
  - o One .dwg file for the steel construction (to be exported to the steel company)
  - o One .dwg file for the glass plate manufacturer
  - o One .txt file for the glass plate manufacturer containing entries with essential data for every glass plate individually (for glass manufacturer)
  - o Two separate files containing all the pairs of plates that form an angle higher than 10 degrees (for glass manufacturer)
  - o One .max file containing the complete segment of 18 m length and 118 points
- Splitting of the last generated point cloud segments (script 1, generates segments of 18m length constituting 118 points) into two 9 m segments constituting 59 points (required by the steel manufacturer bearing in mind the foundation stages) and saving them as separate .max files for the steel manufacturer.

This comprehensive and precise data, processed via the Scripting and Generative design components is further communicated to the manufacturing units for computer aided manufacturing purposes (CAM).

### 5. CAM Techniques

CAM strategies are dealt with in a rather coherent fashion throughout the design and development stages of the acoustic barrier project. A parallel development and maintenance of a database system, which stores the script-



specified timeline. The parametric design conception, filters down to the smallest detail (the point/construction node) and results in the development of two generic details to mount either glass-plates or expanded steel-plates towards the steel-structure.



Figure 8. Assembly of unique construction nodes and vertical frame at Meijers Staalbouw Factory, from parametric 3d model to mass customized production

These details, being parametric in nature, efficiently adapt to the dimensional and orientational (towards the steel structure) variation prevalent in each mounted glass-plate or steel-plate and hence proves to be a vital performative aspect, when conceiving complex spatial topologies. The database, which embeds these variations in numeric arrays is subsequently communicated to and executed by the manufacturing units to produce customized details with utmost ease and precision (Figure 8).

The efficiency and speed involved in the production process, provides both, the architect and the engineers the opportunity to erect and test/analyze 1:1 prototypes (crucial portions of the construct) for spatial and structural purposes at a relatively early stage, hence deploying corrective measures and

speeding up the realization of such complex projects. Hence the assembly phase (Figure 9) is reduced to an exercise of connecting precisely named/numbered parts (more like a kit of parts scenario) in a sequential manner to produce a holistic topological marvel.



*Figure 9.* (left) Perspective view of the assembled façade, (right) perspective displaying the parametrically generated steel structure and glass plate cladding.

## 6. Conclusion

A design-informatics hybrid, the multi-disciplinary techniques exemplified in the research paper, focuses upon a synergetic merger of technology, art and architecture to efficiently manifest much-speculated complex spatial constructs. Such ‘informed-design’ techniques, while promoting a parametric mode of operation, which enables one to communicate smoothly with three dimensional models and the project database, inherently involve a collaborative design approach, entailing derivation and appropriation of diverse tools and techniques (programming/scripting, graphic design, architecture, engineering and CAM) towards manifesting spatial constructs.

The acoustic barrier (looked at as a generic example) validates the effort needed to engage in a rather structured manner of data exchange between geometric and text based/numeric arrays (in an excel sheet) of contextual and spatial aspects and promotes the possibility of controlling and optimizing all the points/construction nodes from a datasheet. Also, the datasheet format makes it easier and faster to apply optimization and correction routines (by means of application of scripts in an iterative manner directly to the data, instead of geometrically intervening and intuitively tweaking a 3D model), which directly update geometrical data, and text-based information. Working with parametric models also creates an active

communication space for the stakeholders in the building process to discuss the qualities of the proposed environments. The parametric approach promotes setting up a relational equation between the design components, the contextual settings and subsequently the manufacturing of the construct, in the process promoting a healthy inter-linkage between the IT, design and the building construction sector. The 3d model becomes an output of a relational structure, promoting an interactive manner of re-organizing the spatial structure by means of manipulating the database underlying its formulation. This approach also helps in generating quick overviews of possible changes in form and structure of the proposed construct after decisive meetings with other stake holders (structural engineers, contractors, project managers etc), hence speeding up the decision making processes involved during the design phase. It hence opens up the design process for collaborative engineering in the phase of the execution of the project and promotes the design process as a meaningful medium of interaction with the clients and the users.

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## DESIGNING WITH MACHINES

*Solving architectural layout planning problems by the use of a constraint programming language and scheduling algorithms*

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**Abstract.** In 1845 Edgar Allan Poe wrote the poem “The Raven”, an act full of poetry, love, passion, mourning, melancholia and death. In his essay “The Theory of Composition” which was published in 1846 Poe proved that the poem is based on an accurate mathematical description. Not only in literature are structures present that are based on mathematics. In the work of famous musicians, artists or architects like Bach, Escher or Palladio it is evident that the beauty and clarity of their work as well as its traceability has often been reached through the use of intrinsic mathematic coherences. If suchlike structures could be described within architecture, their mathematical abstraction could supplement “The Theory of Composition” of a building. This research focuses on an approach to describe principles in architectural layout planning in the form of mathematical rules that will be executed by the use of a computer. Provided that “design” is in principle a combinatorial problem, i.e. a constraint-based search for an overall optimal solution of a design problem, an exemplary method will be described to solve problems in architectural layout planning. Two problem domains will be examined: the design of new buildings, as well as the revitalization of existing buildings. Mathematical and syntactical difficulties that arise from the attempt to extract rules that relate to the process of building design will be pointed out. To avoid conflicts relating to theoretical subtleness a customary approach has been chosen in this work which is adopted from Operations Research. In this approach design is a synonym for planning, which could be described as a systematic and methodical course of action for the analysis and solution of current or future problems. The planning task is defined as an analysis of a problem with the aim to prepare optimal decisions by the use of mathematical methods. The decision problem of a planning task is represented by an optimization model and the application of an efficient algorithm to aid finding one or more

solutions to the problem. The basic principle underlying the approach presented herein is the understanding of design in terms of searching for solutions that fulfill specific criteria. This search will be executed by the use of a constraint programming language, which refers to mathematical as well as to integer and mixed integer programming. Examples of architectural layout problems will be presented that can be solved by the use of this programming paradigm. In addition to this, a second programming approach resulting from the domain of resource-allocation has been followed in this research. It will be demonstrated that it is as well possible, to aid architectural layout planning by the use of scheduling algorithms.

## 1. Introduction

Designing a building is a complex task. It can be compared to composing music, writing a poem or creating an object of art. All these activities have in common, that they share artistically principles. Unfortunately these principles make the modus operandi of the design process difficult to generalize. It seems to be impossible to get an answer to the question of how an architect designs a building. A survey of 25 well-known architects about their individual production steps during the design process resulted in 25 different methods (Lorenz, 2004). Significantly none of these architects cited any approved planning method. At the same time Schill-Fendl (2004) compiled a planning glossary that specifies 130 different planning methods that can be used to aid the architectural design process. As a consequence it can be stated that it is the nature of architectural design that it does not follow predetermined existing methodologies. It can as well be stated that many architects use partial combinations of existing methodologies, thus creating their own personal design method. The above mentioned survey stated as well that architects do not follow clearly defined design goals. From the result of these inquiries one can assume that other than design works from disciplines like mechanical- or aeronautical engineering, buildings have no specific weighted characteristics that have to be fulfilled. At least these characteristics usually do not dominate the design process that is mostly defined as an artistic activity.

In the following chapter it will be pointed out that it is however possible to determine a modus operandi that suits artistically as well as other premises during architectural design. As an example a brief digression will be undertaken to the theory of composition of Edgar Allan Poe's "The Raven". This theory will be adopted to solve architectural layout problems with the application of a constraint programming language that will be described in chapter 3. Two specific problem domains, the design of new

buildings as well as the revitalization of existing buildings will be described in chapter 4.

## 2. The Theory of Composition

In 1845 Edgar Allan Poe wrote the poem “The Raven”, an act full of poetry, love, passion, mourning, melancholia and death. In his essay “The Theory of Composition” which was published in 1846 Poe proved that the poem is based on an accurate mathematical description. Thus, Poe demonstrated that design can be associated with a clear synthetic methodology rather than what we simply name creativity.

### 2.1. WHAT IS DESIGN?

Design can be described as creativity, intuition, even accident would be commensurable. Poe predicated suchlike creative processes on “the beauty of mathematics”. Their realization followed a modus operandi that is as well transferable to architectural design tasks. The beginning of his work was always determined by the intention to create a poem. He started with the definition of an overall objective, e.g. “beauty”. To achieve this, he added specific constraints, e.g. “effects”, whose assignment was to fulfill the criteria to meet the objective. His well-known poem “The Raven” consisted of the following objective and constraints (Table 1):

TABLE 1. The Theory of Composition.

Intention:	Create a poem to satisfy the common and critical taste
Objective:	Beauty
Constraints:	<ul style="list-style-type: none"> <li>Consideration of an effect, to be accessible to the soul (beauty)</li> <li>Determination of the poems scale, with regard to the level of excitement to be achieved (100 lines)</li> <li>Composition of the effect, through the plot or the key (plot)</li> <li>Selection of the key, e.g. mourning (melancholia)</li> <li>Elaboration of artistic attractiveness, e.g. (refrain)</li> <li>Integration of essential consequences, e.g. a refrain leads to staves</li> <li>Determination of sound characteristics, e.g. achieve monotony but vary its contextual application</li> <li>Selection of a single word to support sound characteristics, e.g. choose the most resonant vowel (o) and best consonant to be articulated (r): create a word: e.g. (nevermore)</li> <li>Elaboration of a pretense for plausibility: e.g. let it be spoken by an unreasonable character (a raven)</li> <li>Selection of the most melancholic item: e.g. the death of a woman loved by a man.</li> </ul>

The example demonstrates that it is possible to determine rules (constraints and objectives) that describe artistically pieces of work in a mathematical manner. This approach will now be transferred to architectural design.

## 2.2. THE MODUS OPERANDI IN ARCHITECTURAL DESIGN

The uses of mathematical descriptions imply the following hypotheses: Architectural design is affected by rules. These rules can be of objective and subjective nature. Objective rules are generally accepted. They are defined in legally binding land-use plans or development schemes. They as well contain contextual rules that relate to the surrounding of the proposed building site. Subjective rules rely on the interest of the specific architect. They imply design rules and all aspects that relate to the creative element of the design process (Figure 1). These design rules very much relate to Poe's approach in writing a poem. It is assumed that syntactical forms could be extracted from an architect's specific handwriting, to be compiled into a mathematical language.



Figure 1. Architectural Design Rules.

Rules can be used to constrain the solution space of a design problem. Feasible solutions for a design problem can only be found if the search space is constrained. Even simple design tasks can generate millions of solutions. These solutions might not always be feasible in terms of architectural premises.

Provided that constraints and objectives are specified by the architect, computers can extend the number of feasible solutions for a design problem. Manual design techniques allow the architect to explore a couple of different solutions for a specific design problem. It is hypothesized that the generation

of a larger number of feasible solutions is only a question of computing power.

### 2.3. METHODOLOGY

Two basic questions should arise before an approach to the development of computer aided design tools is made: What is architectural design and how is it possible to define the modus operandi of a design action performed by an architect? Many enquiries have been made to this question during the past (Rittel und Reuter, 1992) and (Alexander, Ishikawa et al., 1977). Some of these proved to be prosperous, whereas other did not. Apart from the theories that evolved from these enquiries it is still questionable if architects really make use of specific predetermined routes that they follow by all means during the design process. To avoid conflicts relating to theoretical subtleness, a customary approach has been chosen in this work which is adopted from Operations Research. In this approach design is a synonym for planning, which could be described as a systematic and methodical course of action for the analysis and solution of current or future problems (Domschke und Drexl, 2005). The planning task is defined as an analysis of a problem with the aim to prepare optimal decisions by the use of mathematical methods. The decision problem of a planning task is represented by a simulation or optimization model and the application of an efficient algorithm to aid finding one or more solutions to the problem. The basic principle underlying the approach presented herein is the understanding of design in terms of searching for solutions that fulfill specific criteria. It is important to notice that the search space of a design problem might be finite or infinite. In the case of a finite search space there will always be a solution to the problem. If the search space is infinite it is not possible to find a solution so that the search has to be stopped according to pre-defined criteria. In terms of methods used in Operations Research it is possible to classify the above mentioned assumptions as integral components of an optimization model.

- The design solution has to meet specific requirements (Constraints)
- The design has to strive for specific goals (Objectives)
- There are choices available that might meet the constraints and objectives (Design Variables)

The optimization model itself consists of a given number of variable and constant parameters, one or more objectives as well as a fluctuating number of constraints. The standard form of an optimization model can be expressed in the following form (Domschke und Drexl, 2005):

Minimize or maximize the following objective:

$$z = F(x) \quad (1)$$

Subject to the following constraints:

$$g_i(x) \begin{cases} \geq \\ = \\ \leq \end{cases} 0 \text{ for } i = 1, \dots, m \quad (2)$$

$$x \in W_1 \times W_2 \times \dots \times W_n, \quad W_j \in \{\mathbb{R}_+, \mathbb{Z}_+, \mathbf{B}\}, \quad j = 1, \dots, n \quad (3)$$

Whereas the symbols have the following meaning:

$x$	A vector of variables with $n$ components $x_1, \dots, x_n$
$F(x)$	An objective function
$x_j \in \mathbb{R}_+$	Nonnegative constraint
$x_j \in \mathbb{Z}_+$	Integer constraint
$x_j \in \mathbf{B}_+$	Binary constraint (binary variables)

### 2.3.1. Objectives:

Formula (1) constitutes the objective function that has to be minimized or maximized. Sometimes it is difficult to define a single objective function that is sufficient to obtain an optimal overall solution for a problem. In this case it is possible to define multi-objective functions whose objectives can be complementary, competing or neutral. In the case of competing objectives a trade-off occurs due to the fact that one objective gets worse whilst others improve. To solve this conflict it is reasonable to assign weights to single objectives ( $w_1, w_2, \dots$ ) and to build the weighted sum of the original functions in the following form:

$$f(x) = w_1 f_1(x) + w_2 f_2(x) + \dots \quad (4)$$

No conflicts occur in the case of complementary objective functions due to at least one state that is an optimum for all objective functions. In this case a so called "perfect solution" has been reached. Neutral objective functions do not interfere in their mode of action.

### 2.3.2. Constraints:

Formula (2) represents a set of equations or inequations which act as restrictions that constrain the search space.

### 2.3.3. Variables:

Formula (3) defines the domain of variables. These can be continuous, integer or binary. It is important to choose correct variable types within the optimization model. Their range of values is of vital importance for the total cost of computation.

## 3. Modeling

Architectural objects are specified according to a parametric-associative paradigm (Lömker, 2004). This means that each object which belongs to the model can be accessed and altered by the use of parameters. A room for example consists as an object with geometric parameters such as length, width and height. Objects can as well imply alphanumerical parameters such as their occupancy or materials used. Parameters are defined in the form of variables or constants, whereas variables can be used as inputs for the optimization process. Responses result from the composition of other variables. If a variable is changed during the optimization process dependant variables will be changed as well (Figure 2).

optimization model:

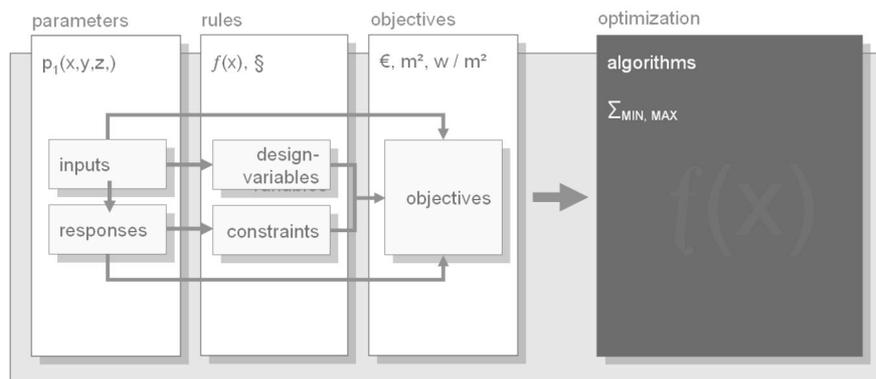


Figure 2. Optimization Model

Inputs and Responses are often named Optimization Variables. These variables form the basis of constraints and objective functions. Both must be functions of one or more optimization variables (Bhatti, 2000). Within an

architectural problem domain a response variable could be the area occupied by a specific room. Through multiplication of two input parameters (width and length) a response variable would be rendered. However, it is of primary interest that suchlike parameters generate serious problems for the optimization process due to their non-linear form. Once the design problem is stated in form of design variables, constraints and objectives, the parameters will be passed to the optimization engine which tries to find a feasible solution to the problem.

The model described above is a general model that can be applied to many problem domains beyond architecture. Within an architectural examination of suchlike problem formulation the model was implemented in the area of architectural layout planning. Referring to the preceding chapter it is obviously difficult to say which routes architects follow whilst designing. It is therefore complicated to code a set of steps that describe how a design problem could be solved by a machine. Thus, the layout planning problem was set up with a different programming paradigm that specifies a set of constraints that must be met without stating how to achieve this task. A programming language that supports this paradigm and that was used herein is OPL (Optimization Programming Language) which was developed in 1995 (van Hentenryck, 1999)

#### **4. Problem Domains**

The architectural layout problem was formulated with regard to the solution that should be achieved. Rooms were defined as geometric objects with parameters that specified their geometric characteristics. Through the use of topological specifications, relationships between various rooms were defined as constraints. An objective function was implemented that had to be achieved under compliance with the constraints. The following item represents an exemplary problem specification in pseudo-code (Figure 3):

```

// Variable Declaration
  (room 1..n)
// Constant Declaration
  (N)
// Specification of Objectives and Constraints
  maximize, minimize (total area)
  subject to
  {
    // Objective Function Specification
    (total area of room 1..n greater than N)
    // Constraint Specification
    (room 1 connects to room 4)
    (room 5 south of all other rooms)
    (room 3 greater than room 1 and 5)
    (rooms 1..n do not intersect with other rooms)
  }
// Output Parameters

```

Figure3. Exemplary problem specification

It is important to note, that a specification like “room 1 connects to rooms 4” has to be transformed into a mathematical representation. The formulation of an appropriate optimization-model is of utmost importance for a successful evaluation of a design problem solved by a machine. The difficulty for sure exists in the mathematical formulation of the model as well as in the selection of proper algorithms to solve the problem. Even more difficulties arise in the description of usable procedures that classify ordinary design processes.

#### 4.1 THE DESIGN OF NEW BUILDINGS

Models for the design of new buildings have been developed through the use of mathematical (MP), integer (IP), mixed-integer (MIP) and mixed-integer linear programming (MILP) techniques that are based on a geometric description of the rooms. Another approach that was followed was the use of resource allocation techniques in conjunction with scheduling algorithms.

##### 4.1.1 The Mathematical Model

The principle of the geometric model adopted was the representation of rooms as rectangular units. Michalek (2001) demonstrated this concept in his work on architectural layout planning. Different from his concept a geometric representation was chosen that describes a rectangular unit through a reference point, a length and a width dimension. Three constraints were taken from this work, that describe the location of a unit inside

another (Force Inside), the intersection of two units (Prohibit Intersection) as well as the location of a unit on the border of another unit (Force To Border). Additional constraints were added, that specify the connection of two units (Force Connection), the location of a unit on the outside of another unit (Force Outside) as well as the prohibition of a connection between two units (Prohibit Connection). Various design constraints (e.g. aspect ratio, symmetry) were implemented that refer to subjective rules. These design constraints as well as constraint-combinations make it possible to extend the architects possibility of intervening into the creative process of automatic layout planning. The use of constraint-combinations for example, led to a new constraint that made it possible to extend the geometric model to non-rectangular units. These so-called Void-Units approve complex shapes that must not be specified different from other units, according to their geometrical measures. The most important aspect of using OPL as a programming language was its ability to specify search procedures as well as upper- and lower-bounds on variables. The use of search procedures is of uppermost interest due many problems in architectural layout planning that are NP-complete. Their application can dramatically influence the total cost of the optimization process. The mathematical model consists of the following variables, constants and constraints (5-13).

Variables:

Unit $i, j$	floor space of units
Unit $R$	floor space of surrounding reference unit
Unit $R'$	floor space of building site
$(I_1, I_2, I_3)$	finite-dimensional index sets of rooms
$\varepsilon \geq 0 ; \delta \geq 0$	contact range ; spacing range
$(x_i, y_i) ; (x_j, y_j)$	non-negative reference points unit $i, j$
$(\Delta x_i, \Delta y_i) ; (\Delta x_j, \Delta y_j)$	non-negative width and length unit $i, j$
$u_{ij}, v_{ij} \in \{0,1\}$	$(u_{ij}, v_{ij}) = \begin{cases} (0,0), \text{ iff. Unit } i \text{ above Unit } j \\ (0,1), \text{ iff. Unit } i \text{ under Unit } j \\ (1,0), \text{ iff. Unit } i \text{ right of Unit } j \\ (1,1), \text{ iff. Unit } i \text{ left of Unit } j \end{cases}$

Variables for Force To Border Constraint:

$$u_{ij}, v_{ij} \in \{0,1\} \quad (u_{ij}, v_{ij}) = \begin{cases} (0,0), \text{ iff. Unit } i \text{ on southside} \\ (0,1), \text{ iff. Unit } i \text{ on northside} \\ (1,0), \text{ iff. Unit } i \text{ on westside} \\ (1,1), \text{ iff. Unit } i \text{ on eastside} \end{cases}$$

Constants:

$$(x_R, y_R); (x_{R'}, y_{R'}) := (0,0) \text{ Non-negative reference point units } R, R'$$

$$X; Y; X'; Y' \quad \text{Non-negative width and length units } R, R'$$

Force Inside Constraint (FInside)

$$x_i \geq x_j; y_i \geq y_j; x_i + \Delta x_i - (x_j + \Delta x_j) \leq 0; y_i + \Delta y_i - (y_j + \Delta y_j) \leq 0 \quad (5)$$

Prohibit Intersection Constraint (PInter) (6)

$$\begin{aligned} x_i + \Delta x_i - x_j + u_{ij} X' + v_{ij} X' &\leq 2X' \\ x_j + \Delta x_j - x_i + u_{ij} X' - v_{ij} X' &\leq X' \\ y_i + \Delta y_i - y_j - u_{ij} Y' + v_{ij} Y' &\leq Y' \\ y_j + \Delta y_j - y_i - u_{ij} Y' - v_{ij} Y' &\leq 0 \end{aligned}$$

Force Connection Constraint (FConn) (7)

$$\begin{aligned} y_i + \Delta y_i - y_j - u_{ij} Y' + v_{ij} Y' &\leq Y' \\ y_i + \Delta y_i - y_j + u_{ij} Y' - v_{ij} Y' &\geq -Y' \\ x_i + \Delta x_i - x_j + u_{ij} X' - v_{ij} X' &\geq -X' + \delta \\ x_j + \Delta x_j - x_i + u_{ij} X' - v_{ij} X' &\geq -X' + \delta \end{aligned} ;$$

$$\begin{aligned}
y_j + \Delta y_j - y_i - u_{ij}Y' - v_{ij}Y' &\leq 0 \\
y_j + \Delta y_j - y_i + u_{ij}Y' + v_{ij}Y' &\geq 0 \\
x_i + \Delta x_i - x_j + u_{ij}X' + v_{ij}X' &\geq 0 + \delta \\
x_j + \Delta x_j - x_i + u_{ij}X' + v_{ij}X' &\geq 0 + \delta \\
\\
x_i + \Delta x_i - x_j + u_{ij}X' + v_{ij}X' &\leq 2X' \\
x_i + \Delta x_i - x_j - u_{ij}X' - v_{ij}X' &\geq -2X' \\
y_i + \Delta y_i - y_j - u_{ij}Y' - v_{ij}Y' &\geq -2Y' + \delta \quad ; \\
y_j + \Delta y_j - y_i - u_{ij}Y' - v_{ij}Y' &\geq -2Y' + \delta \\
\\
x_j + \Delta x_j - x_i + u_{ij}X' - v_{ij}X' &\leq X' \\
x_j + \Delta x_j - x_i - u_{ij}X' + v_{ij}X' &\geq -X' \\
y_i + \Delta y_i - y_j - u_{ij}Y' + v_{ij}Y' &\geq -Y' + \delta \\
y_j + \Delta y_j - y_i - u_{ij}Y' + v_{ij}Y' &\geq -Y' + \delta
\end{aligned}$$

Force To Border Constraint (F2Border) (8)

$$\begin{aligned}
x_i + \Delta x_i - (x_j + \Delta x_j) - u_{ij}X' - v_{ij}X' &\geq -2X' \\
y_i + \Delta y_i - (y_j + \Delta y_j) + u_{ij}Y' - v_{ij}Y' &\geq -Y' \\
x_i - x_j + u_{ij}X' - v_{ij}X' &\leq X' \\
y_i - y_j - u_{ij}Y' - v_{ij}Y' &\leq 0
\end{aligned}$$

Prohibit Connection Constraint (PConn) (9)

$$\begin{aligned}
x_i + \Delta x_i - x_j + u_{ij}(X' + \varepsilon) + v_{ij}(X' + \varepsilon) &\leq 2X' + \varepsilon \\
x_j + \Delta x_j - x_i + u_{ij}(X' + \varepsilon) - v_{ij}(X' + \varepsilon) &\leq X' \\
y_i + \Delta y_i - y_j - u_{ij}(Y' + \varepsilon) + v_{ij}(Y' + \varepsilon) &\leq Y'
\end{aligned}$$

$$y_j + \Delta y_j - y_i - u_{ij}(Y'+\varepsilon) - v_{ij}(Y'+\varepsilon) \leq -\varepsilon$$

Force Outside Constraint (FOutside) (10)

$$x_i + \Delta x_i - x_j + u_{iR}(X'+\varepsilon) + v_{iR}(X'+\varepsilon) \leq 2X'+\varepsilon$$

$$x_j + \Delta x_j - x_i + u_{iR}(X'+\varepsilon) - v_{iR}(X'+\varepsilon) \leq X'$$

$$y_i + \Delta y_i - y_j - u_{iR}(Y'+\varepsilon) + v_{iR}(Y'+\varepsilon) \leq Y'$$

$$y_j + \Delta y_j - y_i - u_{iR}(Y'+\varepsilon) - v_{iR}(Y'+\varepsilon) \leq -\varepsilon$$

$$\varepsilon \geq 0$$

Design Constraints (Length Constraint) (11)

$$\Delta y_i \begin{cases} \leq z_i, & \text{upper boundary of Unit } i \\ = z_i, & \text{exact boundary of Unit } i \\ \geq z_i, & \text{lower boundary of Unit } i \end{cases}$$

Design Constraints (Area Constraint) (12)

$$F_i \begin{cases} \leq z_i, & \text{upper area of Unit } i \\ = z_i, & \text{exact area of Unit } i \\ \geq z_i, & \text{lower area of Unit } i \end{cases}$$

Design Constraints (Perimeter Constraint) (13)

$$U_i \begin{cases} \leq z_i, & \text{upper perimeter of Unit } i \\ = z_i, & \text{exact perimeter of Unit } i \\ \geq z_i, & \text{lower perimeter of Unit } i \end{cases}$$

$$(z_i \in \mathbb{R}_+ \text{ fixed, } i \in \{1, \dots, n\})$$

#### 4.1.2 Mixed Integer Programming

It has to be mentioned, that the mathematical model is as well suitable for implementation in layout problems that deal with the revitalization of existing buildings. In fact it was actually developed for this area of application. Due to its nature of moving and resizing units, it actually alters the plan of an existing building either by breaking down existing walls or by building new walls. Therefore we call this model a “destructive model”. A “non-destructive model” will be explained in chapter 4.2.

The surrounding reference unit in the destructive model was organized in a way, that it could either be the proposed area of a plot to be covered with a new building or the area of an existing part of a building that has to be redeveloped. The following images show an exemplary layout of 9 units within a quadratic plan. The following constraints and objective had to be fulfilled (Figure 4):

##### Topological Constraints:

Force Connection between the red and blue unit, red and yellow unit, red and orange unit.

Force Connection between the yellow and midnight-blue unit.

Prohibit Intersection between all units.

Force all units to stay inside the square.

##### Length Constraints:

Width and length of the red and blue unit must be greater than or equal to 2m and less than or equal to 4m.

Width and length of the orange unit must be 3m.

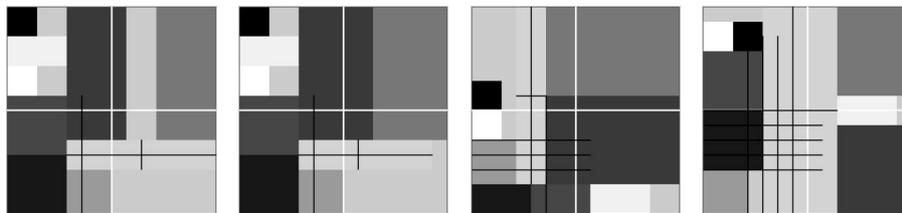
Width and length of the midnight-blue, Indian-red and yellow unit must be greater than or equal to 2m.

##### Ratio Constraints:

Red and blue unit must be symmetrical to the yellow unit.

Midnight-blue and Indian-red unit must be symmetrical to the yellow unit.

Objective: Maximize total perimeter of all units.



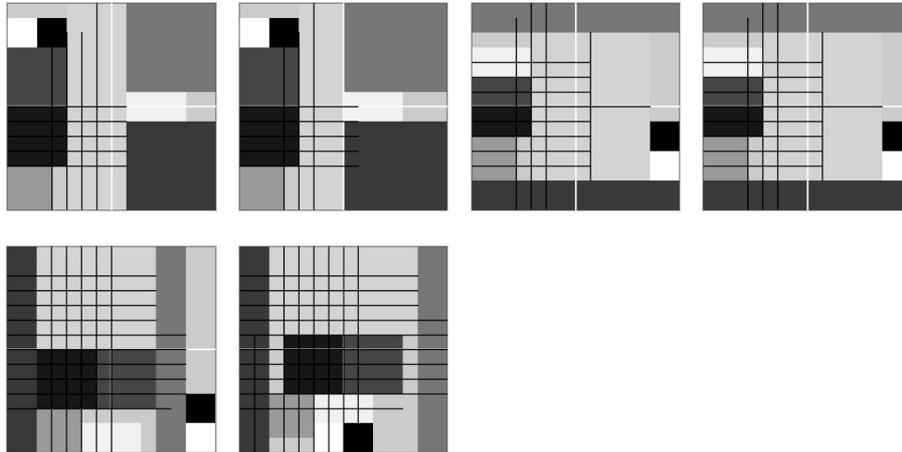


Figure 4. Perimeter optimization of rectangular floor plans

The model calculates 10 different floor plans with a total perimeter of 120 to 144 meters. It reaches an optimum after a couple of minutes. The perimeter objective has been chosen to avoid a non-linear form of the model. This perimeter objective represents an approximation of an area objective which is more common in the architectural practice. Other optimization runs with non-linear constraints showed however, that is as well possible to make use of quadratic representations, particularly if search-methods are implemented in the model.

The next example demonstrates the use of non-rectangular floor plans through the implementation of Void-Units. Constraints were set up through the use of a bubble-diagram (Figure 5). The use of search-methods allowed the solver to calculate the following results in less than 1 second up to 6 seconds (Figure 6).

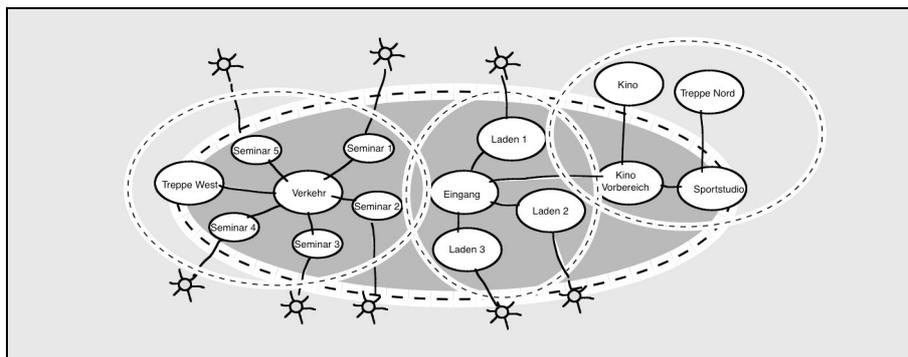
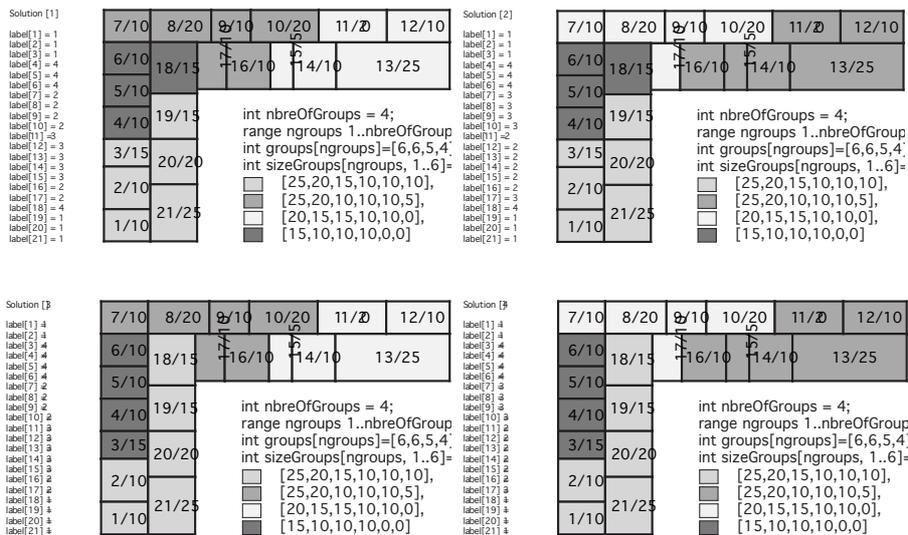


Figure 5. Bubble diagram showing constraints



existing buildings is not used anymore. The most ecological procedure to revitalize these buildings would be through a continuous usage without making any alterations to the stock. Consequentially the model developed for this purpose is a “non-destructive model”. The design problem is related to problems in logistics, e.g. the loading in trans-shipment centers. Our model consists of an adjacency matrix that describes the neighborhood of existing rooms in the stock. Additionally an array stores values of the area of each room. Through the use OPL we defined a procedure that searches for coherent graphs within the matrix. These graphs represent units (groups) of different usage, e.g.  $n$  office spaces consisting of  $x$  rooms. The rooms within such a group must represent a coherent graph, which means that each room has to have at least one neighbor. In addition, all members of a group have to fulfill specific requirements regarding the size of each single room and the total number of rooms within the group. These conditions are fulfilled, if the size of each single member of a group is at least the size of an equivalent room that is specified in an array that contains the desired room-sizes. In existing buildings however, this is hardly ever the case. Due to this, the conditions are also fulfilled, if the total size of a group is equal or greater than the total size of the rooms specified in this array. In either case the total number of rooms in a group found has to equal the number of rooms specified as a search criterion. The algorithm searches for equivalent room-sizes first, before it passes over to check group-sizes. The results of the model developed are encouraging. The images show 8 exemplary assemblies of 21 rooms (Figure 7). All solutions fulfill the requirements made to the size of the rooms, their adjacency and the number of members in a unit (group).



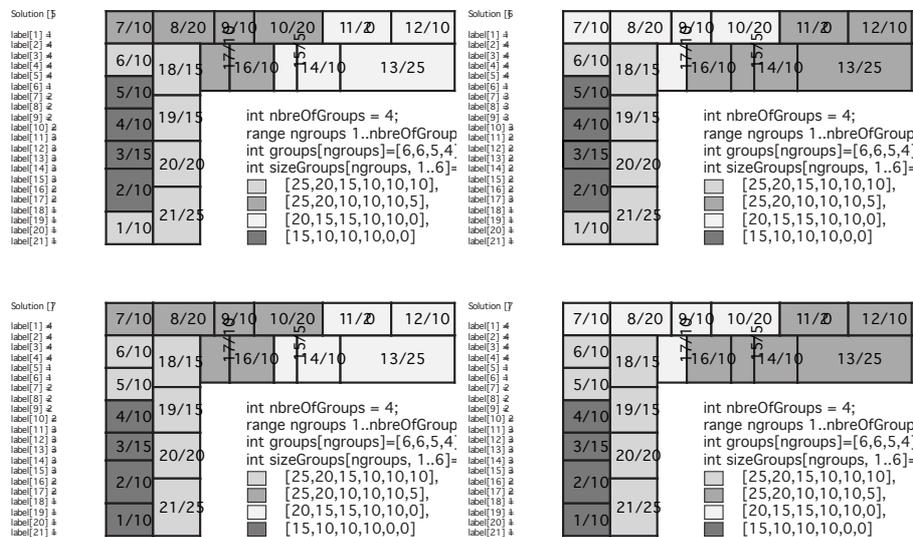


Figure 7. Non-destructive optimization of existing floor plans

We began working with larger models consisting of 78 rooms, respectively 6.084 entries in the matrix. These optimization runs can be solved within 2 hours time on ordinary machines with a reasonable amount of memory. Our latest attempts deal with more than 300 rooms (respectively 90.000 entries in the matrix) arranged on different stories. These tasks are difficult to solve from a computational point of view and might call for parallelization of the program developed.

## 5. Conclusion

Destructive and especially non-destructive models can play an important role in the architectural design process. Our examinations demonstrate that destructive models which are often NP-complete dramatically benefit from the search methods the user is able to define in OPL. The examination of different models developed, also demonstrates that many models were not possible to be solved within an appropriate time range without the use of these search methods.

The non-destructive model description differs fundamentally from the description of the mathematical models. By the use of the constraint programming paradigm it is possible to write descriptions of extremely complex tasks within a few lines of code. But not only from a computational point of view are the results of this model promising. In the perpetual

important domain of revitalization, non-destructive optimization models can aid the architect in finding quick answers to design problems.

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## **AN ANALYSIS OF THE APPLICATIONS OF RAPID PROTOTYPING IN ARCHITECTURE**

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**Abstract.** Rapid prototyping (RP) techniques are widely used within the design/manufacturing industry and are well established in manufacturing industry. These digital techniques offer quick and accurate prototypes with relatively low cost when we require exact likeness to a particular scale and detail. 3D modeling of buildings on CAD-systems in the AEC sector is now becoming more popular and becoming widely used practice as the higher efficiency of working with computers is being recognized. However the building of scaled physical representations is still performed manually, which generally requires a high amount of time. Complex post-modernist building forms are more faithfully and easily represented in a solid visualization form, than they could be using traditional model making methods. Using RP within the engineering community has given the users the possibility to communicate and visualize designs with greater ease with the clients and capture any error within the CAD design at an early stage of the project or product lifecycle. In this paper, the application of RP in architecture is reviewed and the possibilities of modeling architectural models are explored. A methodology of developing rapid prototypes with 3D CAD models using methods of solid freeform manufacturing in particular Fused Deposition Modeling (FDM) is presented and compared against traditional model making methods. An economical analysis is presented and discussed using a case study and the potential of applying RP techniques to architectural models is discussed.

## 1. Introduction

Conventional model making or prototyping in the traditional sense is a long-standing and well established practice within the AEC sector. Architects use models as visual aids in presenting new designs and the primary reason of having a physical prototype model was to visualize the concept of a design. Thus, a prototype is usually required before the start of the construction phase. However, creating architectural models can be an expensive and time-consuming task. The fabrication of prototypes has been carried out in many ways, historically using conventional manual methods such as carving, castings, moulds, joining with adhesives etc, and utilizing basic materials types aluminum, zinc, urethanes, wood, etc. Most model makers would carve a model by hand, but this involves using highly skilled craftsmen. With the aid of rapid prototyping (RP) technology, labor is said to be de-skilled, our views differs as skilled labor is required to operate the CAD equipment, but there is no doubt there is a great potential for models to be created with greater speed and accuracy.

While rapid prototyping technology has been used for years in industrial design, many companies like “LGM” are currently leading the industry in applying this tool to architectural and development applications. Models help contractors, engineers, and architects in several different ways. A well-built model is a functional and informative tool intended to solve potential problems. The application of RP technologies and digital manufacturing offer notable potential to AEC technologists and RP researchers with the focus on 3D modeling of buildings within the application of architectural model making in the AEC sector. Revisions in development and design can be derived from an accurately detailed model. Chua et al 2003 describe that development of CAD and advancements in manufacturing systems and materials have been crucial in the development of RP. Wieneke-Toutaoui and Gerber (2003) have reported this technology is fast developing and is more than competitive to traditional model building techniques considering time and degree of detail. RP in model making within the AEC sector, showing the difference made; now days it becomes possible to involve designer, sells department and the company’s clients in design processes before manufacturing to avoid doing any mistake. The objective of the study presented in this paper was to compare between traditional ways of modeling that depends on the craft men to produce architecture models and RP techniques in architecture. To do this comparison, we have modeled ground floor of a building in 3D CAD and a comparison will be made between producing the same model by using Fusion Deposition Modeling (FDM) as the RP method and traditional way of modeling. Software mainly I-DEAS, INSIGHT and DELCAM POWER MILL software were used to calculate time and cost of RP.

In RP mainly two types of processes are used. They are subtractive process and additive process. In this report the discussion will be about exploring these two methods of making architecture models. It is very important to create 3D CAD design before sending the job to FDM machine, there will be procedure to create a 3D CAD design with the aid of one from the available CAD packages. It is possible to simulate the process inside the Insight software to calculate time and the material cost which the machine needs to build the model. In this paper also there is a discussion about the possibility of producing the architecture models by using CNC machine. This is achieved by simulating the processes in Delcam Power Mill software to see whether the machine has the ability to produce the shape with its small details or not. The final part of the paper discusses the cost evaluation by utilizing both methods of modeling.

## 2. Methodology of 3D Physical Models

### 2.1. DESIGN 3D MODEL IN TRADITIONAL METHODS.

The traditional method is based upon 2D process that can be generated by architect using software like AUTOCAD, or simple hand sketches. Each single part is made separate by all parts are assembled by using standard model making materials, i.e. glue, balsa wood etc, this process requires skill and is labour intensive, which increases the cost, in addition to this it causes loss of material too.

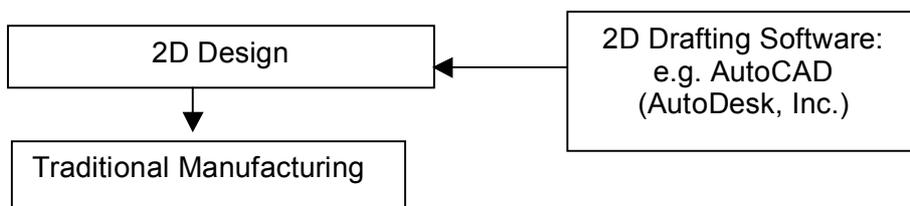


Figure 1: Traditional method of building an architectural physical model.

### 2.2. RAPID PROTOTYPING

Rapid Prototyping (RP) is also often called Solid Free Form Fabrication (SFF), which refers to a specific class of new manufacturing processes that form parts on a layer by layer basis with minimal user assistance unlike conventional CNC model making, which is performed in a subtractive

manner, removing material from a raw block of material to achieve the final shape of the model.

The common methodology they adopt can be described as follows:

- **3D CAD generation:** A 3D model of the component is generated on a Computer-Aided Design/ Computer-Aided Manufacturing (CAD/CAM) system.
- **CAD Export File:** The 3D computer generated model is then converted into a Stereo Lithography file "STL" format, which is commonly known as a "Triangle File", as the model is tessellated into triangles. Obviously, as we cannot exactly duplicate the curved form or rounded surfaces with triangles, the accuracy of the model depends on the size of the triangles.
- **Pre-Processing:** A computer program analyses the STL file that defines the model to be fabricated and at this stage the model can be scaled and oriented to achieve optimum results i.e. nesting for maximum machine utilization. The computer program then simplifies the model into 2D cross sections known as "slices", at different Z intervals. After the model has been sliced, it is necessary to create the supports (to support over hangs) that will allow the part to be built in the RP machine.
- **Model Construction:** A fully processed and verified .STL file is then sent to the Rapid Prototyping Machine to be built. Additive material formation method incrementally deposits, cure, or bind very thin layers of material within the "build chamber" of a particular machine. Most build chambers are relatively small, but larger components are routinely subdivided and built in sections.
- **Post finishing:** This step is used to clean and finish the physical RP model. Depending upon the RP method support material can be removed by either an ultra-sonic or can be removed with various hand tools.

#### *2.2.1. RP Experimentation Using Additive Methodology FDM Machine*

An RP system enables us to develop a model or prototype within minutes or hours, directly from the CAD design. Design includes all activities involved from the original concept to the finished product. The challenge is selecting the right process for the task. Choosing between the various RP technologies can be difficult, we should ask following questions to make a proper selection.

1. What we are looking for?
2. How long will it take?
3. How much will it cost?

Also, we should be aware about the strengths and weaknesses that are inherent in all RP processes. In this paper we have focused mainly on FDM process.

In the FDM process, a 3D CAD model is sliced into thin layers usually 0.25mm in Z-axis. The tool paths of these sliced layers are used to drive an extrusion head of FDM machine. The basic build size is 203 x 203 x 305mm, large parts can be easily made in sections and joined together. Minimum wall section or feature is recommended not to be smaller than 0.8mm. The building material, in the form of a thin solid filament, is fed from a spool to a movable head controlled by servomotors. Second filament is fed from adjacent nozzle for support material, used to give support for over hanged or cantilever features. Figure 2 represents the steps of the RP methodology adopted in this study.

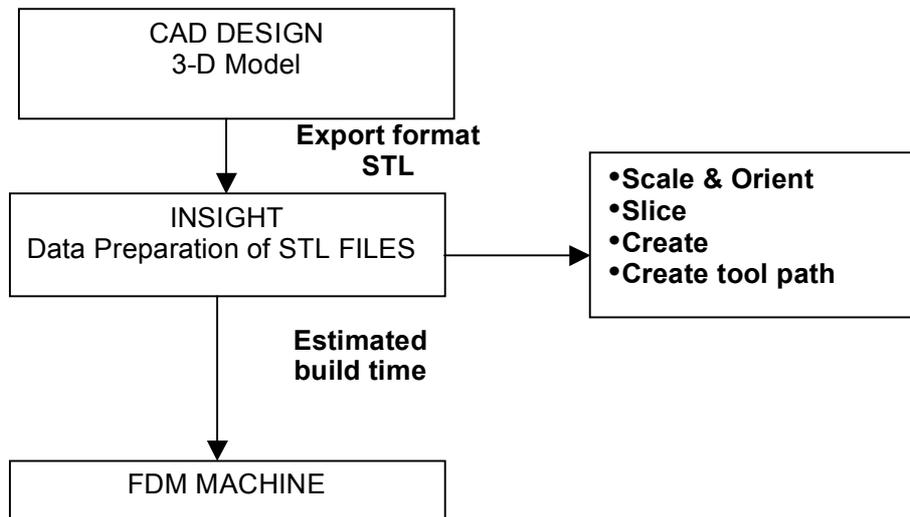


Figure 2: Process flow of RP methodology

### 2.2.2 3D Design within 3D CAD Software Program

Firstly, a design of a building was constructed based around a typical building in Middle Eastern continent. A 3 D-CAD model was constructed for the ground floor of building, using a series of basic parametric modelling functions such as extrude, revolve, cut, join.

The building was modelled to Scale 1:100 factor, and scaled-down further suit the RP machine. Once the CAD model is constructed by use I-DEAS-10 software program, it was then converted to STL “triangle” format for export.

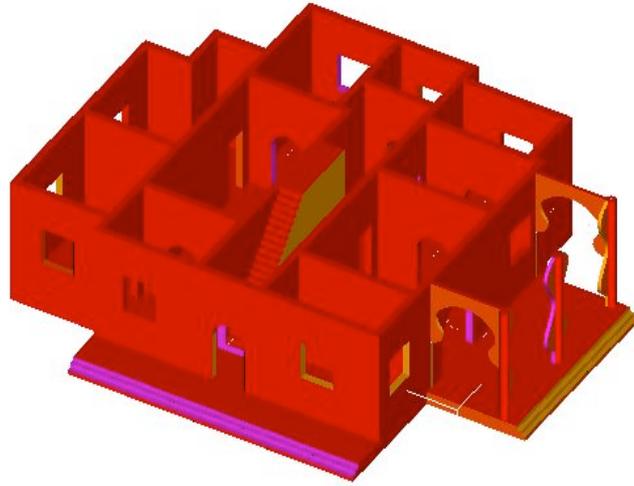


Figure 3: 3D CAD model in IDEAS software

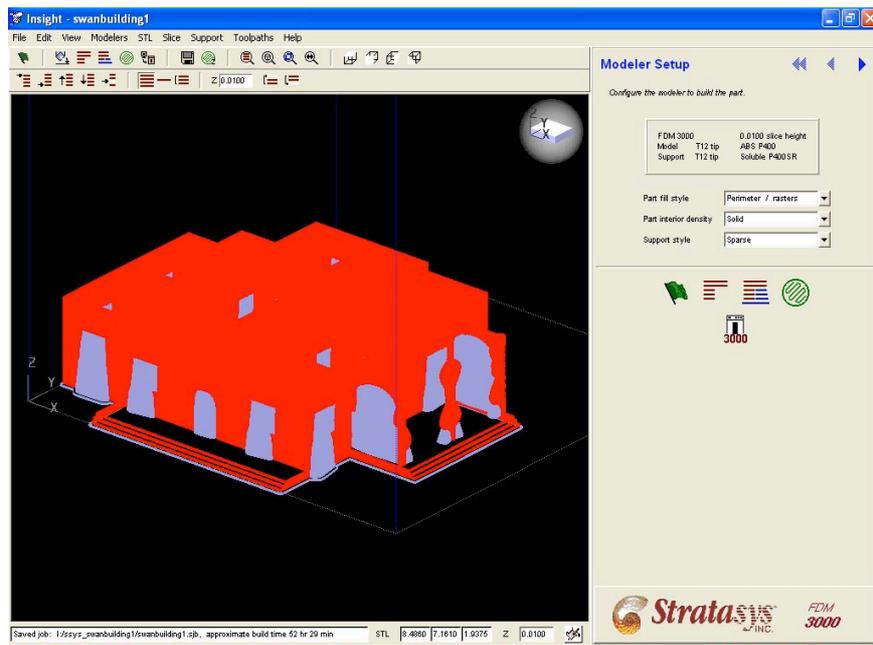


Figure 4: Processing in INSIGHT software showing supports material (blue)

### 2.2.3 Working in Insight Software Program

The STL “triangle” file is imported into Insight software. Firstly, we set the orientation in which we wanted the model to be built. Models seldom come into Insight in the correct orientation. The next step in this pre-processing stage is to consider the working envelope of the FDM 3000 machine which is 10’X10’X16’, hence the need to scale down the model in software by using scale factor of 0.01 before export the model. We then sliced the model it into layers along the Z-axis, and constructed the supports structures. After creating slices and supports, Insight needs to create the tool paths needed to build the part, Insight then computes the paths it will take to build the part and supports and display them in the window.

### 2.2.4 Estimated Build Time

Using the Insight software, we can estimate the required to build the part by FDM machine. In this case, the build time is to be 54 Hours & 18 mins which is presented in figure 2. After full processing of the STL file, it is sent to FDM machine to build the part.

**Estimate Build Time**      ◀ ◁ ▷ ▶

Click the OK button to calculate the approximate time to build the current part.

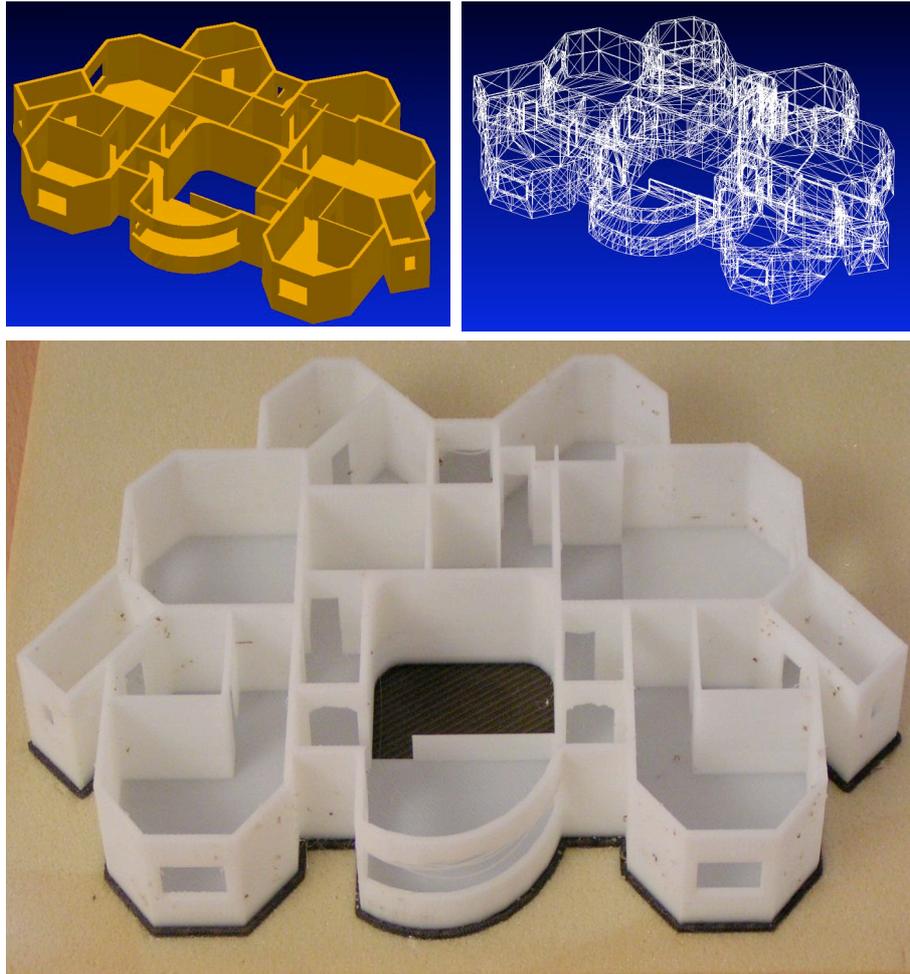
Estimated build time	54 hr 18 min
Model material	366.48 cm <sup>3</sup>
Support material	42.43 cm <sup>3</sup>
Model material	ABS P400
Support material	Soluble P400SR
Model tip	T12
Support tip	T12
Slice height	0.2540

**OK**

Figure 5. Estimated build time form

The main goal is to receive a prototyping quickly, accurately and cost effectively. Cycle time and cost can be then controlled according to the project requirements. The model and supports are removed. The surface of

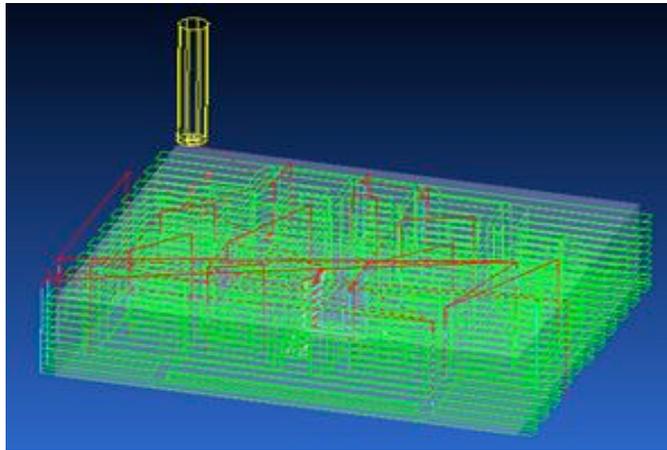
the model is then finished and cleaned, using an ultrasonic bath to wash away the unwanted support material. The University of Teesside is applying Rapid Prototyping Technology for teaching students about the new possibilities. One example processed in University of Teesside is illustrated in Figure 6.



*Figure 6:* Derived from an EDS Ideas 3D CAD Model and manufactured on a FDM Prototype Model created on Stratasys FDM 3000 within hours at The University of Teesside

### 2.3 TRADITIONAL EXPERIMENTATION USING SUB-TRACTIVE METHODOLOGY CAM MACHINING USING DELCAM POWERMILL SOFTWARE

The same CAD model which we constructed using EDS I-DEAS-10 software program, in the STL “triangle” export format, was imported into the CAM software to simulate CNC machining. We started by defining the material block, the block defines the stock size. The part was to be machined from. We then specify Rapid move heights, The Rapid move heights are the heights at which the tool can move safely without hitting the part or clamps. The software automatically calculates the new tool Z heights based on the maximum Z heights of the block size plus the incremental Z heights. We then Specified Tool Start Point. The first operation was to perform a roughing area clearance (in 3D), a major strength of Power Mill is the range of area clearance options it supports, and the ease with which modification can be processed and viewed. The Area Clearance controls the tolerance, thickness, step-over, and step down value of the cutter as well as other machining options, We then performed another area clearance but this time using the finishing strategy with optimised Constant Z Finishing, . Power Mill processes the cutter paths.



*Figure 7: CNC Subtractive Machining: Cutter path simulation of 3D model*

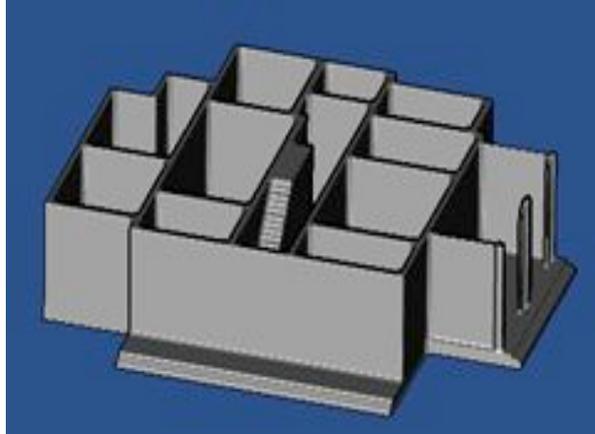


Figure 8: Result of CNC Machining with in DelCAM

Upon completion of pre-processing of simulating the machining we generated the NC code program (post Processing), the CNC program will consist of the number of blocks, tape length and total time

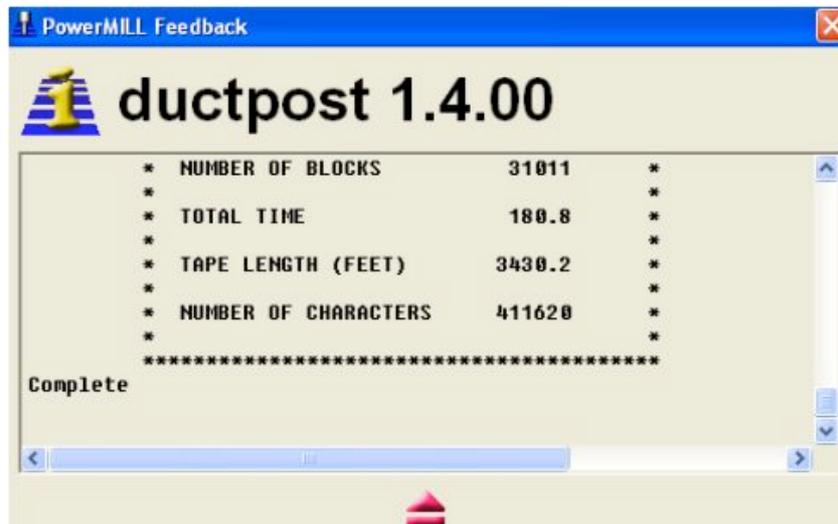


Figure 9: Feedback from Delcam

The Figure 9 shows that the intricate detail within the model will take longer to construct (machine), in order to achieve the same level of definition as Rapid Prototyping hence depending on traditional CNC machining to produce the architecture models is not the best way of the model making in

this particular case, but we do stress this particular process is highly effective and desired for prototyping scaled curved landscapes, of larger sizes, as most RP machines would not be capable of producing models of a larger size.

### 3. Cost Comparison

First, a top-down approach is used to define the major steps involved in applying rapid prototyping. Next, a decomposition approach is used to itemize individual engineering steps involved at each stage. The approach calls for estimating labor hours, material consumption, equipment depreciation, and pricing of other work related to the rapid prototyping process.

- Cost Estimates related to 3D solid modeling
- Cost related to data preparation for solid freeform fabrication
- Cost related to part building

The research study shows the estimated build time by using FDM machine was 54 hr and 18 minutes and the necessary amount of materials which the machine need to build the part were: Model Material 366.48 minutes and Support Material 42 minutes . The spool of material consists of 475 per spool and the cost of the build material is £160 per spool and the cost of support materials is £135 per spool. A detailed calculation of the RP cost has been presented in Appendix 1.

As reported by Grimm (2003) “Build time is often cited as a measure of a system performance. While it is a key component in the total delivery time of a prototype, its value in a system evaluation is questionable”, this also supported in this study from the third-party quotations that were obtained as shown in Table 2.

Whilst this study has used hourly rates during the evaluation, however, this is not seen as a viable measure of system performance or operational costs as observed by industrial analysts as reported by Grimm 2003. The costs used during this evaluation are based upon third party quotations, therefore the calculations have excluded capital and operational cost analysis, and hence are seen as a viable measure for this evaluation, and the results presented in this study.

In the traditional ways of architecture models, there is not a constant role to certain the total building time and cost. This method of modeling depends on the skill of the craft men to perform the job. However, an intuitive estimate has been carried out and presented in Appendix 1, Table A6. The cost has been compared in Table 1. The data presented are approximations only and are based upon our experimental figures, from personal

assumptions. These figures for RP production may vary depending upon the number of components that may be nested into the build envelope as this would offer a more competitive advantage in pricing.

TABLE 1. Total building time and cost in each method of creating architecture models

S. NO	Method	Total time (Days)	Total Cost (£)
1	RP	3.63	1066
2	Traditional method	9.0	1475

Table 1 presents the total cost and time to produce the architectural model using traditional and RP techniques using FDM machine. From the data collection and analysis, it is found that using RP methodology is cheaper and faster than using traditional way of modeling. RP has many advantages, as it offers a quick turnaround in order to test, manufacture and market our idea as well as it is a way to make good quality of 3-D models and prototypes in a matter of hours, instead of weeks, from computer generated data. Also with prototyping our design idea can be created tested and refined quickly and economically, dramatically reducing product development time and improving our final result. Rapid Prototyping outside of mechanical engineering lie in architecture both as integral part of the design process and as a replacement for hand built models representing the final design prototypes. But one key problem in the case of architectural RP is the size to choose, because low cost RP machines are generally no longer than 250mm even the high cost RP machines are no longer than 500mm .

RP Technology is expected to be fast, easy to use, and cost effective that produce reasonable quality for concept modeling. The tests performed within this research found that FDM and CNC machining to satisfy these requirements, although CNC machining of the intricate details to models, led increased machine setup time and proved difficult in comparison to RP method. With its costs and operational demands, CNC machining and manual model making does not satisfy the time requirements when applied the study sample, typical of this industry application. Although research suggests that FDM RP method is time consuming in respect of build time, in comparison to its RP technologies such as 3DP and SLA. Table 2 presents a cost comparison to produce my model by using various RP methods, i.e. FDM, SLS and SLA..

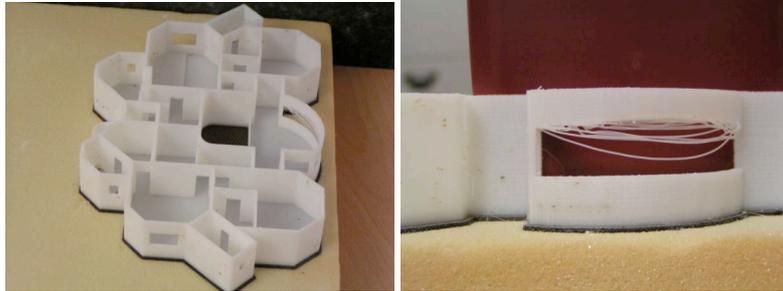
Table 2: RP Cost Comparison Using Different RP methods (all in dollars), quotations obtained from www.quickparts.com.

Method	Part cost with permitting finishing process	Part cost without doing finishing process
FDM	-	\$ 973
SLS	\$ 775	\$ 690
SLA	\$ 1280	\$ 973

As the research shows, the advantages of each model making method whether digital, manual or integration of both, the processes are dependant upon the application. Therefore when evaluating model making technologies, it is essential the specification of the intended application are clearly defined from the start. Grim 2003 stress that “It is important to identify the type of parts that will be prototyped. As seen in time, cost and dimensional accuracy data, results will vary with the size and geometric definition of the prototype”. It is difficult to estimate and analyze the model making methods correctly as there are too many iterations associated to RP and CAD i.e. build parameters, prototyping materials, part definition, & different RP process technologies. Therefore the results presented in this paper are best suited for scaled models when similar parts are constructed with similar modeling parameters.

#### 4. Some RP Modeling Issues Architectural Models

Results obtained from this research strongly demonstrate the importance of using information technology in the development of model making. The 3D CAD model replicas can be extremely accurate in dimension and geometrical shape, and digital methods can allow for simulation of properties, and improved visualization “such as walkthrough, and animations”, which are give a better understanding “closer to the actual product”. Complexity of geometry may be not be problematic within the CAD, however, these complex features such as undercuts and voids, can result in minor deformations in the prototype production, as shown in figure 10, these often result due to errors in processing rather than design i.e. incorrect machine temperature of the FDM Nozzle, in-adequate support material, unsuitable material for process/design. Consequently, with traditional manual model making there is a need to limit intricate features in order to fabricate a high quality replica. Hence, replica models with complexity will increase the amount of preparation required of the manual process and hence increase costs in terms of labor and skill base.



*Figure 10: Errors in FDM RP Prototyping Process*

## 5. Conclusions and Recommendations

Models help contractors, engineers, and architects in several different ways. A well-built model is a functional and informative tool intended to solve potential problems. Revisions in development and design can be derived from an accurately detailed model.

Models may be reviewed by all decision makers before construction begins. If modifications are required on the project, the costs of these alterations are much less before construction begins than during construction. Many times a model pays for itself many times over for this reason.

Plans in a 3D model form can be reviewed and more easily interpreted even by those who don't understand blueprints. A model can help people understand a complex project in minutes or even seconds. Time is more a factor in sales today than ever before.

RP offers the users the ability to present, negotiate, and market their ideas to the customers, thus they can modify their designs before manufacturing. Using 3D CAD systems adds more power to the design process, because it gives a complete idea about the final shape before starting the manufacturing process. As there is a pressure on companies to improve their products development performance, simulation and rapid prototyping will be commonly used to develop products faster, at a lower cost and with better quality, will help them to meet this objective. The findings from this study can be summarized as follows:

- A digital manufacturing method to produce prototypes of models is proposed and recommended in this research, by integrating rapid prototyping and CAD for architectural modeling requirements, a functional prototype model of a scaled building may be fabricated. Due to the versatility of RP and CAD, the integrated approach is

exclusive as it creates opportunities to use materials with properties similar to those of the final products with respect of visualizations without the need for costly prototypes. Additionally, the use of an integrated process reduces the high costs often associated with using prototyping model making alone.

- An essential pre-requisite to use the RP technique is a 3D-CAD strategy for all parts produced using RP. The 3D-CAD models must fulfill the specific process requirements of RP techniques. This research demonstrates the major criteria associated with model making (RP or traditional) is the data preparation, and the understanding of the designer's concept. The requirement from the rapid prototyping perspective is to receive CAD data, which is free from clearance/interference, hence results in an appropriate structure of the activities in the model development process. In order to reduce the total development time by using RP techniques, data having the appropriate quality must be available far earlier in the development process. This means, contrary to today's process, significantly higher costs in the initial development phases. Further, the 3D-CAD strategy permits models to be verified in the computer, which up until now was an achieved using long introduction time where the modeling process was optimised. Using CAD techniques, simulation can also integrated into the overall process and earlier verification of CAD models can lead to costs being reduced in terms of design changes that maybe introduced at a later stage, but only prior to manufacturing commitment, in which case the related costs are similar to those associated with manual model making. Certainly, keeping the cost of labor and material down is a major concern in this research.
- Techniques regarding computer-supported evaluation of development results can be used in each phase of the product development process with different strategic goals. In this case, to use specific techniques, such as RP, in subsequent process segments, preliminary, up-front work is required to check development results using computer-based product specifications. In the aerospace-, automobile-, ship-building- and railway industries, projects are presently underway to define the next steps towards optimized product development using Digital Mock-Up (DMU) and RP.

This paper has reviewed the cost of producing architectural models by using RP and traditional way of modeling. By comparing the result, it is found that RP is cheaper and faster traditional way of hand modeling and it will save significantly the cost of model making in architecture.

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## APPENDIX 1: Cost Calculation Details

Table A1: Total builds time by using RP techniques:

Data preparation for the building ground floor (hrs)	Design in IDEAS software (hrs)	FDM build time (hrs)	Post build operation time(hr)	Process to insert the data in INSIGHT software program (hrs)	Finish Process (hrs)	Total Time in RP (hrs)	Total RP Time (Days)
15	15	1	54.18	1	1	87.18	3.6325

Table A2: Total cost of using Rapid Prototype technique

Data Preparation cost (£)	Design cost I-DEAS (£)	Process to insert the data in Insight (£)	Build cost in FDM techniques (£)	Material cost (£)	Post build operation cost (£)	Finish cost (£)	Total Cost of Rapid Prototyping (£)
75	375	20	271	295	10	20	1066

Table A3: Time and Material Estimate for Traditional Model making

Design (hr)	Drafting in AutoCAD (hrs)	Model Creation/ Assembly time (hrs)	Finishing Process (hr)	Total Time (hr)	Total Model Making Time ( Days)
15	7.5	37.5	7.5	67.5	9.00

Table A4: Cost of Traditional Model making

Design cost (£)	Drawing Cost in AutoCAD (£)	Material cost (£)	Finishing cost (£)	Model Assembling Cost (£)	Total Cost of Traditional Manufacturing (£)
450	75	50	150	750	1475

## INTEGRATING MASS CUSTOMIZATION WITH PREFABRICATED HOUSING

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**Abstract.** The paper will give an overview of mass customization concepts and how they can be applied to prefabricated modular housing. By collecting and evaluating client's requirements with web technology, a methodology can be developed that can generate design options based on the client's needs and available modular components in the market, and simulate the final design before beginning manufacturing. In this proposed model, a process of providing mass-customized prefab housing based on computer-aided design and a web-based product configuration system will be presented.

### 1. Introduction

The design of industrialized housing has been a pre-occupation in architecture since the start of the industrial revolution in the nineteenth century. In the first half of the twentieth century, architects attempted to solve the housing shortage by introducing a production process based on the assembly line. The assembly line was initially developed for the automobile industry by Henry Ford, but soon became a paradigm for the housing industry (Duarte, 2001). For example, the Dymaxion House designed by Buckminster Fuller was trying to achieve the mass production goal by retooling the aircraft factory.

Prefabrication technology groups building components into larger-scale modular units, such as a prefab wall panel with window and door openings. Each module is made in the factory using assembly line techniques, and then transported to the building site to be installed on a permanent foundation.

The construction of a new site-built home in the U.S. typically consists of 80% field labor and 20% material costs (Larson et al., 2004) – an extraordinarily high labor component compared to other industries. With prefabrication technology, the improvements of quality and efficiency are accomplished because factories can offer better working conditions, automation of some tasks, fewer scheduling and weather-related problems, and simplified inspection processes.

If mass production and prefabrication methods of the assembly line were the ideal of architecture in the early twentieth century, then mass customization and the development of computer technology are the recently emerged paradigms of the twenty-first century. The development of the digital revolution has already prompted the shift towards mass customization. In this new industrial model, the computer-aided manufacturing facilitates variations of the same product. Mass production was all about the economy of making things in quantity, but mass customization does not depend on serial repetitions to be cost effective. It is about cultural production as opposed to the industrial output of mass production (Kieran and Timberlake, 2004). Within limited design parameters, customers can determine what options they wish by participating in the flow of the design process from the beginning. This concept has already been implemented in the computer (Dell), clothing (Lands' End), and shoe (Nike) industries, but it has not been fully adopted in housing industry. Presently, only five percent of the population in the U.S. can actually hire an architect and pay them to design and build a home in which is tailored to their preference (2003 AIA Firm Survey). Although home builders who also provide a certain degrees of choice, most of them are focused on interior layout and finishes within standard and popular residential styles.

Today's information technology has become even more interactive and powerful than the last century. Integrating a participatory home design concept with web technology to create an online interface can become the design platform by which the clients can make more choices and establish a better communication with architects and/or manufacturers. Face-to-face meeting time between architect and client is always limited and time consuming, while a computational web-based design approach is infinitely patient and always available (Larson, 2001). One of the problems that prefab housing industries failed to address in the twentieth century was the lack of variability and an individual identified design (Kieran and Timberlake, 2004). How prefab housing design can be evolved from mass repetitive production level to mass customization level to meet flexibility and variability is the primary issue to be explored in this research.

## 2. Prefabricated Housing

### 2.1. WHAT IS PREFABRICATED HOUSING?

Prefabricated housing is a general term that indicates modular building components are pre-made in the factory, and then transported to the building site to be assembled and installed on a permanent foundation. It may include manufactured housing (following HUD code), modular housing (following local zoning and building codes) and production housing (site-built housing produced in a systematic manner). Each name change reveals a different categorization system created by the authorities. Table 1 includes the definition and example of each term.

TABLE 1. Definition of Terminologies in Prefabricated Housing.

TERM	DEFINITION	EXAMPLE
Prefabrication	Any manufacturing process that takes place in a controlled environment, usually a factory.	General term
Mobile Home	Housing made in a factory and transported to a building site that either a permanent or temporary location and hooked up to existing utilities.	Double Wides; Trailer Home
Manufactured Housing	The factory-made home must be permanently affixed to a foundation with the characteristics of site-built housing and meet all HUD code.	Many examples
Modular Housing	The factory-made home must be permanently affixed to a foundation and meet local zoning and building codes.	Habitat '67 by Moshe Safdie, 1967
Panelized House	Panelized factory-built walls are inserted into a modified post-and-beam structure by a builder on-site. It could be sold as do-it-yourself house kits.	Packaged House by Walter Gropius, 1941
Precut House	House made by precut timber with interlocking wedge-shaped joint.	Log House
Emergency House	Immediate relief in emergencies triggered by natural disaster or war.	Paper Log House by Shigeru Ban, 1995
Container Home	Modified shipping container as a modular/ transportable living spaces.	MUD by Lot-ek, 2003

### 2.2. HISTORICAL OVERVIEW OF PREFABRICATED HOUSING

The history of prefab housing began nearly four hundred years ago, when a panelized wood house was shipped from England to Cape Ann, Massachusetts in 1624 to provide housing for a fishing fleet (Arieff, 2002). Swedes introduced a notched building-corner technique for the construction of log cabins just a little over a decade later. By the nineteenth century, portable structures had grown in number as new settlements and colonies were formed to support a demand for immediate housing solutions. The kit houses shipped by rail during California Gold Rush in 1849 are one example (Arieff, 2002). During the early part of the twentieth century, many architects and inventors were experimenting with these systems for housing. The Sears Roebuck catalogue made prefabricated homes available to subscribers as early as 1908 (Thornton, 2004), and prefabrication was later explored by such eminent twentieth-century architects as Le Corbusier,

Walter Gropius, Frank Lloyd Wright, Jean Prouvé, and Paul Rudolph, who saw the technology as a new solution to the problem of housing in modern society. After World War II, this approach was extensively used in the reconstruction of Europe and for the postwar housing needs of the United States. Many aircraft companies turned to producing industrialized housing and component parts. Once the housing shortage was satisfied, the implied degree of repetition became unacceptable by a society increasingly focused on individual freedom and choice (Duarte, 2001).

### 2.3. TYPES OF PREFABRICATED HOUSING SYSTEM

Representing scale of individual components, there are six different types of prefabricated housing systems: fully modular, sectional, panelized, precut, components/ kit of parts, and chassis and infill.

#### 2.3.1. Fully Modular

All the components of a single housing unit are entirely made, assembled and finished at the plant; as three-dimensional modules (like boxes) requiring only simple connections to the foundations and main service conduits once at the site. The size of the modular unit is restricted by highway law or shipping constraints. There are some examples, Habitat '67 in Montreal, Canada by Moshe Safdie and Nakagin Capsule Tower in Tokyo, Japan by Kisho Kurokawa in Figure 1 (Arief, 2002).



Figure 1. Nakagin Capsule Tower, Tokyo, Japan, 1972.

#### 2.3.2. Sectional

Small and easy to transport sectional modules but incomplete, as they need a complementary component or process once they reach the site. There are not many examples can be found from historical review, but it has some potentials for digital fabrication and mass customization. ESG Pavilion

(Figure 2) by graduate students in ETH is an example of creating sectional modules.



Figure 2. ESG Pavilion, Zurich, Switzerland, 2005.

### 2.3.3. Panelized

A panelized home is a site-built house where some of the components are assembled or prefabricated in a controlled factory environment thereby saving on-site framing labor. In most cases, the panelized components, such as the Tilt-Up Slab House (Figure 3), are load-bearing walls to replace post and beam framing system.



Figure 3. Tilt-Up Slab House, Venice, CA, 2001.

### 2.3.4. Precut

Precut wood framing systems have been developed in Japan over 14 years ago. MF Technologies, Minnesota based company, applied this system with precut, engineered lumber and connectors (Figure 4), which allow a group of four to eight untrained workers to assemble a precise frame in several days time. The components of the house are actually numbered, and are constructed as you would a piece of kit furniture. Materials cost 10-20% more than those for conventional framing, but the cost is offset by reduced labor expense.



Figure 4. MasterFit Precut Wood Framing System.

#### 2.3.5. Components/ Kit of Parts

A kit-of-parts is a collection of discrete building components that are pre-engineered and designed to be assembled in a variety of ways. Components are sized for convenient handling or according to shipping constraints. LV Home (Figure 5) is a good example of affordable modernist house by kit-of-parts system.



Figure 5. LV Home Kit, Perryville, MO, 2003.

#### 2.3.6. Chassis and Infill

This is a hybrid system that includes prefabricated posts and beams to form a framing system as the fundamental structure, and using the automobile industry's term – chassis. This is made possible by dividing the house into two notional elements: the chassis, the standardized, mass produced part of the system, provides the structure and services for the building, and the infill, which consists of interchangeable wall and floor components, provides for customization and adaptability. This system was proposed by MIT *House\_n* Research Team (Figure 6).

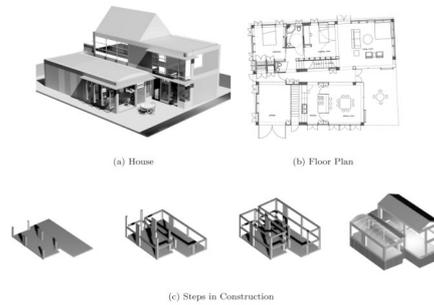


Figure 6. Chassis + Infill System House, 2003.

### 3. New Trend toward Mass Customization

#### 3.1. CONCEPT OF MASS CUSTOMIZATION

At the beginning of the twentieth century, industrialized economies were focused on mass production, mass distribution, mass marketing and mass media. Presently, a combination of advances in information and digital technology is making it increasingly possible to rapidly respond to consumers with customized products at mass-production prices. The fundamental premise of mass customization is to no longer manufacture products "blindly" according to a predicted demand, but instead allow production to be directly driven by actual orders (Schodek, 2004).

The term "mass customization" was coined by Stan Davis in his book *Future Perfect* but the term was popularized by Joseph Pine in his book *Mass Customization: The New Frontier in Business Competition* in 1993 (Schodek, 2004). Mass customization has different implications for different products and in different sectors. There are also different methods and strategies to achieve it (Crayton, 2001). Some products can be tailored or customized directly by the consumer; other products may only have limited degree of customization at the retail outlet or dealer.

One of the most important distinctions running through all the different senses of mass customization is somehow the consumer may involved the design through production process. The choice is configured to what extent the process is "transparent" or "collaborative" and forms part of a dialogue between the producer and the customer.

The key to cost effective customization is modularization and configuration (Crayton, 2001). One of the key ideas and strategies to achieve mass customization is modularization. Products are "decomposed" into modular components or subsystems that can be recombined to more nearly

satisfy customer’s needs. The modularization approach is very close to the spirit of prefabricated housing, and this model can be viewed as a revitalization of mass production housing. The configuration systems present the choices to consumers and determine what goes with what. Using web technology, the configuration systems can be represented as a design interface to convert customer’s input to final product’s configuration, and the on-demand production can combine standard modules together by the assembly line (Figure 7).

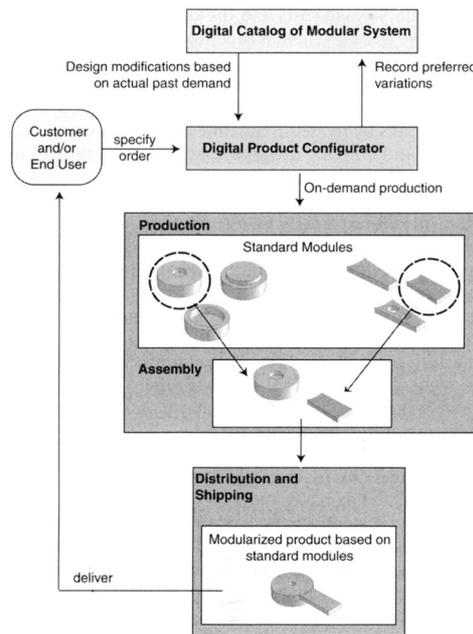


Figure 7. Schematic process diagram of mass customization.

### 3.2. CURRENT APPLICATIONS

Compared to approaches of mass customization in product or furniture design, like Nike-iD series products, there are more challenges to apply this model to architecture. From design to construction, a new building is a complex process involving a number of independent parties. There is usually no one party that is expert in all areas, and the industry-specific fragmentation is a major obstacle to mass customization. Before reaching mass customization in architecture, it is might be easier to apply this model to architectural products. Currently, there are only a few companies that have successfully adopted mass customization concept. E-skylight.com

supported by Architectural Skylight Company (ASC) (Figure 8) is a good example as a case study.

ASC uses object-oriented design approach to the design and manufacturing custom skylights. This system supplements AutoCAD with several plug-ins, including third-party software and programs developed by ASC. The website interface provides step by step customizing process to generate a final design model, and the virtual model is used directly for computer numerical control (CNC) manufacturing of frame members and for the CNC cutting of custom glass sheets.

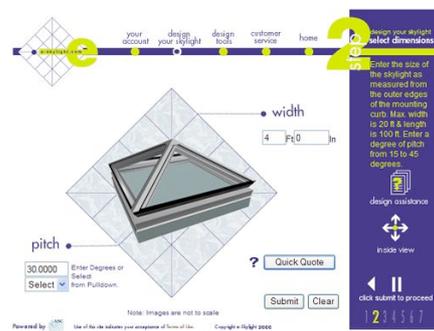


Figure 8. Design Interface of e-skylight.com.

#### 4. Conceptual Framework of Internet-Aided Prefab (i-Prefab) System

In order to achieve the goal of mass customizing prefabricated modular housing, the conceptual design model must combine the results of two important parts: data collection of client's requirement and prefab system design combinations. The web-based prototype can simulate the interaction between clients and the adoptable systems. The evaluation part can include a series of case studies to demonstrate and revise the data-input method within the design interface. Finally, the resultant design can generate building specifications prepared for manufacturing (Figure 9).

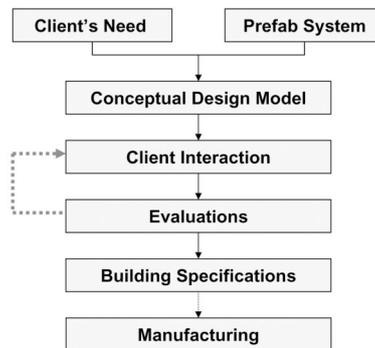


Figure 9. Conceptual Framework of i\_Prefab.

#### 4.1. OBJECTIVES

The main goal of this research is to investigate the possibilities of customizing mass housing by web and prefabrication technology. This framework aims to:

- A. To research how to collect and interpret client's need to become design options to address the issues of individual needs from the end-users.
- B. To explore possible combinations of prefab modular housing according to client's preference.
- C. To construct an intelligent database to host standardized components from existing market, possible prefab housing configurations, and fabrication methods by today's technology.

#### 4.2. SIGNIFICANT OF THE RESEARCH

1. Identified issues of client determination via digital configurator may improve the project delivery process in housing industry.
2. Identify the issues that prefab system should address to be more client-responsive.

#### 4.3. EXISTING MODELS AND PROPOSED MODEL

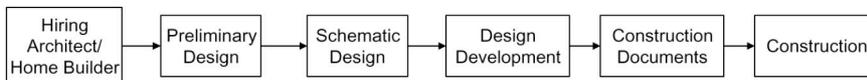
Only five percent of people in the United States can actually hire an architect and pay them to design and build a home in which is tailored to their preference. Besides the architect's fee, clients also need to wait a tremendous time for design and construction. Factory-made prefabricated housing system tried to solve this problem previously. However, most industries failed to address the issues of variability and individual needs. Plants closed due to they produced more than the market needed, and

traditional prefabricated housing provided less value to compete with stick-built housing market (Figure 10).

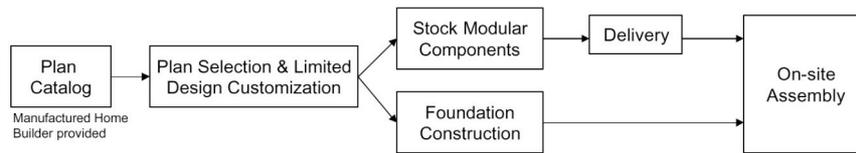
The advanced digital technology makes it possible to communicate design ideas and concepts to others more effectively. Demand-to-order is not a dream for prefabricated housing industry anymore. As long as we have some interchangeable standardized components in the market, mass customized prefab housing does not depend on serial repetitions to be cost effective.

#### Comparison of Single-family Home Design & Project Delivery Process

##### Traditional Home Design:



##### Factory-made Home Design:



##### i Prefab Home Design:

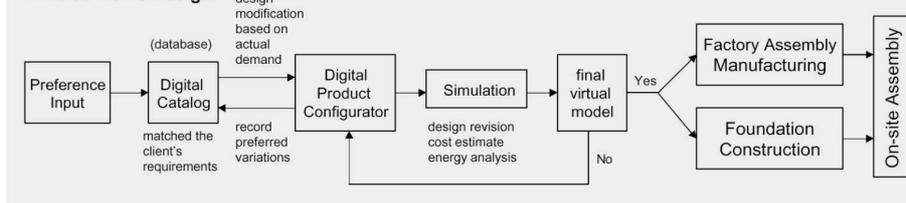


Figure 10. Existing Models and Proposed Model.

#### 4.4. RESEARCH ISSUES

The proposed model will generate other related research issues:

1. How will choices be explained to non-architecture trained clients?
2. How will mass customization affect the housing design process?
3. How will other people (consultants or inspectors) be involved in this design process?
4. What kind of format should be developed as the result of this design process?
5. What will be the architect's role in this new system?

#### 4.5. CONCLUSION

Today, we are immersed in the digital age that created opportunities never before available to connect information, people, products, and tools in a comprehensive manner. Many industries adopted mass customization concept as their business goal and utilized the web as a communication interface to satisfy their individual client's need. Although architecture has not reached this point due to its complexity and industry-specific fragmentation, this is a new concept for architects to consider. Especially in the case of housing, how to create a unique space that reflects end-user's lifestyle out of many ready-made components will be the issue of our generation. Moreover, this approach encourages architects to develop a series of solutions rather than single solutions for a design problem. For the technical challenge in standardizing the various building systems, it will be easier to implement in the government controlled countries, like China, or setup a new standard system for universal and interchangeable parts in developing countries.

#### Acknowledgements

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## SENSOR-BASED AWARE ENVIRONMENT

*Requirements towards establishing a computational self-configuring sensing system*

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**Abstract.** This paper provides an overview of the requirements for a computational model of a Sensor-Based Aware Environment (SBAE) that integrates sensor technologies with the Building Information Modelling (BIM) in order to sense ambient and physical aspects of the built environment. Wireless sensors sense ambient data of a built environment, process, and communicate these data through an ad-hoc wireless network. The BIM, on the other hand, is based on International Foundation Classes (IFCs) and contains data about the physical infrastructure (i.e. Walls, Windows, doors) and abstract entities (i.e. Spaces, Relationships) and relationships between those entities. Therefore, the proposed computational model could sense real time data that are related to the as-built information model allowing for holistic building state information.

### 1. Introduction

Low-powered wireless sensors with on-board computing capabilities hold the potential for applications in aware environments. Mahdavi (2004) defines an aware environment as the one that exhibits a sensor-based, dynamic, and self-updating internal representation of its own context. In these aware environments, sensors and artificial intelligence (AI) computation afford peripheral awareness of human activities, ambient environment, and physical infrastructure (Dong et al. 2004). Such an environment could support a range of facilities management applications such as monitoring and evaluation of the building performance and responding to occupant directives and activities. However, extant methods for collecting ambient environment data and building configuration data for

existing built environments is time consuming and driven by manual labour. Such labour-intensive methods will not be able to cope with the collection and analysis of such data for efficient facilities management.

Existing monitoring systems are concerned with specific building services rather than whole building context. Continuous data acquisition about building facilities is essential for approaching life cycle information and therefore supporting overall facilities management and decision making tasks. The advancement of wireless sensor technology and wide adaptation of Building Information Modelling (BIM) within the Architectural Engineering Construction (AEC) industries offer a potential solution to this problem. Our thesis is that integrating wireless sensors with the BIM could enable a Sensor-Based Aware Environment (SBAE).

Since little work exists in this specific area, it is useful to begin with a working definition for the concept of SBAE:

*It is an environment that is an effect of a self-configuring sensing system. The self-configuring sensing system responds to changes in the ambient environment and built environments in order to achieve ad hoc deployment of wireless sensors and their unattended operation in a changing context.*

The concept of a SBAE raises the following issues:

**Context:** It is important to understand the word context and what it means for this research. The context of a built environment refers generally to two constituents *i)* occupants: who are the people which inhabit, use, and visit the building; and *ii)* components: which include building systems, and physical and digital artefacts (Mahdavi, 2004). The context in this paper refers to the physical constituents of building as a technical artefact (the product called facilities).

**Self-Configuring Sensing System:** is a system that can modify its set number of finite parameters in response to changes in the environment. Algorithms are required to enable the sensing system to exhibit self-configuration within the following configurable parameters:

- a) Localization of the wireless sensors;
- b) Automated discovery of sensible objects for each sensor; and
- c) Automated discovery of new or removed sensors and their type.

**Integration between wireless sensors and BIM:** Wireless sensors can sense data about the ambient environment (i.e. temperature, humidity, and lighting) as well as other technical and operational data such as energy and water consumption, and gas leakage. In contrast, the BIM is based on International Foundation Classes (IFCs) which contains data about tangible entities (i.e. walls, windows, and doors) and abstract entities (i.e. spaces, and relationships) and establish relationships between those entities. The importance of the BIM is that it maintains hierarchical relationships between building components which could be modified to the user's needs.

This paper discusses the requirements for a computational “self-configuring” sensing system that could potentially lead to establishing sensor-based aware built environments. The sensing system self-configures parameters that maintain a representation of sensors and respective sensed objects and their localization. The self-configuring sensing system adapts to changes in the sensor infrastructure and the physical built environment. Ideas for the self-configuring sensing system are based on concepts of machine awareness, pervasive computing systems (wireless sensor networks, embedded computing) and object repositories of building data.

The use of a self-configuring sensing system in the building context could have several implications: *i)* minimise human intervention in acquiring facility state data; *ii)* support the autonomous process of collecting, updating and visualizing the data of the context; *iii)* allow ad hoc deployment of the sensors into an existing facility.

## 2. Related Work

Developments in related research areas are summarized and their relevance discussed in the context of SBAE introduced above. The research comprises two theoretical areas a) intelligent buildings; and b) aware machines, and two technologies c) BIM, and d) wireless sensors. The theoretical areas and the wireless sensor technology will be discussed towards highlighting the requirements of self-configuring sensing system.

### 2.1 INTELLIGENT BUILDINGS

In architectural design, an aware environment has also been called intelligent buildings, intelligent rooms, and sentient spaces. There are many available definitions of intelligent buildings as in Sherbini (2004) that refer to criteria such as automation, responsiveness, and effectiveness in order for the building to ‘be’ intelligent. We consider an aware environment as a different sort of intelligent building. An aware environment is:

*A type of machine which possesses a self-aware model of itself and of its environment and exhibits aspects of intelligence such as knowledge representation, learning and reasoning.*

Regardless of the definition of an intelligent building, there are two generally regarded principles for intelligent buildings: context-awareness and intelligent agents. According to Pascoe (1999), context-awareness, the ability of a device or a program to sense, react or adapt to its environment, is a key technology in ubiquitous computing. That is, an intelligent building should be able to adapt to changes by acquiring data from the context that can be used as informational basis for context awareness. Second, an

essential part of the computing components of an intelligent building are intelligent agents. There are many definitions of intelligent agents in the literature. However, the definition by Russell (1995) that "*An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors*" is the appropriate for intelligent rooms. Intelligent agents are pieces of software that are embedded into a system in order to take decisions and actions. The principal components of an intelligent system based on intelligent agents are according to Russell (1995): 1) the ability to perceive the context; 2) the ability to maintain a representation of the context; 3) the ability to reason; 4) the ability to learn. Learning and reasoning, however, are dependent on the agent's ability to perceive and maintain a representation of the context. Multi-agent systems appear to be the dominant approach for creating intelligent rooms.

Intelligent buildings are typically consisting of a large number of autonomous/self-directed agents (Ranganathan, 2003). Multi-agent systems such as the ScatterBrain system cited by Coen (1997) are already found in operational implementations of intelligent rooms. Because agents are simple entities, agent based systems relinquish the need for complex centralized control (Coen, 1998). These agents work together to transform built spaces into intelligent buildings by coordinating sensors and effectors to achieve desired behaviours.

## 2.2 AWARE MACHINES

The development of aware environments is founded upon fundamental ideas of machine awareness from the field of artificial intelligence. One of the main criteria for intelligent systems is their ability to perceive their world and to respond to this world. In aware environments, the perception of the world would be enabled through sensors. The sensors in an aware environment need to be able to calibrate automatically and adapt to the environment as needed by establishing a communication network. All the sensors in an environment need to communicate their state and their coverage area to each other and develop a model of the context (Essa, 2000). Therefore, the integration of awareness of itself and the context are mandatory components of an aware machine and therefore, an aware built environment. The integration of sensor systems with the digital building representation is one potential way to create an intelligent building that is an aware machine.

### 2.3 WIRELESS SENSOR NETWORKS

Wireless sensor networks with the BIM are basic technologies required to establish the SBAE. An aware environment requires information about its surroundings as well as about its internal context. In order to develop a real-world data acquisition method, pervasive computing systems (i.e. wireless sensor networks and embedded computing) are required. Therefore, it is important to understand how these pervasive systems function. We have chosen to deploy the wireless sensor “motes” commercially developed by Crossbow. There are three components of a Crossbow wireless sensor network as: 1) sensor and data acquisition boards; 2) mote processor radio platform; and 3) gateways and network interfaces.

#### 2.3.1 Sensor and Data Acquisition Boards

Zhao (2004) defines a sensor as: “a transducer that converts a physical phenomenon such as heat, light, sound, or motion into electrical or other signals that may be further manipulated by other apparatus.” A sensor converts the quantity to be sensed into a detectable signal that can be directly measured and processed. Examples of sensor and data acquisition boards from Crossbow (<http://www.xbow.com>) are shown in Figure 1.

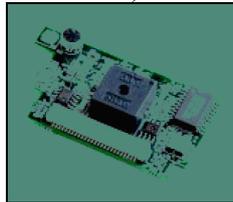


Figure 1. Example of sensor board “MICA”

#### 2.3.2 Mote Processor Radio Platform (“Motes”)

A sensor board can only send data through the wireless network when it is affixed on a radio platform called Mote. The combined package of sensor board and mote processor is known as a Sensor Node (Figure 2).

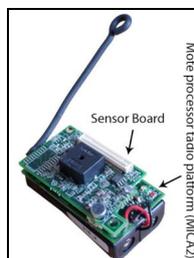


Figure 2. Sensor node with MICA2 and sensor board (photo by the author)

### 2.3.3 Gateway and Network Interface

A base station called a “Gateway” allows the aggregation of sensor network data onto a PC or other computer platform (Figure 3). MICA and MICA2DOT sensor boards can also be affixed onto the MIB510 gateway to be programmed to do certain tasks

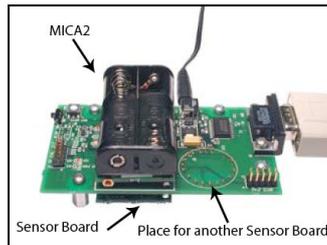


Figure 3. Example of a gateway (MIB510) with MICA2 and sensor board by Crossbow

### 2.3.4 Ad hoc Networks

One of the special features about the motes is the idea of using large numbers of motes that communicate with each other and form ad hoc networks without human intervention. The ad hoc network allows data from each mote to be passed from one mote to another toward the gateway. The range of communication between wireless sensor nodes is between 10m and 30m. The ad hoc network is formed by hundreds or thousands of motes that communicate and pass data along from one to another. (Figure 4) illustrates an example of an ad hoc network.

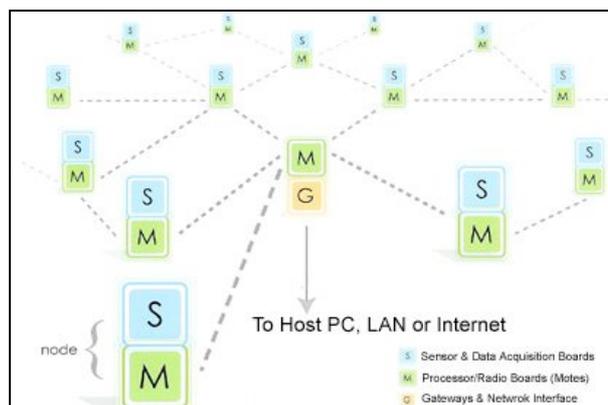


Figure 4. Illustration of the wireless sensor network that forms an ad hoc mesh network. “S”: sensor board, “M”: mote, and “G”: gateway

### 2.3.5 Wireless RFID Motes

Radio Frequency ID (RFID) is a wireless communication technology with advanced features ideal for scanning other RFID tags attached to anything that needs a memory or an ID number (Skyetek, 2005). RFID Readers can read from and write to RFID tags without contact, even through walls.

For the self-configuring sensing system, the wireless RFID mote is called an Anchor Node (“aN”) as in (Figure 5). Each of the anchor nodes acts as a beacon which periodically scans its neighbourhood for sensor nodes. Each of the sensor nodes has an RFID tag. The anchor node consists of two components; 1) RFID reader; and 2) radio transmission board for communication within the wireless sensor network.

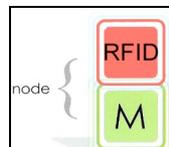


Figure 5. Anchor Node (“aN”) for this research consists of: RFID reader/writer (RFID), and mote (M)

## 3. Self-Configuring Sensing System

Towards establishing a computational self-configuring sensing system that potentially results in an aware environment, the system therefore consists of:

### I. Components:

- 1) Sensor technology to perceive the context;
- 2) BIM technology to perceive the building attributes; and
- 3) A large number of autonomous/self-directed artificial agents.

### II. Behaviour:

- 1) Maintain a representation of the context;
- 2) Autonomously update itself over time; and
- 3) Process and analyse context information.

### III. Parameters:

- 1) Localization of the wireless sensors;
- 2) Automated discovery of sensible objects for each sensor; and
- 3) Automated discovery of new or removed sensors and their type.

### IV. Function:

- 1) Integrate data from sensors with the BIM.

Figure 6 shows the computational framework for the self-configuring sensing system. According to Russell and Norvig (1995), wireless sensors

could act as agents that perceive the external environment. Sensor and BIM agents are inventory software that communicates with the sensing system to exhibit self-configuration for the above mentioned parameters. The output of the sensing system could potentially lead to establish the proposed environment that is aware of changes in the ambient environment, and physical infrastructure of the built environment.

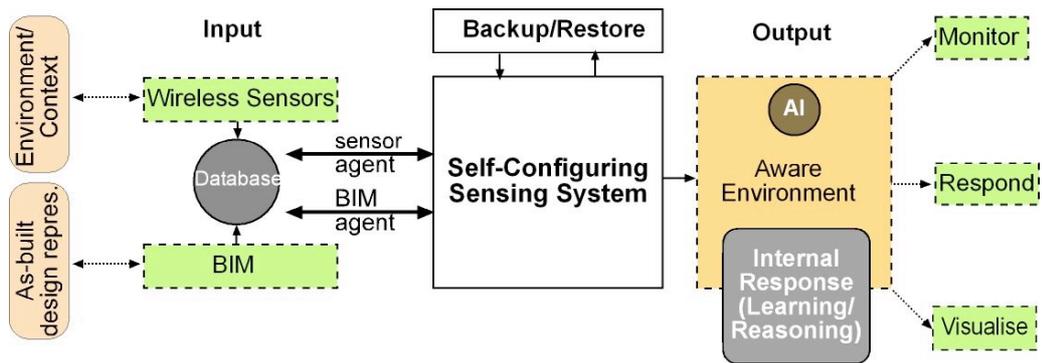


Figure 6. Proposed system framework for this research

### 3.1 INFRASTRUCTURE COMPONENTS

The proposed sensing system consists of the following components:

- **Object Nodes (“oN”)**: are physical and infrastructural components of the building such as (light fixtures, doors, windows, and columns). In another word, they are all effectors inside the built environment that can be sensed by wireless sensors. Object Node representation with relation to location is derived from the BIM using IFC models.
- **Anchor Nodes (“aN”)**: “usually known by beacons” are nodes that are pre-programmed by the user into the system according to their locations inside the building. The anchor nodes periodically scan the location of their neighbourhood for any sensor node that has a RFID tag.
- **Sensor Nodes (“sN”)**: are nodes that consist of: 1) sensor board; 2) mote; and 3) RFID tag (Figure 7).

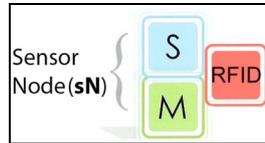


Figure 7. The sensor node design components to be used in this research. “S”: sensor board, “M”: MOTE and RFID tag

### 3.2 LOCALIZATION

One of the important significance of the SBAE system is the ability to accurately locate sources of sensor data inside the building. This is the problem of localization. This is because the wireless sensors should be deployable in arbitrary locations. The following simplified scenario describes the self-configuring localization parameter mentioned earlier.

#### 3.2.1 Localization of Anchor Nodes and Object Nodes

Prior to placing wireless sensors (sN) in different locations inside a built environment, two relationships need to be stored in a database; *a*) relationship between object nodes (oN) and their locations in the built environment (“reln\_oN\_location”), and *b*) relationship between anchor nodes (aN) and their locations (“reln\_aN\_location”).

**a) reln\_oN\_location:** object entities called Object Nodes (“oN”) are stored in database and related to locations in the built environment which is basically derived from the BIM. The BIM contains information about architectural and building components including object’s serial number (“oN\_serial”), object’s description (“oN\_description”), object’s type (“oN\_type”), and object’s location (“location\_ID”). Thus, all information about Object Nodes that are affixed inside a building will be stored in the system (table 1).

TABLE 1. “reln\_oN\_location” The BIM representation of relationship between object nodes and location\_ID

oN_serial	oN_description	oN_type	location_ID
00001	Light fixture	light	274
00002	window	temperatur e	113
...n	xxx	xxxxxx	xxx

**b) reln\_aN\_location:** beacons or wireless Anchor Nodes (“aN”) are assumed to be placed in specified locations inside the building such as

offices, corridors, and plant rooms. Every Anchor Node has a unique RFID represented in the database as (“aN\_RFID”). Every aN\_RFID will be related to a specific location\_ID into the database as shown in table 2 (“reln\_aN\_location”). In practice, this is done by scanning the RFID tag of the aN to an RFID reader and then typing in the intended location of the aN inside the building. The Anchor Nodes are then ready to be manually affixed in the specified locations.

TABLE 2. “reln\_aN\_location” The relationship between aN\_RFID and location\_ID

aN_RFID	location_ID
51151	274
46637	113
...n	xxx

### 3.2.2 Localization of Sensor Nodes

The user selects the type of sensors such as (light, temperature, and humidity) to be placed in one location. Each location could have more than one Sensor Node (“sN”) but may only have one Anchor Node aN. Every sN has an ID (“sN\_ID”) pre-programmed by the user onto sensor board, RFID tag (“sN\_RFID”), and one or more sensing capabilities. The process of sensor deployment and sensor node localization is as follows:

**a) Anchor node scanning:** After the user selects wireless sensor nodes for deployment, s/he needs to walk into the target location and deploy the sensor where it can sense the ambient environment. The periodic scanning for the sensor nodes by anchor node triggers the self-configuring localization of the sensor nodes.

**b) Establishing relationship between aN and sN:** When the aN sensor scans a sensor nodes in its vicinity, the aN sends a message to the system formatted as (aN\_RFID, sN\_RFID). If sN\_RFID is already stored in the database then the system goes to the next message. If the sN\_RFID is not stored in the database, it means that the sensor node is a new node found in location and therefore, the system establishes a relationship between the new sN and aN. This is done by storing the relation into a new table (Table 3) (“reln\_aN\_sN”) and recording the new relation. Following is a pseudocode for establishing relationship phase:

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#### Pseudocode 1: localization of sensor node

- 1: pre-define aN to location\_ID in the BIM and write into database (table “reln\_aN\_location”)
- 2: deploy aN into specified location
- 3: deploy a sN

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```

4: aN frequently scans the location for any sN
5: aN sends message to system upon scanning the room with a relation msg
   (aN_RFID, sN_RFIDs)
6:   for each msg received from aN_RFID, compare the associated
   sN_RFIDs in msg with existing sN_RFIDs in database
7:     if sN_RFID in msg == sN_RFID in database, then this
   sN_RFID is active
8:     else if sN_RFID is not in database, then this sN_RFID is new
   and should be stored in database
9:     else if sN_RFID in database has received no match from msg,
   then this sN_RFID is inactive or removed from aN_RFID
   location and should be deleted
10:  end if
11: end for
12: end

```

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TABLE 3. “reln\_aN\_sN” The relationship between aN\_RFID and sN\_RFID

aN_RFID	sN_RFID
51151	83332
46637	28783
...n	...n

### 3.2.3 Self-configuration of Sensible Objects:

The wireless sensor network works as a monitoring system of the ambient environment. Each wireless Sensor Node sends raw data through the network to the sensor board or sensor network Gateway. The raw data requires an interpreter to display information about the sensor which could include sensor ID (“sN\_ID”), data stream value (“sN\_value”), sensor type (“sN\_type”) engineering units of data (“sN\_unit”), and time of reading (“time”) (see table 4). These data could be stored in a database which will be accessed by the self-configuring sensing system for the final integration step.

TABLE 4. An example of the sensor information that could be stored in a database after being interpreted

sN_ID	sN_value	sN_type	sN_unit	time
14	420	light	lux	07/10/2005 11:35:54
23	42	humidity	percent	07/10/2005 11:42:20
27	25	temperature	deg C	07/10/2005 12:44:07

Self-configuration of the sensible objects is completed when the system finds a match in type between sN and oN from table 1 and 4. The system then establishes relationships between the two nodes in the same way as before (see pseudocode 1). The system then stores new relationships in a new table. Thus, for every location inside the building, the user identifies where Sensor Nodes are placed, but the system automatically determines sensible objects as Object Nodes.

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**Pseudocode 2: final integration**


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```

1: begin
2: LOCALISATION PHASE
3: for i = 1 to locations
4:   read every location (i)
5:   check what object (m) is in location (i)
6:   check what sensor (n) is in location (i)
7:   for j = 1 to m
8:     read all object (j)
9:     check what is object_type (j)
10:    for k=1 to n
11:      read all sensor (k)
12:      check what is sensor_type (k)
13:      if sensor_type (k) == object_type (j) store new relationship in
        final table
14:    end if
15:  end for
16: end for
17: end for
18: end

```

---

#### 4. Future Directions

We plan to develop a prototype of the self-configuring sensing system according to the scenarios and specifications described above to test its workability. The notion of the aware environment as an effect of the sensing system will be then developed to exhibit aspects of artificial intelligence, learning and reasoning.

##### 4.1 CONCLUSION

The paper introduced the concept of self-configuring sensing system towards sensor-based aware environments (SBAE). We believe that such computational models could benefit several domains such as facilities management in that real-time visualising and updating of the ambient and physical infrastructural information about the facilities could be possible. This information could be used in different applications when it is fed back to the system for analysis of the current status, predicting the future through simulations, and responding more effectively to the occupants and building needs. With such computational models that automatically update themselves to reflect changes in the built environment, the human intervention, which currently limits the process of collecting and visualising data, could be overcome or at least significantly reduced. Dynamic monitoring of changes in a facility, when systematically collected in real-time through wireless sensors and the BIM could provide valuable information and feedback to a number of building professionals, not the least to building designers, who currently know very little about the long-term behaviour of their designs.

#### Acknowledgements

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## **Section III: Theory and Critical Evaluation**

## REDEMPTIVE TECHNOLOGIES II: THE SEQUEL (A DECADE LATER)

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**Abstract.** Nearly ten years ago I published an article in the Dutch journal *ARCHIS* called "Redemptive Technologies." It derived from comments I made during a conference held in New Orleans in 1994. At that point the machine aesthetic associated with the "new technologies" generated by the computer had not established a precise formal vocabulary but were generating great excitement among the architectural *avant-garde*. It addressed the limits of the imagery and data produced by this machine and the simple but very political problem of cost and obsolescence. Now the millennium is well past and the somewhat apostolic fervor that accompanied the interaction of a very expensive consumer device with architecture has cooled. Discussion has generally moved from the titillating possibilities opened up by the device, many of which have so far not come to pass, to the sorts of hard and software available. An architectural language closely associated with the imagistic potential of new programs, biomorphism, has now come and gone on the runways of architectural taste. And yet, in recent articles rejecting the direct political effect of architectural work, the potential of new programs and virtual environments are proposed as alternative directions that our perpetually troubled profession may pursue.

This paper will assess the last decade regarding the critical climate that surrounds cyber/technology. In the economic context of architectural education in which computers are still a central issue, the political issues that evolve will form a backdrop to any discussion. Furthermore, the problem of the "new" language of biomorphism will be reiterated as an architectural grammar with a 100-year history - from Catalan Modernismo and Art Nouveau, through Hermann Finsterlin and Eric Mendelsohn's projects of the 1920s, to Giovanni Michelucci and Italian work of the post-war, to Frederick Kiesler's Endless House of the late '50s, continuing through moments of Deconstructivism and Architectural Association salients, etc. These forms continue to be semantically simplistic and hard to make. Really

the difference is the neo-avant-garde imagery and rhetoric involved in their continuing resurrection.

Computer images, but also the ubiquitous machine itself, are omnipresent and often their value is assumed without question or proposed as a remedy for issues they cannot possibly address. This paper will underline the problem of the computer, of screens and the insistent imagistic formulas encourage by their use, and the ennui that is beginning to pervade the discipline after initial uncritical enthusiasm for this very powerful and expensive medium. But it will also propose other very valuable directions, those relating to reassessing the processes rather than the images that architecture engages, that this now aging "new" technology can much more resolutely and successfully address.

### 1. Redemptive Technologies II

"We live in a world populated by structures - a complex mixture of geological, biological, social, and linguistic constructions that are nothing but accumulations of materials shaped and hardened by history." Manuel De Landa (1997)

In the beginning of 1996 I wrote an essay called "Redemptive Technologies." (Stanton, 1997) It was published in the Dutch journal *ARCHIS*. It also appeared in the *Proceedings* of the 1996 ACSA International Conference in Copenhagen as "Redemptive Technologies: Millennialism and the Loss of History," and in the *Proceedings* of the ACSA Southwest Regional Meeting in New Orleans, again in 1996. It derived from comments I made during a conference held in New Orleans in 1994. At that point the machine aesthetic associated with the "new technologies" generated by the computer had not established a precise formal vocabulary but was generating extreme "nostalgia for the future" (Silvetti, 2003/2004, p.26) among the architectural *avant-garde*. While an uncritical almost-evangelical enthusiasm for what was then a relatively new and very commercially successful mechanism was at its maximum, the look of its product was not yet formulaic. The essay urged caution regarding the historical problem of transcendental belief in technology. It addressed the limits of the imagery and data produced by this machine and the simple but very political problem of cost and obsolescence.

Now a decade has framed the millennium and the apostolic fervor that accompanied the interaction of architecture with a very expensive consumer device has cooled. Discussion has generally moved from the titillating possibilities predicted for the device, many of which have not yet come to pass, to the sorts of hard- and software available. (It is disturbing to me that so many conversations I participate in these days with fellow practitioners

and academics focus on the material aspects of this one very minor aspect of our complex endeavor.) Biomorphism, an architectural language closely associated with the imagistic potential of new programs, has now passed on the runways of architectural taste. And yet, in recent articles rejecting the direct political effect of architectural work, the potential of new programs and virtual environments are still proposed as alternative directions that may redeem our perpetually anxious profession. In a recent one Michael Speaks dismisses architectural theory as having "lost its allure and all connection to the real world," and "not just irrelevant but was and continues to be an impediment to the development of a culture of innovation in architecture." (Speaks, 2005, 74) This simplistic condemnation of theory in the last decades appears to be politically complicit with very American and neo-conservative anti-intellectual agendas that dismiss thought as essential to action. His accusations of leftist irrelevance, apparently leveled at the entire body of late-20th-century architectural discourse, seem to reflect market concepts and regime strategies as they now exist. Speaks makes the strangely tautological statement, "Few, however, have recognized that we don't just need a new 'theory,' but instead we need a new intellectual framework that supports rather than inhibits innovation." (Speaks, 2005, 73) It is clear that this is not a rejection of theory but of his immediate predecessors, whom he names specifically, and of their *avant-gardist* leftist version of theory as he defines it. In a predictable reaction to the "anxiety of influence," (Here I sample Harold Bloom. The poetic struggle against the strong figures that shape immediate creative action is perhaps most clearly described in Bloom, 1973)

Speaks is attempting to make room for his brand of "operative criticism," his own form-friendly theory in other words. (see all of the work of Manfredo Tafuri but particularly Tafuri, 1976 and Passerini, 1992) The insistence on innovation also clearly reiterates the mantras of *avant-gardism*, but the rejection of a critical or resistant role for that innovation then places it in the service of the marketplace, a seminal contradiction that much of the neo-*avant-garde* seems to overlook or even accept. (Stanton, 1992, & Stanton, 1998) In order to do this Speaks ends up agreeing with the large conservative element of the profession that rejects the clearly essential ideological aspects of our work in favor of a practice-friendly business model in better accord with late-capital. After several pages of easy dismissals of the very complex and rich formulations that have critically redefined our discipline, Speaks then predictably turns the discussion toward computer applications, to "...new, digitally driven forms of prototyping, where the prototype, which can be analyzed, tweaked, and adjusted, becomes a tool of innovation and not just a version of the final design." (Speaks, 2005, 75) His proposal for a theory after theory is again one in which software seems to provide the answer to the problem of architecture's

increasing irrelevance - much the same promise I encountered more than a decade ago in New Orleans. In the economic context of architectural education in which computers are still a central issue, the politics that evolve form a backdrop to any discussion.

Certainly, in the ensuing decade, the computer has replaced the drawing table. Occasionally one finds a dust- or document-covered board in some corner of an architectural firm but now the workspace for designers has been transformed into a simulation of that of other workers in the cyber-office, an isolated cubicle with computer as focus. The distinct and romantic vocational environment of the architect, and of other designers, is gone and we take on the universal attitude of late-capitalism's generic laborer, a setting that extends to the home and the commute to work (screens, isolation, spun information, gadgets). The implications of this are alarming of course in the basic context of labor relations and environment as they have manifested themselves in the 21st century but they also generate specific questions in relation to architectural practice. Was there a value to drawing and model-making? Has that value, if it existed, been supplanted by greater value generated by working with mouse, keyboard and screen? Given my generation's experience and love of the craft of design, I certainly believe in the importance of the physical interaction with form that occurs when one represents in two or three dimensions. The connection of hand and eye, passing through the intellect, seems to be a crucial one to me. In order to draw the designer had to access either visual information or the imagination or generally both, filter it through a perceptive sieve and then act with the hand to produce image. To replace that with the automatic translations that can be made by the computer, which replaces not so much hand or eye but brain in this formula, must be questioned. My students no longer sketch even when I ask them to, either as a design tool or when we travel for study. They take photos instead, often digitally to download and doctor on computer afterwards. This has its value as a recording but plainly does not enable the connection of eye, brain and hand, and the mnemonic possibilities inherent in that relationship, to flourish as sketching did. This may partially explain some of the recent tendency throughout the architectural critical community to downplay the importance of the given and the past, as was the unfortunate tendency before the Post-Modern period made its most valuable if short-lived contribution, that of reclaiming history. The formats of cyber-work tend toward a floating bite-drenched present.

Very clever programs tend to do a lot of the work for us and I have found that most designers who depend primarily on the computer as a design device are ready to abdicate a great deal of responsibility to the automatic formats and extrapolations that these programs provide. Certainly one can suppose, and this is always the argument given by enthusiasts, that these programs empower to greater acts of imagination and more creative formal

interpretations but, in office and as an educator, I have found this not to be the case so far. Instead I have found that the instrument often tends to control the product, given the ease with which form can be extrapolated and the exponential permutations that can be produced almost instantly. As with all laborsaving devices, we tend toward complaisance in the gentle embrace of their systems. We have replaced the learned and personal interpretations that representation forced on the individual designer for somewhat generic choices of pre-packaged formats provided and already crafted by the software we adopt.

The labor involved in learning to draw and in devising personal systems of representation had great value. The time it took to draw generated a form of image-responsibility, a conciseness that more accurately reflects the difficulties and costs of construction. When one had to draw a thousand windows one thought about their applicability and modularity. Now a button will replicate and another distort. Until construction can reproduce the slickness of this process, there will be grave disparities. This can be seen in the fissure that has formed between incredibly complex designs generated by new software and the failure to construct those designs or the poor results and shortcuts taken when they are constructed! (see the discussion later in this paper of the Korean Presbyterian Church built in Queens in 1999 by Douglas Garofolo, Greg Lynn and Michael McInturf.) It may be possible however that the synaptic value lost with drawing will be replaced by other synaptic values generated by mastering the complex processes and methods that computers demand of their users. More polemically it might be said that the same processes are really in place in drawing and computing. Attempting to resolve vision, in both its meanings, with an image produced, is a procedure of arriving at visualized form but also of allowing its representation to enter into a critical relation with the original vision. It is indeed possible, although only intermittently realized, that the formats offered by new technologies are a launching-point for intense and novel investigations on a formal or methodological level. They certainly facilitate the more mundane aspects of architectural production. For instance, the assembling of contract documents has undoubtedly been made more efficient both to initiate and to change due to computer applications. Construction and reactions to changing conditions while constructing are vastly more efficient now due to the new technologies. Communication and work from different locations are likewise facilitated. But the more complex interaction of new softwares with design work and the often numbingly ersatz nature of renderings done by computer need to be further perfected to arrive at generally satisfactory levels.

Those who easily shrug off the potential damage done by computers to architectural design often compare it to the decade-earlier effect, or lack of effect, of word-processing programs on the field of writing. This comparison

ignores a crucial issue. Writing is a means to an end in most cases. The words on the page communicate by association. Our art on the other hand is producing form, the end product of our endeavor, by hand or computer. Therefore, since the final result is affected by the means of representation and since, in this final product has visual and artistic qualities, many other issues come into play, aesthetics only being one among others, formal, ideological and symbolic. I would continue with a similar argument to that made by Alan Colquhoun about the then-trendy introduction of literary critical models, in particular semiotics, into the discussion of meaning and form in architecture in his seminal article from 1972, "Historicism and the Limits of Semiology." (Colquhoun, 1981) The ease issue in the comparison of writing and design softwares is probably apt. It has become easier to edit than it used to be and this does not seem to have damaged the art of writing particularly, although I am sure some literary purists believe that the rigor and responsibility entailed in hand-writing or typing a text has been abdicated in the smooth world of cut-and-paste grammar-check. It is also the ease of certain quotidian architectural processes not unlike editing that may be so far the greatest value of this very expensive and pervasive device, not the ease of making strange forms or luscious visualizations but in the ease with which working drawings can be changed and react to changing construction parameters for instance.

"...the investigation and application of technology by architects must consider the ramifications of the potentially reckless and uncritical coercion of technology's powers into architecture." Peter Zellner, (1999)

In the decade following my first article, the call for "new technologies" gelled as a relatively homogenous global representational system facilitated by flexible visualizing and rendering programs such as Maya, 3ds Max, Rhino, ArchiCAD, Form Z, Softimage, etc. The agenda of much architectural discourse seems to be to arrive at novel forms. While this direction is historically problematic it is also compelling. In 1994 I wrote "For all the intellectual subtlety demanded by the internecine practice of architecture, our community remains very literal in its hermeneutics. Connective tissue of a critical-productive sort is lacking, and theory itself remains largely formalist in its excavations and conclusions. Should an interpretation of Gilles Deleuze's meditations on the Baroque in *The Fold* (Deleuze, 1988) legitimize a formal strategy for making folded buildings? Do cultural chaos or fragmentation call for their doubles in architectural form? These exact transpositions are problematic and they again indicate that the search for pure form remains a primary and problematic goal of theory. Shouldn't it find parallel or analogous constructs rather than identical forms? Literalness both in the interpretive actions of theory and in the

perceptions of its audience affects the possibility of an active link between theory and making, and tends to contribute to a severe skepticism on the part of the latter toward the former, its very essential discursive other half." (Stanton, 1994.)

Much of the excitement generated by the images offered by the computer was for those 3D images produced, rather than for the myriad other ways this instrument could invigorate practice, resolving complex issues on a statistical basis or aiding in various organizational tasks. (Stanton, 1997; Stanton, 2001; Stanton, 1996; Stanton, 1994; Stanton, 1994.) In a field in which the finality of image is teleologically inevitable and in which all the formats of presentation emphasize the look of the end-product, perhaps it is inevitable that our critical community should be focused on this particular aspect of an incredibly complex discipline. It is certainly not wrong to make or try to make form, as the strangely puritanical anti-formalist movement seems to imply. Form is the bottom line of our practice, not philosophy nor social responsibility although both obviously have a relation to forms produced. The problems inherent both in the development of a distinctly image-based theory paradigm and its antithetical relation to a very superficial and often self-serving call for "social" architecture couched in a rejection of the inescapable image-nature of architectural form is the topic of another discussion but one that should be engaged rigorously since it seems to pull architectural work in two extreme and dubious directions. (see an approach to this issue in my discussion of the archtypical struggle for the *avant-garde* mantle between Peter Eisenman and Diane Ghirardo, in Stanton, 1999; Stanton, 1998; Stanton, 1998.)

Whatever discursive flack may surround this phenomenon, computer imagery, but also the ubiquitous machine itself, are omnipresent in our field and now consume large sectors of office and school budgets. Often their value is assumed without question or proposed as a remedy for issues they cannot possibly address. This paper underlines the problem of the computer, of screens and the insistent imagistic formulas encourage by their use, and the ennui that is beginning to pervade the discipline after initial uncritical enthusiasm for this very powerful and costly medium. But it should not be seen as a simple rejection of this consumer device and all it offers and stands for. While encouraged by the modern age and Manfredo Tafuri toward skepticism I am not a Luddite. This paper will propose other potentially valuable directions, those relating to reassessing the processes rather than the images that architecture engages, that this now aging "new" technology can much more resolutely and successfully address.

Jorge Silvetti said in 2002 "...the sudden outburst appeared strange, a few years ago, of shapeless creatures, seemingly from outer space or some bad intestinal condition...The computer intimated that it could produce forms that not only do not have precedent, but more perplexing, may not even have

referents! Freedom from semantics, history and culture was perhaps made possible for the first time in civilization." (Silvetti, 2003/2004) Among the Dutch adherents are Lars Spuybroek and Ben van Berkel, but not Claus en Kaan, MVRDV or Wiel Arets. Few Swiss seem involved. London and Paris have some enthusiasts. Graphic design seems to have had a profound effect on new architectural form-making in its embrace of bubble-formats and soft corners in emulation of the work of the '70s. Americans are thinly represented and those who are, are mostly connected to the superb architecture schools at Columbia University and SCIArch in Los Angeles.

Biomorphism is not new. In fact, as a representational system, it may be as old as human culture itself. Perhaps it has always been present as a foil for the hard-edged and right-angled and their very arbitrary appropriation of human aspirations toward rationality and order. Certainly the very first attempts at depiction that still exist were dominated by images of animal and human activity portrayed in a semi-abstraction that acknowledged the soft lines that characterize the biological world. It was the first images of centralized culture, those of the Egyptians and other cultures of the Middle East, that presented a more rigid format for describing the rituals and hierarchy of court life and divine intervention. From then on a dialogue between the corporeal and the right-angled took on the accepted responsibility for projecting the "natural" and the "rational", themselves both extremely artificial cultural constructs. (Stanton, M., 1991) In Classical Art this dialogue is thematic and intense. It carries especially into the somewhat contrived polarities established between the Gothic and its Renaissance "other." Particularly, the attempts to place religious imagery with one or the other has tended to blur the arbitrary semantics they have accrued. This was particularly embodied in the regionally ubiquitous and structurally problematic form of the dome with its references to both flesh and the heavens. The dome's elaborate constructional prerequisites placed it firmly in the realm of engineering and its rationalisms while its transcendental allusions and sensual form set it against them. The biomorph has thus been positioned firmly in opposition to the lines and angles related to hegemonic order, and has joined forces with all the manifestations of expressionism against what have been designated as society's favorite forms for control and reason: the grid, the Platonic figure, the parallel and perpendicular.

The next historical step, taken at the dawn of Modernism, was an automatic association with freedom, even revolution, tending toward perpetuations of the random and wild dear to the classical *avant-garde* and embodying all the contradictions inherent in the relation of the *avant-garde* phenomenon to the bourgeois culture that it was both part of and antithetical to. (see, among many texts, Poggioli, 1968). In the Modern Age the antagonism of the biomorphic to the more orderly representational disciplines has taken on an even more emphatic and sometimes simplistic

demeanor. It is a grammar with a 100-year history in Modern Art, from Art Nouveau to the blob. A particular example from the late-19th-century is Catalan Modernismo, not just the well-known work of Antoni Gaudí but also that of Lluís Domènech i Montaner, Josep Puig i Cadafalch and others with whom Gaudí was a collaborator. This tendency in Barcelona continued throughout the history of Modern Architecture there influencing Josep Antoni Coderch and resulting in the extraordinary contemporary work of Enric Miralles and Carme Pinós, Elías Torres and José Antonio Lapeña, and of younger Catalans who have devised a response that is surprisingly independent and preemptive of the computer-generated forms evident in other less-traditional expressionist locales. To my knowledge, before his untimely death in 2000, Miralles never used the computer as a design tool in fact and rarely for any professional applications. A large triangle placed at any angle on the drawing board substituted for the parallel rule that was obviously not applicable to his work.

Expressionism's close relation to the "new" forms generated by computers should be noted. This is not to discredit their novelty. Through their unique permutations, all forms are novel and, at the same time, almost none are, in the sense that they refer to, or extrapolate from, existing models. Both the ideological and formal manifestations of anti-rationalism continued and increased in volume during the early Modern period and the apex of Expressionism immediately following the horrors and vast social upheavals brought about by World War I. In painting Wassily Kandinsky innovated with both abstract and explosive forms. In direct complicity with an international *avant garde*, Hermann Finsterlin's, Hans Scharoun's, early Mies van der Rohe's and Eric Mendelsohn's architectural projects of the 1920s, juggle jagged and visceral forms in clear resistance to the orthogonal associated both with Classical form and the rational. These may have found a more comfortable place in the less mimetic media of architecture rather than in the fine arts where figuration remained preëminent. Artistic Expressionism tended to remain distortedly representing know objects and conditions. (It is obvious that architecture does imitate things other than buildings, even sometimes directly, in reference to mountains [setback skyscrapers] or tools and machines [from Claude-Nicolas Ledoux to Neil Denari and Shin Takamatsu] for instance. In a slightly less direct way this is a theme conveyed from Marc-Antoine Laugier through Gottfried Semper to the current semantic/syntactic controversies. Nevertheless the drive to imitate is more compelling in the fine arts and the direct attempt at mimesis that characterized them until this century has had to be less overt in architectural work whose forms, controlled somewhat by practical constraints and often intense tradition, are primarily self-referential rather than capable of imitation universally.)

The dominance of Rationalism in Modern architecture is more of a critical construct than a universal fact, even at the most ostensibly doctrinaire Weissenhoff-Siedlung times. Furthermore, many of the most committed proponents of Rationalism were clearly experimenting with more expressionistic, primitivist or surrealist modes by the 1930s. The Purist painter Le Corbusier in the Pavillon Suisse, the Bestegui apartment, the Maison du Weekend, etc., was employing all three and moving toward the organic and away from the engineering references that were even compromised in his early villas and projects of the 1920s. (Here I use *organic* without the various references to naturalism, vernacular culture, pastoral and new age enthusiasms, health and goodness, hippies and conservationists, anti-authoritarians, etc. that have become attached to the term. Instead I refer directly to the organs, to the materially visceral, both formally and in relation to the emotional and behavioral conditions that are associated to the guts and to the senses other than that of sight to which they respond.) In Le Corbusier's works like the Maison La Roche-Jeanneret, the Villa at Garches and the Villa Savoye, the white and orthogonal is always set in juxtaposition to curvilinear shapes and intense colors, sometimes, as in the master bath at Savoye, recalling both body and landscape. The rise of a truly-abstract expressionism was again provoked by the even-more-drastic horrors and implications of World War II and was centered in New York. (Stanton, 1994; Stanton, 1994 [2]; Stanton, 1993; Stanton, 1992; Stanton, 1991; Stanton, 1985.) The effect of the works of Willem de Kooning, but also of abstract organicists like Isamu Noguchi and Constantin Brancusi and their contemporaries is historic. Expressionist architecture followed by Brutalism adopted a language intensely tactile and non-rational, sometimes irrational. The names of Eero Saarinen, Paul Rudolph, Oscar Niemeyer and Le Corbusier of the Ronchamp period are obvious but far from comprehensive.

In Italy more than most places this occurred with unusual finesse and acknowledgment of history as is typical. Luigi Moretti and his contemporaries developed a reaction to the controls levied on architecture during the Fascist period, controls that nevertheless produced extraordinary syntheses. I wrote "In the Fascist era the service required of architecture was clear, if numbingly contradictory. To simplify the criteria of a complex mandate, the Futurist-Classical requirements set forth, the simultaneous call for progress, in its early-20th-century force, and alignment with the Roman Empire, in its imperial promise, led to the tense juxtapositions and compromises that made the architecture of the period between the World Wars so rich in Italy." (Stanton, 1997[3]) Giovanni Michelucci's church of San Giovanni Battista on the Autostrada in Florence of 1962 is such a reaction. Its facades are contorted and sculptural but it is the interior, with reference to bones and flesh, that is most extraordinary. I wrote "This design

of 1960 by Michelucci does indeed evoke the dynamism of the highways in its winged and tent-like forms, and it refers to the nomadic nature of the both site and of religious myth. The rough stone of the base contrasts with the flowing, bronze-sheathed roofs. Upon entering the building, the visitor is swallowed in an organic surround. Columns and roof form bones, joints and skin. Poured concrete hangs on the sharp and cracked structural network. More literally than at Ronchamp, the body of the viewer and the broken body of the building are compared directly. Mortality is stressed and stillness echoes within the frame of the chapel." (Stanton, 1995)

Frederick Kiesler's Endless House of the late '50s, whose particular relation to Frank Gehry is seminal, more emphatically refers to the bodily organs or their contents. Gehry's particular use of the computer is inventive and practical. Early sketches and trash models are converted to cyber-forms that are then adjusted in relation to analog investigations. When these forms have to be frozen as built-form, sophisticated programs take over and convert them into modules and surfaces that can be communicated directly to machines to mill, extrude or cut, producing unique surfaces within the constraints of material, gravity and structure. Zaha Hadid also seems to largely design in an analog practice and to use computers for construction and development purposes. The production of forms like those generated in Gehry's or Hadid's offices or in other more-computer-influenced practices has proved to be very difficult given the unique nature of episodes within the total compositions and the complex and expensive fabrication and construction processes that entail. In Gehry's case in particular, the use of computers has concentrated on immediate relation of form-making to construction and to make the impossibly complex possible to construct.

Biomorphs and expressionism are inescapably allied when discussing the imagistic formats enabled by computer rendering techniques. Deconstructivism was the reinvention of these historic attitudes in the period following historicist Post-Modernism and just before the computer tsunami. Preceded by Architectural Association salients including the early work of Hadid and OMA elaborating expressionist form as social action Deconstructivism revived many of the ideological formulas and forms elaborated so far in this paper. The work of Cedric Price and Archigram, the epistemological mentors of Koolhaas and company, was an elaboration, in nonsculptural terms, of the monolithic objectification of Brutalism. The domineering object became the mobile, but equally domineering, event. Thus the neo-Brutalism that is dominating our contemporary architectural stage has direct roots in the exciting if overbearing textures and forms of the late '50s and '60s: from rude organic concrete to rude event to the excesses of metropolitan "bigness." Deconstructivism's historic reference back to Russian Constructivism clearly ignored all the subsequent development of what was a dominant theme throughout the 20th century. The reason was

ideological. Constructivism was literally revolutionary, in service of a real and extremely violent revolution, while the forms of artistic expression that followed tended to be personal, surrealistically psychological, or in the case of Brutalism in the West, directly in the service of capitalist economy. To jump back past all this compromised representation to the jagged vocabulary of '20s Soviet form placed the "discovery" of Philip Johnson and Mark Wigley, and its *couture*-Bolshevik discoverers, comfortably in the center of neo-*avant-garde* discourse.

Whatever their complex history might imply, biomorphs and expressionist explosions continue to be hard to make. The lessons of Brutalism, largely produced in poured concrete with complex form-work that allowed a ductile material to take shape, seem not to apply to current computer generated shapes. Shouldn't the computer itself aid in the formation of emerging techniques for construction of organic forms? So far it seems to only have been intermittently applied to this purpose. The extensive and portentous publishing of the rather ordinary and scattered Korean Presbyterian Church built in Queens in 1999 by Douglas Garofolo, Greg Lynn and Michael McInturf, was often accompanied by the excited claim that it was designed entirely on computer and in interaction between geographically separate designers. Hasn't this been standard corporate practice for at least a decade? The real difference is the neo-*avant-garde* imagery and rhetoric involved. The church's actual making, in the reduction of curved forms into faceted ones that can be constructed more readily with the straight members that characterize quotidian building in the U.S., seems to not have innovated where innovation would have really made a difference with intense formal consequences, in the making of the thing. The early drawings of this building, soft, amphibious and beguiling, became radically altered when built. Ways of production and material permutations have to be addressed in conjunction with the revival of, and reassessment of, organic form in this period of technological transformations.

Given the reluctance on the part of the building industry to adapt to new formal requirements and the unwillingness of the design community to investigate these images beyond their tantalizing shape, these forms continue to be hard to make. The moment of blobs seems to have passed without much production, like Deconstructivism did before for similar reasons, as Rem Koolhaas described "undone by one section of the present *avant-garde* in compositions of almost laughable pedantry and rigidity, behind apparent wildness." (Koolhaas, 1995) Economy and inertia in relation to the making of buildings have made refined realization of biomorphic form very difficult if not next to impossible in this era. The complex computer translations used by Gehry somewhat contradict this, but at dizzying cost.

Strangely, in other periods of similar syntactic interest like those of Modernismo and Brutalism, much more "primitive" technologies were

effectively brought to bear to produce tactile realizations. Perhaps this is because, in those instances, the "new technologies" of the era were addressing the ways and means of construction while in this era it is imagery that is the focus of experimentation. This is a real shame because, while these forms are no longer revolutionary or even particularly radical, they do set up a counterpoint to other design strategies and, if they could be effectively made they could expand the possibilities of both the appearance and, more importantly, of the methods of architectural work, as did their Brutalist progenitors 40 and 50 years ago through the reinforced-concrete technology with which they were realized. Shouldn't new or different forms be made in new and different ways? And isn't our tired and retrograde discipline badly in need of such ways?

Why not use the computer to analyze and reform the way we do things in the office; labor relations, production cycles and human resources, client interaction, economic flow, etc.? This instrument is really skilled in these arenas in which statistics and impossibly complicated assessments can be easily made. Here, on a methodological level, architectural theory will find a firmer base than the formal investigations that so often require damaging compromise or post-rationalization in the leap from idea to image to built form?

"The second strategy, disappearance, transcends the question...of massive presence - through an extended engagement with simulation, virtuality, nonexistence." Rem Koolhaas (1995)

Computer imagery, but also the ubiquitous machine itself, are omnipresent. Obsolescent cyber-gear, usually only a few years old and put out of business by cunningly escalating software, litter the landfills. At architecture shows, the viewer is invited to sit at monitors and browse more flashy formats. In other words, one is asked to exchange the "aura" of the exhibition for the quotidian one of office or home. While this is possibly an interesting shift in representation, in an exhibition it seems almost entirely tedious and alienating. Who goes to a great exposition to sit at another computer? This underlines the problem, of screens and the insistent imagistic formulas encourage by their use, and the ennui that is beginning to pervade the discipline after initial uncritical enthusiasm for this very powerful and expensive medium.

Finally, like other innovations in representation, technology, methods of production and the critical formats that accompany them, the computer will change what we do, just as the elevator, Socialism, steel and reinforced concrete, Expressionist art, parallel rules, one- and two-point perspective, air conditioning, French theory, Andy Warhol, etc. have done, for better and worse in each case. It is necessary, as I urged ten years ago, to weigh the

inherent values of this pervasive new medium, for we should search for value in all innovation and not just accept it as good as has been the custom throughout the Modern era with its *avant-garde* cult of novelty. Again as I urged, now that "nostalgia for the future" (Silvetti, 2003/2004) has become real-time, we must realize its inherent position at the center of turn-of-the-century consumerism whose cycles of obsolescence, software and hardware incompatibility, etc., have begun to engulf all other academic and professional budgets. Is it worth it? How can it be made most cost-efficient? How can it best be directed to address the cultural dimensions of our very engaged discipline? Should we give up all other hand operations to the mouse? This may lead to real innovations in the relation to practice, method, even form.

"What criticism ought to ask about architecture is, instead, in what way does it, as an organized institution, succeed or not in influencing the relations of production." Manfredo Tafuri (1974)

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## THE AUTOPOIESIS AND MIMESIS OF ARCHITECTURE

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**Abstract.** The use of digital technology in architecture has proven to be more assertive than originally thought: it has reconditioned the nature of the design process, and established new practices and techniques of fabrication. The 21<sup>st</sup> century began with the technology of art. There is a new responsiveness to the reading and understanding of digital space, which is characterized by complexity and the uncanny. Recent applications in digital technology show inquisitiveness in the contentious subject Genetic Algorithms. This new architectural process is characterized by two main shifts: from poiesis (or poetry) to autopoiesis, and from authenticity to mimesis. Since evolutionary simulations give rise to new forms rather than design them, architects should now be artists and operators of both Inventive and Systematic design. Inventive design: The digital media should bring about poiesis (poetry). Digital spaces reveal and visualize the unconscious desires of urban spaces and bring forth new dreamscapes, mysterious and surreal. This implies a Freudian spatial unconscious, which can be subjected to analysis and interpretation. "Space may be the projection or the extension of the physical apparatus", Freud noted<sup>1</sup>. Space is never universal, but subjective. A space would be a result of introjection or projection – which is to say, a product of the thinking and sensing subject as opposed to the universal and stable entity envisaged since the Enlighten. There is a spatial unconscious, susceptible to analysis and interpretation. Systematic Design: Digital media should bring about an autopoiesis. This approach calls into question traditional methods of architectural design – which replace the hierarchical processes of production known as "cause and effect" - and proposes a design process where the architect becomes a constructor of formal systems. Will the evolutionary simulation replace design? Is metric space dead? Is it replaced by the new definition of space, that of topology? The new algorithmic evolutionary conditions give architecture an autopoiesis, similar to biological dynamics. The use of algorithms in design and fabrication has shifted the role of the architect from design to

programming. Parametric design has introduced another dimension: that of variation and topological evolution, breaking the authentic into the reused. Architecture now is about topology than typology, variation than authenticity, it is mimetic than original, uncanny and subconscious than merely generic. In a parallel universe, which is both algorithmic and metaphysical, the modeling machine creates a new abstraction, the morphogenesis of the “new hybrid condition”. The emphasis of the exploration is on morphological complexity. Architecture may become – paradoxically - rigorous yet more uncanny and introverted.

### 1. Digital Uncanny

I would argue that from its inception, digital media were considered a discipline external to architecture. By definition the digital in architecture does not exist. Despite this, architecture seems to truly lend itself to digital exploration. It creates a topology of symbolic forms as digital constructs. More importantly, it manifests itself in the most ambiguous element – space – within which any projection moves freely and without fixed boundaries. The new technology of the digital media has managed to unravel the repressed condition and abandoned projects of 20<sup>th</sup> c architecture (Futurists and Surrealists), and to challenge the only ideology that created it: modernism and its associated technology. One may talk about the relationship between the digital uncanny and introjections.

In architectural terms, the search for modernism’s repressed condition was concentrated in the domain that the modernists had clearly and polemically identified as the basis of their attack on tradition: the irrational, the decorative and the uncanny. A good example is Tzara’s indictment of modern architecture as a “complete negation of the image of the dwelling.” “Modern architecture,” Tzara argued, “as hygienic and stripped of ornaments as it wants to appear, has no chance of living...because it is the complete negation of the image of the dwelling” (Tzara, 1933).

In the modernists’ tradition, the line between nature and machine, between the organic and the inorganic seemed clear; organicism was a metaphor, not reality. But for the current digital media, the boundaries between organic and inorganic are blurred; the body itself, invaded and reshaped by technology, in turn invades and permeates the space outside, even as this space takes on dimensions that themselves confuse the inner and the outer, visually and physically. As Walter Benjamin (1982) presciently observed, “The work of Le Corbusier seems to arise when the ‘house’ as mythological configuration approaches its end.” Digital technology attempts to reincarnate these “mythological configurations,” repressed by modernism, with the monstrous and anamorphic merging of animal and house as an

oneiric machine, a machine for dreaming. After all, there is no architecture without dream, myth or fantasy.



*Figure 1.* The blurring of lines between the mental and the physical. House interior project by author

The blurring of lines between the mental and physical (Figure 1), the organic and inorganic was transformed by the surrealists, especially Dali, into a formulation that stressed the intersection of the biological and the constructional, building and psyche, architecture and hysteria, in order to produce the ultimate object of desire, or its reification at least. Characterized by its mimesis of the digestible, it was an architecture that, in Dali's words "verified that urgent "function," so necessary for the amorous imagination: to be able in the most literal way possible to eat the object of desire." Walter Benjamin (1982) stated that the intersection of technology and nature was represented by the displacement of symbols from Romanticism to Modernism. Here we may begin to trace the affiliations of Surrealism and modernism on the level of technique - affiliates that were stated by Benjamin in the aphorism: "The reactionary attempt that seeks to detach the forms imposed by technique from their functional context and to make natural constants out of them - that is to say, to stylize them..." In Benjamin's terms, the structure that unified the two was fetishism. For fetishism, in its multiple displacements, "suppresses the barriers which separate the organic from the inorganic world." It is as "at home in a world of the inert as in the world of the modern mechanization of the dwelling in its mission of repression against the bric-a-brac of the nineteenth century."

## 2. Mimesis

What happens, then, when the fusion between the organic and the inorganic takes form? Mimesis? A mimesis that has a multiple interpretation. Digital technology is mimicking architectural space so much that it becomes believable and “real,” that organic and inorganic matter, animate and inanimate forms become indistinguishable. Form becomes malleable and changeable and interactive, as though it imitates its occupants. The body fuses with its surroundings.

According to Walter Benjamin and Theodor Adorno's biologically determined model, mimesis is posited as an adaptive behavior that allows humans to make themselves similar to their surrounding environments through assimilation (Adorno, 1984). Through physical and bodily acts of mimesis (i.e. the chameleon blending in with its environment), the distinction between the self and other becomes porous and flexible. Rather than dominating nature, mimesis as mimicry opens up a tactile experience of the world in which the Cartesian coordinates of subject and object are not firm, but rather malleable.



Figure 2. The act of mimesis as a means for survival

Adorno's discussion of mimesis originates in a biological context in which mimicry (a mediator between life and death) is a zoological predecessor to mimesis. Animals are seen as genealogically perfecting mimicry (adaptation to their surroundings with the intent to deceive or delude their pursuer) as a means of survival (Figure 2). Survival, the attempt to guarantee life, is thus dependant upon the identification with something external. The manner in which mimesis is viewed, as a correlative behavior in which a subject actively engages in "making *oneself* similar to an Other", dissociates it from its definition as merely imitation (Adorno, 1984).

According to Adorno (1984), “by means of the mimetic impulse, the living being equates himself with objects in his surroundings.” This surely holds the key to exploring the question of how human beings situate themselves within their environment, and points to an area in which the domain of psychoanalysis may offer crucial insights into the mechanism by which humans relate to their habitat. It begins to suggest, for example, that the way in which humans progressively feel 'at home' in a particular building, is through a process of symbolic identification with that building. They may come to identify with technological objects. This symbolic attachment is something that does not come into operation automatically; it occurs gradually. Mimesis in Adorno, and in Walter Benjamin, is a psychoanalytic term - taken from Freud - that refers to a creative engagement with an object. Mimesis is a term, as Freud himself predicted, of great potential significance for aesthetics.

To understand the meaning of mimesis in Adorno we must recognize its origin in the process of modeling, of 'making a copy of'. In essence it refers to an interpretative process that relates not just to the creation of a model, but also to the engagement with that model. In mimesis imagination is at work, and serves to reconcile the subject with the object. This imagination operates at the level of fantasy, which mediates between the unconscious and the conscious, dream and reality.

It is important to recognize here the question of temporality. Symbolic significance may shift, often dramatically, over a period of time. What was once shockingly alien may eventually appear reassuringly familiar. The way in which we engage with architecture must therefore be seen not as a static condition, but as a dynamic process.

Mimesis for Benjamin offers a way of finding meaning in the world, through the discovery of similarities. These similarities become absorbed and then rearticulated in language, no less than in dance or other art forms.

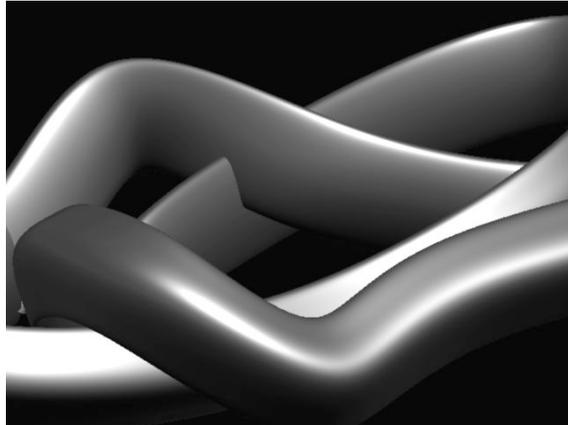
Architecture along with the other visual arts can therefore be viewed as a potential reservoir for the operation of mimesis. In the very design of buildings the architect may articulate the relational correspondence with the world that is embodied in the concept of mimesis. These forms may be interpreted in a similar fashion by those who experience the building, in that the mechanism by which human beings begin to feel at home in the built environment can also be seen as a mimetic one.

Mimesis, then, may help explain how we identify progressively with our surroundings. In effect, we read ourselves in our surroundings, without being fully conscious of it. “By means of the mimetic impulse,” as Adorno comments, “the living being equates himself with objects in his surroundings.” The aim throughout is to forge a creative relationship with our environment. When we see our values 'reflected' in our surroundings,

this feeds our narcissistic urge, and breaks down the subject/object divide. It is as though - to use Walter Benjamin's use of the term mimesis - in the flash of the mimetic moment, the fragmentary is recognized as part of the whole, and the individual is inserted within a harmonic totality. It is within the new digital spaces that the act of mimesis happens (Benjamin, 1986).

### 3. Algorithms and the Breeding of Digital Forms

One technique by which mimesis is be constructed is by Algorithms. Algorithms may be defined as a detailed sequence of procedures to solve a problem. As such algorithms may be programmed to execute a series of mimetic tasks. Genetic algorithms constitute a class of search algorithms especially suited to solving complex optimization problems. In addition to parametric optimization, genetic algorithms are used in creative design, such as combining components in a novel and inventive way and ultimately creating a new complexity of language and form. Genetic algorithms transpose the notions of evolution in nature to computers by imitating natural evolution (Figure 3 and Figure 4). They find solutions to a problem by maintaining a population of possibilities according to the 'survival of the fittest' principle. Because of this ability to “search” algorithmic scripts or codes generate form, which is precise and complex and which would be impossible to have conceived using the basic software interface and tools. Inevitably, a new universe of formal and compositional possibilities opens up and techniques for digital form-finding.



*Figure 3.* Evolutionary forms. Project by author

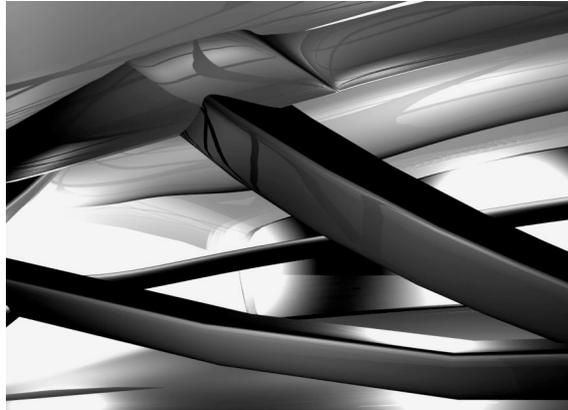


Figure 4. Algorithmic digital form. Project by author

A common approach is to define a building envelope in terms of a series of parametrically defined elements such as the structural ribs. Some forms are curvilinear, non-planar and irregularly shaped, yet precise. Furthermore, some approaches that involve rule structures seek to generate designs via various forms of growth and/or repetition algorithms. Additionally, there are approaches that seemingly abandon any kind of formal approach to shape generation but that seek to allow designers to “discover” meaningful shapes that exist within more complex geometrical patterns. Most of the approaches using formal shape-identification algorithms require specially written computational algorithms. Architects can now use advanced software to breed new forms rather than specifically design them. As De Landa (2001) notes, “...only if what results shocks or at least surprises, can genetic algorithms be considered useful visualization tools.”

Algorithms are based on non-linear wave function that through parametric differentiation organizes vectors of density. Can we then talk about fabricating of dense and large cityscapes, employing poly-directional structural networks?

On another level, the role of design has now been transformed into that of breeding fit and beautiful forms. There is clearly an aesthetic component: the “sculpting” of beauty and the development of a personal artistic style. As with any socio-technological revolution throughout history, architecture inevitably invents a new formal language.

Ultimately, if traditional architectural representation has been based in resembling and describing the appearance of the architectural object, through its use the algorithm architectural notation has become operational; to design the choreographing of the transformation process. The architectural object is transformed into event and performance, either by understanding

architecture as the dynamics of spatial conditions, or by the object being understood as the actualization of built-up potentials.

#### 4. Genetic Algorithms: Intuitive vs. Systematic

Through this highly refined algorithmic process, both intuitive and logical form-making processes are necessary. A grid-like structure transforms gradually into a convoluted scheme with numerous overlapping coils or folds revealing complex patterns. As the new architectural forms become complex, interconnected nodes and parameters change and, in a chain reaction, affect the outcome. Algorithms offer a degree of rationality therefore allow the designer to become a free form maker.

One assumes the role of the artist, not of computer programmer. The outcome requires being visual, and it is about inventing form than about solving problems in a systematic way. The resulting exuberance of formal composition should be judged as any architectural proposal, i.e. first on its visual impact, and the potential to become a building.

Architects may start thinking less in terms of typology and more about topology and variations. One way to introduce this thinking process is by contrasting the results. More variations are necessary in order to keep the “search” exciting. One of the design goals of the generative process is not only to support both the “designer’s” (intuitive) view and the “programmer’s” (formal) view, but also to reconcile these two views and create appropriate mechanisms as an interchange between them.

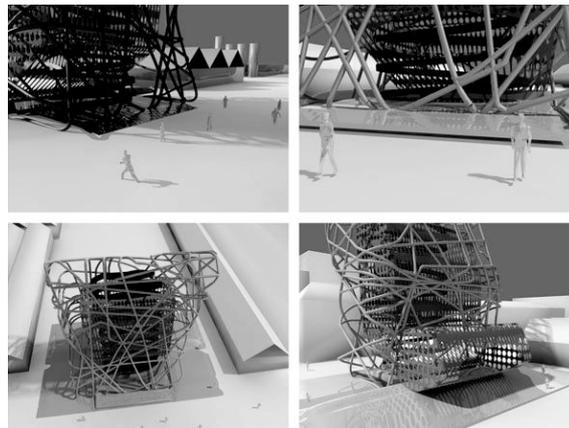
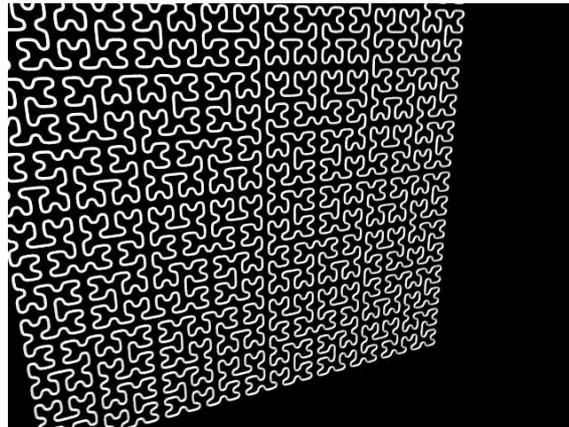


Figure 5. Composite algorithmic forms. Project by author

New possibilities may be the introduction of a new kind, a heterogeneous structure, as layers of form generated by different codes. Complex behavior

comes from the interaction of simple parts (Figure 5). The basic principle of Generic Algorithms is searching for optimum balance, and the eventual survival of the fittest. Evolutionary Algorithms can be both a structural making device and a search mechanism. The structurally oriented form-finding approach becomes a useful tool for composing space through repetition. Structural members define both the surface and the volume of forms.



*Figure 6.* This image was created by placing the algorithm onto a unit sized NURBS plane

The new digital approach to architectural design is based on computational concepts such as topological space, isomorphic surfaces and parametric design. Architecture is recasting itself, becoming - in part - an experimental investigation of topological geometries. Digital media is employed not as a representational tool for visualization, but as a generative tool for the derivation of form and its transformation – the digital morphogenesis. It explores the possibilities of “finding form”. Topological space opens up a universe where essentially curvilinear forms are not stable but may undergo variations, giving rise to new possibilities, i.e., the emergent form (Figure 6).

In the task of designing rich search spaces, certain philosophical ideas, which may be traced to the work of Gilles Deleuze (1993), play a very important role. Though not invented by Deleuze, he was the one who brought them together for the first time, making the basis for a brand new conception of the genesis of form. According to Manuel De Landa (2001) in his essay “Deleuze and the Use of the Genetic Algorithm in Architecture,” the productive use of generic algorithmic implies the deployment of three forms of philosophical thinking:

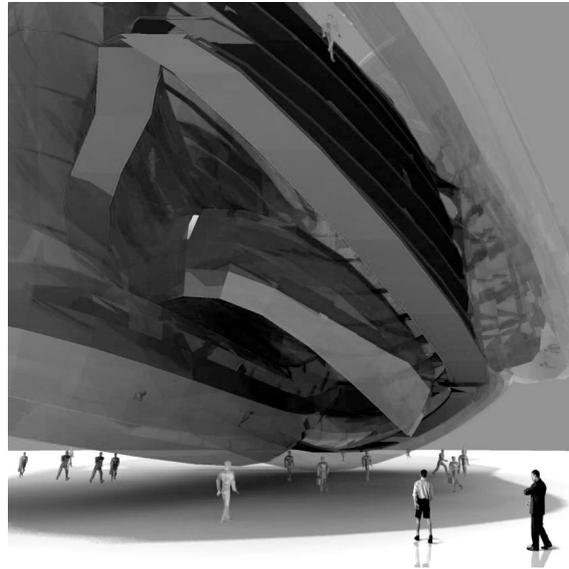
1. Populational thinking: The sequence of operations points at

spontaneous and multiple mutations.

2. Intensive thinking: Without the structural engineering and distributions of stress, a virtual building will not evolve as a building.
3. Topological thinking: The obtained with the genetic algorithm must demonstrate an incredible combinatorial productivity like in natural forms, with thousands possibilities.

The employment of the genetic design strategies develops autonomous architectural concepts, which replace the traditional hierarchical processes of production known as “cause and effect”: new organizational patterns and weavings and performative morphologies that can modulate and differentiate the environment. This morphogenetic process includes pattern, repetition and permutations.

The tendency towards architectural autonomy might be understood as a moment of overall societal process of differentiation. Traditionally, architecture and good design were inseparably connected with society and harmony. The new algorithmic evolutionary conditions give architecture an autopoiesis. The autopoietic system as a complex, historically evolving system always uses time and involves series of events in its "responses," so that simple and predictable one-to-one correlations between environmental impacts and system responses are out of the question. Recent developments in digital technology expose a degree of autonomy that architectural discourse has established by differentiating itself from the immediacy of everyday talk about buildings, and thus the complexity of the discursive detour, which mediates a particular impact/response, should grow with the overall complexity of society (Figure 7).



*Figure 7. Controlled Complexity. Project by author*

Current experimental work focuses on issues of organizational complexity (layering, interpenetration of domains), on the production of diversity (iteration vs. repetition), on the spatial recognition of fuzzy social logics (smooth vs. striated space), on ways of coping with uncertainty (virtuality vs. actuality), and on engagement with new production technologies.

What is important about the morphogenetic model is the degree to which it allows for a coexistence of various forces, engendering an autogenetic, autopoietic and mimetic system. Autopoietic systems produce theories of complex self-organization that nevertheless can become problematic. Self-organization or autopoiesis is thus impossible without the necessary random influx of external forces. This is precisely Felix Guattari's point when he talks about the machine and its arrangement that a machinic arrangement of heterogeneous forces and heterogeneous autopoietic processes are much more interesting than simple models of poiesis (Deleuze and Guattari, 1993).

Moving beyond the design of an envelope alone, only spatial relationships may incorporate another layer, that of interiority, by "weaving" in one (enclosure) into the other (interior). There are two levels of complexity: that of weaving of the skin and that of the volume.

In weaving, the linear fluidity of wrapped objects creates exciting visual forms. A repeated line gives the forms an organic and often mystical quality. Because of the predictability of a wrapped surface, their generation lends

itself to scripting and procedural methods using wrapping algorithm. One can imagine a solid shape being "mummified" or wrapped at various layers.

This dual process is what it is known as the "exogenous" and "endogenous" control of plant development. Diffusion-limited aggregation and cellular automata provide models of *exogenous* mechanisms of branching pattern formation. In this case, components of the growing structure communicate through the surrounding space, in contrast to the *endogenous* control mechanisms, which rely on information flow within the developing structure. In nature, endogenous and exogenous control mechanisms are often combined. For example, the development of a tree is affected by the genetically controlled formation of meristems (apices), the flow of water, nutrients, and phytohormones through the branching structure, and the plant response to environmental factors, such as the shading and crowding of branches. *Environmentally sensitive* systems represent one of the approaches proposed to create comprehensive models integrating endogenous and exogenous phenomena. Architectural design, as well as fabrication, can now employ and imitate these operations.

## 5. Programmed Morphology

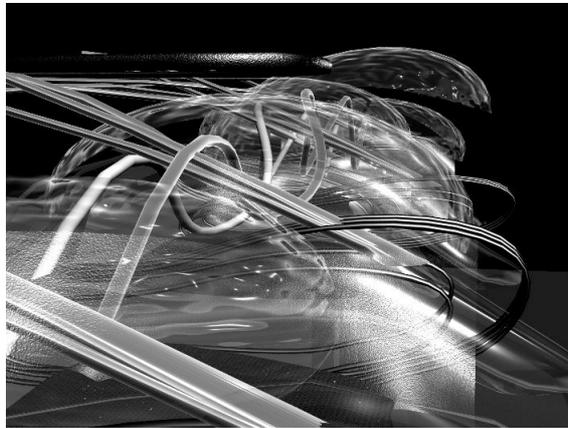
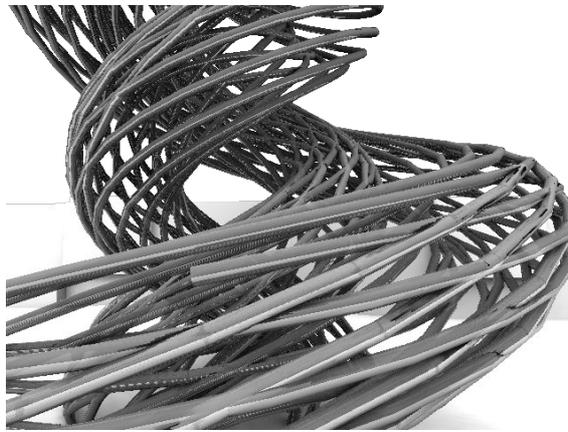


Figure 8. Space vs. structure. Project by author

The new space is the outcome of the synthesis between space-oriented and structure-oriented models, developing self-regulatory patterns in which potentialities are regulated by the developing structure itself (Figure 8). These techniques result in the simulation of evolutionary and environment based three-dimensional structures and surfaces. The new research in

architecture involves structural morphology and generative modeling of architectural form. The design process now has even now turned from the mimetic into one of growth, based on given data (directions or restrictions). Algorithmic structure represents abstract patterns that are not necessarily associated with experience or perception. Algorithmic processes result from events that are often neither observable nor predictable and seem to be highly intuitive. In this sense, algorithmic processes become a vehicle for exploration that extends beyond the limits of perception.



*Figure 9.* Double weaving. Project by author

```

proc pipe()
{
  string $inputCurve[];
  float $posB[];
  float $posA[];
  vector $pointA;
  vector $pointB;
  vector $norm;
  float $normal[];
  string $selectedObjects[];
  $inputCurve = `ls -sl`;
  string $selectionString = $inputCurve[0] + ".u[0.5]";
  select -r $selectionString;
  $posB = `pointPosition`;
  $selectionString = $inputCurve[0] + ".u[0.0]";
  select -r $selectionString;
  $posA = `pointPosition`;

  // create the approximate normal for the curve at 0,0
  $pointA = <<$posA[0], $posA[1], $posA[2]>>;
  $pointB = <<$posB[0], $posB[1], $posB[2]>>;
  $norm = unit($pointB - $pointA);
  $normal[0] = $norm.x;
  $normal[1] = $norm.y;
  $normal[2] = $norm.z;

  // create the circle and extrude it
  circle -c $posA[0] $posA[1] $posA[2] -r 0.1 -nr $normal[0] $normal[1] $normal[2];
  CenterPivot;
  select -tgl $inputCurve[0];
  $selectedObjects = `ls -sl`;
  extrude -ch true -rn false -po 0 -et 2 -ucp 1 -fpt 1 -upn 1 -rotation 0 -scale 1 -rsp 1 $selectedObjects[0]
  $selectedObjects[1];
}

```

Figure 10. Example of a script to pipe curves

Algorithmic Architecture employs methods for creating new architectural morphologies (Figure 9 and Figure 10). By using scripting languages and working with codes it is possible to create forms through methods analogous to the evolution of intelligent life: emergent behavior and self-organizing systems. It pursues various methods through which the role of the designer can shift from "space programming" to "programming space". What the new scripts and codes can achieve is conceptual broad gestures at the beginning, and precision later on, only when the underlying geometric relationships have been defined and tested. This is an ideal process in any design, starting from broad ideas and gestures and which then are developed in more detail. Beyond CAD tools and the interface of even advanced modeling software, this requires new methods. These new tools should be open-ended and programmable. As parameters change so do the variety and topological permutations. Well-established and used scripts are those that generate what is called weaves and braids. Given the specific surface or volume, they achieve an interconnectedness of elements for bracing and strength, like continuous materials. Structurally, both tension and compression are in a new set of relationship; more a network of structural matrix. Weaves are

based on parameters for surface topology description, density, and number of strands or threads. They can adopt a helicoidal or crosshatch pattern.

The applications of this new emerging technology are numerous. This paper attempts to look into the future a mention needs to be made of the article “The New Paradigm in Architecture” by Charles Jencks. Although almost impossible to categorize Jencks has identified five approaches that broadly represent the range of current digital architecture: Organi-Tech, Fractal Architecture, Blobitecture, Enigmatic Signifier and Landform.

The architectural process is evolutionary and intuitive. As if re-enacting Surrealism in a new form, the modernist repressed condition may have been liberated, replaced by the uncanny and the myth and the new autopoiesis of architecture.

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## **PLAN IS DEAD: TO BIM, OR NOT TO BIM, THAT IS THE QUESTION.**

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**Abstract.** Drawing, modeling and the explicit abstraction embedded in the traditions and conventions of visual communication through composition and representation are fundamental to the how, why and what of architectural design. BIM presents simulation as an anti-abstract means of visual communication that seeks to displace the discreet representation of plan, section and elevation with the intelligent object model. If plan is dead, the implication is that the value of abstraction is dead or dying as well. How can architectural education prepare students for digital practice with such an assault on the underlying role of abstract representation of formal and spatial constructs that constitute architecture? This paper explores a possible path for engaging digital media in education that explores the gap between design theory and digital practice. The investigation centers on ways of exploring architecture by developing teaching methods that reprioritize ways of seeing, thinking and making spatial design. Digital architectural education has great opportunity and risk in how it comes to terms with reconceptualizing design education as the profession struggles to redefine the media and methods of architectural deliverables in the age of BIM.

### **1. Introduction - Plan is Dead**

"To be, or not to be, that is the question. Whether 'tis nobler in the mind to suffer the slings and arrows of outrageous fortune, or to take arms against a sea of troubles, and by opposing end them? To die: to sleep; no more; and, by a sleep to say we end the heartache and the thousand natural shocks that flesh is heir to, 'tis a consummation devoutly to be wish'd."

-William Shakespeare

Building Information Modeling (BIM) has the potential to radically transform the way in which architectural education engages issues of design

and representation and creates opportunities to question the roles and rules of the traditional architectural conventions of visual communication. The ubiquitous two-dimensional, orthogonal projections that today constitute the traditions and conventions of visual communication that contemporary architects take for granted took root in the fifteenth century (Lonna, 1997) as architects found geometry and geometric projections increasingly useful to convey architectural intent and meaning in spite of the inherent abstraction in the two-dimensional portrayal of three-dimensional form and space. This foundation in geometry was acutely revealed in the development of most CAD applications as programmers solved the problems of describing and drawing geometry digitally (Ibrahim, 2004) in order to replicate drawing in the form of plan, section and elevation, the conventions of visual communication. To the extent that architecture and its graphic representation is understood in terms of its communicative potential as a language (Holtzman, 1994) of sorts, it can be seen as a purely abstract system. Architects, at their essence, construct abstract representations of ideas and those ideas constitute buildings. Architects deal in abstract representational means of communication, drawings, to convey the intentions, ideas and meanings of their designs. This is the fundamental position that leads to the traditional conventions of plan, section and elevation as means of communication that abstract form and space through a process of fragmentation and isolation of discreet representations of the whole through descriptions of its parts.

Building Information Modeling presents an object oriented, intelligent component/database synergistic promise of virtual assemblage through simulation. BIM has the potential to remarkably alter the conception and production of architectural design and representation for the first time since the fifteenth century. Building Information Modeling obfuscates the role of composition, scale and abstraction by displacing the primacy of abstract representation with literal re-presentation while simultaneously clarifying the holistic relationships in the architectural design of form and space. Plans (and sections and elevations, etc.) are merely representations of ideas composed in distorted two-dimensional abstractions of three-dimensional space. Plans and sections, the traditional conventions of architectural communication, are not literally the space, or a literal assembly of forms, they are simply the representation of such. They are a linguistic system, a visual, graphic language, and as such they are inherently an abstract system of symbolic representation. Lines drawn in a particular configuration mean 'wall' in another configuration they mean 'window' the context sets the definition. Orthographic, axonometric and perspective projections are each profoundly distorted, abstract ways to communicate architectural ideas and intentions. Yet, this is how architects imagine buildings, through abstraction. Architects have been educated to represent their ideas through a series of

representational processes that lead to increasingly abstract and distorted forms of communication. Architectural education currently is a process of acculturation that privileges the abstract, privileges representation rather than re-presentation. This culture is maintained by the profession at the expense of creativity, creativity that is now encouraged by the promise of BIM. Creativity that can emerge now from an imagination stirred by a confrontation and convergence between, and of, abstraction and the literal, representation and simulation. BIM offers the double-edged promise of displacing abstraction with simulation. There are profound conceptual differences between the translation of ideas and the transcription of ideas (Lonna, 3) and how architecture exists between the common forms of representation and to that to which they refer. The virtual building model is the thing as well as the representation of the thing. There is no abstraction. The building is literally (virtually) constructed, the space is the space, and the forms are the forms. The plans, sections, and elevations, the traditional conventions of representation are an illusion. Plan is dead.

## **2. To BIM, or Not to BIM**

“The only true wisdom is knowing you know nothing.”

-Socrates

BIM presents simulation as an anti-abstract means of visual communication that seeks to displace the discreet representation of plan, section and elevation with the intelligent object model. Building Information Modeling obfuscates the role of composition, scale and abstraction by displacing the primacy of representation while simultaneously clarifying the holistic relationships in the architectural design of form and space. The evolution of the *'intelligent'* CAD objects in BIM and their associated pedagogies are transforming the way in which architectural education engages issues of design and representation and creates opportunities to question the roles and rules of the traditional conventions. The research examines the relationship between the scale of design (or lack there of) and the scale of representation (or lack there of) and how this relationship undermines the primacy of abstract representation in architectural design. The future of architectural production vis-à-vis architectural representation in practice and concept is at a crossroads between Parametric Modeling (PM) and Building Information Modeling (BIM) as the profession moves beyond traditional practice and its drawing-centric model into a dynamic process/component oriented model for digital practice and the subsequent re-definition of professional services and contractual deliverables. The profession and academy will come to terms with these new modes of thinking and making constituted by PM and

BIM solutions in different ways and at different paces. As the cultural shift from traditional practice to digital practice takes place there will be numerous and varied hybrid relationships of the two technologies undoubtedly yet to evolve. The convergence of these two technologies point to a new conceptual foundation for architectural thought and production that focuses on a fluid relationship between design, construction and maintenance in which data is the medium (Risen, 2005). It is in this spirit that BIM is discussed here, one that presumes a convergence of best-of-class technologies that leverages data management and knowledge production as the prevue of the architect and the true goal of the design process. The greatest potential BIM promises is the opportunity to re-invigorate and re-center contemporary practice and education simultaneously on ways of exploring architecture by developing and exposing design processes and methodologies that reprioritize ways of seeing, thinking and making in the design process.

If truly, "...the medium is the message" as Marshall McLuhan (1999) stated, now more than 30 years ago, then digital practice with BIM as a shift from traditional practice clearly harkens in the era of a new message. The building information model represents a fundamentally altered medium from the traditional representation in contemporary practice of the constructed image. What is the new message? That answer is unclear at present precisely because the discipline at large has not absorbed or acknowledged the underlying premise of BIM; a cultural shift is required in the profession and academy to completely and beneficially realize the potential that BIM has to offer. BIM affords the opportunity (or obligation) to model a project down to the bolts, washers, and nuts of every connection and detail. In digital practice with BIM it is completely possible to have extremely high levels of detail in the model that in traditional practice would require and enforced abstraction (Schodek, 219) in translation of the model to representation. However, in true digital practice with BIM the subsequent translation is unnecessary and affords the designer additional time and resources to focus on design. The primary question is, does the education of the digital practitioner still require representational abstraction in the era of BIM? And if not what is the reciprocal knowledge that the academy should now address to enable the digital design process? Abstraction and representation have been about fragmentation and isolation of the parts from the whole. The educational models for the contemporary education of an architect presume this relationship of the *parts to the whole*. The BIM process is much more of a context driven anti-fragmentation, anti-isolation design process that is dependant on contextual relationships in the modeling environment and data to fundamentally re-conceive the relationship of the *whole through the parts*. To BIM, or not to BIM, that is the question. And the answer on both counts is yes. It is not a choice. The future resides in both sides of the choice,

abstract representation and literal simulation. How one walks that line has yet to be seen but the professional, cultural, and pedagogical consequences will be vast and substantial.

### **3. The Profession and BIM**

“I have often conceived of projects in the mind that seem quite commendable at the time; but when I translated them into drawings, I found several errors in the very parts that delighted me most.”

- Leon Battista Alberti

The conventional practice of architecture today assumes a traditional set of orthographic projections, 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 (Lonna, 1997) and the interpretation of the design of buildings. Contemporary construction documents reveal this assumption, these abstract, fragmented representations of the building and its components rely on reductive syntactic connections (Lonna, 1997) where by each abstraction is part of a dissected whole and when taken as a summation these fragments exceed their individual abstraction and constitute a literal description of the complete building. BIM conversely begins 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 a transcription of ideas in to a simulated construction?

Acutely aware of the impending cultural shift that BIM represents to the profession some leading practitioners, such as Paul Seletsky of Skidmore Owings and Merrill, have mused about the opportunities and consequences for the transition from traditional practice to digital practice with BIM. As Seletsky (2005, 2) has said, “Properly ignored, the results [of BIM] may very well promote Construction Managers into a lead decision-making role...” presumably out pacing architects ability to leverage the profession’s knowledge base to regain lost ground. Architects can perhaps re-gain lost territory taken by the contractors, construction managers, interior designers, facilities managers, and others. BIM affords architects the opportunity to ‘deal themselves back in’ to the knowledge management (Zigo, 2005) of a project from beginning to end and beyond. BIM shifts the focus away from representational development (drawings) and towards formal and spatial development (ideas) through the development of the three-dimensional model. At the current time too much attention is being paid to the ‘quick’

extraction of two-dimensional drawing/representational information. The profession has been leading the BIM charge and in the initial enthusiasm of the movement has not reflected on the potential changes in deliverables and continues to dumb down the building information model to the lowest common denominator, the drawn sheet set. The reasons for this are vast. From legal contractual and liability issues, to procedural and cultural issues this technology is outpacing the discipline's ability to respond. 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 BIM might reshape the design process and conceptually shift to production of architectural ideas and objects like nothing has since orthographic and perspective projection in the fifteenth and sixteenth centuries (White, 121).

#### **4. Academia and BIM**

“How can teaching proceed within a framework that demands its own subversion?”  
- Marc Angéilil, “Inchoate,” 2004

The academy must seek out new methodologies for exploring architecture that reflect the pedagogical shift represented in BIM by developing teaching methods that reprioritize ways of seeing, thinking and making in the design process. What are the skills and ideas that contemporary architectural education must employ to prepare students for this new digital practice that is based on a modeled construction of architectural assemblages that transcends previous definitions of convention in design and construction representation? The expanded use of digital design represented by BIM technology exposes the relationship between the scale of design (or lack there of) and the scale of representation (or lack there of) and how this relationship undermines the primacy of abstract representation in architectural design. When and if BIM supplants the need for drawn representation in two-dimensions how might/should the education of an architect be affected with regard to issues of scale usually addressed in the production of drawn representation? Does the continued prolonged use of the ‘scroll wheel’ scale-less place of the BIM environment present any advantage or disadvantage to the designer (especially the young) or is the ability to continually scale and scroll a drawing simply a new ‘convention’ of the new traditions yet to emerge from BIM?

Digital architectural education has great opportunity and risk in how it comes to terms with re-conceptualizing design education as the profession struggles to redefine the media and methods of architectural deliverables in the age of BIM. Building Information Modeling has the potential to radically transform the way in which architectural education engages issues of design and representation and creates opportunities to question the roles and rules

of the traditional architectural conventions of visual communication. BIM so fundamentally shifts the priority away from abstraction to simulation and is at its foundation based on a component/assemblage mindset that the academy will have to subvert its own canons (Angélil, 2004) to find new direction in its fundamental suppositions and foundations. How the academy might prepare students of architecture for a digital practice in this period of transformation is the focus of this paper. The promise of BIM to the professional practice of architecture is profound. The cultural shift just emerging in digital practice has been grossly underexposed in the contemporary discourse. As firms move from a CAD-centric view of practice where architects and consultants compose ideas through drawings to communicate design intent to the new BIM-centric view of practice where the virtual simulation of assembled building components and systems a critical tipping point will be reached where architects will no longer compose abstract drawings that represent the design of a building they will instead construct a virtual replica of that building that is increasingly less an abstract representation and increasingly a literal re-presentation of constructed components.

Newly focused on the virtual building model simulation as the primary means of communication and representation the academy must take pause to critically engage and reconceive educational models and pedagogical positions relative to this fundamental shift away from abstraction as the *modus operandi* embedded in the traditional projected conventions of plan, section, and elevation. The foundation issues of composition, depth and flatness, space, scale and size, shape, line, movement, light, color, intent and interpretation all need to be reconceived. BIM represents a design process that does not prioritize abstract representation or fragmented conventions of communication but instead privileges the contextual construction of a formal/spatial systemic '*intelligent*' simulation. The conceptual and practical advantages and consequences of BIM provides both the profession and academy a unique moment filled with great potential for the critical analysis of the professional architectural design process and how architectural design is fundamentally conceived and taught. The associated pedagogies are transforming the way in which architectural education engages issues of design and representation and creates opportunities to question the roles and rules of the traditional conventions of communication.

## **5. Conclusion**

Academia must seek out new methodologies for exploring architecture that reflect the pedagogical shift represented in BIM by developing teaching methods that reprioritize ways to reconcile the traditions of abstraction and

the new potentials of synergetic simulation. The opportunity to question and re-position the role of abstraction in terms of visual communication and the growing need for systems integration and simulated visualization can only be met if the profession and academy look forward together.

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## FUTURE OF COMMUNICATING DIGITAL DESIGN IN ARCHITECTURE

### *Overcoming the Divisive Power of Computer Aided Design*

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**Abstract.** A few decades ago architects, engineers and the building industry relied on a set of self-developed tools for drawing and standards for communication within the profession and beyond. Everyone involved in the process of building understood these standards that were developed, controlled and updated by the profession. Today the situation appears more ambiguous. The introduction of Digital Media, and specifically Computer Aided Design, has greatly enhanced the potential for productivity gains. On the other hand, the lack of standardized open file exchange formats in CAD has created communication barriers by making data exchange more confusing and ambiguous. Frequently this has consumed the very productivity gains that were originally envisioned by industry. Problems with proper and fluent data exchange between software applications to no small extent are due to fundamental disagreements between software designers on the proper digital description of a building, leading to nearly insurmountable communication obstacles, designed to potentially divide the profession, practitioners and the educational environment. Consequently construction has not partaken in the productivity gains that other industries have enjoyed. Proprietary file formats and closed software systems have fostered the development of design camps that rally behind one software. Others reluctantly buy into certain “solutions” for they are perceived to be *standards*.

Innovation is hampered as development of industry design tools is no longer controlled by architects, engineers and the construction sector but instead by private software companies frequently pursuing their Based on 20 years of experience with CAD in the profession and academia this paper critically investigates the status quo of CAD in the building industry. It points towards strategies of overcoming the current problematic situation and putting the profession back in control of its own communication process.

## 1. Ramifications of CAD-use on the Professional Practice of Architects

### 1.2 HISTORIC BACKGROUND

“The technical drawing has developed over a considerable period of time, with the goal of delivering clear instructions for the assembly or construction of an object (Robin Baker, 1993).”

In the “paper age” architects and all the parties involved in the building process, had control over the process of designing and sharing the design with the other parties involved. Countless rules for communication had been developed over the process of hundreds of years, some of them by the profession as a whole; some of them were developed locally between building participants in different regions or countries. All of these rules had basically one goal in mind: to facilitate the communication about the object of interest, *the building*.

The profession itself controlled the rules of communication, and therefore it was relatively easy for the people involved to develop rules and systems of passing along this knowledge from one generation to the next. Different architecture schools have tried (sometimes radically) different methods of teaching this knowledge, but eventually a roughly similar canon of skills and knowledge was passed along from one generation to the next. Changes were implemented in an evolutionary fashion.

These skills involved the use of *real tools* such as pencils, colored pencils, rapidographs, rulers, T-squares, parallel bars, stencils, etc. Each and every one of these tools usually served only one task or a very limited amount of tasks, but that ability was usually almost self-explanatory by simply looking at the tool. In those cases that the tool was not self-explanatory, one usually had to watch someone else use the tool and then could pick up its inner working within a few minutes. The tools themselves were so neutral that they permitted the cast of architects to develop its own working rules and styles.

This is not to say that mastering these tools was easy, in fact whole semesters were (and still are) spent in the schools trying to teach these representational skills. But the mastery over these tools did allow the user a certain freedom to develop an individual style out of the core skills. The knowledge over this core of skills made professionals qualified enough to be compatible (and employable) across vastly different offices.

It was therefore common practice that in a job interview the office manager would ask: “can you draw?” and when the answer was affirmative (as it usually was) the person in question was hired for a limited time-span, after which there usually was an evaluation just how good that person “could draw” and what his other skills were.

## 1.2 CURRENT STATUS

This situation has changed dramatically with the introduction of computers in general and CAD systems in architecture in specific. The introduction of digital media was a revolutionary change to a profession in which representation had not changed substantially within hundreds of years. Disengaging the medium (the CAD file) from its representation (the printout) has radically changed the way in which architecture is drawn. Within a brief transition time the question of “can you draw” was replaced with “do you know how to operate a CAD system?” (general question) and if the answer was affirmative, the candidate was hired. But the older architects, who mostly purchased CAD systems not out of an inner determination, but for alleged market forces (everybody else had one and they did not want to fall behind) started to gather that there are different CAD systems, while the young architects knew that already out of school.

Before long, the question of “do you do CAD” was therefore replaced by the current question: “can you operate the ‘*enter certain brand name here*’ CAD system?” Often enough the answer to this question is negative, and that forecloses any possibility of employment in that very architectural practice. This gives rise to the legitimate question of: does the profession still control its tools or do the tools start to control the profession?

## 1.3 RAMIFICATIONS OF THE STATUS QUO ON THE PROFESSION

This qualification to operate whatever specific “market leading” CAD-application has started to dominate other qualifications that comprise an architect. That trend may be considered dangerous, for several reasons. First of all software applications change their version numbers quicker than architectural trends (which already change at a breathtaking pace) to the point that an architect has to spend a significant amount of time simply trying to stay current in the field of software. This is especially strange since the basic *principles of CAD* have not changed very much over the past decade.

The situation has deteriorated to a point that the mastery over one specific CAD application, or a core suite of software titles, has often become the primary reason for employment. This neglects or belittles the many other skills and knowledge that any (prospective) architect has acquired throughout his career and education and potentially reduces the young architect to a mere computer operator, just that he/she does not operate mainframe terminals, but a CAD-workstation.

### *1.3.1 Trivializing Knowledge*

The reduction of the knowledge of an architect primarily to his capabilities of operating a specific suite of CAD-programs, modeling and rendering applications, trivializes the body of knowledge that has accumulated within the profession over decades, if not centuries. It potentially devalues the standing within society and self-esteem of an entire profession.

Ultimately this will have an effect on the institutions that harbor this body of knowledge, the schools of architecture, and the educators working within. How shall the educators of CAD maintain their status within two systems (that one of architecture and that one of educators) if potential students start to question a five year long architectural education costing them (or in most cases: their parents) large five-figure or six-figure amounts for their architectural education? What if the sentiment starts to dominate that their chance of employment would be infinitely better by taking a six-month long crash-course in “abc-CAD?”

This trend could be enhanced by the (somewhat heretic) comparison of what the three possibly most influential architects of the 20<sup>th</sup> century (Le Corbusier, Mies van der Rohe and Wright) have in common? They all lacked a formal architectural education. Has this harmed their careers? This anti-academic trend is being fostered by happenings in other fields, primarily the booming computer and software industry. The role models of the information age, the Gates', Jobs' and Dell's all share being university dropouts. Has this harmed their careers? Why should someone invest hundreds of thousands of dollars into the education from a highly recognized university? With the same money, he/she could found an upstart company on one of the many “insanely great” ideas floating around in cyberspace, take the company public after two or three years and enjoy oneself for the rest of the life. With all the money made during that brief time, one can buy all the architects and/or lawyers in the world.

This trend could be called the “cannibalization of education.” A set of values that has developed within the bourgeoisie over the past two centuries, namely that “a good education” is the primary insurance against poverty and towards a migration into the upper ranks of society, possibly even the highest ranks. This understanding is being gutted in light of the “revolution of information technology.”

In the field of architecture, the vision of capital-intense “CAD-sweatshops,” where countless numbers of architectural drones are working in droves to finish their individual chunks of drawing tasks is not entirely far-fetched. What may remain are a few (and far between) star architects, the pop-icons of an “educated” elite, and countless nameless drawing clones which spent way too much money and time on their education.

This would be a return to times of the past, when the emperors only held a handful of architects, and the overwhelming mass of buildings were

designed and constructed by masters of the building trade (either masons or carpenters). It is at this point in time that the profession of architects has to decide where it wants to head from here, if it wants to lead, follow or get out of the way.

#### 1.4 AN ANALYSIS OF THE UNDERLYING PROBLEMS

##### *1.4.1 How did it get this way?*

The computer is an odd tool, in that it claims to being able to do just about anything one could possibly imagine. It converts itself from a number cruncher into a game machine, into a stereo system into a communicational device into whatever-else-you-can-think-of by merely launching a new application. It is therefore difficult, if not impossible, to develop a correlation between what the computer does, and how it should look, or how it should work, as there is no immediate correlation. There is nothing imminent in a computer as is in a compass or a pencil.

It is therefore possibly not proper to call a computer a tool; it is more of a *container for tools* (the software applications). This jack-of-all-trades image has unfortunately colored off to the software itself, the individual applications. These applications are the objects inside the computer, which most likely resemble traditional tools. Unfortunately this opportunity was soon missed by the industry as the makers of software tried to stuff as many functions into their applications as possible. What usually suffers is the functionality. Purists still claim that the original versions of the Apple Macintosh applications, MacWrite and MacPaint, are still unrivaled in their immediateness and understandability. Some people claim that new Apple applications such iTunes, iPhoto, iMovie, etc. have regained some of that original spirit. To cite Ludwig Mies van der Rohe: "Less is more!" This is what good tools should be all about, no matter if they are real drawing tools, or computer tools.

Floating palettes are only the most recent admission of software makers, that they themselves are increasingly at a loss *just where* to put all these functions on the computer screen. That people actually have to memorize these functions, and work with them, appears to have passed them by. This is a classic case of the mix-up of quantity and quality, an example of bigger not automatically being better.

#### *1.4.2 Different ways of working*

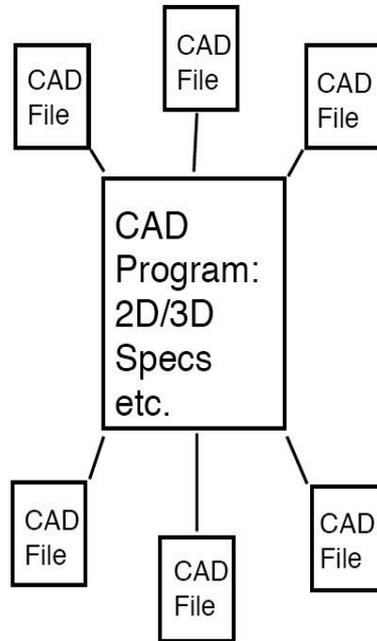
Computers developed as *application centric* machines, which is usually very different from the *document centric* way in which humans normally operate. Especially architects traditionally would span a document onto the drawing table and then place all the tools (pencils, rapidographs, rulers, compasses) on that drawing or in its immediate proximity. The document was the very center of attention, sometimes for weeks and months. There are many reasons why this document-centric approach is far more comprehensible to the human mind. And whether it is a writer, a photographer or an architect, they all usually deal with documents and all their traditional tools (typewriter, pen, camera, dark room, drafting table technical pens) all gravitated around the creation of these documents.

In the original days of computing, this lack of document-centeredness was justified by the lack of power of early PCs.

Current computers are approximately 1000 times as powerful (calculation power, volatile and permanent memory) as PCs in 1980, when the first mass market CAD applications were developed. The question may therefore very well be posed *just when* computers will be powerful enough to challenge the traditional application centric ways of computing?

As it turns out the software industry itself has little if any interest in changing this status of application centric computing. For one, CAD applications are among the most complex software applications and many companies simply shy away from rewriting millions of lines of code. On the other side, CAD vendors have found that the application centeredness is the easiest way of binding clients to the own software (see Figure 1). Making computer users depend on a single software application, the alleged *standard*, has enabled the development and solidified the power of software empires.

Wikipedia defines: “As each CAD system has its own method of describing geometry, both mathematically and structurally, there is always some loss of information when translating data from one CAD data format to another. The intermediate file formats are also limited in what they can describe and can be interpreted differently by the sending and receiving system.” It is troubling that this definition simply accepts this problematic as a status quo.



*Figure 1:* In an application-centric model the exchange of data is limited to a specific software, at times even a specific version of the software

This not only happened in the field of CAD, but in Word Processing, Spreadsheet Applications, Databases, Graphics, etc. In these fields, however, in most cases it is possible to move information back and forth in a loss-less way, by way of neutral file formats which are supported by an increasing number of software vendors, if only with grinding teeth. Some of them still make every effort to introduce “features” into their software that will not interface correctly with the neutral exchange standards and therefore render it useless once a substantial amount of users uses this software. The Open Source Software movement has created additional momentum towards the free flow of information by use of open file-exchange standards. Free-of-charge applications such as OpenOffice (office application set), Firefox (webbrowser), Apache (web server), SQL (databases), clearly started to challenge their respective proprietary market leaders.

On the other hand, the file content of all the applications above is of a substantially simpler structure. Text documents, Spreadsheets and Databases, for example are all based on pure ASCII-text, while pixel-based graphic formats contain binary information, but of a comparatively simple structure. CAD data is dramatically more complex and consequently CAD files have a drastically higher level of internal complexity.

### 1.4.3 Establishing Empires

Over the past decade or two we could witness the establishment of such overwhelming organizations as the “AutoCAD Nation,” the “MicroStation Republic,” the “Empire of Allplan,” the “Land of ArchiCAD,” the “Dukedom of DataCAD,” etc. The largest one of them wields the biggest sales argument in its own favor: the alleged *compatibility* for few of them really have an interest in facilitating data exchange with other applications. This ties the clients to the vendors (compare Figure 2).

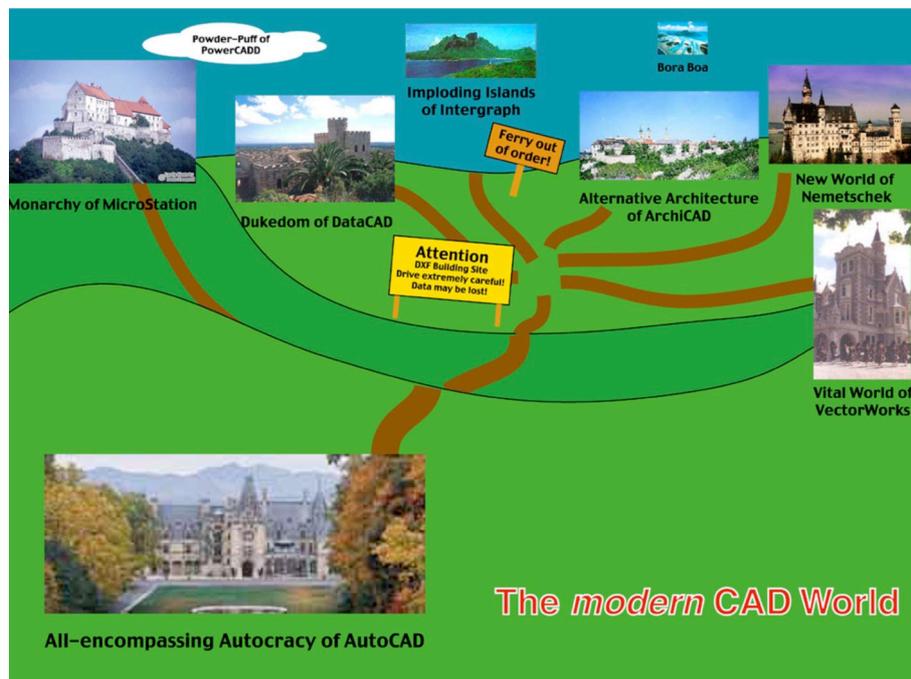


Figure 2: A view of the data exchange between selected mainstream CAD-applications

As most users need to communicate their designs, file compatibility all of a sudden becomes the facilitator of mere survival in the digital world.

There was a time when the trade groups themselves (the architects, the engineers, etc.) decided over their own drawing tools, over their own drawing rules and subsequently over the rules for information exchange. In general, each and every participant in the process couldn't care less, *how* the drawing was created, and *what tools were used* in the process, for as long as the final document spoke for itself.

Today many of these standards developed by profession, are in vain, as the software in use generally lacks any kind of intelligence and does not

understand the simplest drawing if it originates from another application. At times the applications in use do not even comprehend their own data output.

What good are standards for printed copy when an increasing amount of documents is being exchanged in electronic form?

Where does this leave the profession of architects, and all those involved in the building process?

#### *1.4.4 Exchanging Data*

AutoDesk, the maker of AutoCAD, by its own market dominance developed and pushed the data-exchange-format (DXF), and later AutoCAD's native file format (DWG), as file exchange standards into the market. Due to AutoDesk's power every one else had to follow their conventions or face a tiny market niche. In the process the building trade groups surrendered most of the authority over information exchange to the maker of one CAD application. The CAD-data-exchange standards proposed by the American Institute of Architects are nothing but a reflection of the (limited) abilities of AutoCAD.

Especially for the field of building, the purely geometric approach of DXF and DWG leave many things to be desired. While architecture and building construction play a small role in the overall CAD software market, problems faced in the building industry, may be by an order of magnitude more complex compared to the abilities that normal CAD applications usually show. Most instances of building construction produce small, if not smallest, production runs, and therefore usually do not warrant the design of complex geometries, and the necessary molds. Consequently building geometries are usually simpler and Architectural CAD systems need not be as *geometrically* complex.

#### *1.4.5 Architecture is Different*

While most people have a pretty good idea about the overall looks and proportions of a mainline brand name car, only few, even architects, are able to comprehend even approximately the relationship of all the parts and components of a medium sized building. This is because (good) architecture is *spatially* complex.

Let this be illustrated by the example of a simple doorknob. That knob belongs to the door, which itself belongs to a frame, which is installed in a wall, between two rooms, on a floor in a certain wing of the building. These are already six levels of dependencies, something that even most of the specialized Computer Aided *Architectural* Design applications cannot deal with today. Another big problem is that buildings tend to be relatively repetitive from one floor to the next. It therefore makes a lot of sense to organize drawings into different *classes of objects* on the one side (walls,

columns, slabs, openings, etc.) and the *individual floors* on the other side. Today only the fewest of advertised CAAD applications support this need. Most CAD applications do not support organization of objects beyond the ability of using layers.

To sum it up, architects and other planners currently face:

- Software that is so complex that it often requires months to grasp the core working of the software.
- Individual CAD-applications, although they all do similar work, often do it in a vastly different way. Knowledge and skills acquired in one application are of a substantial smaller value when using a different application.
- A data exchange format which lends itself to the description of two-dimensional objects, but falls short when it comes to the true *volumetric* description of 3D-objects and their behavior (e.g. structural and thermal).
- Data-exchange format lacks proper dimension support. That means it does not know if the objects drawn in it are dimensioned in meters, feet, apples or oranges.
- Software that is difficult to scale by the user, if at all. Scaling means the ability to purchase the software according to ones own needs and not in the increments prescribed by the respective vendor. This means the ability to purchase individual components, which are able to interact with one another.
- Unnecessary and undesirable dependencies to CAD-applications and the software vendors that make them.
- Innovation cycles over which the users have little, if any, control. The core of most of the CAD software in use today is some 15 to 20 years old, only has been repackaged several times since with incremental innovations at the discretion of the vendor *not the clients*.
- Ideological debates, not over the design content, but the politically correct CAD software to use.

## 2. An Outlook

It is not the intention of this paper to devalue the potential benefits of CAD for architects. CAD, used correctly, may be one of the biggest liberators of redundant and repetitive work and will allow the creative designer to concentrate on the true issues at hand. Such systems may continuously and immediately provide the designer with the necessary information to make competent design decisions. These are not restricted to spatial or aesthetic decisions but could involve, for example, thermal simulations where design decisions could be immediately effected by their energy impact, especially with high energy prices.

Currently these interactive schemes do not work in most cases, not because of a lack of power of the computer hardware, but mainly because of

the deficient software. The way in which most CAD systems describe the building is, at best, an arcane graphical representation, and not a holistic volumetric description.

It also does not work, because most CAD-applications are closed-off worlds of their own that do not interface or interact with other applications.

In the view of the author it is high time for the profession of architects, but especially for the academicians who (should) work on the forefront of CAD education, to think about how architects can emancipate the profession from the dominance of the software makers. This would be the first step towards regaining the control over the very own communication tools of the profession.

The dominance of the CAD industry over the modes of communication can only be overcome by individual professional bodies starting to recognize the problems and develop actions.

## 2.1 ACTIONS

While the average CAD users currently spend a fair amount of time disputing which is the alleged best CAD-software, the target is increasingly lost out of sight: architecture and the process of building itself. Would it not be great if the discussions over the alleged best CAD-software would be a matter of the past? Would it not be great if the exchange of building data would simply *work* independent from the used software?

### 2.1.1 A Call for a Different File Format

Currently the biggest stumbling block towards a greater freedom of data exchange is a file format as neutral as the traditional architectural paper plan.

The dominating DXF/DWG-format have one advantage and several deficiencies. The advantage lies in the fact that it is in many cases a least common denominator. One of the disadvantages is that it follows a simplistic model metaphor. Why should DXF/DWG support the description of volumes (something that architects are usually interested in the moment it comes to specifying the quantities in the plan for bidding) when the mother application (AutoCAD) is still mainly focused on the description of complex surfaces? For as long as CAD is utilized primarily in a two-dimensional fashion and only interchanges the 2D-plans of the building, DXF/DWG works relatively proper, for as long as sender and recipient of the file are aware of the restrictions imposed by limitations of the underlying file format.

The biggest obstacle is, however, that DXF/DWG is *not* a standard. It belongs to a privately held company that follows its own interests. These interests lie, due to mere numbers of licenses sold, outside of the field of building. It is therefore no surprise that the company does not support the

building sector and its metaphors in a desirable fashion. It is primarily marketing that tries to convince architects and civil engineers that what is good for the electrical engineers, and the aeronautical engineers and the mechanical engineers, simply *has* to be good for the building industry as well! A carpenter would have to be able to do good work with a mason's hammer. After all, it has been tested millions of times with masons, so there should be no reason that the carpenter should have any problems.

Every time that AutoDesk introduces a new version of its market leading CAD-application, it also introduces a new version of DXF/DWG, which usually raises backward compatibility issues. Then all the other vendors play catch-up for the following year in order to make their programs compatible once again.

*Standards*, on the other hand, are so prevalent in just about every single aspect of our lives that we all but forget about them. From the cement in the foundations of our houses, to the quality and the dimensions of the wood, to the dimensions of the pipes, to the color and durability of the paint on the façades, just about everything we use in the building industry follows established standards. There is simply no reason why this should not be the case for the very documents we produce to properly document the building as a whole. These standards do exist, for as long as the drawings are done on paper. By comparison there are precious few standards for digital CAD-documents in the building industry? Most of them were developed within the constraints of the dominating CAD application, AutoCAD.

As the industry transitions to an all-digital planning process it would appear normal that digital standards emerge that are as specific to the building industry as the paper standards used to be.

There are few independent bodies, which oversees the proper definition and implementation of a data exchange standard in the CAD field and not one of them is fully acknowledged by any professional organization such as the American Institute of Architects, the Royal Institute of British Architects or the German Chamber of Architects, to name just a few. While CAD files are dramatically more complex than web pages, there is no reason why data exchange should remain the proprietary privilege of one or a few single software vendors. Open file formats have been proven to work in the field of word processing using RTF, computer graphics in the form of JPEG, TIFF, PNG, etc, with databases in the form of SQL, spreadsheets utilizing SYLK, and several other areas. The very existence of the World Wide Web is based on the adoption and use of public open file formats. Consequently it is possible for the average user to use the web focusing on the content rather than the technology behind it.

In order to facilitate an open system of free flowing information between various applications of differing vendors, the development of a stringent, yet flexible data format for the comprehensive description of buildings should

be a prime objective. There have been efforts in this direction since the mid-1980s that have led to the development of the “Standard for the Exchange of Product Model Data,” or better known as STEP (STEP ISO 10303). This is a whole family of data format standards. The part of STEP that is of the biggest interest to architects is ISO 10303-225 “Building Elements Using Explicit Shape Representation.” More recent standardizing efforts to facilitate file exchange between CAAD software led to the standard ISO 16739 (About SC4 Standards). These “Industry Foundation Classes (IFC) are a standardization initiative by the International Alliance for Interoperability (IAI) to produce an open standard that properly describes buildings as a set or system of interrelated objects and components that all have specific properties, such as dimensions, relations (to other objects and/or components), costs, thermal conductivity, thermal mass, etc. Important is the fact that IFC is conceived as an *open* standard that can be expanded and developed. The most recent version is IFC 2x2 (July 2004). Software vendors may write their own interfaces to support IFC and may request verification and subsequently label themselves as IFC-certified. Several applications have requested the verification procedure (List of verified applications). Overall the initiative tries to include a much broader set of information into the description of the building, an effort that will lead to more precise planning through digital simulation before construction. This could be called *smarter planning and building*, consequently it is also referred to as “buildingsmart” (Description of Buildingsmart).

Addition: The author is delighted to find that some momentum is gathering behind the IFC standardization efforts. After submission of this paper, several articles were published on the website of the American Institute of Architects (AIA). One article about the development of the US National CAD standard (NCS) makes specific reference to the IFC format and the International Alliance for Interoperability (Tardif). Another article by Dianne Davis, president of AEC Infosystems explains that “BIM [Building Information Modeling] is what we all expected computer-aided design (CAD) to be...” and Glenn W. Birx, AIA explains in his article of December 2005, how the introduction of the BIM concept changed the work culture in his company.

Also, at the upcoming BuildingSmart Conference in April 2006 in Munich, Germany a representative from the US General Service Administration will report on their experience with IFC.

### 2.1.2 More open software

Once this mutually beneficial and inherently flexible data format is in place and supported by all relevant forces in the building industry (planners,

administrations, contractors, material manufacturers, etc.) the dependency of the industry to proprietary software is greatly reduced. No longer is the possession of one specific piece of software required for compatibility and the legitimate communication requirements of the industry. Instead all market participants may opt to purchase software of their own liking for as long as it is certified to support the open standard.

Consequently the industry may progress to a different business model in which the individual application is no longer in the foreground. Instead the document (the plan) becomes the point of focus once again. Remember, this used to be the case up until the introduction of the computer and software into the planning process.

Various groups may start to develop specialized components in place of what used to be one behemoth CAD application. Programs of various kinds, such as 2D drawing, 3D modeling, massing analysis and rendering software would share that common standard format. Just the same specialized applications such a bidding and tendering software or thermal simulation software would be able to use the same set of data. Redundancies and errors would be minimized. It remains to be seen how quickly the industry adopts this new standard. Similar to the adoption of open standards, such as the set of Internet-protocols or the universal database query language SQL, this is primarily a political issue requiring large governmental players to force the open standard into the marketplace.

Customers would increasingly want to purchase only those functions in their CAD applications, with which they work, and therefore require. In short, they would start to demand modularity in their CAD applications. This approach would also introduce for the first time, a market competition at the "function level." Currently, entire CAD empires compete with one another. Once customers have bowed their heads in the direction of one of these fiefdoms, their choice of functionality is usually dramatically limited. The customer has one set of tools with which to work and little if any alternative.

A new modular approach and implementation would allow the choice of individual tools required for specific design tasks. Users will be able to scale software solutions to their own desire and financial abilities.

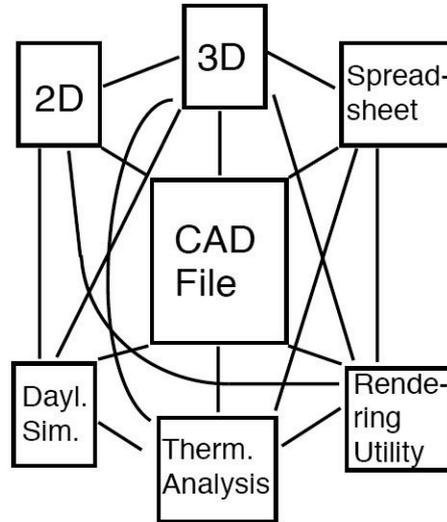


Figure 3: Free exchange of information in a modular, data-centric model

This approach would foster the development of dramatically more modular software. The traditional CAD-application, which we know today, may change to a mere *container* for nearly infinite plug-ins that the user purchases independently. Strategies like this are entirely possible, and are even executed by the industry. Software applications like Adobe PhotoShop<sup>®</sup> are almost unthinkable without the myriad of plug-in filters that come along with the application and are offered by independent vendors. Even open source applications such as the Mozilla Firefox project permit the addition of specific functions through the add-on of various plug-ins. AutoCAD and most of the other CAD applications usually offer programming interfaces, by which the software may be expanded upon from the outside.

This container application will contain all the basic intelligence in order to provide a platform for the internal data interchange between the various components, such as tools and (design) objects. These CAD-container applications may be distributed for free, similar to the PDF format where the Acrobat Reader application may be freely downloaded by anyone. So, while the toolbox itself may not cost anything, users would start to pay for the tools that they plug into the tool chest. On the other hand, different vendors, may sell this tool chest with a starter set of tools for a moderate price and offer additional functionality as add-ons.

All applications, however, would follow the same internal program interface guidelines (though not developed yet, this may be yet another

standard outgrow of the IFC initiative) in order to stay compatible and make the tools completely interchangeable between different applications. Just as one used a traditional compass here, there, or somewhere else, one may use a little compass application plug-in, in whatever CAD-application. For the first time this would give software users *choice*, one of the mantras of a free market society.

Standardization would allow for all the tools within such an application to be little applications of their own, which could be selected individually and easily plugged-in and plugged-out of the “mother ship” so to speak. This approach would cater to the designer’s needs to custom-tailor the software and its capabilities determined by individual user requirements. The Internet provides an excellent medium for direct sale between the developers and customers. As the tools would usually be fairly small in size, they could easily be downloaded from the net.

Standardization on the software side is only a logical move after the standardization efforts on the hardware side. “Fast networks may assist realization of a vision in which the machine one works on only plays a role in local graphics processing. Otherwise the local machine may easily convert into a virtual super computer by accessing other processors via the network. The analogy to the power grid becomes evident now: nobody in industrialized nations, apart from special cases, runs his own power plant. We are all used to consuming different amounts of electricity via the power grid.” (Schmitt, 1993).

This development could well bring about considerable expansion within the CAD industry including a shift away from monolithic and inflexible applications. It would allow small vendors to concentrate on specialized tools without the need to invent the entire CAD-application around it.

It would permit for more rapid introduction of new ideas and concepts into the industry as the pace of development is no longer controlled by a few software giants that may follow a different agenda than what the building industry and its participants would want to head towards.

## 2.2 EFFECTS ON EDUCATION

Most Schools of Architecture stand at the receiving end of this development today, unfortunately. Not being in the field of software development, they have to pretty much accept anything the industry throws their way. Development of open standards would benefit the academic sector as well. No longer would schools of architecture and engineering face the walk on a thin wire of more or less openly acting as sales agents for private software companies. CAD applications are difficult to learn and research shows that professionals frequently are reluctant to changing away from software applications that they learned in the university unless the new applications

offer dramatic improvements and larger capabilities. Given the complexity and steep learning curve this complacency is an all too understandable human behavior. The reason why CAD-software vendors usually offer substantial academic discounts is not entirely altruistic as the software companies try to bind their future customers early on. This behavior is not unlike the illegal drug industry. Unfortunately it stabilizes the status quo as opposed to fostering innovation. Once the free flow of information is established through an open file exchange standard, the software wars in schools of architecture should be an issue of the past, replaced by a re-emergence of focus on content rather than technology, semantics rather than syntax.

Schools of architecture and engineering may shift their focus away from individual CAD-applications towards a more holistic approach of digital media and their underlying philosophies. This would dramatically expand the shelf life of the knowledge they transmit. While individual software applications are currently updated at 12-18month intervals and their vendors would like users to believe that they will fall hopelessly behind the technology curve if they do not continuously upgrade to the newest versions, their underlying philosophies have not changed dramatically in the last two decades. CAD applications still use geometric entities to describe objects and they usually use layers to organize these drawings.

The only major paradigm change the industry faces at the moment in the field of building CAD is the shift away from simply drawing 2D or 3D shapes towards designing real building entities using real construction objects inside the computer and trying to simulate the building as closely as possible prior to construction.

The shift away from the monolithic software model would liberate the users as the change of software becomes similar to the changing of car models. While each new generation of a specific automobile may embody improvements over the previous, improvements in safety, comfort, power, fuel economy, etc. the basic concept is not put in question. If one can drive the current model one should be very able to drive the future model just the same. This extension of the shelf life of knowledge is of enormous importance to students, the profession, as well as, to the academic institutions. In such a scenario the body of knowledge of what is an architect should become dominant once again over what software the individual prefers. This would allow Schools of Architecture to turn away from the race with the software vendors and be permitted to focus on the topic of properly designing buildings once again.

### 3. Conclusion

There are many trends in the computer industry today. While certain software organizations appear to be firmly established or just solidifying their position in the entire software industry, independent standardization bodies such as the ISO, ANSI, DIN or the W3 Consortium, more than ever before, are trying to establish open and public standards. The development and distribution concept of the open standard Linux operating system currently poses the biggest threat towards established commercial software, and the dependency of the user to large software corporations. This is a good reason for optimism with respect to the opportunities for the development of open standard CAD applications.

Architects and engineers, for the sake of the survival of their profession are called upon to, once again, set the rules for the exchange of information in their domain.

This way, eventually and hopefully, the discussion over what CAD-application is in use or that one can operate becomes as important as the daily talk about the weather or the dispute over the most recent architectural fad: important but not earth-moving.

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## CRITICAL ENVIRONMENTALISM AND THE PRACTICE OF (RE)-CONSTRUCTION:

*Applications of Digital Technologies for Increased Participatory Interaction in Architectural Urban Design and Community Development Scenarios*

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**Abstract.** This research focuses on the implications and applications of “critical environmentalism” as a quintessential epistemological framework for urban interventions while implementing digital applications that foster collective, round-table approaches to design. Essentially centering the environment (*Umwelt*) as an encompassing and interconnecting catalyst between multiple disciplines, philosophies, and modes of inquiry and technologies, the framework reciprocally fosters individual and critical identities associated with particular places, belief systems, and their participants as a primary concern. Critical environmentalism promotes a comprehensive, reciprocally unifying epistemological framework that can significantly inform architectural interventions and the tethered use of its technologies in order to foster increased vitality and a certain co-invested attention to the complexities of the greater domain.

Grounding the theory in pedagogical practice, this paper documents an approach to urban design and architectural education, implemented as a case-study and design scenario, where divergent perspectives amalgamate into emergent urban configurations, critically rooted in the conditional partialities of place. Digital technologies are

incorporated along with analogical methods as tools to integrate multiple perspectives into a single, working plane. Engaging the above framework, the approach fosters a critical (re)construction and on-going, co-vested regeneration of community and the context of place while attempting to dialogically converge multiple urban conditions and modes-of-thought through the co-application of various digital technologies. Critically understanding complex urban situations involves dialogically analyzing, mapping, and modeling a discursive, categorical structure through a common goal and rationale that seeks dialectic synthesis between divergent constructions while forming mutual, catalyzing impetuses between varying facets.

In essence, the integration of varying technologies in conjunction, connected to real world scenarios and a guiding epistemic framework cultivates effective cross-pollination of ideas and modes through communicative and participatory interaction. As such it also provides greater ease in crosschecking between a multitude of divergent modes playing upon urban design and community development. Since current digital technologies aid in data collection and the synthesis of information, varying factors can be more easily and collectively identified, analyzed, and then simultaneously used in subsequent design configurations. It inherently fosters the not fully realized potential to collectively overlay or montage complex patterns and thoughts seamlessly and to thus subsequently merge a multitude of corresponding design configurations simultaneously within an on-going, usable database.

As a result, the pedagogical process reveals richly textured socio-cultural fabrics and thus produces distinct amplifications in complexity and attentive management of diverse issues, while also generating significant narratives and themes for fostering creative and integrative solutions. As a model for urban community and social development, critical environmentalism is further supported the integrative use of digital technologies as an effective means and management for essential, communicative interchange of knowledge and thus rapprochement between divergent modes-of-thought, promoting critical, productive interaction with others in the (co)constructive processes of our life-space.

## 1. Introduction to the Epistemic Model

*“In such disconcerting and magnificent times,  
knowledge becomes the only source to restore meaning,  
and thus meaningful action.”- (Manuel Castells 1993, p.477)*

*“...We are in a tunnel, at the twilight of dogmatism  
and the dawn of real (authentic) dialogues.”  
- (Frampton 1992 cited Ricoeur 1961, p314)*

Although cosmopolitanism implies global and even universal notions, encompassing compound readings of the urban fabric, it is essential to cultivate the specificities of place, especially during significant changes. Paradoxically, following Paul Ricoeur (1964), how does participation in modern, universal civilization also involve surfacing rich, inherent sources for our interpretive thinking? As society becomes evermore complex, urban designs are mandated to critically correspond and emerge from systemic processes that foster productive and effective interchange of ideas from broad ranges to consequently respond with significant courses of action in the greater, immanent domain, while reciprocally preserving the inter-subjectivity of the individual-in-place. Participation in modern, universal civilization and its new technological manifestations need not leave behind cultural foundations but intrinsically surface rich, inherent sources for its future.

Urban design is affected by a fluxing array of forces and conventions. As society becomes more complex, architectural approaches to the urban fabric diversify to handle new situations, each of which mandate a dynamic, paradigmatic review of current knowledge bases and the processes effecting design reasoning. Complex urban designs must emerge from synthesizing approaches to pluralistic and interactive, systemic contexts to consequently respond with meaningful courses of action. Since knowledge is accessed and interpretably incorporated in varying fashion, there is a tendency for fragmentation within the system that leads to disjunction and marginal relations with the greater domain. The issues are in part accelerated by recent changes and exponential increases in the complexity of such systemic forces mixed with escalating and un-tethered informational and technological advances, which has compounded in varying degrees of separation between the significant totalities of the life-space we reciprocally embody. While a rift can be found even between the technologies we incorporate, it is important to maintain the intrinsic need for communication and thus mediation between disparate facets as the basic impetus.

This research focuses on the implications and applications of “critical environmentalism” as a quintessential epistemological framework for urban

interventions while implementing digital applications that foster collective, round-table approaches to design, amalgamating multiple perspectives into a single, working plane. Critical environmentalism is an inclusive philosophy that addresses common issues currently emerging across numerous disciplines, but has not yet become part of mainstream architectural thinking. The concept incorporates critical social theory, practical hermeneutics, phenomenological embodiment, critical regionalism and place studies, as well as wide-ranging environmental and socio-cultural praxis. The tenets of critical environmentalism promote broader definitions of architecture, critically embodied and epistemologically accountable within a total life-space. Essentially centering the environment (Umwelt) as an encompassing and interconnecting catalyst between multiple disciplines and philosophies, it reciprocally fosters individual and critical identities associated with particular places, belief systems, and their participants. Critical environmentalism promotes a comprehensive, reciprocally unifying epistemological framework that can significantly inform architectural interventions and the tethered use of its technologies to foster increased vitality and a certain co-invested attention to the complexities of the greater domain.

Critical environmentalism references critical theory and its inherent bearing in hermeneutical and dialogical processes. The studio-design scenario incorporates a process identified as a “hermeneutic dialectic” (also referred to as “collaborative” or participatory “interactive inquiry”) (Erlandson et al 1993, p.124; Lincoln and Guba 1989, pp.142-155). The process is ‘hermeneutic’ because it is (co)interpretive and “constructivist in nature” and ‘dialectic’ because it “seeks a synthesis through comparison and contrast of divergent views,” but also forms connections “between them that allows for mutual exploration by all parties”(Erlandson [et al] 1993; Lincoln and Guba 1989). It promotes a divergent inquiry, “that is also in tune with the emerging thought of the time and significance for the world outside itself,” (Erlandson et al 1993) and allows for ‘other’ fields of inquiry to be drawn into the periphery of research. Dialog reveals varying points of view within a community, in this case the community of knowledge currently informing the urban fabric.

The method takes a constructivist view toward hermeneutic inquiry that allows knowledge bases to dialectically emerge from the cross-pollination of knowledge. The focus and content of the research methods is allowed to change or emerge in the process of discovery, rather than a set of predetermined outcomes, a flaw of many reductivist design solutions. The method intrinsically promotes a dialogic between a multitude of knowledge bases in order to interpretively generate a way of seeing the total picture. Dialogical methods are “built on the idea that education is a continuum of dialogs between participants rather than monological” (singular, reductivist

approach) that “takes part in the collective enterprise of learning” (Ricoeur 1961; Frampton 1992, pp.314-327). Transactions between participants are conducted on the basis of exchange of experience, knowledge, and ideas between informed individuals on a particular facet of the design. The meeting process in the event-space of dialog sets stages for relationships to be reflected and then put into action (movement) through communicative processes to evaluate and assign values to unique circumstances in their milieu. Habermas proceeds to connect interactive communication, in which the norms of a community and the social roles of actors become important constraints of perceived socio-moral appropriateness of actions. Expressive communication focuses upon the fact that individual actors respectively constitute a public for each other, negotiating the truthfulness of communicative actions. Habermas states that a “decentered understanding of the world presupposes that relations to the world, claims to validity, and basic attitudes have become differentiated. De-centering draws attention to the structures of interaction themselves within the life-world as the context for embodied interaction and thus communal understanding (Habermas 1990, pp.116-188).

Hermeneutics is by its nature initially subjective and transactional. To Gadamer (1989), there is no true universal other than the hermeneutic process of all “inter-human experience,” in action, bound in the textual. He presents that critical understanding emerges through communicative interaction seeking a “fusion of horizons” between participants, through which an ‘authority’ and applicability emerge (Palmer 2000, pp.381-393; Lincoln and Guba, 1989). Hermeneutics appropriates knowledge through iterative, interpretive processes that proceed to fine-tune the system, where the inquirer(s) can construct the world and in-turn allows for new unfoldings. Gadamer’s view (1989) of the hermeneutic processes entails circular reiteration of the three basic components: interpretation, understanding, and inevitable application. In this way, a practical hermeneutic is a viable proposal to serve social purposes as in urban design processes, in this case, the educative design processes of a community in productive action and its relation to an overall, expanding view toward knowledge integration into greater systems of thought. Understanding is interpretive and grounded in action (in situ) with the addedness of our rationale to organize action (Gadamer 1989). This rationality is further modified through phenomenological approaches, rooted in interpretation. To Merleau-Ponty “To say that there exists rationality is to say that perspectives blend, perceptions confirm each other, a meaning emerges. But it should not be set in a realm apart, transposed into absolute Spirit, or into a world in the realist sense” (Olkowski 1996 cites Merleau-Ponty 1962, p27). Human perception is in itself a “creative process” of knowing and “handling

the world” (grasping) – thus simultaneously making [authentic] meanings as well as (understanding of) ourselves through “transactions with the world and with other beings.” (Merleau-Ponty 1962). This realization embraces the synthesis of the subject as part of an overall system. Knowledge is derived from the world, thus our constructions, with others, are immanently connected.

Grounding the theory in pedagogical practice, this paper documents an approach to urban design and architectural education, implemented as a case-study and design scenario, where divergent perspectives amalgamate into emergent urban configurations, rooted in the conditional partialities of place. Following the above framework, the approach fosters a critical (re)construction and on-going, co-vested regeneration of community and the context of place while attempting to converge multiple urban conditions and modes-of-thought through the dialogic co-application of various digital technologies. In essence, the integration of varying technologies in conjunction cultivates effective cross-pollination of ideas and modes through communicative and participatory interaction and as such provides greater ease in crosschecking between a multitude of divergent modes of thought playing upon urban design and community development. Since current digital technologies aid in data collection and the synthesis of information, varying factors can be more easily and collectively identified, analysed, and then simultaneously used in subsequent design configurations. It inherently fosters the not fully realized potential to collectively overlay or montage complex patterns and thoughts seamlessly and to subsequently merge a multitude of corresponding design configurations simultaneously, which also has long-term implications as an on-going, usable database. The media, at various levels of technologies, can be used as devices to effectively mediate divergent interpretive design processes effecting complex urban settings.

## **2. Analog to Digital Dialog**

Creative production initiates with corresponding models that foster a productive and effective interchange of ideas from broad ranges. The design education process is viewed as an “embedded case study” of a certain community’s views on a particular subject at a particular point in time (Groat and Wang 2002; Stake 1995, 2000; Yin 1994;). The urban design process incorporates a model case study method developed by the ETH-UNS Zentrum Zürich Nord whose “main objective has been to obtain an encompassing understanding of the genesis, dynamics, and impacts of the complex relationships between natural systems and social or technical systems,” shaped by overall environmental issues for informed urban development (Scholz and Tietje, 2002). The case study allowed students to

gain a deeper insight into the complex problems of their site from objective and divergent points of view.

Similar the Gadamer's model, the case study is organized in three basic phases. First, students gain basic knowledge about the case through research and data collection in the "*learning and identification*" phase and then construct a working categorical list of critical aspects and principal interests for project organization. Rigorous documentation of the process is vital to the process. Second, in the "*realization phase*," interpretive understandings occur through dialogic cross-pollination (co-tutoring), as a process of mutual learning and shared interest, to develop connective modes between the complex relations of the 'whole' environmental context. Interpretative perspectives and findings are combined and collectively analysed. Finally, "*synthesis*" is performed between various interpretive and well as quantitative data, composed into a multilayered working model for the design (Scholz and Tietje, 2002).

The implemented case-study and design scenario for this project is East London's Lower Lea Valley, as it presents a complicated relationship consisting of polluted marshland and small wooded areas, brown-fields, industrial sites, refuge dumps, railway and storage, transportation lines, septic lines, flood plain regions, dilapidated buildings, housing, sports and education facilities, historic and archaeological sites, and conservation zones. Multi-cultural in aspects, the various boroughs engaged with the site have shared as well as disputed desires, each with their own agendas for their affective regions. The surrounding areas are typical English suburbs with low-income housing supported by local business and industry, which have to be maintained and connected at the perimeter of development. However, while the structure of the urban fabric is typical of the area, the socio-cultural framework is more global. Diverse eastern cultures are prevalent and with this are observed subtle urban images and language inflections. While a predominately historic and culturally structured, the areas now sponsor new, large-scale developments of the Stratford international train station and its associated commercial developments that encroach upon the local fabric and promote an immediate homogenous global connection as well as dramatic changes in scale. In addition, at the time of this scenario and part of the reason for choosing the site, the area is also being considered as the future site of 2012 Olympic facilities, a significant and radical environmental change with little regard for the localities of the place and its long-term effect.

The ciphers of critically understanding complex urban situations involve dialogically analysing, mapping, and modelling a discursive, categorical component structure through the underlying, catalysing, rationale that seeks dialectic synthesis through comparison and contrast of divergent

constructions while also forming connections for mutuality, finding shared impetuses contingent with place between varying facets of the epistemic and physical framework. Therefore, the process involved heuristically identifying varying facets of urban design into differing, even conflicting categories, using the technologies-at-hand effectively as the synthesizing tools. Diverse historiographies, contextual and social patterns, cultural manifestations, socio-economic phenomenon, technological and physical constraints and needs, long-term sustainable and conservation issues, various local particularities as well as connectivity to global, cosmopolitan concerns are filtered and then cross-pollinated to reveal new, collective re-readings of the localized urban space where all factors simultaneously come to bear. In addition, the development of the categories inevitably heads toward the periphery of other fields, as trans-disciplinary to what would otherwise be more centralized studies.

### 3. Learning and Identification Phase

In architectural design, as with many other disciplines involved in social interactions, it is virtually impossible to remove all individual biases that impact and influence interpretations of real situations and thus design solutions. The site is in effect the product of diverse communities and forces inhabiting it; therefore as a way to de-centralize the project, the students assumed divergent categorical positions affecting the urban design. Through these categorical units of spatial constructions, the students role-play as interest groups or stakeholders in order to promote a certain vested interest and focus in the site development, using the critical environment and the goal of comprehensive redevelopment as a common, unifying theme. The point of which is to maximize the stock of distinctly divergent constructions and points of view so that as many as possible stakeholders can affectively contribute, thus increasing complexity as well as specific focus on particular contents. This promotes a *bricolage* or 'magpie' type appropriation of divergent (and sometimes conflicting) ideas-at-hand to be integrated into a new or emergent collective work. It helps develop thicker or broader views as well as developing the possibilities of connection within and of the complex greater domain.

For management purposes, the coding categories were generalized into typical categories, but open for subcategories depending on varying levels of engagement. The initial categorical stances included: *historic contexts; mobility and transportation patterns; building density, type, and use patterns; public & private space relationships; parks, open- and green space; environmental impact and waterways; socio-economics and cultural aspects*. Similar to Kevin Lynch's *Image of the City* (1960, pp.46-49),

descriptive sub-categories included significant *paths, edges, districts, nodes,* and *landmarks* that were extended to notions of identity, connections, suitability, conservation spaces, landscaping types, names of places, boundaries, boroughs and neighbourhoods needs, among others. In addition, students were also encouraged to address these issues with sub-categories in terms of *Place studies*. In *Maintaining the Spirit of Place*, Harry Garnham (1985) recognizes three basic information systems that help "*understand, record, and communicate the basic sense of the region.*" These include: *Natural* (landforms, vegetation, water, etc.); *Cultural* (open space, land development, utility systems, public infrastructure, landmarks, circulation, etc.); *Visual* (viewpoints, unique areas, places of interaction, sequence of views, outdoor activities, visual clues, etc.). Since the cultural context is found to be diverse, extending beyond English descendents to distinct areas of Bengal, Indian, Pakistani, and others, the cultural and visual aspects become increasingly significant and viable to design interpretation. How the local inhabitants view their life-space is incorporated as an interpretive design generator.

Within the historical context, the research included urban plans of John Evelyn, Christopher Wren, and the later extreme Sir Ebenezer Howard. Studies also discussed and documented London's Olympics dating back to 1908 and 1948 as a way of placing the Olympic notion to components already in place within the overall city context. Further research also included researching names of places, historical areas of significance as well as archaeological considerations. Transportation patterns research consisted of studying types and modes of transportation including railways, main access roads, secondary roads, pedestrian walkways and walking distances, bicycle paths and water transportation and then mapping them across the site. Research also found historic pathways and nodal connections. Documentation of built structures and patterns identified an array of residential, educational, religious, governmental, industrial as well as medical on site and at the perimeters. Figure ground studies were completed as well as the study of building typologies. The relationship between public and private spaces included private and public courtyards, green spaces, public spaces that emanate a specific degree of privacy, typified London spaces, plazas, gathering areas, events-spaces, retail, mixed use buildings, multiuse spaces, combination rental and owned housing, combination business retail and housing, and visual and physical spatial transitions. Environmental impact studies pertained to sustainability and landscape and included green spaces, natural links, pathways, parks, wooded areas, environmental hazards, swamp and water run-off, climate, biological habitat, and electricity and waste management. The socio-economical and cultural

viewpoint concentrated on studying the social, cultural, demographical and economical factors pertaining to the site and the surrounding areas of impact.

In the early stages, the data is gathered and compiled using both digital and analog means ranging from literature review, census and environmental reports, web-logs (*blogs*) and web-conversations (*chat*), downloaded PDF's of site information from associated agencies, GIS metadata sets, political websites, local concerned citizen groups, city webpages, site photos and maps, etc. During site reconnaissance, students used digital cameras, recorders, and other measuring devices to document various aspects of the site. They were also asked to qualitatively evaluate aspects of the site and to talk with firms and local residents in regard to their positions. The observers discuss and diagram key aspects to their categorical stance, becoming experts in certain aspects in relation to the site that can then be conveyed to others. The computer now plays an extraordinary role in the ease and multitude of data resources and subsequent management and transfer. Multiple materials can be brought in, digitized, and mixed with other sources and interpreted collectively. The goal is to find connections that can mediate issues, while rigorously documenting in digital form as a way to make those connections quantifiable and identifiable (co-tutoring) to all involved.

The work is compiled into both analog and digital montages to promote multiple and even abstract readings within each category. Some of the initial dialog involves interpretive mental/memory mapping, diagramming, eidetic drawings and analysis to evaluate the discursive nature within the categories themselves. The students begin through typical sketching, collaging, mapping, modelling, and interpreting in terms of their specific interest, but through their readings also begin to find external connections. The interpretations are deliberately kept loose to promote generalized approaches and idealized viewpoints. The students draw into the scene qualitative imagery, poetic notions, site sketches, and photos, while identifying critical relations to associated site conditions.

The groups rigorously studied their respected viewpoints and were then asked to interpretively design specific site schemes by method of large-scale sketches and diagrams based solely upon to their primary categorical viewpoint. They draw in their sub-categorical positions into a collective, singular format. Ideological solutions, while rough in nature, are then digitized and brought into a collective scaled CAD file to be re-filtered through other points of view in the subsequent realization phase. A collective vision becomes finalized as it is digitalized and mapped to a tangible and applicable scale. Interpretation becomes literal thought-in-action as it is re-interpreted and transcribed into real substances. Composed collectively into a single database, the site develops as a multilayered and collective response, an already rich palette before the actual design is implemented. Interpretive and even qualitative modes are mapped with

quantitative site information to further bind the collective response to real world issues.

#### **4. Realization Phase**

Upon developing categories within the environment, the students work at developing common or shared threads between varying facets where the playing field can be integrated (“meeting of horizons”)(Buroway et al 1991; Gadamer, 1989). As part of this, the students are asked to identify a common goal and motivating title for the project, “*Continuous Fusion, Blurring the Lines between Divergent Perspectives.*” By identifying the complex and unforeseen nature of the site, they also identify the need to bring together the disparate facets of the environment into a systemically connective model, one that allows for future synthesis beyond their initial analysis and design and away from preconceived shape, geometry, or formal structure. Knowledge integration was intrinsically motivated by a common goal of sustainable development in the connecting medium of exchange, the urban environment as shared, ideal life-space. During this phase, participants identify others respondents that support or show consistency to their view. The validity of the design approach is grounded in the belief that a contextual reading of the site inevitably involves social agreement between various disparate facets affecting the site.

The categorical responses and subsequent master plans sketches were overlaid and merged into a collective field of spatial connectivity using two separate but connected ‘round-table’ approaches: a scaled physical site model with an overlay and a CAD modelled 3d site plan. Both analog and digital composite overlays were created to simulate, forecast and interpret direct patterns and connections between various site locations and divergent viewpoints. From this, the students visualize and discover emerging patterns as well as diversions and consistencies between conditions.

During the realization phase, a physical model was constructed of the site with a series of clear plastic overlays mounted directly over the model as a shared plane of synthesis. This plane not only fostered the collection of multiple layers into direct contact with the city fabric, but emulated a process developed by London’s Space Syntax to create computer-generated spatial, socially oriented models and to subsequently analyse their physical attributes (Hillier, 1996). This allowed comparison and contrast to the existing site model emulating the real, physical context. Lines were drawn onto the overlay that allowed for malleability and change, where lines could be easily identified and articulated in order to merge or avoid conflict. For example, a new roadway emerged that had to be accommodated and merged

with other features and was easily conformed along the lines of other components. By mixing the approaches, the design process is open to on-the-fly refining as new information is brought to the table.

The computer model is used synonymously as a mediating and substantiating device to even the playing field between divergent points of view and in turn promotes an increased 'meeting of horizons.' The use of the computer model aids in a gradual but rigorous understanding of the system, but also becomes the primary mode of intercommunicative exchange and for building design solutions. In addition, once brought into the multilayered field of the computer space, new collective readings are derived and as such promote a closer view of the complex realities of the site. Each participant now has a collective digital model, which allows all learners to see it as a single, scaled site and literal relation to real entities. It thus fosters the ability to neutralize primacy or privileging of one system over another. Commonalities are identified between facets as immediate ways to solve conflicts within the scheme not otherwise as easily identifiable until placed in a single, workable database. As design alterations are promoted, the interactive field encourages productive crosschecking of responses and thus the validation of solutions. Authority is gained only when it provides a viable 'fit' within the total field.

While interpretation was loose in the previous phase, the realization phase leads to literal interpretation and application of the data. For instance, the historic analysis, if taken literally, could simply be transcribed ideologically directly onto the site with no real connection to emerging needs. However this interpretation changes during the realization phase, with aspects of the linear connections and spatial public nodes playing an effective role when mixed with new transportation and public space analysis. In addition, an analysis of green space from London's AA promoted a similar nodal and "fuzzy network" of "emergent public space," which was digitally overlaid into the overall spatial scenario with multiple connections (Mostafavi, 2003). Public space is merged with historic models and placed within the actual transportation scheme proposed by the city. The digital model allowed for only slight inflections of these three modes to develop a context rich, new and viable fabric that moves forward while retaining an inherently deep cultural palimpsest. Other modes are then easily adapted to conform to this prevailing and connective structure.

## **5. Synthesis Phase**

Through mutual inquiry, discursive perspectives of realities are initially discovered as divergent constructions of reality, which the evaluating participants themselves present, compare or contrast, evaluate and/or

integrate with other views presented in the dialog. These build up into co-constructions, then re-constructions, as they are articulated and evaluated by all involved, while “progressively documented” into a single connective and virtual space leading to a finalized design. Preconceived notions are also under bi-mutual scrutiny and subject to critique by all participants. This dialogic process enables individuals to act as experts to elucidate underlying ideas, issues, and theoretical perspectives (even those that are not shared) and to understand the context within which work is made. Individual constructions are re-read through others perspectives – they set conditions that dialectically generate new ideas, images, processes, and are part of new constructions that have to be integrated into an ever changing context as new ideas are merged (Danvers 2003, p.56). Interpretively mapping a rich, self-deriving context, an informing framework for their final design solutions emerges.

Beyond traditional means, the digitally oriented tools foster the ability to generate the comprehensive storage of the material and leads toward rigorous and disciplined documentation. The combination of layering systems in rendering, illustration, GIS, and CAD programs allows for layers to be named and separated for comparative or singular analysis. Clear comparative coding, attributed to categorical concepts, aids in the understanding of the various, multifaceted components, as seen in emerging information management software. The long-term goal will be to build interrelating software packages that seamlessly transfer data between varying methods and applications. In essence, combining technologies cultivates effective cross-pollination of ideas and modes through communicative and participatory interaction. Since the digital technology creates the inherent mode of a collective space as a medium of exchange. As with the CAD model, a mock full-scaled version of the site can now incorporate preliminary interpretive sketches that become ‘scaled’ and now can possess the possibility of actuality. This allows for more loose type, interpretive drawings to play the same or an even more enhanced role than it played before digital technologies. Reciprocally, the digital imagery now can retain an added level of prose and of loose content that may have been overlooked if contained to digital technologies alone. For instance, a line sketch delineating an abstract or simply diagrammed connection can now be digitally traced onto its own layer in the CAD drawing ‘as-is’ and then altered to meet specific site restraints, while maintaining the initial looseness of the gestured idea. The idea can now be simply clarified by quantitative comparison with a modelled and scaled reality. While initially simplistic in nature, if this notion is taken to a rigorous level, it has the potential to collectively overlay or montage complex patterns and thoughts seamlessly and to then merge a multitude of corresponding design configurations simultaneously. In this, the quantitative version of design can retain

qualitative, thick descriptions, and deep cultural connotations in denotative forms. The epistemic conditions for all methods and disciplines being synonymous, this notion also celebrates an intrinsic connection between traditional and emerging technological modes, linking them through the common impetus of architectonic creation (with respect to Kant) and environmental concerns.

Within our urban model, a collection of fieldwork, site and social analysis, web publications, preliminary hand sketches, interviews and presentations, photography and imagery, material and product research, consultant work, GIS data sets as well as working CAD and digital 3D models are all merged and synthesized into a single database and finalized design scheme, readily accessible and presentable to all participants, including those outside the immediate design setting. Collected work was then easily converted to transfer exchange formats for correspondence with others, as in this case international groups of architects in London that can now perform spatial analyses, assess the actual applicability, and provide critical input, thus increasing potential understanding of real-world scenarios.

## 6. Conclusion

“One result of formal education is that students graduate without knowing how to think in whole systems, how to find connections, how to ask big questions, and how to separate the trivial from the important. Now more than ever...we need people who can think broadly and who understand systems, connections, patterns, and root causes.” –(David Orr, <sup>1992</sup>)

Currently, modes of digital and technological means, by their very nature, are connected to universal notions, homogenized casting of the world, and globalization. As technology increases exponentially, our ability to organize and adapt must correspond or find itself disengaged from the world and thus the very epistemic structure that enables technological means in the first place. It is a change that humankind is mandated to recognize and re-organize in order to reevaluate its significance with real-world issues. With the emergence of today’s virtuality (so-called virtual-reality), both what are considered reality and non-reality are likely to have a broad array of confusing definitions. There is the increasing potential that digital technologies are displacing the user and the participant, and thus direct accountability, from what is now termed the *life-place*.

The foundations of current modes for architectural thought, especially those empowering notions of virtual or digital constructions, mirror the Greek conception of numbers and points (pure mathematics) as something separated from human experience, something separate from the world and

thus not directly engaged with our *being-in-the-world* (with respect to Heidegger's concept of *Dasein*). This experiential separation, dualistic in the philosophical sense, redirects engagement generically and homogeneously from 'alienated universalized modes of being,' not from particularized, localized modes that are by their differences transcendent and co-enabling between locales and direct experience points-of-view (Moore, 2001).

Philosophically, there is the general misconception that 'virtuality', as typically used in digital discourse, implies something 'other' than the world (non-real), a mere abstracted sphere independent and thus not accountable within real(-time) existence. This is used in lieu of the idea that the 'virtual' still retains essential *virtues*, the connections to the very-real as a basis for tethering ideas in themselves, no matter what technologies we incorporate. This concept is based on idea that the 'virtuous' (of or relating to a real force of virtue, that is, relating to strength in character or morals), is essentially something very real and very connected within the life-place. Thought of otherwise, is indeed a repeated flaw within a flaw, two circular and dualistic wrongs that never become reconciled. Our engagements with our environment are not digital (as in atomistic, separable) or 'virtual' in most usages of the word; they are embodied in the very-real life-space we all mutually inhabit (*oikos*), our environment within which we co-interact to create meaning and gain essential knowledge. But in the face of changing technology and new information, the nature of these epistemic boundaries and those of inter- or trans-connectiveness must be recognized.

There is an increasing need to foster ways in which architectural thought and thus practice (thought-in-action) can more effectively and holistically deal with complex environmental concerns. The herein stated process promotes a synthesis of communicative approaches that strengthen the central role of architects in the systemically participatory and interdisciplinary, social environment, as part of technological creation, use, and advances. Integration of common knowledge (and information) bases and distinct interdisciplinary methodologies can address the discursive concerns and their correlation with application in the community, thus developing a positive and meaningful effect with its context. Digital technologies are placed at the core of this interaction to be used as tools for complex management, but also as a way to link technological modes to the same set of epistemic conditions that are also immanent with environmental and social needs. This useful relation also reciprocally places and 'tethers' technological advances and practices within the total environment.

The goal of this process was to build a strategy for learning about the complexities of urban situations based on hermeneutic approaches. Digital technologies are used as facilitating devices for managing multiple methods and divergent modes of inquiry. Since epistemic systems exist mentally and

spatially as meaningful constructions of social interactions, an interactive approach attempts to view the context from as many different points of view and to promote a multitude of affections before a form is presupposed. That way, the informative material is already in-place as an *a-priori* set of conditions with which already rich solutions and emergent knowledge can intermingle. Reciprocally, the positive transformation of the structural framework for the communicative exchange of knowledge in turn transforms the corresponding social structure and thus critical human consciousness where knowledge, as well as technological constructions occur.

Critical Environmentalism, an idea partially founded in ethics, is not primarily concerned with universal foundations of norms or laws (*nomos*) guiding specific human thought-in-action, but is fundamentally concerned with our engaged dwelling or inhabiting within the world itself and how divergent horizons can critically and interactively co-enable each other in particular, complex situations. As a model for architectural education in general, critical environmentalism is further supported the integrative use of emerging technologies as effective means and management for essential, communicative interchange of knowledge and thus rapprochement between divergent modes-of-thought, promoting critical, productive interaction with *others* in the (co)constructive processes within a total environment, our shared life-place.

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## MUSING HEIDEGGERIAN CYBERSPACE

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**Abstract.** Where we do we make our “being?” Since our existence [being-there = Dasein] is the original place of intelligibility, fundamental ontology must clarify the conditions of having any understanding which itself belongs to the entity called Dasein. Today Dasein is increasingly becoming more and more digital, in fact all activity is digital or becoming digital in one mode or another, it’s ubiquitous! On the pragmatic side corporate architecture as well as its daily interaction and transaction are all digital. With the advent of games as well as webmasters using VRML or some equivalent of it poses the questions and concerns as who will design the digital domains, graphic artists, IT personnel, game developers and where will we make our being? As architects and designers where will our “digital gesamtkunstwerk” be? Making places for human inhabitation in a nonphysical space raises interesting questions concerning presence, authenticity, adaptability, orientation, and suspension of disbelief. What kind of activities can be supported by nonphysical spaces? What will it take to support them in a socially and psychologically appropriate manner? And **WHO** will design them? On the applied side this ontological view is demonstrated in an Interior Design Corporate Office Design Studio that has been taught for a decade wherein students are required to develop an E-Commerce, a business deemed to succeed including the Corporate Office, facility program, space planning, corporate image, interiors, graphics, webpage, and logo. The semester project has one unique design stipulation: The one major design requirement is that the “feel” of the reception has the same “feel” as the website. A phenomenological sameness...all work is accomplished with a plethora of digital media. This design process is still in its infancy.

## 1. Musings

Where we do we make our “being?” Since our existence [being-there = Dasein] is the original place of intelligibility, fundamental ontology must clarify the conditions of having any understanding which itself belongs to the entity called Dasein. Today Dasein is increasingly becoming more and more digital, in fact all activity is digital or becoming digital in one mode or another, it’s ubiquitous!

On the pragmatic side corporate architecture as well as its daily interaction and transaction are all digital. A prime example is the design and construction of the new 2.7 billion Wynn Casino in Las Vegas. In February 28, 2002—Autodesk, Inc announced that it had teamed with TRIRIGA INC. to provide Wynn Design & Development with a digital design data environment that will manage the development of Steve Wynn’s multi-billion-dollar Le Rêve hotel casino and resort for Las Vegas. TRIRIGA is a leading provider of business automation software for the hospitality, aerospace, and design/build industries. This combination of Autodesk Architectural Desktop used with TRIRIGA Intelligent Business System (IBS) represents a major shift toward an intelligent design framework capable of streamlining all phases of a project’s life cycle—from concept to facility management. This is in fact the equivalent to Boeing design and construction of its 777.

The walls be they actual wood stud, metal stud with gypsum board, brick, concrete, glass or metaphorical representations as firewalls, WebPages, URLs are becoming blurred as to what is “reality” between the physical and the digital. The construction industry is becoming increasingly reliant on new electronic technology, ranging from project-specific Web sites and online equipment auctioning to bid analysis software and negotiation tools. Even though the construction industry has been slow to warm up to the technology, usage is increasing every day. Surveys indicate that 80 percent of contractors and owners use Web-based communications, 25 percent purchase or sell products over the Internet and 17 percent bid for jobs online. Fifty-eight percent of owners report they have used a project management Web site. Project Web Sites and Extranets (Berning, 2000). Project-specific Web sites and extranets may present the biggest change to how construction companies conduct day-to-day business. These systems promise reduced paper consumption, lower costs, improved communications, and quicker turnaround on requests and timely (or even early) project completion.

Numerous companies have been using computerized systems for years to manage and schedule projects. Today’s project Web sites and extranets claim to provide more opportunities for consistent document review, multi-

party collaboration and expanded communications, both on the site and in the office. As an example, companies can post drawings and documents on the system so everyone can easily access and share the latest changes and additions. With many programs (known as interactive collaboration), users can mark up documents online without changing the original drawings, allowing for resolution of design and engineering conflicts in the field without expensive and cumbersome CAD software. Other online applications such as TRIFIGA are more complex; combining the interactive collaboration features with a workflow tracker that posts and records communications and other documents between architects, engineers, contractors and subcontractors. These systems provide for lightening-quick (compared to traditional methods) responses to requests for information and change orders, streamlining the field process, thwarting disputes and speeding up the project. Furthermore, the Web site or extranet becomes a common depository for communications, creating an accurate and comprehensive virtual paper trail for the project. Because these systems create a record of all requests, orders, submittals and other communications during a project, the Web sites supposedly create a greater sense of accountability and ward off disputes. However, before project Web sites are embraced as a solution for all of the industry's problems, there are several significant legal and practical concerns to keep in mind, as well as the theoretical paradigm shifting the metaphysical concept of what is, design... space... and place.

This is nothing new, being that these metaphysical concepts have been prophesized by such futurists as Bill Mitchell, father of CAD in architecture and Ray Kurzweil. Ray Kurzweil is a prize-winning author and scientist. He was named Inventor of the Year by MIT in 1988 and was awarded the Dickson Prize, Carnegie Mellon's top science prize, in 1994. Collin McGinn The New York Times Book Review notes, "His book *The Age of Spiritual Machines* ranges widely over such juicy topics as entropy, chaos, the big bang, quantum theory, DNA computers... neural nets, genetic algorithms, nanoengineering, the Turing test, brain scanning... chess-playing programs, the Internet--the whole world of information technology past, present, and future. This is a book for computer enthusiasts, science fiction writers in search of cutting-edge themes, and anyone who wonders where human technology is going next" (Publishers Weekly, 1999). If Kurzweil has it right, in the next few decades humans will download books directly into their brains, run off with virtual secretaries and exist "as software," as we become more like computers and computers become more like us. Still others are more realizable: human-embedded computers will track the location of practically anyone, at any time. More problematic is Kurzweil's self-congratulatory tone. Still, by addressing (if not quite satisfactorily) the overpowering distinction between intelligence and consciousness, and by

addressing the difference between a giant database and an intuitive machine, he has a provocative, if not very persuasive, view of the future from a man who has studied and shaped it (Accardi, 1999). Kurzweil does more than simply prognosticate about the future; he provides a blueprint for the next stage of human evolution, in which we will begin to develop computers more intelligent than ourselves. We must ask ourselves whether these new thinking machines are indeed conscious entities.

The theses of this applied research and studio agenda integrates this blurred reality in an exercise to wholly adopt the world, as it is wherein we make our "digital" being. Today's complex business environment demands that organizations find new ways to streamline and coordinate workplace activities. In the past, workplace functions - including real estate, facility management, asset management, project management, and employee self-service have often been handled by different systems with individual functions and goals. Increasingly, organizations are recognizing that a variety of business functions related to creating, supporting and maintaining the workplace can be brought together to create efficiencies, reduce operational costs and provide management with more accurate and current information about their business and assets.

According to Bill Mitchell architect and author of a plethora of texts on the future of design comments, "The global digital network is not just a delivery system for email, Web pages, and digital television. It is a whole new urban infrastructure--one that will change the forms of our cities as dramatically as railroads, highways, electric power supply, and telephone networks did in the past. Picking up where his best-selling *City of Bits* left off, Mitchell argues that we must extend the definitions of architecture and urban design to encompass virtual places as well as physical ones, and interconnection by means of telecommunication links as well as by pedestrian circulation and mechanized transportation systems. He proposes strategies for the creation of cities that not only will be sustainable but will make economic, social, and cultural sense in an electronically interconnected and global world. The new settlement patterns of the twenty-first century will be characterized by live/work dwellings, 24-hour pedestrian-scale neighborhoods rich in social relationships, and vigorous local community life, complemented by far-flung configurations of electronic meeting places and decentralized production, marketing, and distribution systems. Neither digiphile nor digiphobe, Mitchell advocates the creation of e-topias--cities that work smarter, not harder. With *Me++* Mitchell completes an informal trilogy examining the ramifications of information technology in everyday life. The transformation of wireless technology in the hundred years since Marconi--the scaling up of networks and the scaling down of the apparatus for transmission and reception. It is, he says, as if "Brobdingnag had been

rebooted as Lilliput"; Marconi's massive mechanism of tower and kerosene engine has been replaced by a palm-size cell phone. If the operators of Marconi's invention can be seen as human appendages to an immobile machine, today's hand-held devices can be seen as extensions of the human body. This transformation has changed our relationship with our surroundings and with each other. Hence, Mitchell proposes, the "trial separation" of bits (the elementary unit of information) and atoms (the elementary unit of matter) is over. With increasing frequency, events in physical space reflect events in cyberspace, and vice versa; digital information can, for example, direct the movement of an aircraft or a robot arm.. He argues that a world governed less and less by boundaries and more and more by connections requires us to reimagine and reconstruct our environment and to reconsider the ethical foundations of design, engineering, and planning practice.

An unusual stage of players usually not identified are players from such domains as AI, merchandising, digital advertising and game developers. J.C. Herz (1997) is the author of *Joystick Nation*, which talks specifically about the development of video games from historical, social and psychological point of views. The author, Herz, discusses the pre and early development of video games, which is dated before the development of Pong and Atari 2600, two consoles that marked the very beginning of video games' frenzy. She argues that there is more than video games as a game. It is important, according to what she implies in her book, to realize that video game, in its twenty years of its development, consists of such a complexity that sometimes we cannot comprehend. She discusses the importance of character design in the development of console's game. Character could be an element that attracts people to play, but could also be the negative factor of a video game, according to the book. This could be considered as a factor in which the development of video games impacting the psychology of people. They could, as Herz implies, like the character, especially children, and be influenced by the character. In other words, the players would likely to identify themselves with the characters that they play when they are playing a video game. Secondly, the settings in which the video game running could affect people psychologically. The third one is the fact that video game could be used as a means to deliver a method of education. It is quite evident that video games are used for simulation education at military schools. There are a lot of opinions (including the governor of Illinois) saying that video games are only a means of violence delivery that destroys children's moral, this one fact that video games could be used for education is a complete opposite and add to the other research about the impact of video games in a positive way. With the advent of games as well as webmasters using VRML or some equivalent of it posses the questions and concerns as who will design the digital domains, graphic artists, IT

personnel, game developers and where will we make our being?...as architects and designers where will our "digital gesamtkunstwerk" be?

Yehuda E. Kalay is a professor of architecture and director of the Center for New Media at the University of California, Berkeley comments, "Historically, the inability of computers to comprehend any design activities that take place outside the computational environment itself, hence the need to design "in" the computer, had the unintended but critical effect of transforming the computer from a design "tool," in the traditional sense of the word, into a design environment: a "place" where design occurs. Instead of following the designer, like a pencil does, allowing him or her to design wherever and whenever desired, computers force designers to come to them. By becoming the environment where design occurs, the computer has changed the culture of the design profession. In the early days, when computers were too expensive to sit idle, designers had to work in shifts — a most unnatural imposition on the intuitive and serendipitous process of design.

In its 21st-century incarnation, the vision of inhabitable environments infused with many computational devices has taken the form of computer-controlled temperature, humidity, lighting, security systems, elevators, doors, even electronic building "skins," creating seamlessly networked and ever-changing electronic landscapes. The diffusion of computers into our everyday environment has the effect of making the environment more "intelligent" — at least more cognizant of our presence and activities — and enabling "it" to take action on our behalf.

The third and potentially most radical effect of computers is the advent of cyberspace — a term coined by William Gibson in *Neuromancer* to denote the information space created by the Internet — and its steady assertion of itself as a "place." William Gibson is the New York Times bestselling author of *Virtual Light*, *Count Zero*, *Burning Chrome*, *Mona Lisa*, *Overdrive*, *Idoru*, and *All Tomorrow's Parties*. Here is the novel that started it all, launching the cyberpunk generation, and the first novel to win the holy trinity of science fiction: the Hugo Award, the Nebula Award and the Philip K. Dick Award. With *Neuromancer*, William Gibson introduced the world to cyberspace--and science fiction has never been the same.

Although it can only be experienced through the mediation of computers and can only be inhabited by proxy, cyberspace is fast becoming an extension of our physical and temporal existence, offering a common stage for everyday economic, cultural, educational, and other activities.

Making places for human habitation in a nonphysical space raises interesting questions concerning presence, authenticity, adaptability, orientation, and suspension of disbelief. What kind of activities can be supported by nonphysical spaces? What will it take to support them in a

socially and psychologically appropriate manner? And **WHO** will design them?

The opening of a new kind of space made possible by computers and networks promises to revolutionize our perception of reality like no other invention before it and challenges the professions of architecture, town planning, and interior design, which have been striving to accommodate human activities in the physical domain for thousands of years.

On the applied side this ontological view is demonstrated in an Interior Design Corporate Office Design Studio that has been taught for a decade wherein students are required to develop an E-Commerce, a business deemed to succeed including the Corporate Office, facility program, space planning, corporate image, interiors, graphics, webpage, and logo. The semester project has one unique design stipulation: The one major design requirement is that the “feel” of the reception has the same “feel” as the website. A phenomenological sameness...all work is accomplished with a plethora of digital media. This design process is still in its infancy.

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## **Section IV: Conceptual Design and Digital Design Process**

## **A COMPARATIVE STUDY OF DIGITAL AND TRADITIONAL TOOLS FOR PARTICIPATIVE DESIGN**

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**Abstract.** Computer tools have been used by experts for a wide range of activities including design and planning, historical conservation, urban management, education, and marketing and promotion. However, the difficulty of using these tools has meant that they have only been used by experts and their benefits have not been available to the public when engaged in participative design exercises. This paper reviews the extent of computer tool usage within urban design and goes on to propose a new way of utilizing digital tools in order to involve non-experts. The work that is presented here takes the form of an experiment which compares the traditional participative design approach with one that employs a three-dimensional digital approach. The setting for the experiment is based on the design of student housing on the University of Bath campus in the United Kingdom. Findings from the experiment demonstrate that the digital toolkit that is proposed has considerable potential to aid the process of participatory design.

### **1. Introduction**

Although there are many ways of using computers for design, there are very few examples where three-dimensional computer models have been used for direct interaction with the public during participative design. This paper proposes just such an approach and impetus for the research came from the fact that public participation is an obligatory part of the planning and development control process in the United Kingdom (ODPM 2004; Owens 2005). The UK government is also promoting electronic governance. And digitally-based public engagement as part of the design process therefore embraces that spirit.

## 2. Computer Tool Usage Within The Built Environment

Within the realm of urban design, the techniques and technologies associated with the representation of urban spaces have undergone many changes (Ratti and Baker 2003; Mitchell 2002). Technological advancement has enabled the creation of several computerized urban models, including the Glasgow model (Ennis et al 1992), the Edinburgh Old Town model (Grant 2005), the Bath model (Day 2005), the Los Angeles model (Liggett and Jepson 1995), the Cairo model (AlSayyad et al 1996) and the Sheffield SUCoD model (Peng et al 2002; Peng and Jones 2004). The Bath model, for example, has shown that a digital urban model need not only function as a form of three-dimensional database but can also be of direct use in the planning, building and conservation of the city. The model has been used as part of the development control process in the City of Bath, which has a strict planning policy because of its World Heritage status. Digital urban models have also raised the possibility of the user-client being brought directly into the process of design along with the architects and planners. This paves the way to facilitating active client and public participation in the future planning of the city.

### 2.1. UTILISING COMPUTER TECHNOLOGY FOR PUBLIC PARTICIPATION

Within urban design circles, the exploration of computer technology for public participation has been rather limited, and even the professionals still tend to be stuck at the clerical phase of IT utilisation (Littlefield 2004). One of the most successful approaches to participative design and planning is *Planning for Real* (Pearce 2000; Wilcox 1994), a method for actively engaging the public in design (Kernohan et al 1996; Sanoff 2000). The way it operates is that members of the public work with a facilitator on a project by making use of drawings, sketches, maps, simple physical models and even post-it notes. The models tend to very basic so that they can be constructed quickly and this has the advantage that participants are not inhibited when it comes to making changes. However, there is a huge divide between this and the sophistication of photo-realistic images and animations employed by designers and developers when communicating directly with their corporate clients. It is generally accepted that laymen have difficulty in comprehending architectural drawings such as plans, sections and elevations (Robbins, 1994) and the use of interactive 3D computer models provides a way of allowing non-experts to understand the form of a proposed building without having to use the relatively abstract two-dimensional representations.

## 2.2. EXAMPLES OF DIGITAL-BASED PUBLIC INCLUSION

There are a number of examples of digital tools being used as part of the participatory design process. These range from examples which engage with very small groups of participants to those which involve the population of an entire city.

### *2.2.1. Small Scale Public-User Inclusion Utilising Desktop Technology*

Hall (1996) and Pietsch (2001) have discussed the issue of designing directly on the computer during design negotiation. The immediate relationship among participants in these cases was limited to the designer, the client and the planning officer as they tried to resolve planning issues relating to visual appearance, building overlooking and shadow casting. The participants sat around a computer screen and went through the process of making design changes together. In these examples the design had already been prepared by the architect using a CAD system and the participative design exercise involved altering that model in order to explore alternatives. The need to get planning permission required the client to sit with the designer and a representative of the local authority at the end, rather than the beginning, of the design process. In an ideal situation participative design would occur from the very start of the design and would be employed on larger projects which are more likely to have a significant impact on the urban environment.

### *2.2.2. Small to Medium Scale Public-user Inclusion Utilising a Hybrid of Desktop/Laptop Technology with Non-Immersive Virtual Reality*

An investigation involving the public has been carried out using the non-immersive setting in a VR suite at Teesside University (Reeves and Littlejohn 1999). It involved a dozen or so laymen in the design of a community centre. Although the participatory session was deemed successful, the public's comment about not feeling comfortable in such a formal set-up is a point which should be considered when planning a participative design exercise. Accessibility is not just about the number of people taking part, or whether the venue is easy to get to, but also whether the event can be replicated elsewhere without too much difficulty. In practice most public participation sessions take place in school halls and community centres rather than in specialised VR facilities.

### *2.2.3. Large Scale Public-User Inclusion Utilising Web-based Technology*

There have also been studies into using the computer to involve a wider range of the public. Notable among these is a project carried out on the West Cambridge development to build a new Computer Laboratory (Richens & Trinders 1999). Computer tools were used as a means of being accountable to the main client, Microsoft, who commissioned the project in

a joint venture with the University of Cambridge. In this case, Microsoft specifically required that all aspects of communication between their representatives, the consultants and other related parties should be carried out via e-mails and the Internet. Furthermore, the design and visualization of the new building was to be carried out through computer modelling. The whole process of development, from the sketch-design stage to construction, was documented, presented and shared with the users through an official web-page. Communication channels were expanded through an Internet design-forum and web-based questionnaires. Traditional tools were also utilised where plan drawings were displayed on notice-boards for people to draw or write their comments. Feedback was routed directly to the designers and constant design revisions were displayed. The design evolution of the new computer laboratory was progressively visualised using gaming software, Quake II where visitors could walk around the spatial simulation using avatars, which could be customised if desired.

The key to this large public inclusion is the use of the Internet, which was appropriate to the well-networked university community. In the normal world, however, this level of Internet access is seldom available, which hampers the noble intention of digitally involving all the public in participative design. This is illustrated in another project utilizing on-line planning in North London (Hudson-Smith 2003). A web-site was supposed to run in parallel with the start of the public consultation for the regeneration of the Woodberry Down area in Hackney. However, free Internet access and computers had first to be provided to a selected group of residents. This involved the installation of telephone lines so that Internet access could be provided and there was often insufficient room within the dwelling to provide a dedicated space for the equipment. If web-based public involvement is to reach disadvantaged groups, hardware and Internet access often has to be provided along with the necessary training and support.

### 2.3. THE DIGITAL TOOLKIT AND PARTICIPATIVE DESIGN

Whilst the approaches discussed above have served their purposes, there have been limitations in their implementation. In order to be effective, any participatory session has to first of all be accessible. The logistical requirements for immersive virtual reality and for web-based methods are very costly to set up and to maintain. The approach outlined in this paper is framed within the lower end of computer technology. It attempts to build on the success of the approach used by *Planning for Real* with the intention of complementing, and hopefully enhancing, current well established practice. If digital participative design is to be more widely accepted, the approach has to be simple and cost effective enough to be put into practice. Simple CAD software, a standard laptop computer and an inexpensive data projector

can be afforded by even the smallest design practice and this equipment should be all that is needed in order to run the digital toolkit. Table 1 summarises the proposed approach and locates the digital toolkit in relation to other participatory methods.

TABLE 1. Spectrum of Traditional and Computer-Based Participative Design.

Approach	Traditional	Digital	Digital	Digital
	Planning for Real-type events	Proposed Digital Toolkit	Immersive Virtual Reality	Web-based or On-line Planning
<b>Roles of Players</b>	Equal roles for experts and lay public.	Equal roles for experts and lay public.	Extensive roles for experts. More limited participation to lay public due to logistics.	More roles for the experts. Limited roles for lay public as end consumers giving feedback and viewpoints.
<b>Mode of Social Interaction between expert and non expert during design</b>	Direct visual and verbal communication. Face to face.	Direct visual and verbal communication. Face to face.	Visual communication via specialised medium such as 3D glasses, head-mounted displays.	Detached and indirect textual communication.
<b>Participatory design level</b>	Deciding together	Deciding together	Possible to decide together	Informative and reactive consultation
<b>Design Involvement Level</b>	Total design involvement. Manual hands-on.	Total design involvement. Digital hands-on.	Partial involvement, more design consultation.	Partial involvement, more design consultation.
<b>Time-lapse implication</b>	On the spot resolution and real-time decision.	On the spot resolution and real-time decision.	Some real-time decision	Long time lapse or sporadic time-interval of feedback.
<b>Technique</b>	Traditional	Desktop Digital	Immersive VR	Digital Web-based
<b>Tools and Equipment</b>	Cardboard and post-it notes.	Simple 3D digital model and spreadsheet.	Immersive VR such as CAVE system with sophisticated animated 3D environment.	Sophisticated web-page and interface
<b>Technical Sophistication upon users</b>	Low.	Medium.	High.	Medium.
<b>Skill level required</b>	Basic model making skills.	Some computer skills useful although a facilitator is available.	Limited to navigating in a VR environment.	Basic computer skills – web navigation and e-mail.
<b>Documentation</b>	Need to store models or to rely on photography.	Digitally-based and easy file transfer.	Digitally-based and easy file transfer.	Feedback/data to be compiled and interpreted.
<b>Usage Cycle</b>	One time cycle, models being disposed of after event.	One time cycle with re-use, layering of models possible – can be repeated easily.	One time cycle with re-use of models possible – can be repeated easily.	Continuous or until stipulated period ends.
<b>Visualisation performance</b>	Good but inaccurate dimensions.	Good with accurate dimensions.	Very good if high quality model is built.	Good with realistic end-product views possible
<b>Ease of understanding what is proposed</b>	Good but lacking in detail.	Very good with accurate dimensions and ability to change model.	Very good although model cannot be amended in real-time.	Good but limited to views of the model with no direct interaction.
<b>Logistics</b>	Large work space	Highly portable – a	Fixed location and	Costly to set up

	needed and can be messy.	laptop and LCD projector.	very costly to set up and to keep running.	and to keep running.
<b>Criticism</b>	Limited by model sizes and scales and amount of details to be incorporated.	Cost of proprietary software licensing.	Limited by logistics and costs	Limited public access to Internet.

### 3. The Experiment: Traditional Versus the Digital Toolkit

The setting for the experiment is based on the design of student housing on the University of Bath campus. The basic parts of the scheme for both the physical and digital settings comprised eight choices of student rooms with a variety of showers/washbasins etc, three sizes of kitchens, four types of staircases and a lift. Other facilities such as a TV-lounge/common room and study room/computer room were built or improvised during the experimental process. Supporting services such as housekeeper's office, laundry area, and re-cycling and refuse collection, mechanical and electrical facilities were not included in the brief although the approximate cost for them was incorporated in the cost calculation. The reason for this was to reduce the design complexity in order to suit the time limitation of the experimental session. Each participant decided on the choice of room types and facilities that he/she preferred for the student housing scheme. The experiment was done within one hour as a one-to-one session and comprised four parts: the project briefing, the interactive design stage, the cost calculation and questionnaire administration.

#### 3.1. THE TRADITIONAL AND DIGITAL SETTINGS

The experiment compared two settings. In the traditional setting full use was made of freehand drawing and pre-built physical models whereas in the digital setting a three dimensional digital toolkit was employed using SketchUp, an inexpensive and easy to use CAD package. This digital toolkit can be thought of as electronic version of LEGO that can be interactively manipulated. This may involve simple copying, moving, stacking, rotating, flipping or mirror-imaging or grouping, as well as enlarging and reducing the various forms created. More detailed versions of the different spaces showing furniture layouts were also prepared to allow participants to fully visualize the different types of study bedrooms that were available. A digital model of the University of Bath campus was used as the context for the project (Figure 1).



Figure 1. A participant's exploration using the digital toolkit

In the physical setting the individual student rooms, kitchens, staircases, etc were pre-built at 1:50 as hollow models (Figure 2). This size enabled the participants to see the interior of each study bedroom, including the furniture and equipment. The 1:50 scale makes the smallest building part, the single shower cubicle, big enough to hold and these 1:50 models were used to allow the participants to create the layout of the study bedroom clusters. However, because of space a resource restrictions a smaller site model at 1:200 was utilised for the site planning part of the exercise.

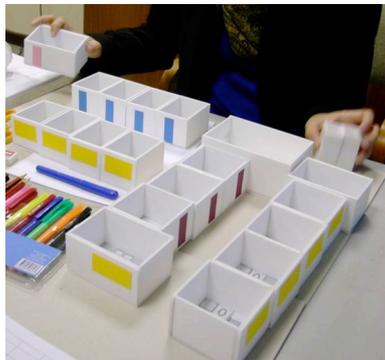


Figure 2. Pre-built hollow models at 1:50

Another aspect of the experiment was the provision of a spreadsheet to calculate the cost of each scheme. Both groups had access to this spreadsheet which provided a way of converting the capital cost of their proposal into a weekly rental for each of the room types. At the beginning of the interactive design stage, each participant was asked how much rent per week he/she would be willing to pay for each of the room types they had selected. This provided a comparison between what the user was willing to pay and what it would actually cost the University to cover building and maintenance costs. A participant who was not willing to pay more than

his/her budget usually resorted to making changes to their earlier space decisions. The experiment not only offered an opportunity for the users to voice their opinions on their preferred design for student housing, but also became a way of helping them to understand the cost implications behind every decision they made.

The setting for the experiment was a large office which had a table in the middle with the participant and facilitator seated opposite each other. A projection screen was placed about 1.8 meters from the end of table with the LCD projector placed at the other end. The table held the site model and pre-built block models during the physical setting. A laptop to show slides for the project briefing and the spreadsheet was placed on a smaller table near the facilitator. Other extra units of pre-built models were placed on top of file cabinets behind the participant. During the digital session all the physical models were hidden away and the laptop was placed on the table but slightly skewed towards the facilitator. The projection screen was the main viewing panel by both the participant and the facilitator.

### 3.2. SAMPLING TECHNIQUE

The experiment was carried out with eighty participants. Forty participants used traditional participative design tools to form the Control Group while another forty participants used the digital toolkit in the Digital Group. Each group consisted of nineteen males and twenty one females. None of the participants had any architectural or design background. The total number of participant was determined based on previous studies of a similar nature as well as using the 'Sample Size Calculator' by *Creative Research System* (<http://www.surveysystem.com>). Using the worst case percentage of 50% with confidence level of 95% based on the total UK population of 60 million, a sample size of 80 persons gave a confidence interval of 10.96 which is deemed acceptable for this kind of research.

The participants were enlisted through open advertising of the experiment in the University of Bath electronic and paper-based notice boards. It was open to postgraduate and undergraduate students from throughout the university. The project was described as an architectural experiment for a PhD without indicating what was involved in order to avoid the participants coming into the experimental sessions with pre-conceived ideas about student housing or of the tools being tested. The participants took part based upon a first come first served basis until the quota of 80 persons was reached. The researcher usually asked for an indication of gender and program of study to achieve a balanced ratio in the allocation of the control and digital groups.

### 3.3. QUESTIONNAIRE DESIGN

The questionnaire was divided into three sections. The first section was the Introduction which outlined the three purposes of the experiment. The first was to gain the participants' feedback on the student housing experimental session. The second purpose was to seek the students' input on the type of student housing they would welcome. The third indicated that the experiment would look at the implications of having the students participate in the design process. These purposes were directly related to the design exercise undertaken and simultaneously camouflaged the primary examination of the tools being used for designing. This was in order to secure the participants' responses via an indirect and non-pressured or neutral approach. The final section of the questionnaire elicited demographic data from each participant which included information about age; gender; nationality; program of study; types of accommodation; and their willingness to be contacted for another version of the experiment.

The main body of the questionnaire elicited responses from each participant about his/her experiences while using the traditional or digital tools. This segment contained 24 items that were a mixture of closed and open-ended questions. The closed questions required rating a semantic differential scale of 1 to 10 with responses such as; Very Unsatisfactory/Very Satisfactory; Very Poor/Very Good; Not Very Well/Very Well; Very Little/Very High; Very Little/Very Highly; Very Difficult/Very Easy; Not At All Useful/Very Useful. Another type of closed question required a 'Yes', 'Uncertain' or 'No' answer. The questions were devised to secure feedback in three main areas namely the suitability of tools and equipment for design; design satisfaction and enjoyment; and ideas exchange and design communication.

The questions to evaluate the suitability of tools and equipment for design were as the following:

- "How well did you feel the equipment and tools for designing helped to materialise your ideas during this project?"
- "Please rate the ease of handling tools/equipment/materials for designing."
- "Would you have wanted other equipment during this exercise? If Yes, what? Why?"
- "Please rate the ease or difficulty of creating a number of alternative designs."
- "How did you find the duration of the session?"
- "Please rate the ease or difficulty of manipulating each design."

The questions to gauge design satisfaction and enjoyment were as the following:

- "How would you rate the final design that was produced?"

- "How would you rate your design input for the final creation?"
- "How would you rate your knowledge of student housing before doing this exercise?"
- "How would you rate your knowledge of student housing after doing this exercise?"
- "Please rate the introduction (Project briefing)."
- "Please rate the usefulness of the costing element."
- "How much did the costing element influence the final design?"
- "How well did you enjoy participating in this exercise?"
- "Do you think that the University should undertake this kind of exercise for future student housing development?"
- "Do you feel that this kind of exercise may also work with other types of buildings?"
- "Which aspect(s) of the session did you like most?"
- "Which aspect(s) of the session did you like least?"
- "Overall, how would you describe your experience of the session?"
- "Do you have any additional comments?"

The questions to appraise ideas exchange and design communication were as the following:

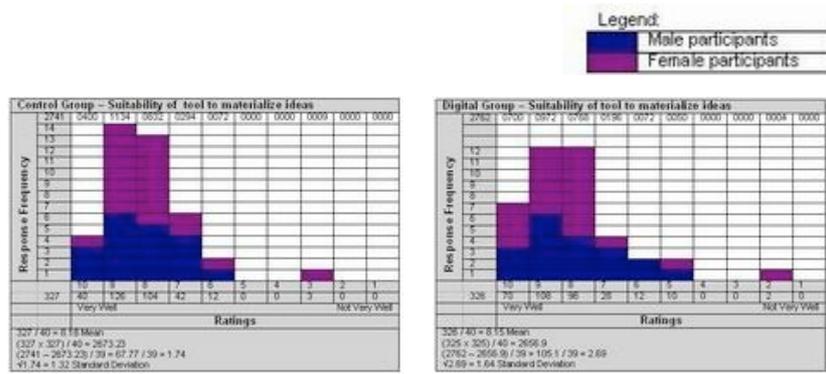
- "How would you rate the room setting during this session?"
- "How much interaction was visible during the session?"
- "How well did you think the researcher-facilitator understood your ideas?"
- "How well did you feel you were able to express your own ideas verbally during this project?"
- "How well did you feel you were able to express your own ideas physically or graphically during this project?"
- "How much design cooperation was visible during the session?"
- "How much did you have to rely on the researcher-facilitator throughout this session? Please comment."
- "Please rate the ease or difficulty of visualising the design form."

#### **4. Preliminary Findings**

The first part of the findings looks at the experience of the participants in using the two participatory tools. This is descriptively analysed from their feedback in the questionnaire as well as through recorded observation during the experimental sessions. No statistical analysis has been carried out at this stage beyond the calculation of group means with standard deviations (sd) and percentage indicators.

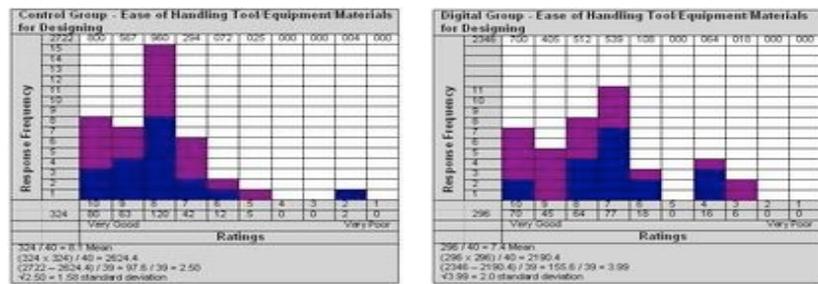
4.1. THE SUITABILITY OF TOOLS AND EQUIPMENT FOR DESIGN

Both groups shared virtually the same mean for their assessment of the tools' suitability to realize their ideas at 8.18 (sd1.32) for the Control Group and 8.15 (sd1.64) for the Digital Group. This implies that either tool suited the design task rather well (Figure 3).



Control Figure 3. Tools suitability to materialise ideas Digital

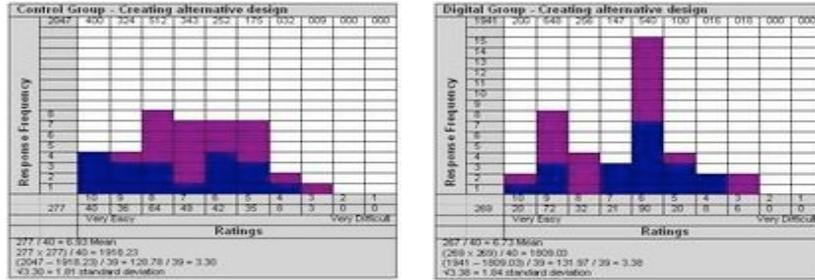
However the Control Group felt that it was easier to use the traditional tool (mean 8.1, sd1.58) compared to the Digital Group (mean 7.4, sd2.0) (Figure 4).



Control Figure 4. Tools handling Digital

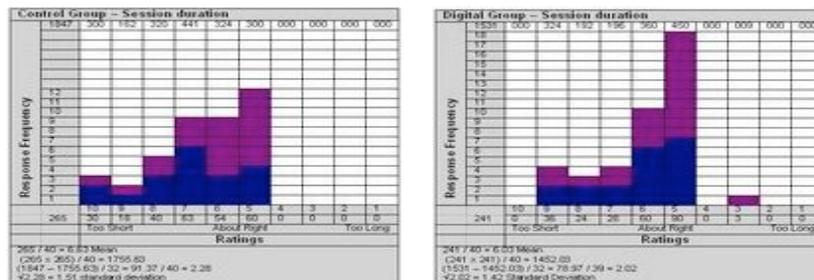
On both occasions several participants wanted other equipment during the exercise (17.5% among the Control Group and 15% among the Digital Group). The requests from the Control Group included some form of computer software as well as different shapes and types of building blocks. This indicates a need for a sense of design accuracy and variability or modifiability in the models they used. The requests from the Digital Group included physical models or LEGO blocks which they felt would be quicker to build. The other requests were for touch-screen or e-board interfaces and a faster computer.

When evaluating the ease of creating a number of alternative designs, the Control Group had a mean of 6.93 (sd1.81) whilst the Digital Group fared slightly lower with a mean of 6.73 (sd1.84) (Figure 5).



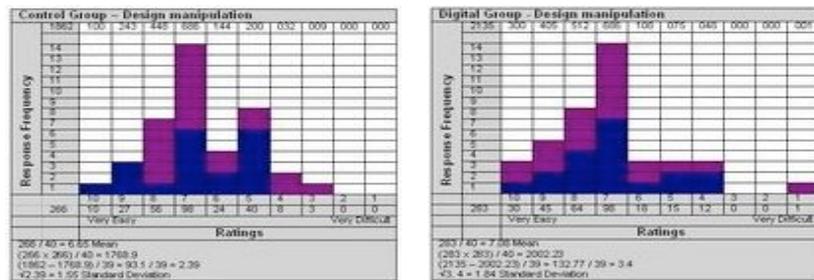
Control Figure 5. Creating alternative designs Digital

Surprisingly, the Digital Group (mean 6.03, sd1.42) evaluated that the session’s duration for design was about right. The Control Group meanwhile (mean 6.63, sd1.51) implied that longer design time was required (Figure 6).



Control Figure 6. Session duration Digital

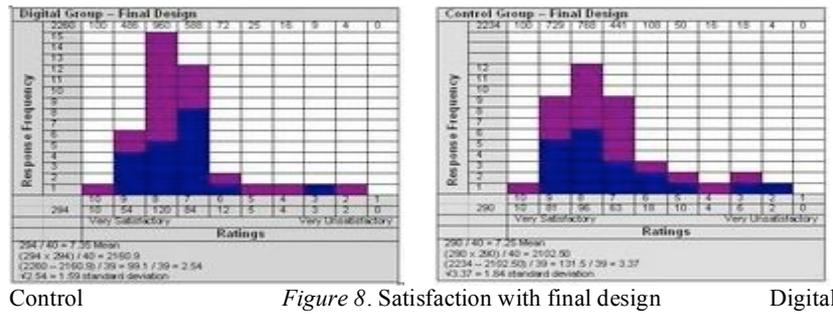
These results are congruent with their assessment of the ease or difficulty of manipulating each design. The Digital Group was more positive with a mean of 7.08 (sd1.84) compared to the Control Group (mean 6.65; sd1.55) (Figure 7).



Control Figure 7. Design manipulation Digital

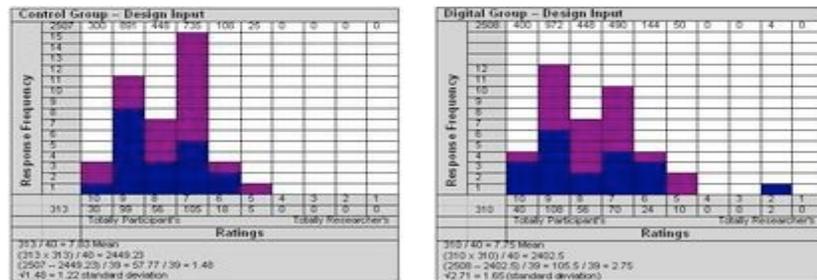
4.2. DESIGN SATISFACTION AND ENJOYMENT

The mean for satisfaction with the final design from the Control Group (CG) is 7.25 (sd1.84). It is slightly higher in the Digital Group (DG) at 7.35 (sd1.59) and both fell within the satisfactory range.



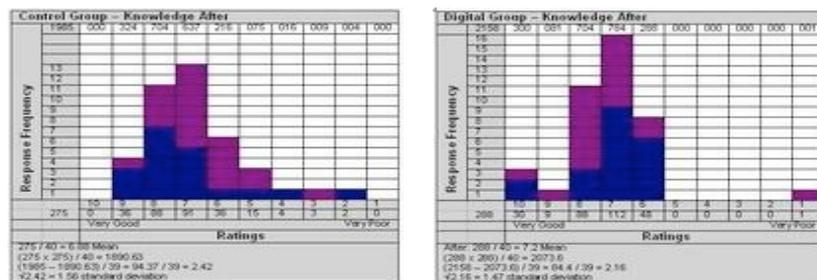
Control Figure 8. Satisfaction with final design Digital

However the Control Group felt that they contributed slightly more design input compared to the Digital Group with a comparative mean of 7.83 (sd1.22) to 7.75(1.65) (Figure 9).



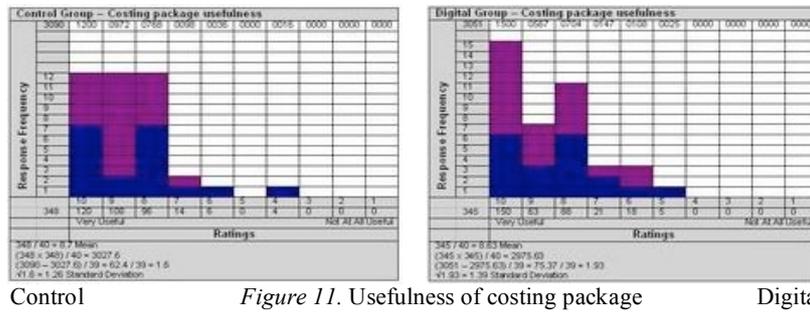
Control Figure 9. Design input Digital

The Digital Group on the other hand recorded a higher mean for their knowledge about student housing after doing the exercise at 7.2 (sd1.47) compared to 6.88 (sd1.56) for the Control Group (Figure 10) even though both groups started with fairly the same mean of 5.38 and 5.35 (sd1.94 for CG; sd1.54 for DG) or moderate knowledge of student housing before doing the experiment.

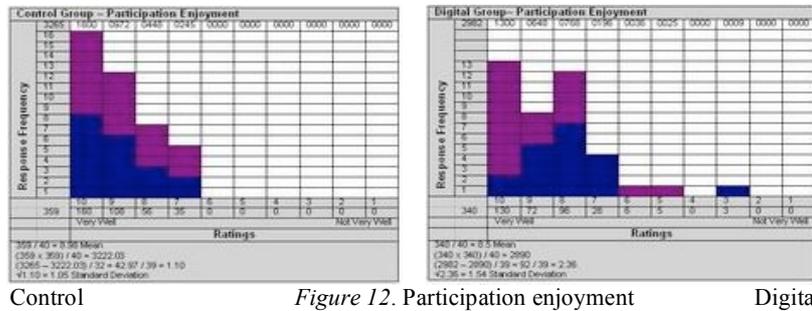


Control Figure 10. Knowledge after Digital

There was a slight discrepancy in the groups' evaluation of the project briefing. The Control Group gave a much higher rating at mean 8.73 (sd1.01) whilst the Digital Group gave a rating of mean 8.15 (sd2.39). The introduction shared exactly the same contents (two slides of the same illustrations/photos of the project site and surrounding) and the facilitator spoke from a prepared script. Both groups also used the same costing package and here again the Control Group gave it a slightly higher rating at a mean of 8.7 (sd1.26) whereas the Digital Group gave a rating of mean 8.63 (sd1.39) (Figure 11).



In terms of their enjoyment of participating in the exercise, both groups gave a high rating. The Control Group gave a mean of 8.98 (sd1.05) while the Digital Group recorded a mean of 8.5 (sd1.54) (Figure 12).



These results were echoed in both groups' agreement that the University should undertake similar participatory processes in future student housing developments. 95% of the Control Group agreed completely with this proposition while 90% of the Digital Group shared their view.

When asked about the most liked aspect of each setting, 12.5% of the Control Group refrained from giving any comments. This can be construed as an indicator about their reservations towards this approach. The rest (87.5%) gave positive comments about liking all aspects of the process.

With the Digital Group, only 2.5% refrained from giving any comment, which is a substantial contrast and implies the public’s openness towards the digitally-based approach. 97.5% of the Digital Group gave positive comments about enjoying seeing their design materialise on the screen. Other positive comments included their freedom to choose and express opinions, being consulted or included in the design process, and also seeing the cost implications.

On the least liked aspect of the sessions, 50% of the Control Group gave negative comments. These included disliking cutting fiddly bits of paper, difficulty with integrating various spatial functions, trying to adapt to practical requirements such as all rooms needing windows, having to draw and time pressure. With the Digital Group 58% gave negative comments which included difficulty in using the computer, practical planning consideration such as fire escape or design functionality, landscaping and time pressure.

Overall, the participants’ response towards either setting was positive. In both groups the adjectives and phrases which were most common when describing their experiences of the session included: enjoyable/very enjoyable; educational/informing; insightful/new insight; eye-opening; expanded learning; excellent understanding of design difficulties; interesting/very interesting; fun/great fun; very interactive; excellent/good/very good/great; useful; entertaining; thought-provoking. There were also suggestions that all students should do the exercise and that the exercise should be implemented for the design of lecture rooms and staff offices. Several participants also commented that they should do the costing aspect first before embarking on the design.

### 4.3. IDEAS EXCHANGE AND DESIGN COMMUNICATION

The experiment also gauged the potential for ideas exchange through communication and interaction between participant and facilitator within each setting. Both groups were satisfied with the room setting for the experiment (CG mean 8.35, sd1.2), and for the Digital Group (mean 8.33, sd1.37). Both groups express fairly similar ratings for the level of interaction visible during the session at a mean of 8.43 (sd1.15 CG; sd1.17 DG) (Figure 13).

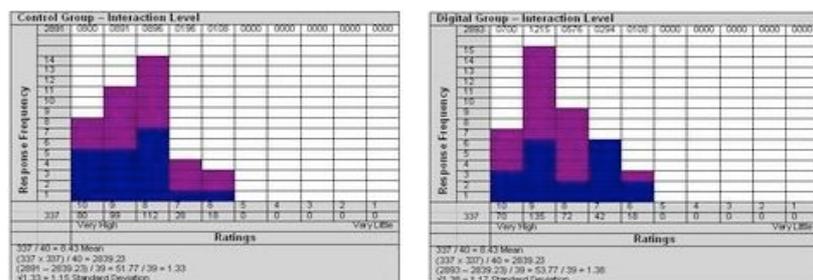
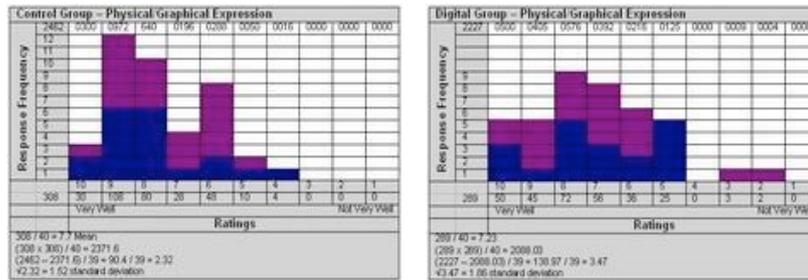


Figure 13. Interaction level

Control

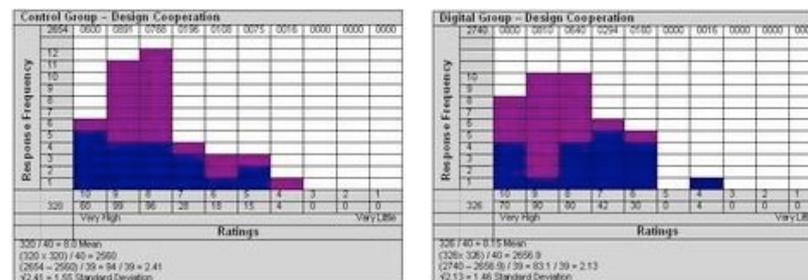
Digital

However the Control Group consistently gave higher ratings for other aspects of communication. The mean for their evaluation of the facilitator’s understanding the participants’ ideas was 8.75 compared to 8.38 (sd0.93 CG; sd1.3 DG). The mean for ideas expression whether physically or graphically was 7.7 compared to 7.23 (sd1.52 CG; sd1.88 DG) (Figure 14).



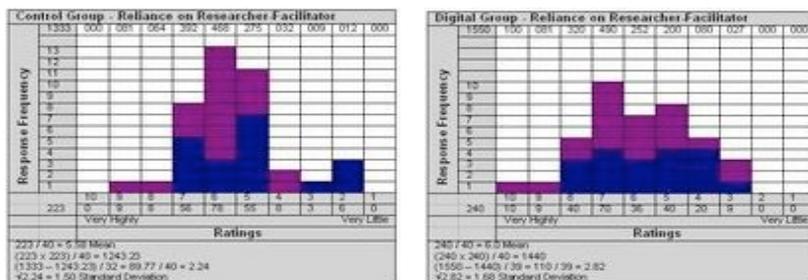
Control Figure 14. Physical/graphical ideas expression Digital

One inconsistent evaluation was for the expression of verbal ideas. It was assumed that both groups would share similar means given that verbal expression is a natural and thus neutral condition. However the Control Group gave a more positive rating at 8.28 (sd1.28) compared to the Digital Group at 7.9 (sd1.96). Despite this, the Digital Group recorded a more satisfactory level for design cooperation with a mean of 8.15 (sd1.46) compared to the Control Group mean of 8.0 (sd1.55) (Figure 15).



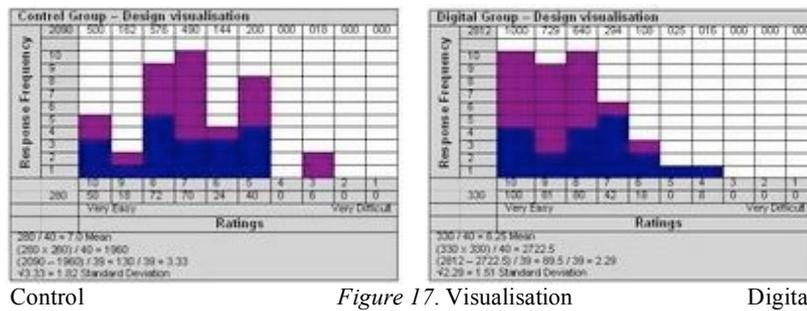
Control Figure 15. Design cooperation Digital

This was also true for the amount of reliance each group had on the facilitator. The means were 6.0 for the Digital Group compared to 5.58 for the Control Group (sd1.68 DG; sd1.5 CG) which are rather moderate (Figure 16).



Control Figure 16. Reliance on researcher-facilitator Digital

Perhaps the most significant difference between the physical and digital settings related to the issue of design visualisation. The purpose of the participatory process is, after all, about communicating and negotiating with the public about design issues. On their evaluation of the ease or difficulty of visualising the design form, the Control Group had a mean of 7.0 (sd1.82), while the Digital Group gave a much better rating with a mean of 8.25 (sd1.51) (Figure 17).



This is a significant contrast. As one participant in the Digital Group put it, the most liked aspect of the digital setting was, “Seeing the design build up from scratch into a recognisable building” (Figure 18).

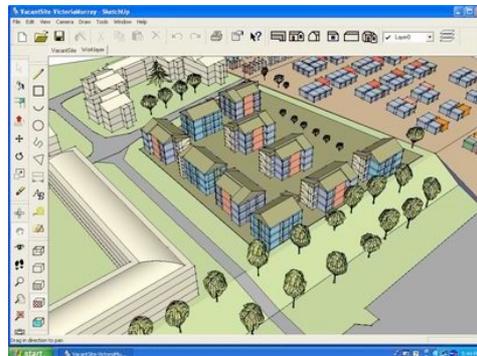


Figure 18. From digital toolkit to recognisable building

The results indicate that both groups were very satisfied with the technology that they were using to engage in participative design. The most important result (Table 2) was that the Digital Group found it easier to visualise the design as it emerged and this represents a significant improvement over existing practice. This improvement also implies that it will be easier for the designer to interpret the proposal into a fully developed scheme.

TABLE 2. Summary of results.

Experimental Aspects	Control Group (Mean)	Digital Group (Mean)
Suitability of tools	8.18	8.15
Ease of use of tools	8.1	7.4
Ease of creating alternative designs	6.93	6.73
Time available for design	6.63	6.03
Ease of manipulating the design	6.65	7.06
Satisfaction with the final design	7.25	7.35
Own contribution to the design	7.83	7.75
Knowledge on student housing before exercise	5.38	5.35
Knowledge gained on student housing	6.88	7.2
Evaluation of project briefing	8.73	8.15
Evaluation of the costing package	8.7	8.63
Enjoyment with participation	8.98	8.5
Satisfaction with the room setting	8.35	8.33
Level of interaction	8.43	8.43
Facilitator's understanding of participant's ideas	8.75	8.38
Visual and physical expression of ideas	7.7	7.23
Verbal expression of ideas	8.28	7.9
Level of design cooperation	8.0	8.15
Level of reliance on facilitator	5.58	6.0
Ease of visualising design form	7.0	8.25

There is one final stage to the experiment to be undertaken. This will involve independent professionals comparing the design proposals created during the two sessions. In this appraisal, each final design will be evaluated in terms of its spatial planning, its cost and its appropriateness to its context in order to provide a way of establishing whether the Digital Group or the Control Group produced the best schemes from the functional and aesthetic points of view.

## 5. Conclusion

The results that have emerged to date show that each of the two approaches has its advantages and also limitations. The strengths of the traditional approach lie in these following areas:

- Suitability to realize ideas and ease of using the tools (despite complains about disliking paper cutting and the inaccuracy issue).
- Ease of generating alternative designs.
- High level of participatory enjoyment.
- Better verbal and physical expression of ideas.
- Less reliance on the facilitator-designer during the session.

The strengths of the digital toolkit approach meanwhile lie in the following areas:

- Good visualization in three dimensions with immediate realization of the design decisions at every move.
- Ease of manipulating the design form.
- Shorter duration for design production.
- Improved knowledge attainment.
- High level of design cooperation.
- Better satisfaction with the design product.

Both groups of participants agreed on the usefulness of the costing element in helping them understand the implications of their design decision. Whilst the conventional approach of participative design is clearly successful, there are nonetheless several limitations to its usability, namely the problem of scale and amount of design details that can be incorporated in a typical study model. The digital method enhances this process by utilizing the properties that digital-based tool can offer, especially rapid copying and true to scale depiction at any level of detail. This research draws upon the capacity of computer hardware and software that is readily available and uses it to involve the public in design. The interim results of the experiment have illustrated that digital tools can perform at least as well as their traditional counterparts when used for participative design. The CAD package that was used in the experiment, SketchUp, has an in-built programming language that allows it to be customized to suit particular applications. This means that it could be developed to suit the particular requirements of participative design thus overcoming some of the difficulties that have been identified in this experiment.

### **Acknowledgements**

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## AN APPROACH TO 3D CONCEPTUAL MODELING

*Using Spatial Input Device*

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**Abstract.** This article presents a 3D user interface required by the development of conceptual modeling. This 3D user interface provides a new structure for solving the problems of difficult interface operations and complicated commands due to the application of CAD 2D interface for controlling 3D environment. The 3D user interface integrates the controlling actions of “seeing – moving –seeing” while designers are operating CAD (Schön and Wiggins, 1992). Simple gestures are used to control the operations instead. The interface also provides a spatial positioning method which helps designers to eliminate the commands of converting a coordinate axis. The study aims to discuss the provision of more intuitively interactive control through CAD so as to fulfil the needs of designers. In our practices and experiments, a pair of LED gloves equipped with two CCD cameras for capturing is used to sense the motions of hands and positions in 3D. In addition, circuit design is applied to convert the motions of hands including selecting, browsing, zoom in / zoom out and rotating to LED switches in different colours so as to identify images.

### 1. Introduction

Conceptual modeling serves as a stage full of active creativity in the process of architecture design. In the stage of conceptual design, designers usually develop models in various scales in order to provide visual thinking for further creations and modifications on the original design concept. In traditional architecture design, card papers, clay, gypsum or foam are used to form a model. Here comes a problem. The development of such forms is limited to the characteristics of modeling materials used. However, the existing CAD system has strong modeling function without being limited by the characteristics of practical materials used. The CAD system also has the

functions of direct zoom in / zoom out and viewpoint adjustment for the convenience of designers' visual thinking. The existing CAD system is still hard to understand and less intuitive. It lacks quick and direct interactions for developing forms. The CAD system is still unable to fulfill the requirements for early design and development (the original configurations of CAD are for engineering graphics instead of the interface required by conceptual modeling).

Since the beginning of Sutherland's Sketchpad Ph.D. thesis (Sutherland, 1963), this system allows users to make 2D sketches like arcs and lines by using optical pens. Afterwards, it has been a long story to develop the computer graphic system and the interactive system of manual 2D graphics for designers (Kato, 1982 ; Lenkins, 1993). The above-mentioned research and development are all within the extent of 2D graphics. The applications of 3D graphics did not fully start until the nineties. Tools for forming 3D sketches (Pugh, 1992 ; Eggli, 1995) were developed during that period. In the evolution of computer graphic capability, the input device used by designers for interacting with computer is maintained at the level of 2D mouse and keyboard input. As to 3D graphics, it is worked with computation plus Z-axis control. Users can only create simple 3D geometric objects (Zelevnik, 1996 ; Lipson, 1997) and further to simple free forms (Igarishi, 1999 ; Karpenko, 2002). However, the extra control of Z-axis is not intuitive at all.

During the period of 3D computer graphic development, the technology of virtual reality (VR) was also developed. VR technology facilitates the development of the operations between physical and virtual space. Through the discussions of HCI (Human Computer Interface / Interaction), possible interactions between design behavior and human computer interface have been developed. For example, IDEATE projects (Gribnau and Hennessey, 2000) and Gesture Modeling project (Mark and Ariel, 2001) have developed a hand-simulating clay modeling method. Besides, approaches such as 3D responsive workbench system (Schkolne, 2000), 3D SketchMaker project (Pratini, 2001) and Free Hand Form Generation (Diniz, 2003) allow free hand controlling of profile so as to generate surface. These approaches are developed in a self-defined 3D environment. These systems simply provide a single generation method which does not sufficiently support complete control functions for architecture designers.

Though the existing CAD software (like MAYA and MAX) has been designed with complete 3D manipulating functions for a long time, it lacks a 3D input device ideally working with 3D software. The development of conceptual modeling is still at its preliminary stage. An input device under a comprehensive operational environment and with complete modeling functions for designers has not been provided yet. Therefore, the study develops new spatial input interface under the environment provided by the existing CAD system so as to improve the poor intuition of interface and

retard interactive process. Hopefully, an interface more suitable for designers can be provided.

## 2. The Loads of Human Computer Interface

It is not popular applying CAD to develop conceptual design even if the existing CAD software had an amazing modelling function. This is because it requires great efforts in the operations of interface while applying CAD to develop conceptual modelling. Meanwhile, designers also bear great loads of planning how to operate the interface, which weakens the attention to form development. The biggest problem comes from users' being forced to use 2D-interface input device operating fixed points under a 3D environment. Poor input device results in tough designing control.

The human computer interface is connected with a computer by way of programming which provides an operational interface for people to use. However, knowledge load will be burdened in human mind if the operational approaches are different from the way human mind works. When the gap between human mind and an operational approach becomes greater, complicated and difficult operations may occur to users. Such condition is called "non-intuition" (Figure 1).

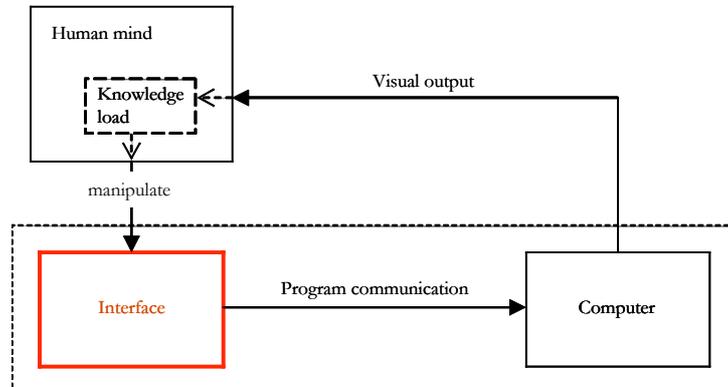


Figure 1. The framework of human computer interface

Design is a process of "seeing-moving-seeing" (Schön and Wiggins, 1992). Designers develop forms in the process of "seeing-moving-seeing". Under traditional human computer interface with the combination of a mouse and a keyboard (a keyboard controls character input and access keys while a mouse controls 2D directions), designers have to make plane coordinate control first and then the vertical coordinate control so as to achieve spatial moving before controlling the moving of spatial positions. Designers also have to make

controls of moving, rotating and zoom in / zoom out before completing “seeing”.

Such system has a serious problem in operational sequences. The operation of commands happens before designers’ modelling process, which results in interruptions of process by command operations. The development of conceptual modelling under such an interface is only a test on user’s ability in transforming spatial concept into commands while creating. Other than that, such development is not meaningful to design itself. Consequently, the study re-establishes a new spatial input interface and attempts to improve the interactions between designers and computer (Figure 2).

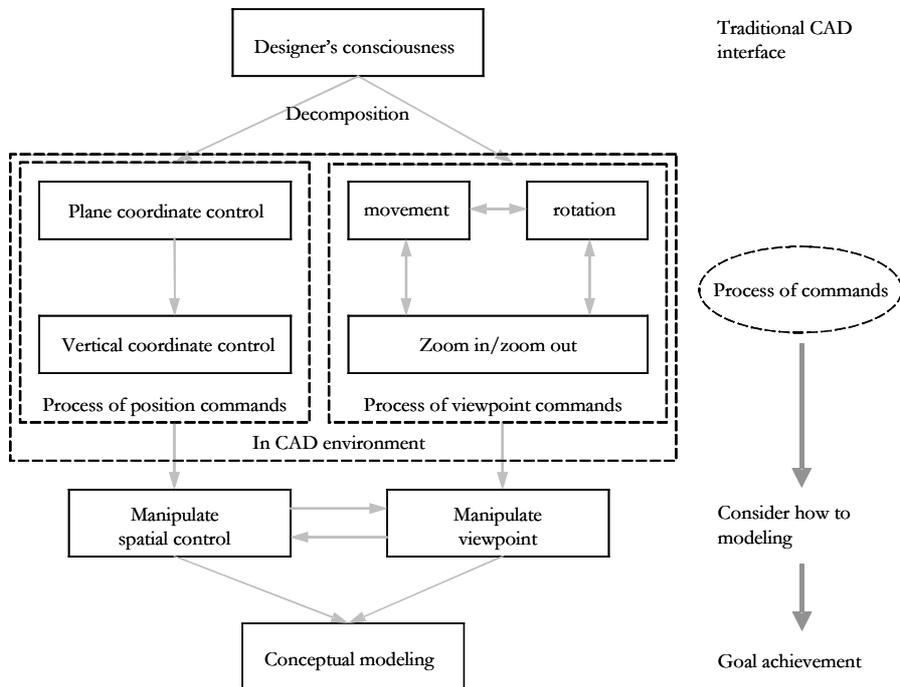
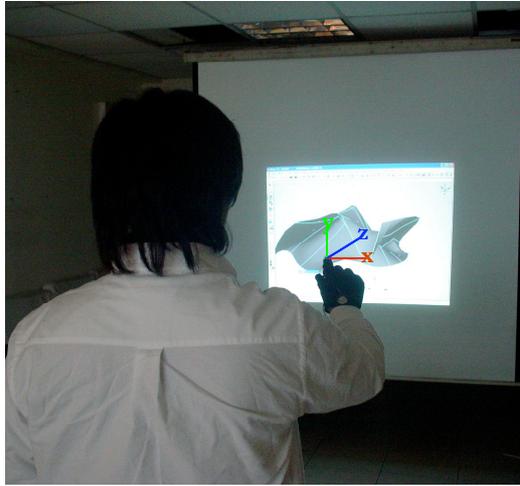


Figure 2. Sequence of operation by traditional CAD interface

### 3. The Spatial Input Device

The spatial input device allows designers standing in front of a large screen directly analogizing a position in physical space to a spatial cursor position under a MAYA environment. Designers can also use several simple gestures directly manipulating viewpoint and mouse-selected functions. Apart from the above, the pre-configurations of MAYA interface are kept as usual.



*Figure 3.* Using hand control to manipulate in MAYA

### 3.1. THE PROCESS OF SYSTEM

The interactive pattern of the system combines two cameras and a pair of LED gloves. For improving the interruptions of modeling thinking caused by the process of commands using the traditional interface, the system takes the advantage of gestural spatial interface to allow users directly manipulating spatial positioning and viewpoint without complicated process of commands. The circuit design of LED gloves is used to analyze gestures and LED colors will change accordingly. Afterwards, the automatic process from Visual C++ programming, image capturing, LED color recognition, data computation to MEL commands will implement under the MAYA environment which transforms the process of commands into automatic program control. Therefore, the process of design will not be influenced (Figure 4).

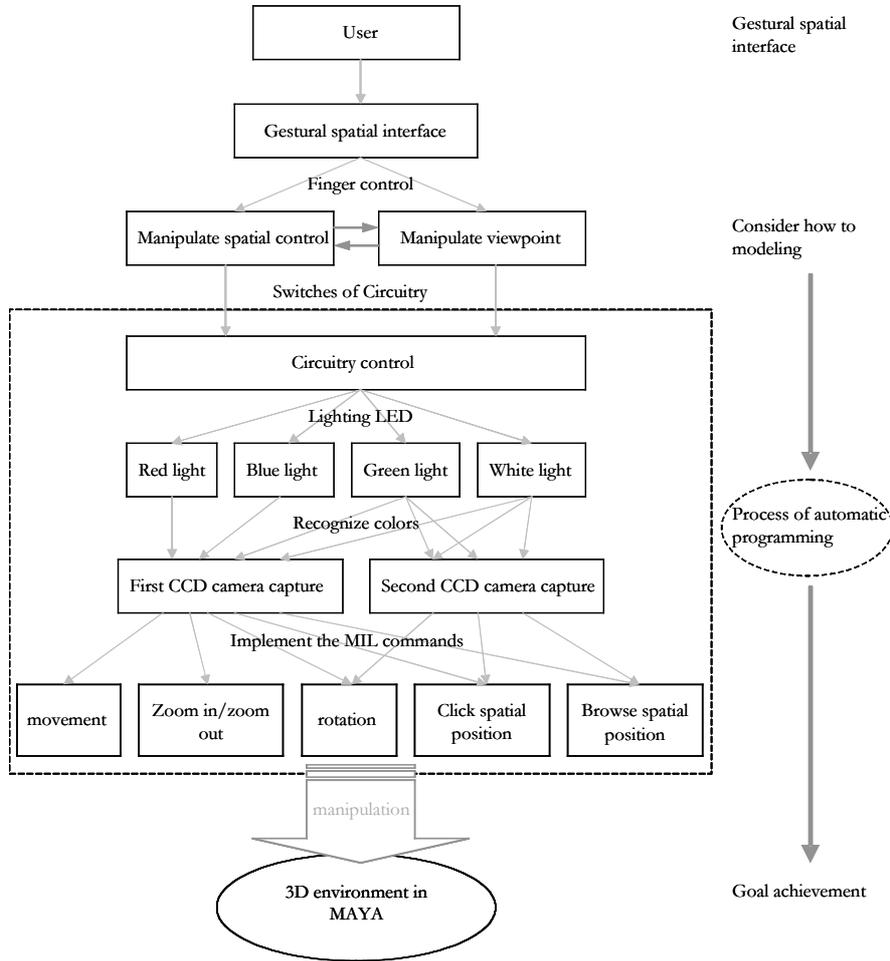


Figure 4. Sequence of operation by gestural spatial interface

### 3.2. IMPLEMENTATION

The development of the interface includes the application of software and production of hardware. As to software, there are MAYA 7.0, Visual C++, MIL (Matrox Imaging Library) as well as MEL (Maya Embedded Language). As to hardware, there are one PC, two SHARP 1/3" CCD (Charge Coupled Device) cameras, two LED gloves and one Matrox-CronsPlus board. The practice is divided into four phases.



Figure 5. Equipment of hardware

### 3.1.1. Early Test for Technique

Test RGB values of light points recognized by using webcam and Lua program and apply the coordinate values of light points tracked to sketches (Figure 6). The test shows the limitations on the speed of image capture, resolution and image quality in addition to the lack of 3D support. Therefore, high-quality system will be planned to overcome these limitations in the next phase.



Figure 6. Test of simple image recognition and sketch technique in Lua programming

### 3.1.2. Software and Hardware Planning

The system is set up in an environment with a large screen and two CCD cameras facing towards a user. The system is placed parallel so as to detect a user's gestures and movements. The system is connected with a desktop computer which is equipped with an image capture device (Matrox-Cronos Plus) to receive the messages coming from cameras. Then, MIL(Matrox Imaging Library) and MEL (Maya Embedded Language) can be applied together to MAYA software through Visual C++.

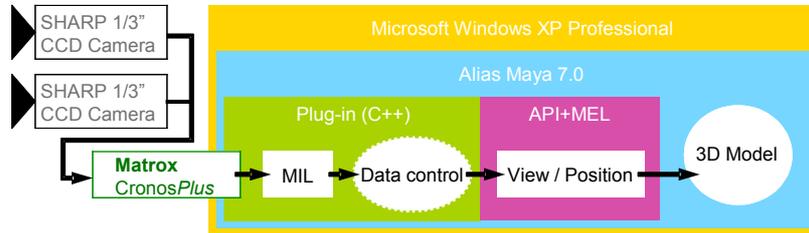


Figure 7. Software architecture

### 3.1.3. Image Recognition and Conversion of Spatial Positions

Place one CCD camera at a distance of 5.5 cm from the other. Define the valid range as that being detected by both cameras. Through the connection of CronosPlus board, use MIL to set the functions detecting the images derived from both cameras under Visual C++ operational environment. Then, recognize LED light point coordinates (Figure 8) based on RGB values. 3D coordinates against light points in the execution of program can be obtained by establishing an equation (Figure 9) in connection with the relative distance and depth between two light points.

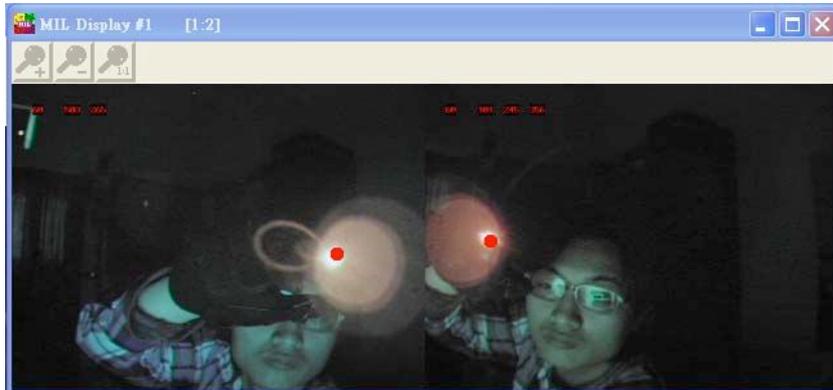


Figure 8. Simultaneously recognize the positions of light points shown from the two cameras

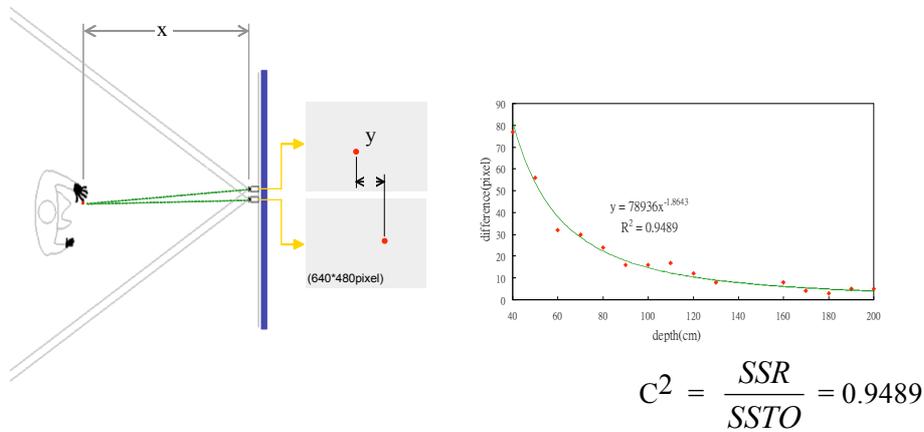


Figure 8. An equation in connection with the distance and depth between two light points

### 3.1.4. Increase of Interactive Control

In this stage, LED in different colors will be activated by the circuits of LED gloves while sensing the gestures of selection, browsing, zoom in / zoom out, rotation and movement (Figure 10). LED colors are recognized through images which generate correspondent MEL commands for further execution under a 3D environment.



Figure 10. Using gesture to manipulate functions of select position, zoom in/zoom out and rotation

The above-mentioned stage is still in process. The part of executing MIL commands by connecting with MAYA has not been finished yet. The circuit functions for selecting and browsing have been put into practice so far. The selection function is defined as the movement when the index finger and thumb get closer to each other while the browsing function is defined as when fingers do not intentionally show strength according to the circuit design. Then, the circuit switching can be achieved through the combination of reek switch, magnet and two-color LED (as shown in Figure 11).

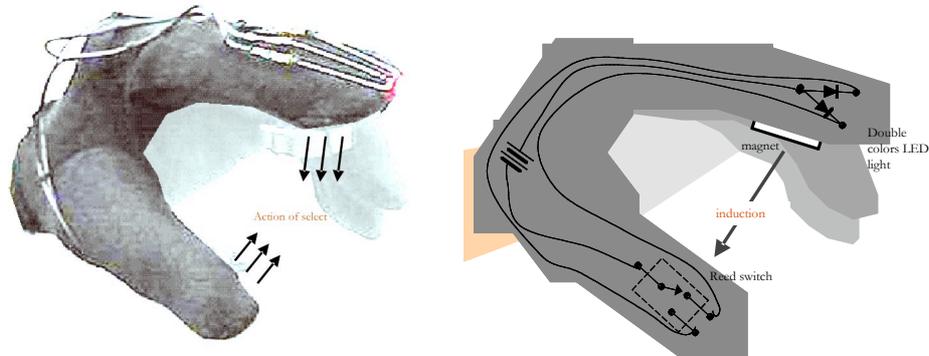


Figure 11. Circuits for Selection and Browsing Gestures

#### 4. Conclusion

Though this study has not been completely finished yet, some practical functions have been implemented during the process of the study, for example, image recognition. The precision of spatial coordinates is acceptable. However, the precision decreases when the detecting distance increases. As to gesture interactions, the results of gesture signal switching via circuits are good. The switch control works very clearly which leads to easy image recognition. After the implementation is finished, further user tests will be conducted. Discussions will also be made on if the improved interface is able to generate more possibilities in forms than the traditional interface did.

Adding a new interface in MAYA will be useful for implementation. MAYA will become more comprehensive which can be directly applied to design at different stages. The spatial input operation contributes to an easy learning for interface operation. The communications between designers and computer are drawn nearer. The whole set of such equipment only costs 400 US dollars. Hopefully our further study may enable the computer for a more automatic execution so that the designers may concentrate more on creativity rather than technical steps.

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# COLLABORATIVE ARCHITECTURAL DESIGN AS A REFLECTIVE CONVERSATION

*An agent facilitated system to support collaborative conceptual design*

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**Abstract.** In this paper, definitions of collaborative design are discussed and understood in terms of a designer's cognitive collaborations to explore his/her experiential memory for remote idea associations. Based on Schon's reflective practice theory, Valkenburg and Dorst's (1998) description of collaborative team designing is adopted as a model for a proposed design conversation system. The design conversation system is aimed at triggering the experiential memory of the designer by associating significant ideas from different design domains to provide different perspectives of a design situation. The paper describes a proposed framework for the design conversation system incorporating computational agents in a blackboard architecture environment.

## 1. Introduction

Collaboration is an integral part of creativity in design for generating and evaluating design ideas. Valkenburg and Dorst (1998) have explored the concept of collaborative team designing using Schon's (1995) reflective practice method. In this method, they describe team designing as episodic and categorize these episodes into four activities – naming, framing, moving and reflecting.

In this paper, we propose a computational framework based on Valkenburg and Dorst's (1998) model of team designing. The designer converses with a team of software agents to recognize and analyze the possibilities of concepts for specific design situations. The conversation is

aimed at triggering the experiential memory of the designer through words/text.

## **2. Design as a Collaborative Act**

Architectural design is a response to a wide range of demands such as aesthetic, functional, material and ecological, which though often inconsistent, are combined through architectural design in a novel way (Haapasalo, 2000). For these reasons, it is generally common for architectural practices to employ design teams rather than individual project designers. The former provide a rich collective experience from different domains. Brainstorming (Osborn 1963) is a well-established technique for collaborative creativity. Although research has shown that brainstorming can generate a vast array of ideas, this technique is often criticized for the lack of provision of analysis of the generated ideas (Lawson, 1997).

Kvan (2000) argues that to be successful, a collaborative project must establish a definition of the team, identify the desired outcomes, ensure there is a purpose in the collaboration and clarify the interdependencies of the members. Traditionally, architectural design has been generally regarded as a close-coupled process wherein the different members work closely on the design project providing their expertise at each stage of the design development. Gero and McNeill (1998) have shown that the design process is actually made up of distinct events that occupy discrete and measurable periods. Designers come together, provide the relevant expertise for a particular situation, go back to their drawing boards and come back later for further negotiation. It is cyclical. Further, Maher et al (1998) in their experiments on collaborative design also found that exclusive collaboration produced more effective results than mutual collaboration.

### 2.1. THE DESIGNER AS A TEAM OF ONE.

Even with collaborative design, a designer still has to think individually and collaborate with other team members. In design-oriented fields like architecture, the designer may consult with colleagues and peers, but the responsibility is personal with the chief designer's initial sketches given as a *fait accompli* (Goldschmidt, 1996). In these instances, the designer is expected to have an outstanding capability for integration, evaluation and synthesis of concepts. Therefore, we have two issues to look at in aiding conceptual architectural design: conversations within the designer's own thinking process and conversations with members of a design team.

## 2.2. AGENTS AND COLLABORATION

In this work, we recognize a strong parallel between collaborative design and the use of computational agents in general problem-solving. Agents are designed to interact with an environment that is continually changing within its own limits (Parunak, 1998). The design environment is a complex and dynamic environment and multi-agent systems provide a means to manage collaboration in this ill-structured context. Zambonelli et al (2003) distinguishes between two classes of multi-agent systems: *distributed problem-solving systems* in which agents operate to achieve a common goal and *open systems* where agents do not share a common goal, but are developed to achieve different objectives. Design is generally a loosely coupled process (Kvan 2000) in which domain experts contribute at different times based on their knowledge of a design situation. This corresponds to the use of open agent systems for a conceptual design stage.

### 3. Design as a Reflective Conversation.

In the conceptual design stages, architects produce drawings that are meant for their own understanding. In essence, they are conversing with the drawings. Following Schon's paradigm of 'design as a conversation' (Schön, 1995), a trigger springs out of the conversation, the architect makes a move on the drawing and enters back into the conversation mode, this time reflecting on the move. This conversation continues until the designer is satisfied with the result produced. The concepts that emerge from this conversation are richer when the relations or links between the different domains of design conversation get re-structured. This re-structuring is generally dependent on experience and, as Schön and Wiggins (1992) state, it helps distinguish experts from novices.

In light of the above, we must mention that due to the limitation of individual short-term memory, designers, including experts, always have production-blocking problems in terms of creative ideas. Techniques like idea association or memory triggers are often used to make up for the limitations of human short-term memory. Many of the design techniques used to promote creative thought are based on the simple idea of shifting the designer's attention and changing the context within which the problem is perceived.

Valkenburg and Dorst (1998) came up with a rich model that explores Schon's theory of reflective conversation in team designing. In their method, the basic elements of designing are actions and the team's design ability is making intelligent decisions about those actions. Four types of actions are proposed: *naming* relevant elements in the design task, *framing* design issues

and sub-issues, *moving* (associating ideas and concepts) and *reflecting* (knowing what to do next). This is illustrated in Figure 1.

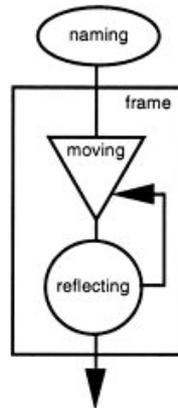


Figure 1. The mechanism of reflective practice; the four design activities and their interplay (Valkenburg and Dorst, 1998)

Architects work with words or texts that are products of linguistic choices and construct reality in particular ways (Markus et al, 2002). Language provides new perspectives on a design situation. The advantage of words rather than pictures in expressing early design ideas is their ability to sustain a range of interpretation (Lawson and Loke, 1997). The first body of text that the architect uses in a design project is the 'design brief', wherein the client communicates his or her ideas to the architect. This marks the beginning of the design conversation, with written words communicating assumptions or possibilities for the design outcome, as envisioned by the client. The architect continues the conversation by making objective and subjective judgments of the brief and then going on to analyze those judgments. Designing depends on such qualitative judgments (Schön and Wiggins, 1992).

#### 4. A Proposed Framework for a Multi-Agent System to Support Conceptual Design

In the light of the above discussion, we here outline a proposed framework for a multi-agent system that supports conceptual design by imitating a collaborative conversation in which the agents act as experts across a variety of domains to suggest associated concepts that we believe may trigger the experiential memory of the designer and thereby promote more creative thought. The proposed framework aims to support the conceptual design

stage where the designer is beginning to develop the design brief and starts evolving conceptual design ideas for the situation presented by the brief. For our prototype, it is proposed that the knowledgebase for the multi-agent system will incorporate the knowledgebase of IDEAs, a web-based tool hosted by the Department of Health, UK, aimed at supporting professionals in various aspects of healthcare design process (<http://design.dh.gov.uk/ideas/>). Within this framework, the design brief evolves as the design conversation proceeds and forms a dynamic and ever-changing environment for the proposed prototype. In keeping with Schon's principle of treating every design task as unique, the environment changes to suit the evolving requirements of the design brief, as it is refined through a conversational process.

A *blackboard* style architecture is proposed for the multi-agent system as illustrated in Figure 2.

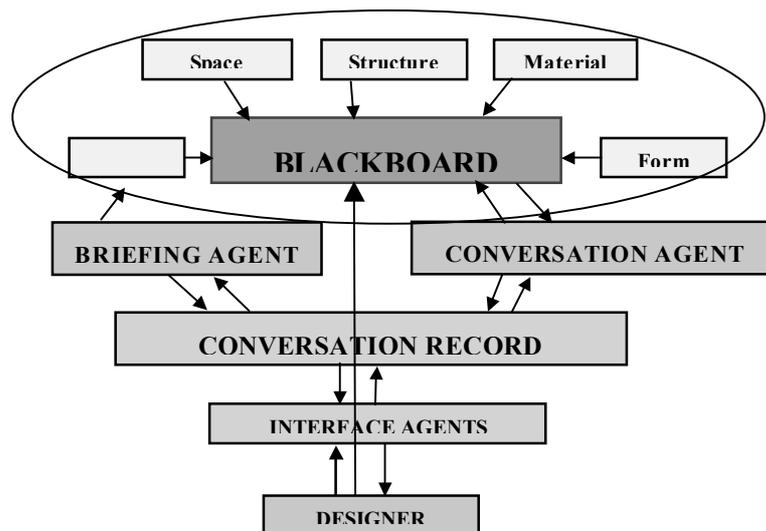


Figure 2. Proposed Agent Architecture for Conceptual Architectural Design

A blackboard is a global database for sharing information and is used by the agents to put forward different ideas. In this prototype, we propose to use MICA as the multi-agent architecture. MICA is based on the blackboard architecture where a group of agents use the blackboard to share knowledge and communicate (Kaddous and Sammut, 2004). The agents that form the multi-agent system would include *domain* agents, a *briefing* agent, a *meta-level conversation* agent that manages the conversations, *interface* agents

and the designer them self as the *human* agent who is the controller of the system. All these agents work in collaboration with each other by continuous monitoring the blackboard.

We envisage that a designer would begin by entering in the requirements of a generic design brief through the *interface* agents. These requirements are recorded in the conversation record and then captured by the *briefing* agent through internal reasoning mechanisms. The task of a conversation agent is to acquire and filter data before forwarding it to the blackboard or to the conversation record. The style of the conversation is based on Valkenburg and Dorst's (1998) design model and begins by *naming* an important aspect from the design brief that then becomes the focus or theme of the conversation. This is followed by *framing* one or more design issues that are relevant to the chosen design aspect. The designer or the domain agents can initiate the 'framing' process. As the conversation proceeds, the domain agents and the designer capture keywords from the conversation record and offer their responses based on their analytical judgment of the situation. Domain agents perceive data (keywords) posted onto the blackboard by the conversation agent. This data triggers their individual reasoning operations for choosing a relevant association.

Based on the study of Rhodes and Maes (2000), the triggering and reasoning actions of the agents are proposed through employment of 'just-in-time information retrieval agents (JITIR)' that proactively present information based on a person's context in an easily accessible and non-intrusive manner. Features of the environment in the person's current local context are used as predictors or proxies for usefulness; in this case it's the contextual keywords. While the domain agents converse, the briefing agent captures appropriate exploratory ideas from the conversation record and adds them to the design brief, this in turn is being continually reviewed by the domain agents thus doing a loop in the briefing process. The brief develops and the conversation is able to take new directions.

Following the idea of design process to be episodic (Kvan, 2000), it is proposed that the designer can work on one or multiple agent conversations simultaneously. At some point of time in the conversation, the designer may choose to carry out a new conversation on a different issue. The designer does this by informing the conversation agent, who in turn initiates a new conversation board.

A design conversation is also based on an 'ontology', a design world in which the designer realizes the design situations. Agents in a design conversation need to share a common understanding of the designer's world. Schon's normative design domains along with IDEAs considerations provide the backbone for conceptualizing the design ontology for the proposed multi-agent system. Designers create their design worlds, as Schön (1992) states, through the processes of appreciation, by which is meant the active

sensory apprehension of the stuff in question and the construction of an order to that stuff including the naming and framing of things, qualities and relationships. We focus on the latter objective part for the formation of design ontology to classify and relate the different knowledge requirements for conceptual architectural design.

#### 4.2. DOMAIN AGENTS

The architecture of the domain agents would be based on the following proposition: a domain agent detects a keyword during the conversation and then looks for associations in its knowledge base and compares the association with the updated brief from the briefing agent. It then detects a novel or a remote association based on the brief and enters the idea on the blackboard. Based on IDEAs, domain agents represent the different architectural considerations for the design of a healthcare centre. A possible conversation fragment could be as follows:

The designer frames a design issue around the ‘entrance’ for the healthcare centre to begin the conversation.

DESIGNER - The entrance needs to be friendly and welcoming.

VIEW AGENT - There should be uninterrupted and clear views of the entrance from the approach to the site.

MATERIAL AGENT - Natural stone and timber building materials can make an entrance friendlier.

BRIEFING AGENT – What is your (designer’s) interpretation of welcoming?

DESIGNER – The entrance area should be uncluttered and spacious.

LIGHT AGENT – Well lit entrances create a feeling of spaciousness.

### 5. Conclusion

This paper suggests a computational method for deployment of a design brief within a multi-agent system to accelerate the production of richer concepts through a reflective exploration of the brief. The team-design paradigm of naming-framing-moving-reflecting provides a powerful mechanism to drive an exploratory conversation of ideas in the conceptual stages of architectural design.

Novices and experts alike can use the prototype, each benefiting from the system from their own perspective. The system is expected to learn with each design session and this learning is added to its future conversations.

An added advantage of the system is that new domain agents can be incorporated into the system at any stage of the design process. This

supports the ill structured nature of conceptual design stages wherein the problem domains are rarely clearly identified.

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## THE DIGITAL DESIGN PROCESS:

### *Reflections on architectural design positions on complexity and CAAD*

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**Abstract.** These instructions are intended to guide contributors to the *Second Architecture* is presently engaged in an impatient search for solutions to critical questions about the nature and the identity of the discipline, and digital technology is a key agent for prevailing innovations in architectural design. The problem of complexity underlies all design problems. With the advent of CAD however, Architect's ability to truly represent complexity has increased considerably. Another source that provides information about dealing with complexity is architectural theory. As Rowe (1987) states, architectural theory constitutes "a corpus of principles that are agreed upon and therefore worthy of emulation". Architectural theory often is a mixed reflection on the nature of architectural design, design processes, made in descriptive and prescriptive terms (see Krufft 1985). Complexity is obviously not a new issue in architectural theory. Since it is an inherent characteristic of design problems, it has been dealt with in many different ways throughout history.

Contemporary architects incorporate the computer in their design process. They produce architecture that is generated by the use of particle systems, simulation software, animation software, but also the more standard modelling tools. The architects reflect on the impact of the computer in their theories, and display changes in style by using information modelling techniques that have become versatile enough to encompass the complexity of information in the architectural design process. In this way, architectural style and theory can provide directions to further develop CAD. Most notable is the acceptance of complexity as a given fact, not as a phenomenon to oppose in systems of organization, but as a structuring principle to begin with. No matter what information modelling paradigm is used, complex and huge amounts of information need to be processed by designers. A key aspect in the combination of CAD, complexity, and architectural design is the role of the design representation. The way the design is

presented and perceived during the design process is instrumental to understanding the design task. More architects are trying to reformulate this working of the representation.

The intention of this paper is to present and discuss the current state of the art in architectural design positions on complexity and CAAD, and to reflect in particular on the role of digital design representations in this discussion. We also try to investigate how complexity can be dealt with, by looking at architects, in particular their styles and theories. The way architects use digital media and graphic representations can be informative how units of information can be formed and used in the design process. A case study is a concrete architect's design processes such as Peter Eisenman Rem Koolhaas, van Berkel, Lynn, and Franke Gehry, who embrace complexity and make it a focus point in their design. Rather than viewing it as problematic issue, by using computer as an indispensable instrument in their approaches.

## 1. Introduction

Design methods have been at the core of researcher's attention since the early sixties. Many of the early approaches (Jones, 1996; Habraken 1976) were inspired by the paradigms of systems theory and rational problem solving (Simon, 1969). Innovative work was done on the systematic description of the design process, structure of design problems, study of designers and their methods, and reflection on the nature of design.

Cross (1984) provides an overview of the changing understanding of design problems. In broad lines, the field started with a systems theoretical view which stressed the systematic approach to charting and solving design problems (period 1962-1967). This research yielded insight in the complexity and large scope of design problems.

The focus changed from encompassing methods towards inquiries into the structure of design problems in the period 1966-1973. This work showed how various structures play a role in structuring processes and solution types. In the following period, 1972-1980, attention shifted to the study of designers and their every-day working procedures. Work done in this period highlighted the importance of understanding designers in action.

In 1980-1982, the work to that moment prompted many researchers to rethink their basic stance to design research. Cross (1984) notes a renewed interest in the basic assumptions that found research in design.

From the 1980's onward, computation has become a substantial part in research on design, in the cognitive research approach, the field of Artificial Intelligence, and information modelling techniques.

Throughout the development of the field, the complexity of design became more and more apparent. In the early eighties there was dissatisfaction when it gradually appeared that design methodology did not

live up to its expectations (Cross, 1984). Design methods were conceived as rigid, inflexible, and with limited application. The research field expanded into design research: a broad range of investigations into the nature of design, design thinking and cognition, organization, management, and other aspects. Much of design research today happens in laboratory-settings (Hamel, 1990; Cross et al. 1996), or takes its research data from everyday practice (Valkenburg, 2000; Lawson, 1994). Design methods did not fall out of the research scope altogether (Rozenburg and Eekels, 1994); Cross, 2000) and currently there is increasing attention to the distinction between the rational problem solving paradigm and the reflective practice paradigm (Valkenburg 2000; Schön, 1983; Dorst, 1997).

Design methodology, to conclude, has a rich and varied history. The translation of the research findings to concrete methods is not always obvious. Furthermore, The research group – SAR notes that the methodological reflection on design is not very popular, both with students and architects, he also notes from his experiences in architectural design methodology teaching and research, that there are five main reasons:

1. Comprehensive and systematic descriptions of design are productive for research purposes to provide a framework, but are too complex and cumbersome to effectively use in practice.
2. The architectural profession and the Building and Construction Industry did not undergo major changes, removing the immediate need for design methodological reflection.
3. Design methodologies age and have to be updated so that they tackle the relevant questions of current practice; this updating often did not take place and therefore design methods lost credibility.
4. Architects do not in general view a more transparent representation of the design process by means of methods favourably for fear that their own input will be conceived as trivial.
5. There has been a shift of attention from the design process to the design product; with an increasing emphasis on architecture theoretical positions rather than methodological positions.

At the same time we note that while using CAAD systems, architects and students are exploring new ways of designing with great enthusiasm, albeit seldom with design methodological underpinning. Architects have integrated CAAD in their everyday practice in various degrees. There are now a number of leading offices that use CAAD in innovative and creative ways, typically using a wider range of computer tools than the traditional CAAD software (such as animation and morphing software, e.g. Lynn,) or mixing it with various media (such as Gehry and Eisenman). New organizational forms of the design office appear, allowing for example round-the-clock

design teams world-wide and collaborative design. This innovative work invites methodological reflection on the design process.

## **2. Role of Design Drawing in Handling Complexity**

Drawing plays an important role in design process. For example, design educator Lockard argues that the act of freehand drawing allows our mind to “see, comprehend and respond” to information (Lockard, 1973). Laseau in *Graphic Thinking* argues that conceptual drawings are drawn to present points of concern and to provoke further design decisions (Laseau, 1980). Designers use drawings to develop their designs. Designers often work by making sketches or transcribing drawings from their design team colleagues for further development (Graves, 1977). They use drawings to represent “movement, access, sound, view, function, and time” (Fraser and Henmi, 1994, p. 110). Lawson describes that the designers “find it hard to think without a pencil in their hand” (Lawson, 1994, p. 141). Herbert argues that drawings are “the designer's principal means of thinking” (Herbert, 1993, p. 1). He further argues that designer “must interact with the drawing” (p. 121). Designers use the terms of “diagrams”, “sketch” and “schematic drawing” Somewhat interchangeably. Here we use the term drawing and sketches to refer to the drawings designers make during early design process. Therefore a key aspect in the combination of CAD, complexity, and architectural design is the role of the design drawing. The way the design is presented and perceived during the design process is instrumental to understanding the design task. Lynn (1998) talks in this respect of “ambiguous yet rigorous shapes” (meaning that the design drawing can appear to be ambiguous, but is based on a precise and exact definition that can be constructed every time. More architects are trying to reformulate this working of the representation.

## **3. Protocol Analysis of Design**

Protocol analysis studies have been used to study design problem solving. This research involved the collection of both verbal and visual data. In one of the first design process protocol studies, Eastman observed designers sketching to improve a bathroom layout to argue that designers' words and drawings correlate with the problems they find and solve (Eastman, 1968). Akin's *Psychology of Design* (Akin, 1986) followed Newell and Simon's information processing model (Newell and Simon, 1972). He studied architects sketching and recall analyzing the chunking of design actions and attention shifts. His study revealed several chunks: the wall and window segments, steps, and furniture of similar size that have close spatial relations.

a more recent chunking study done by Suwa and Tversky (1996) video taped architects designing an art museum. From the verbal post-design review protocols, they argued that seeing different types of information in sketches drives the refinement of design ideas. They further classified the information in the protocols into different categories such as spaces, things, views, lights and circulation. Akin and Lin designed a two-part experiment (Akin and Lin, 1995) that asked subjects to do two tasks: to reproduce a drawing from a printed transcript, and to predict verbal data from a video of the design drawing process with the sound track suppressed. They concluded that the verbal transcripts and drawings are complementary. Schön analyzed protocols of architects' sketches in an attempt to infer their design reasoning (Schön, 1985; Schön and Wiggins, 1992). He described design sketching protocols to illustrate the idea of "reflection-in-action." He argued that designers first "see" then "move" the design objects. Goldschmidt's design protocol studies, like Akin, examined drawing as well as verbalization. She viewed sketching as an operation of design moves and arguments that results in the gradual transformation of images. Sketching, she argued, is a systematic dialectic between the "seeing as" and "seeing that" reasoning modalities. Her studies showed that the act of sketching is a vehicle for design thinking.

All the above studies described the association of thinking, verbal protocols with design drawing.

In this Paper we propose to construct design methods of particular architects on the basis of written material about their work. This leaves out the study of design methods based on observation and/or interview. The main reason for this approach lies in the aim to provide students with a working method that allows them to assess architects who use computer in the early stages of their design process. Students usually only have access to written documents for this purpose. Rather than trying to construct 'strong' design methods that have wide applicability in multiple domains of design (thus having weak implications for the design outcome itself), we aim to construct methods that are narrowly focused on a specific architect – and thus have strong implications for the design outcome. We have to emphasise therefore that the results of the analysis have limited applicability to design in general, and that the expected 'life-span' of the design methods will be brief due to changes in style and working method of the architects in question. The design studio is titled Architectural and Urban Design with CAD, and is an advanced CAD and design course. It consists of lectures combined with an exercise. The goal of the course is to give a sophisticated understanding of the relationship between the use of computers, working methods in design, and the products of this process.

Two architects are discussed with respect to their use of CAAD in design: Peter Eisenman and Frank Gehry; the author has gathered the information on

these architects beforehand. By studying and emulating the methods of these architects, students must be able to define their own insights and attitudes towards the use of CAAD.

The architects are discussed in the light of the general theoretical focus areas mentioned above. In the course, these become more specified in the following aspects.

### 3.1 THE POSITION OF THE ARCHITECT (ONTOLOGY)

Which elements/concepts does the architect distinguish in his theoretical position?

### 3.2 DESIGN METHOD

How does the architect organize his process; where and how does he use CAAD?

### 3.3 RESULT

How do ontology and method influence the result of the design process? Second order headings are in 10 pt caps, beginning at the left-hand margin.

## 4. Architects Dealing With Complexity

The problem of complexity underlies all design problems. With the advent of CAD however, Architect's ability to truly represent complexity has increased considerably. Besides being systems for achieving aesthetically pleasing results, architectural styles also provide means to tackle complexity in design. They point to a hierarchy of issues that have to be dealt with first in order to get a successful design. These issues not only concern organization, structure, relation diagrams, but also elements, composition, and order (see for example Broadbent 1990 for an overview of approaches in this area).

Another source that provides information about dealing with complexity is architectural theory. As Rowe (1987) states, architectural theory constitutes "a corpus of principles that are agreed upon and therefore worthy of emulation". Architectural theory often is a mixed reflection on the nature of architectural design, design processes, made in descriptive and prescriptive terms (see Krufft 1985). Complexity is obviously not a new issue in architectural theory. Since it is an inherent characteristic of design problems, it has been dealt with in many different ways throughout history.

Contemporary architects incorporate the computer in their design process. They produce architecture that is generated by the use of particle

systems, simulation software, blobs, animation software, but also the more standard modelling tools. The architects reflect on the impact of the computer in their theories, and display changes in style through using it. In this way, architectural style and theory can provide directions to further develop CAD. Most notable is the acceptance of complexity as a given fact, not as a phenomenon to oppose in systems of organization, but as a structuring principle to begin with. In this paper, we will be interested in precisely this aspect.

Complexity is obviously not a new issue in architectural theory. Since it is an inherent characteristic of design problems, it has been dealt with in many different ways throughout history. Complexity has been picked up explicitly by for example Venturi (1966) and more recently by Koolhaas and Mau (1995). Architects who incorporate CAD in their design process, such as Franke Gehry Peter Eisenman, and Lynn, van Berkel (UN Studio), etc. utilize complexity in their work and also formulate new positions in architectural theory and style.

#### 4.1 PETER EISENMAN'S WORKING METHOD

Peter Eisenman's working method, as described in Galofaro (1999), relies on a simultaneous production of drawings, scale models, and computer models. The technique of superposition is used to combine historical readings of the site into material that forms the basis of a design (this is very well documented in Bédard, 1994). In this way, Eisenman is looking for complexity in material related to the history of the site (he regards the site as a 'palimpsest' – an old parchment with traces of previous texts). In a later phase, this already complex superposition gets an additional layer by means of a diagrammatic model: an image that is associated with the project (e.g. the image of the structure of a liquid crystal display as related to the design task of the headquarters of a software firm). This image is used to distort the current design by making the design follow lines and directions present in the diagrammatic model. This is done either in two dimensions, on the plan level, or in three dimensions, in a computer model.

Eisenman's method progresses through the following stages.

##### *4.1.1 Cas Study*

University Art Museum, Long Beach

##### *4.1.1.2 Phase 1: Reading the site (Figures 1-4)*

- a- Eisenman finds as much (historical) maps of the site as possible.
- b- Eisenman categorizes the material with keywords about the content.
- c- He Finds relations between objects of the maps and the design brief.

He uses the trace technique to find relevant forms in the map material.  
 For Eisenman form has meaning.  
 He looks for important lines in the site (references to shapes, objects, places)?  
 He uses scale, rotate, and move to reinterpret objects relative to each other.

d- Eisenman superimposes the maps and selected objects on the site.

Eisenman tries to read the site not as a *Tubule Rasa*, but as an area with history, information, and influence on the design. He refers to the Palimpsest metaphor.  
 He tries to find connections between the maps/objects and the site.  
 He looks for special places that emerge from this superposition.

#### *4.1.1.3. Phase 2: Deformation strategy (Figures 7-12)*

e- Eisenman Finds a diagrammatic model that is relevant for the design.  
 A diagrammatic model is an image that depicts some kind of structure, organization, or working of forces.  
 A diagrammatic model may not be derived from the discipline of architecture.

f- He Studies the properties of the diagrammatic model.  
 He superimposes the diagrammatic model on the design.  
 He finds an interpretation of the structure that he can use for deforming the current design.

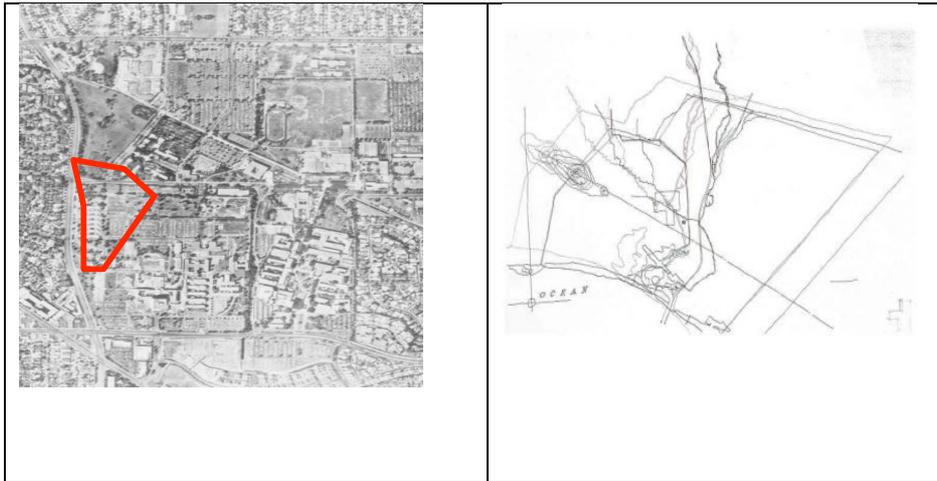
g- He translates the properties to deformations of the design.  
 He uses for example densities in the diagrammatic model for contracting or expanding the design.  
 He changes the geometry of the model along for example the lines of the diagrammatic model.

#### *4.1.1.4. Phase 3: Reflections about the design (Figures 13-21)*

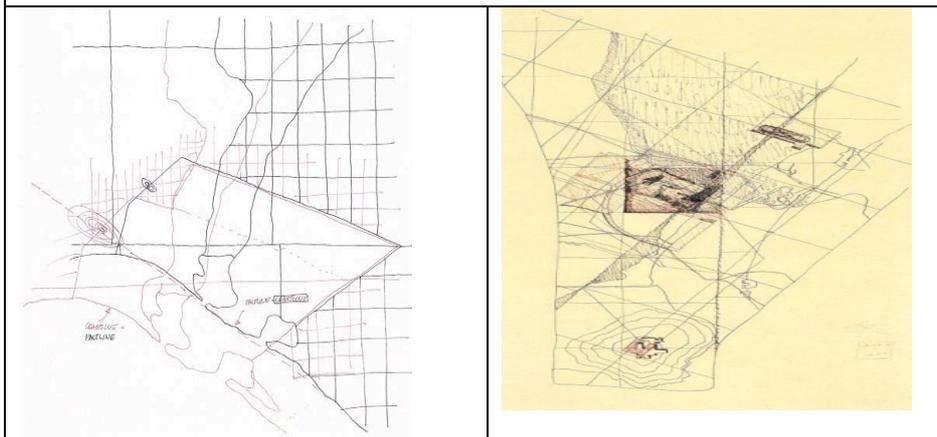
h- Eisenman's method is very analytical and needs a lot of referential material.  
 i- Reflections on how the superimpositions influence form and location of objects on the site.  
 j- Reflections on how the deformation strategy influences the design.

The diagrammatic (Figures 5 and 6) model is an image of an organizational structure that is related to the core issue in the design task. It

forms a metaphor for thinking about the design, and in which direction it should progress. In their work, the development of the building design and how it relates to the diagram is an important aspect. The diagram provides a handle on complexity as it hints to directions in which the solution can be developed.



*Figures 1-4. Phase 1: Reading the site: Eisenman tries to read the site not as a Tubule Rasa, but as an area with history, information, and influence on the design. He refers to the Palimpsest metaphor. He superimposes the maps and selected objects on the site. He tries to find connections between the maps/objects and the site. He looks for special places that emerge from this superposition. He uses Superposition techniques: CAD: layers & objects, Layers: AutoCAD / Photoshop- Objects: CorelDraw Operations: Scale, rotate, translate, retrace (source: Galofaro (1999), Bédard (1994), Eisenman (2001)).*



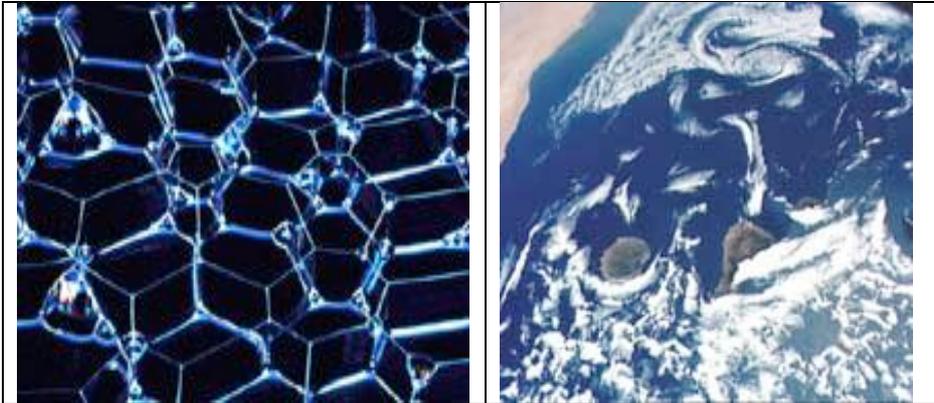
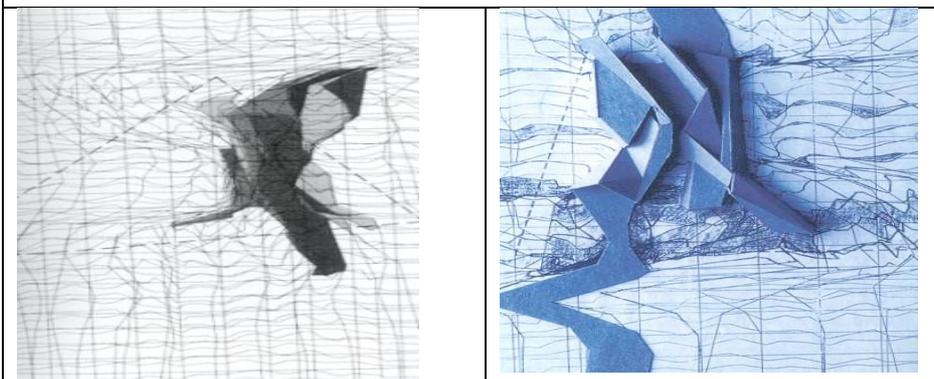
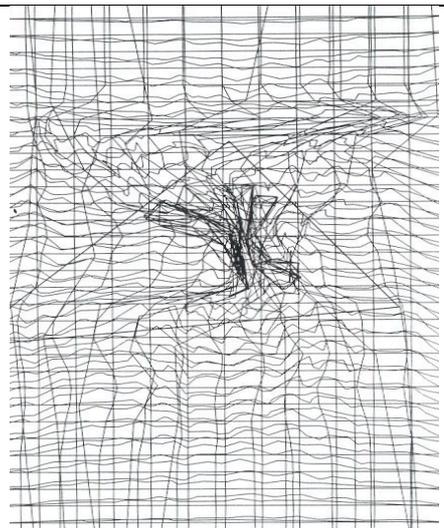
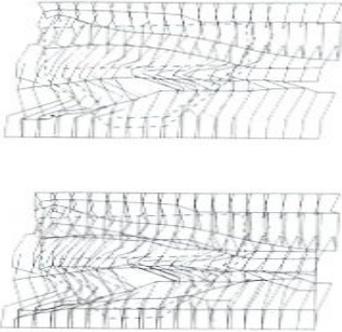
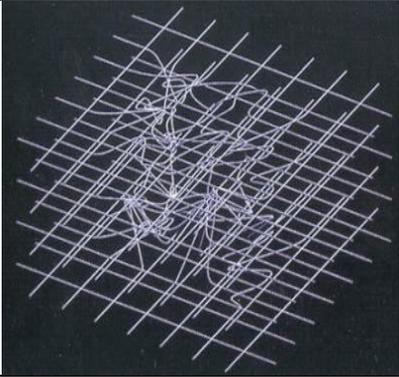


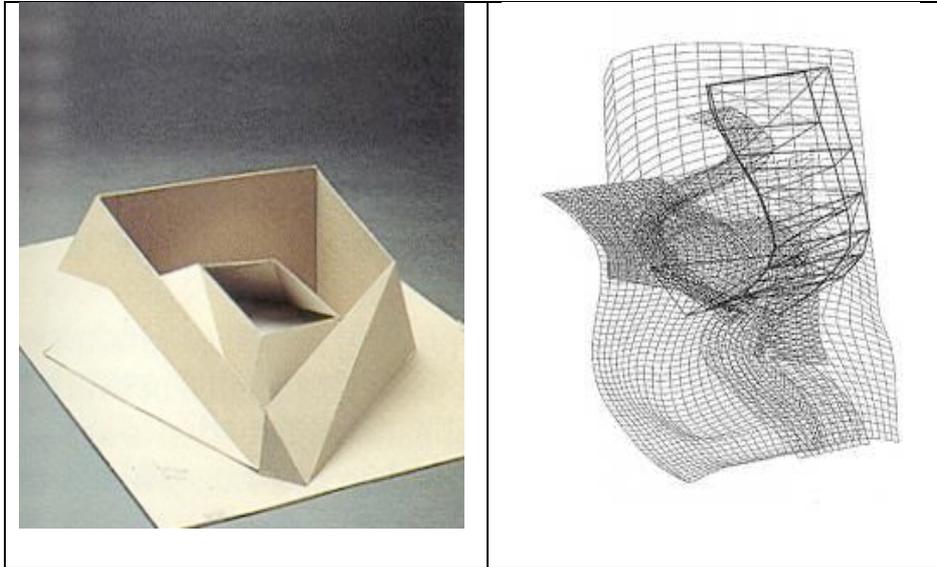
Figure 5-6. The diagrammatic model is an image of an organizational structure ((source: Galofaro (1999), Bédard (1994), Eisenman (2001))



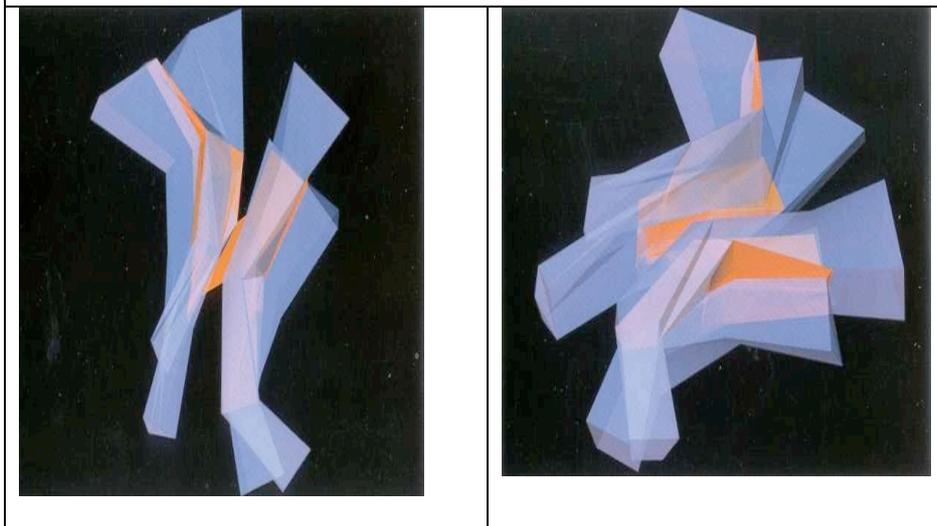
Figures 7-12. Phase 2: Deformation Strategies: Eisenman Finds a diagrammatic model that is relevant for the design. A diagrammatic model is an image that depicts some kind of structure, organization, or working of forces. A diagrammatic model may not be derived from the discipline of architecture. He Studies the properties of the diagrammatic model. Superimposes the diagrammatic model on the design. Finds an interpretation of the structure that he can use for deforming the current design. He translates the properties to deformations of the design. He uses for example densities in the diagrammatic model for contracting or expanding the design. Changes the geometry of the model along for example the lines of the

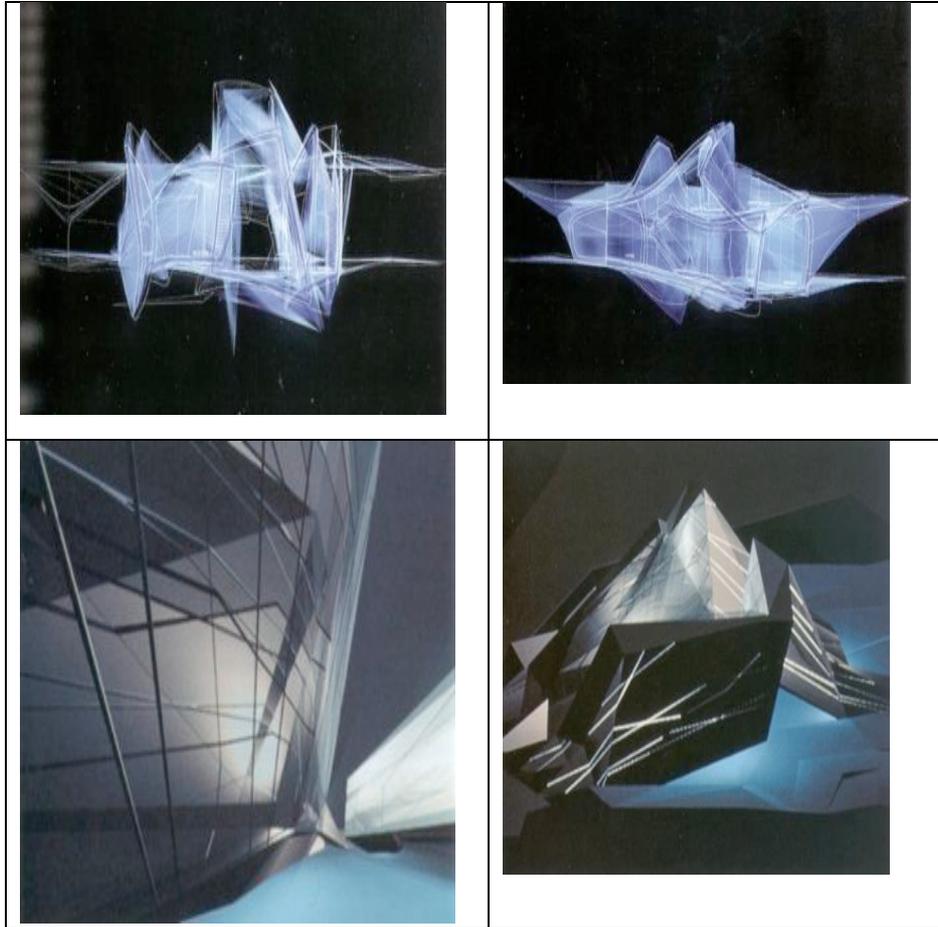


<p>diagrammatic model (source: Galofaro (1999), Bédard (1994), Eisenman (2001)).</p>	
	
	<p><i>Figure 12. Diagrammatic mode: Eisenman studies properties of the schematic model. The schematic model is superimposed on the different superimposed layers. He defines the influence of the schematic model on the superposition according its relation to the concept. He distorts the existing superposition on the basis of the schematic model. And he lets the drawing for example compress itself there where the schematic model shows a concentration of lines. Then he Follows lines in the schematic model (source: Galofaro (1999), Bédard (1994), Eisenman (2001)).</i></p>



*Figures 13-21.* Phase 3: Reflections about the design: Eisenman's method is very analytical and needs a lot of referential material. It needs reflections on how the superimpositions influence form and location of objects on the site. And how the deformation strategy influences the design. The diagrammatic model is an image of an organizational structure that is related to the core issue in the design task. It forms a metaphor for thinking about the design, and in which direction it should progress. In his work, the development of the building design and how it relates to the diagram is an important aspect. The diagram provides a handle on complexity as it hints to directions in which the solution can be developed (source: Galofaro (1999), Bédard (1994), Eisenman (2001)).





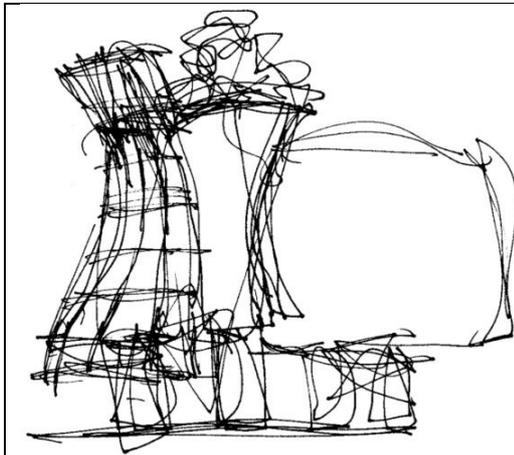
#### 4.2. FRANK GEHRY'S WORKING METHOD

Working method, as described in Friedman (1999), relies on experimentation with materials extends to process too. He works from a series of loose sketches and rough models that are scanned in 3-d and then developed as working drawings. The sketches and models are overlaid on the basic program requirements and Gehry sculpts the forms from there. The building is literally designed through the working models.

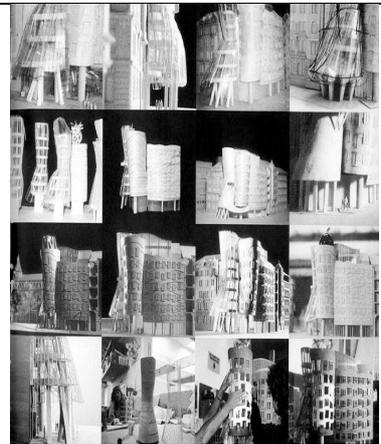
##### 4.2.1 Case Study (Figures 23-26)

The National Nederland building, Prague (1992-1996), it is one of the more controversial buildings in Prague is the "Dancing Building" also known as "Fred and Ginger". Designed by the California architect Frank O. Gehry along with the Croatian architect living in Prague Viado Milunic. It seems

out of place at first. Prague is one of the few cities in Eastern Europe to have escaped World War II with minimal damage. So this modern building almost stands alone amid the many historical buildings in Prague. It is designed in the tradition of deconstructive architecture. The building is situated on a site where American bombs accidentally destroyed a building at the end of World War II. When first looking at the building the left side seems to have been crushed thus recreating an allusion to the effects of the violence from the bombs. And yet at the same time it appears to be whimsical and dancing. In early sketches, Gehry envisaged the building as a scrumpage of boxy and pillow-like forms, to which Milunic added a geyser-shaped tower. Despite its undeniable panache and presence, the overall effect of Gehry's anthropomorphic collage is slightly disorientating (source: Fialova and Gehry (2003), Friedman and Gehry (1999)).



*Figure 22.* Sketch of the National Theater building, Prague, 1992-19: Gehry works from a series of loose sketches and rough models that are scanned in 3-d and then developed as working drawings (source: Fialova and Gehry (2003), Friedman and Gehry (1999)).



*Figure 23.* Scale models: Start of the design process Gehry sculpts the forms from physical models (source: Fialova and Gehry (2003), Friedman and Gehry (1999)).

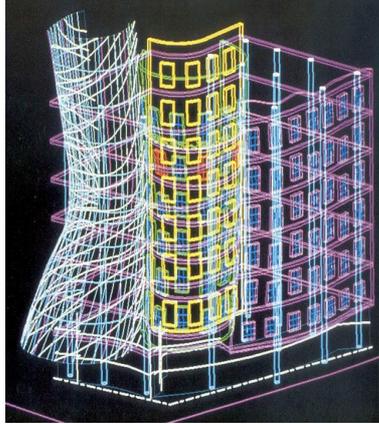


Figure 24. CAD model



Figure 25. Verification model: Verification of: Design Database For: Drawings (source: Fialova and Gehry (2003), Friedman and Gehry (1999)).



Figure 26. National Nederland building, Prague, 1992-1996 Frank Gehry's Search for Architectural Form Design process ,Sketches, Scale models, CAD models, Verification models, Finalised design (source:: Fialova and Gehry (2003), Friedman and Gehry (1999)).

## 5- Conclusion.

The work presented here shows a particular approach to teach CAAD in the context of architectural theory and design methodology. The aspects of ontology, method, and product provide a structure to derive teaching

material from literature on architects. The analysis can be extended to other architects provided they have some body of theoretical work. The goal of the course is to make students aware of the varied ways to use computers in design, to understand the reciprocal relationship between CAAD and theory, and to formulate their own position in this respect. A theoretical basis in terms of architectural theory and design method seems to be in contrast with the perceived freedom of design. As Christopher Alexander stated: "If you call it, 'it's a Good Idea To Do', I like it very much; if you call it a 'Method', I like it but I'm beginning to get turned off; if you call it a 'methodology', I just don't want to talk about it" (Taken from Cross, 1984). Design methods however, capture 'good ideas' and aim at a higher level of abstraction so that they can be more generally applicable. Design methods however, capture 'good ideas' and aim at a higher level of abstraction so that they can be more generally applicable. CAAD software now enables us to move freely through a number of design methods, and use them as a vehicle to question the design process, the design task, the design outcome, and the position of the architect.

However Many of these approaches rely on modelling geometry only, where the meaning still has to be inferred from the designer him- or herself. The research area of Information Modelling is aiming to tackle just this issue of semantics. The Design Systems group, at the Faculty of Architecture, Building, and Planning, Eindhoven University of Technology in Netherlands, is focusing on FBM as developed by van Leeuwen (1998) as the information structure. In order to link FBM with graphics representations, the group is aiming to describe so-called generic representations in terms of Features.

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## THE RELATIONS BETWEEN DESIGN-IDEA EMERGENCE AND DESIGN-SOLUTION DIRECTION

*Digital-Media Use in Mass Exploration of Architectural Design*

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**Abstract.** The unfolding of research is that design is a creative activity of problem-solving, directed to achieve what architecture should provide man with. The first part of the research investigates Design-Idea Exploration in the initial phases of design process, in terms of exploring the links between Design-Idea Emergence and Design-Solution Direction. The second part of the research presents a use of digital media in Design-Idea Exploration of three dimensional shapes throughout the initial phases of design process. The research has concluded the links between Design Ideas Emergence and Design Solution Directions, and presented the features of the program, which distinguish it from other standard modeling software.

### 1. Introduction

Working in three dimensional forms demands the architect to be more than just a problem solver. Design is much more than mere problem solving, however, this depends on the definition of the word of problem. Rowe (1987), citing Thorndike (1931), maintains that “to paraphrase Thorndike’s venerable definition, a problem can be said to exist if an organism wants something but the actions necessary to obtain it are not immediately obvious. It is hard to imagine circumstances under which the impetus for design is not covered by this definition”. In other words, designing is problem solving in a creative way. In addition, design problems are classified under ill-defined problems, which need various courses of action along the design process to be continuously defined.

A design idea and its exploration process, therefore, should be goal-directed to the main objectives of design and architecture, in order to provide man with his needs, as creatively seen by the architect. Media use should

correspond to the same context of thinking, not a deviation towards one objective (for example, esthetic, form, function, etc.) over the others.

## **2. Design-Problem Solving and Creativity**

Creativity plays an important role in the way design is created and completed. The bounded rationality that is a characteristic of design, refers to the concept that designers are rarely in a position to identify all possible solutions to a given problem; rather, they settle for what seems to relate to the required properties architects see at the time. According to Simon, this process is called “satisficing”.

In order to comprehend Design-Problem Solving, it is important to conceive how designers perform the tasks of the design process. There are many tasks and activities, which elaborate the unique nature of this process. The tasks of design-process phases (i.e. problem definition, conceptualization, representation, form giving, and evaluation) are simultaneously conducted without any particular paradigm. The design process has no ideal algorithmic pattern.

Design-Problem Solving encompasses an exploration activity of problem space. Design priority in the initial phases of design process is to collect and sort information related to the program, create the content of design concepts, and then shape the initial masses.

Design-Problem Solving manifests common characteristics of different individual styles of decision making and design making. The similarity of these characteristics is derived from differentiable streams that architects employ to solve the design problem. The solution direction chosen by an architect emerges from many realms (creativity, design problem, design thinking, etc.)

The strategies of design-idea generation and the overall organization of search through a problem space, are areas in which no general theory seems to exist. Many researchers, however, introduce the idea of the streams for partial solutions of design problems, by which the designer/architect utilizes assistance during the design process. From these streams of partial solutions, complete solutions can be derived, for example ‘patterns’ of Alexander (1977), ‘elements’ of Krier (1988) and Thiis-Evensen (1989), ‘enabling prejudices’ of Schon (1988), ‘visual chunks’ of Akin (1986), and ‘heuristics’ of Rowel (1987); A heuristic is any procedure that contributes to reduction in the search for a satisfactory solution.

### **3. Design-Idea Exploration and Digital Media**

Media and visual design thinking are inextricably related. Specific media or individual uses generate certain ideas, which may not emerge through different tools or uses of media. Media play an important role not only in Design-Idea Emergence but also in Design-Idea Evaluation, and consequently in Design Solution Direction. For design-idea exploration, three-dimensional modeling is the essence of digital media while sketching is the essence of manual media.

Each way of media use has its own characters that architects employ to benefit, modify, or reform the design ideas. The output derived from a certain use of media may defer from one architect to another, according to the personal style of design thinking and of media use. In other words, what might be conceived, perceived, and comprehended of a design idea, is related to how this design idea is modeled, presented, and represented by the type of media.

Three dimensional forms digitally generated by algorithms may introduce surprising results. However, delaying the validation of form, until it is digitally completely created, strays the content of design away from important architectural issues, and gives formalism the priority over main functions of architecture (such as: environmental, social, etc.) The initial ordering of Design Solution is relatively difficult to abandon and long lasting even against backtracking periods of design thinking.

Exploring design ideas along the initial phase of design process, through three-dimensional modeling of digital media, elevates the bases on which further design decisions are made. This media-use gives architects the clarity of what is being made, without depending on their imagining.

### **4. Design-Idea Emergence and Design-Solution Direction**

The research maintains that design ideas may emerge from different streams, namely: 1) inside or outside of design-problem context, 2) subjective or objective interpretation of design-problem ambit, 3) creativity, 4) use of media, or 5) prejudice of design thinking. Through processes of exploration and evaluation, impacted by the same foregoing streams, design ideas lead to design solutions. Creativity has not only an important role in these processes, but also an influence on the use of other streams. (Figure 1) illustrates the relationships between Design-Idea Emergence and Design-Solution Direction, which are linked through these different streams.

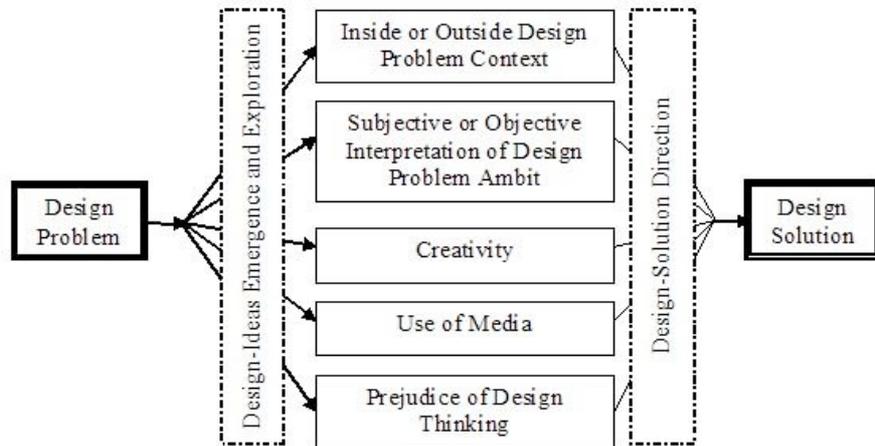


Figure 1. Relation between Design-Idea Emergence and Design-Solution Direction.

In most cases of design (one may maintain in all cases), more than one stream act as conspicuous features to dominate the design process, as one stream or organizational principle rarely suffices for all that is required to solve a design problem. In other words, Design-Solution Direction is generated from the array encompassing design problem's constraints and architect's interpretations.

## 5. A Program for Design Idea Exploration

This part of the research presents a Java program based on creating 3d shapes, in order for architects to create and explore initial shapes related to design ideas. This initial version of the program helps in the exploration of a 3d shapes combination that is used in design or urban design. The program displays eight camera positions that are located around the created drawing, with the option of controlling each camera position in Z direction through mouse drag, (Figure 2) to (Figure 8). The users of the program can explore a created drawing through two different ways: changing the position of camera from the selected eight positions, or rotating the drawing in one direction (X, Y, or Z) or all the three directions.

The main features of the program are functions of rotating and transforming the created form or forms in the directions of X, Y, and Z, by mouse clicking and dragging any point inside the boundary of one form to rotate or transform the chosen form (Figure 5), or by mouse clicking and

dragging any point outside the forms to rotate or transform the whole combination. The grid, also, can be solely rotated or transformed. The snap, grid limit, and grid view can be reset from the edit menu of the program. The program is based on creating 3d shapes, through controlling their dimensions and insertion point in two different approaches, namely: pull down menu, and mouse click and drag.

The famous 3d modeling programs (AutoCAD, 3ds max, FormZ, Sketch-Up, etc.) apply the approach of transforming the created drawing, when the user changes the camera position. The unique difference of the program from other standard modeling software is the approach of transforming the camera position (at eight positions) without transforming the created drawing, which allows the manipulation (of both the objects and the camera position) in the new created views. Rotating and transforming the created drawings in X, Y, Z, or all the three directions are available functions of the program.

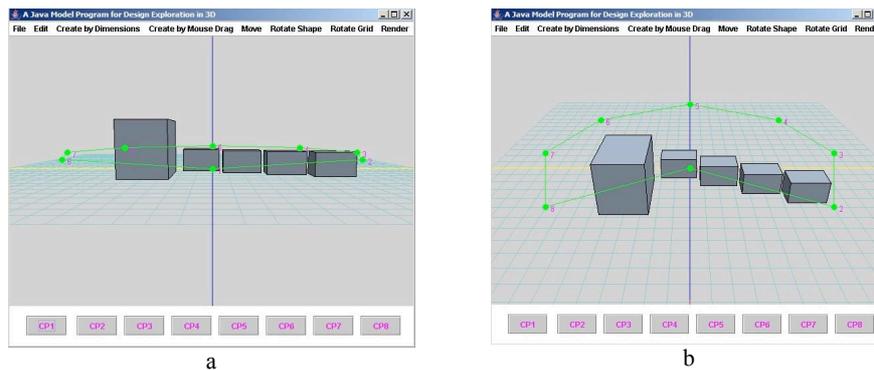


Figure 6. Camera position 1, a is from the default position, and b is from a higher position after dragging the point of camera 1 in Z Direction.

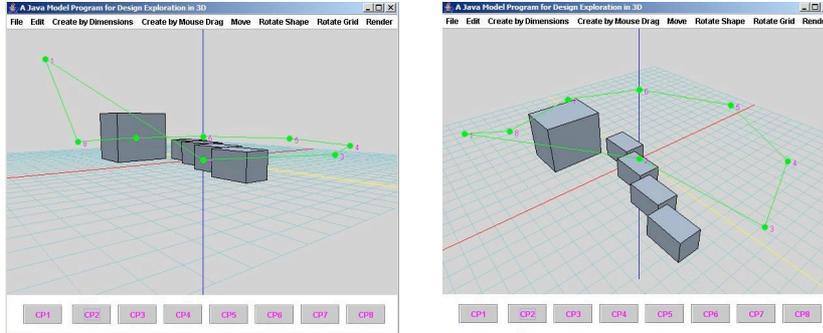


Figure 7. Camera position 2.

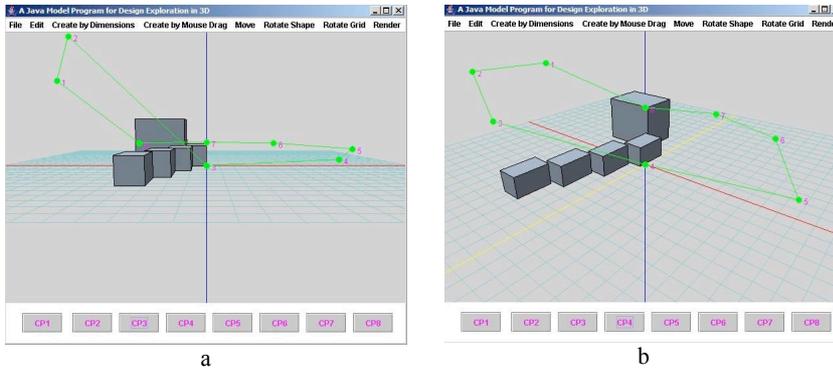


Figure 8. a is Camera Position 3 from the default position. b is Camera Position 4 from a higher position after dragging the point of camera in Z Direction.

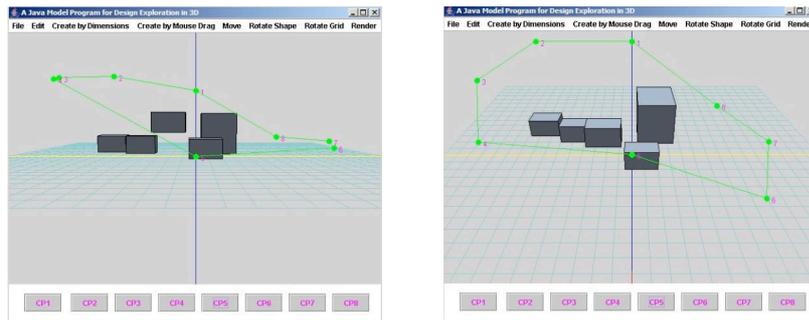


Figure 5. Camera position 5, (after moving 1st and 2nd shapes from the right in X and Y directions, and 3rd shape from the right in X, Y, and Z directions).

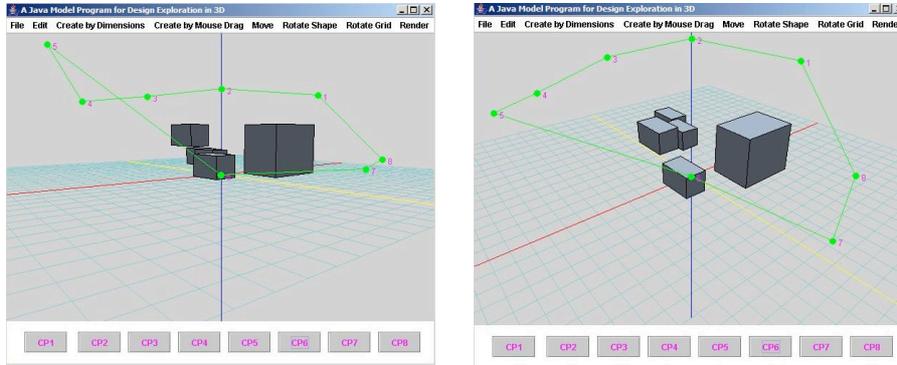


Figure 6. Camera position 6, displaying the transformed shapes.

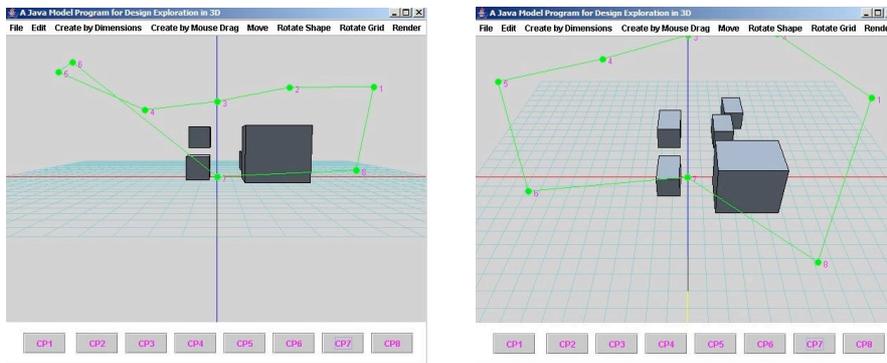


Figure 7. Camera position 7, displaying the transformed shapes.

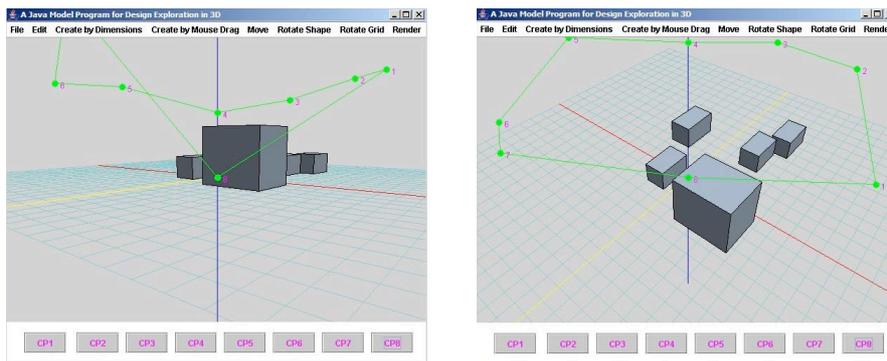


Figure 8. Camera position 8, displaying the transformed shapes.

The program creates simple three dimensional shapes (prism, pyramid, cylinder, and cone), in two different ways. First is by specifying the insertion point, the dimensions of base and height, and the number of sides (Figure 9). Second is by clicking the mouse to insert a shape with the specified default dimensions and number of sides, and then through dragging the mouse according to the specified snap and grid, shape's dimensions can be controlled.

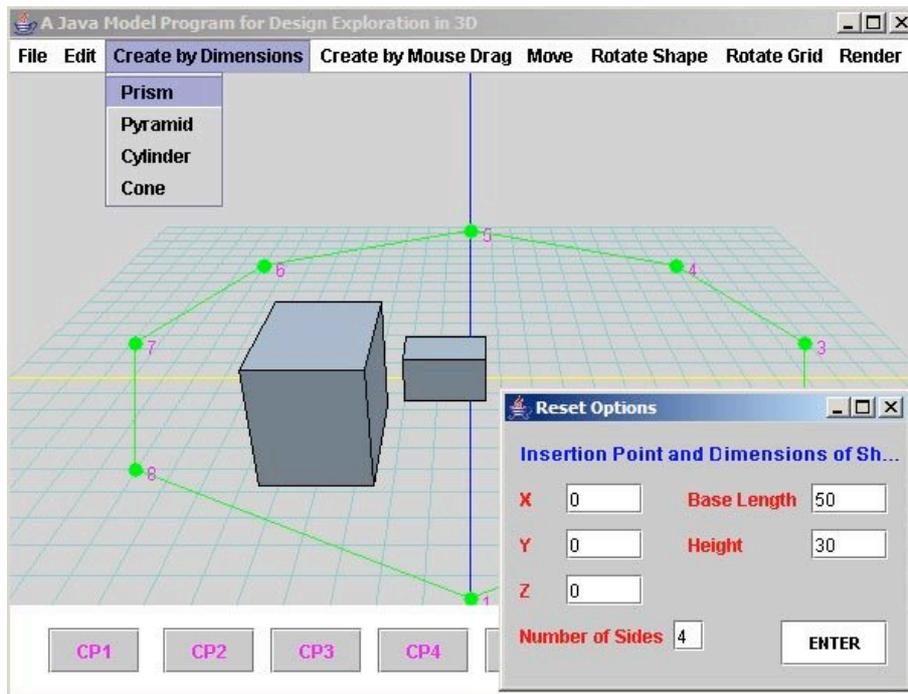


Figure 9. The default camera position of the program with a combination of shapes, created by specifying the insertion point and dimensions from the program poll down menu.

The program help architects explore 3d masses of design ideas they work with. This exploration process, through program's potentials, raises awareness of the proposed forms and their relationships. The feed back derived from these processes effectively helps in choosing between tentative design ideas and design solutions, and consequently in performing the design process. Decisions made in the initial phase of design process, therefore, would have clearer bases than ones that depend on our imagining. To continue in conducting the design process, architects may proceed or modify their initial designed forms. Finalizing the initial design into the proposed forms, architects may have the design into different media types for more details.

## 6. Conclusion

Design ideas and their exploration process should be goal-directed, derived from the creative vision of architect. The research explores the streams from which Design Ideas emerge, and builds the links between Design-Idea Emergence and Design-Solution Direction.

The research presents a java program in order for architects to create and manipulate three dimensional shapes, and explore their combination. The main approach of the program, which represents the unique difference from the other modeling software, is applying the transformation of camera position (at eight positions) without transformation the created drawing, which allows the manipulation (of both the objects and the camera position) in the new created views.

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## **Section V: Digital Visualization and Reconstruction**

## STRUCTURAL PERFORMANCE MODELING IN ARCHITECTURAL DESIGN EDUCATION

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**Abstract:** In architectural education the process of design has evolved with the development of CAD technology. In many design schools throughout the world, the computer has extended its role beyond that of a drafting machine to become a tool for performance modeling. Applications currently used by students test lighting, thermal conditions, and structural validity, to name a few. However the goals in education are not identical to those in practice, and digital modeling can support learning in many ways that are not particularly useful or appropriate in professional practice.

In the design of structures there are three fundamental levels of understanding: *behavior, form, and performance*. Each has its place in design education and uses digital modeling in different forms. This paper describes various pedagogical models that incorporate computer aided drawing and performance modeling in the teaching of structures. Examples of student exercises and projects are discussed.

### 1. Beginnings: Computer Aided Structural Modeling in Education

Modeling plays an important role in design and is a key element of the design process. The introduction of digital modeling in architecture has had a powerful influence on the manipulation of form, so much so that many designers equate the transformation in design thinking to that which was attributed to the invention of tracing paper or even further back, to the discovery of perspective drawing. Each tool was a means towards better visualization and provided the designer with a new way to envision space and three-dimensional form.

In architectural education digital modeling has penetrated many areas of study in addition to design. One of the first was probably building technology, namely structures. Civil engineers adopted structural modeling as a primary design tool years before architects adopted CAD for production

use and later, 3D modeling. Early structural modeling programs such as STRUDL and SAP were introduced in engineering schools in the eighties. The early versions of these applications were not visually oriented. They were primarily programmable calculators designed to solve simultaneous equations in matrix format in order to determine member forces and stresses in a loaded structure. Hence the input and output was numerical. Using the method of finite element analysis enabled engineers to analyze even more complex structures such as shells, warped surfaces, stressed skins and membranes.

With the advent of the graphic user interface and the development of improved vector imaging, the presentation of structural behavior and performance in graphic form (as opposed to lists of coordinates and computed numerical values) gave designers a tool with which to visualize the effects of load and stress on a structural framework. This new ability to demonstrate behavior (e.g. the representation of deflected members) was recognized by educators as a potentially powerful teaching tool. A significant article published in the architectural journal JAE in 1994 described a new approach in structural education that employed digital modeling for observing structural behavior (Black and Duff, 1994). In the article the authors outlined an approach for teaching structures in architecture that incorporated digital modeling and finite element analysis. Their methodology was based on twelve tenets that ranged from defining the scope of engineering content appropriate for the education of architects to reaffirming the use of labs in teaching structures. Fundamental to their approach, however, was an integrated studio-based curriculum that incorporated both digital performance and physical form models in exploring structural concepts, and verifying structural behavior.

This methodology went against conventional wisdom that had more or less excluded the use of advanced structural modeling in architectural education on the assumption that architecture students did not have the structural background or knowledge to be able to correctly model structures (input) or comprehend the results of the analysis (output). Those opposed to using the computer saw it, as a "black box" that would provide numbers and 'results' that could not be verified by the non-professional.

Digital computer analysis can and should be supplemented by other methods of evaluating structural behavior, such as by approximate hand calculation or physical modeling. A good structural designer will know before performing a detailed computer analysis what the outcome is likely to be. By analogy, one might say that the computer is more like a device that sharpens one's eyesight as opposed to enabling a totally blind person to see. An informed intuition for structure should always accompany the precision of a digital analysis. It is also essential to see the computer not simply as a tool for making analysis easier (or possible, as in the case of indeterminate

structures) but rather as a new instrument for discovery. The example of Galileo using the first telescope not simply as an aid to navigation but as a tool for planetary discovery is quoted by Black and Duff (1994). In this sense the computer might be used as a device to reveal new information and thus encourage the exploration of structure in new ways. For the computer does possess enormous potential to enhance our understanding of the behavior of both simple and complex structural systems.

## 2. Types of Digital Models: Form, Behavior, and Performance

In design education, three forms of structural modeling can be identified. First, computer modeling in architecture can be used to evaluate and study the *form* of structure. An architect requires visual representations; both representative and abstract, in order to make decisions about the formal characteristics of a building structure, especially where the skeleton of a building is revealed and tectonics play a more significant role. This is a more qualitative aspect of the design process and computer modeling has introduced many sophisticated techniques that enable designers to visualize form more easily and see the implications of structure on other aspects of the building design.

Second, the computer can be used as a tool for revealing the structural *behavior* of systems, subsystems or individual elements. In this role a digital structural model is especially useful as a teaching tool to explain concepts and foster an understanding of the basic structural principles. The graphic display capabilities of today's modeling programs (with both static and animated representation) provide many options for depicting the behavior of structures under loading and thereby providing a visualization of the otherwise unseen structural response.

A third use of modeling is for the verification of design proposals. Most often the term structural modeling refers to the use of structural analysis software to predict the effects of load on elements of a building structure so that member types and sectional properties can be determined. In this role the computer is used to test the *performance* of a structure by calculating the structural model's response to applied loads. This is a quantitative analysis and is the traditional function of computing that the engineer employs to size members, predict deformations, and check overall stability.

In the text that follows each of these applications is described and illustrated with studio exercises that demonstrate various approaches in using modeling software to understand, evaluate, and employ structures in building design.

### 3. Visualizing Structural Behavior

Architecture students traditionally encounter difficulty with aspects of structure that involve the calculation of forces and mathematical modeling. In particular, the construction of internal shear and bending moment diagrams is an especially abstract exercise for non-engineering students. Yet the insight that can be gained from these graph representations of structural member forces makes them an invaluable aid to understanding structural behavior.

The introduction of computer analysis has simplified the process for architecture students. Digital structural models that can be 'tested' are easy to create using current software. Once the basic parameters of a structural model (joint type, reaction type, member section, load representation and placement, and overall geometrical configuration) are known, it is a straightforward process to model and test a structure using any of the new graphically oriented structural applications. Using a program such as *MultiFrame®* for example, a basic truss can be modeled in minutes and, with loads identified and placed, an analysis will instantly produce performance measurements in the form of member forces/stresses, reactions, and accurate deflection profiles indicating the predicted movement of the structure in an exaggerated, and thus, visually enhanced plot. If desired, these shear and moment diagrams can be displayed for any member in the structure. Varying a single parameter (eliminating half the loads, for example) will produce new results that can be compared to the first and so on, leading to insights into the behavior of the structure and the potential for improvement. The model is interactive and the designer can test any number of assumptions about the geometry of the truss, the effect of pin versus rigid joints, the efficiency of the member sections, or the effect of alternative materials.

The interactive nature in using structural analysis software in this way offers many interesting pedagogical applications. Black and Duff (1994) have introduced a series of exercises in structural behavior that is reminiscent of *reverse engineering*. In a lab class, Black provides his students with a partial analysis of a simple structure in the form of load, shear, moment and deflected shape diagrams. From this output information students are asked to work backwards to 'discover' the configuration and support conditions of the original (and unknown) structure. (Figure 1) It is a challenging puzzle that induces students to consider the relationships between load, shear, moment, member deflection, and the types of connections or supports involved. The computer model can quickly test hypotheses in an informed trial and error process. The author has also used the exercise with excellent results.

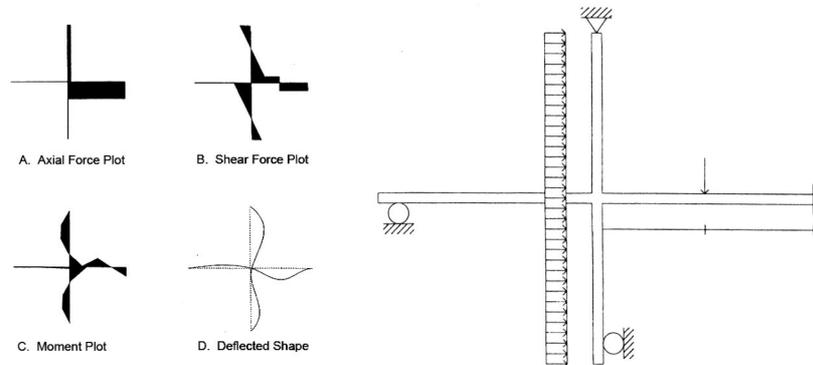


Figure 1. Example of a “reverse engineering” exercise. (Black and Duff, 1994)

For some structural behavior investigations an ordinary CAD drawing program is all that is needed. Take for example graphic statics. This is a vector drawing analysis technique developed in the 19th century to predict the behavior of many types of structures including trusses, arches, frames and beams. It was devised with the drafting table in mind. However, since the method only requires the accurate positioning of vector lines, any application that enables line drawing can be used to construct a graphical analysis of a proposed member such as an arch. The analysis will reveal the magnitude and direction of forces in the structure and lead to its design. This process can also be inverted into what Edward Allen; a leading proponent of graphic statics refers to as 'form finding' (Allen, E. and Zalewski, W., 1998). On the computer, a graphic analysis diagram can be easily modified to account for changes in loading and geometry.

A way to make the above interactions even more dramatic as a visualization is to employ some form of animation. Using *Flash* for example, the effect of force on a structural form can be made into an animated clip enabling the displacement of the structure to be viewed as a continuous motion. This can be very helpful in describing lateral force effects such as those due to wind or seismic loading. Using *Java* programming language, interactive programs known as 'applets' can be created to produce interactive loading diagrams (Luebkehan, C.H., 1996). In 'Pencil Tower Loading' a multi-story tower is illustrated with wind forces acting on one side. Shear, moment and deflection diagrams are shown alongside the tower. There are three 'controls' that the user can interact with: building height, building width, and wind load. Increasing or decreasing the

magnitude of either of these controls instantaneously modifies the diagrams giving a visual and numerical measurement of the behavior of the tower.

#### 4. Visualizing Structural Form

Computer modeling can be used to create a detailed, realistic image of a proposed design. This type of rendered 3D image has advanced to the point that one can barely tell the difference between the real and the imagined project. Walk-throughs enable a designer (or client) to experience views of an un-built work and decide if further improvement or change is needed before construction begins. These forms of rendered 3D models can be used to illustrate aspects of structure for the purpose of studying the relationship of scale, detailing, material selection and many other structural characteristics in relation to space, lighting, building envelope, and other systems.

In studying the formal relationships of buildings: abstract, diagrammatic views are helpful in visualizing the principle formal characteristics of architecture. A building case study analysis will generally attempt to deconstruct the finished project in order to discover important structural relationships that may be obscured by the complexity of the totality of the work. The pattern of the structural supports and framing, the alignment or placement of structure in relation to the spaces of the building, and the relationship of the building's exterior envelope and the structure are revealed more clearly in an edited image. For this kind of analysis the computer is a powerful tool. Two common features of most 3D modeling software that are especially useful for depicting hidden relationships are *layers* and *transparency*.

The concept of layers is fundamental to CAD software and needs little explanation. Different types of information are grouped and drawn in a layer, which can be turned on or off. This enables a designer to examine various systems of a building in isolation or in relationship to any other system or group of elements. In design education this can be a valuable tool for revealing the sometimes hidden formal organizations and strategies that are fundamental to the best architecture. Pattern, proportion, thematic variation, hierarchical strategies, zoning, even the concept of 'layering' can all be isolated and made more visible and comprehensible. By reducing the amount of information and eliminating unrelated and visually obstructing portions of a building, the structural design can be revealed as a form itself.

In a building with a repetitive structure it is common to study a single unit or bay. The CAD model can easily isolate a bay and focus on its primary design characteristics. In a student analysis of the Tung Chung MTR Station, a built project of Rocco Yim Associates in Hong Kong, a series of layers is used to illustrate the different components of the structure and

envelop assemblies (Figure 3). Seen in succession, the 3D images re-create the sequence of construction illustrating how the building is built. Each drawing adds the next layer of assembly: primary structural frame, curtain wall frame, glazing and skylight, and finally cladding and sheathing elements.

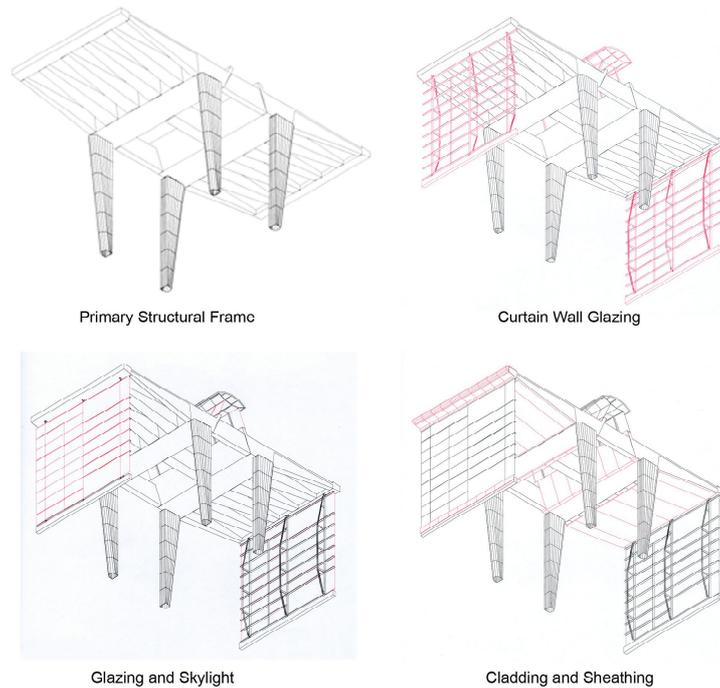


Figure 2. Analysis of a bay of the Tung Chung MTR Station. Student Project by Chiu Chun Kit and Lee Shuk Fun.

For the same case study, an investigation of the frame uses a structural analysis application (*Multiframe 2D*) to determine the effect of the position of the columns on the bending moment distribution of the frame. As the loadings used in the analysis do not attempt to reflect the actual loads that might act on the structure, the results are qualitative in nature. Nonetheless, the graphic visualizations of deflected shape and moment distribution offer insights into the behavior of the structure and its implication on the form of the double-cantilevered frame structure. (Figure 3)

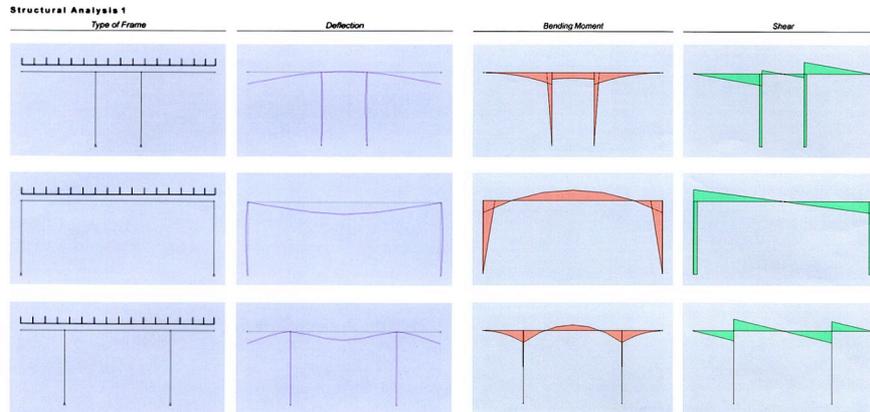
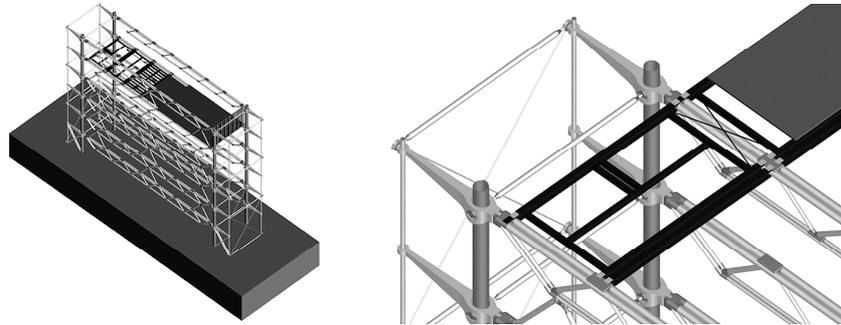
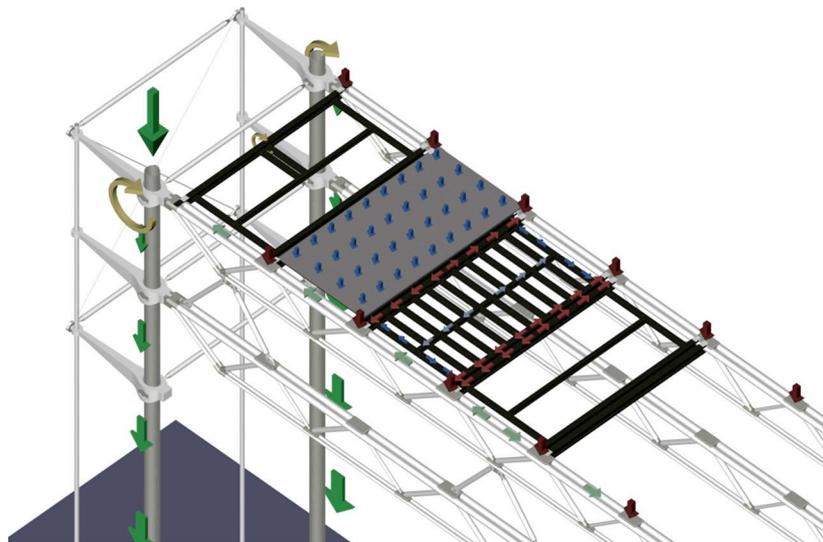


Figure 3. Structural behavior analysis of Tung Chung MTR Station. Student Project by Chiu Chun Kit and Lee Shuk Fun

A rendered model is sometimes preferable to a line image for highlighting particular features. In a case study of the Centre Pompidou in Paris, a key work of the mid-seventies, the configuration of the floor framing is accentuated with a solid model rendering. (Figure 4) The relationship of the floor framing to the long span trusses is isolated and the layers of floor construction are peeled away. The contrast of the dark floor components against the light-toned structural frame reveals clearly the hierarchy of structure. An additional advantage of the digital model is the ability to zoom in to a critical element or connection. A close-up view of the model shows the floor framing and its relationship to the principal trusses, the cast steel gerberette end supports, and the connections of the truss members. (Figure 5) Using the same model, arrows are inserted to indicate the load paths and explain the built-up, hierarchical layering of the framing system. (Figure 6)



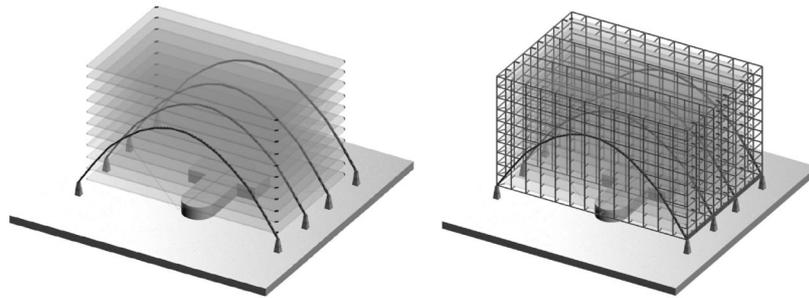
*Figure 4. A structural bay and detail of Centre Pompidou by Piano and Rogers. Student case study project by Abdulilah Saad, Andaleeb Taher, Fatma Al-Sahlawi and Talal Al-Ansari*



*Figure 5. Load trace diagram on Centre Pompidou. Student case study project by Abdulilah Saad, Andaleeb Taher, Fatma Al-Sahlawi and Talal Al-Ansari*

In a case study analysis of the Exchange House, a building designed by SOM for the Docklands Development in London, transparency is used in addition to layers to illustrate the position of the four main structural arches and the framing structure that is carried by them. The first view identifies the primary structure of the four parabolic arches enmeshed within the floor

plates of the building. The second view adds the layer of the columns, beams, and hangars that comprise the secondary orthogonal framing system. (Figure 6)



*Figure 6.* Two views of Exchange House, Skidmore, Owings and Merrill. Student Case Study Project by Mona Ganjineh, Leila Motahedan, Tarik Nour, and Mohamad Rushdie

## 5. Digital Models in Studio Design Projects

In architectural education a design project is an exercise in synthesizing form to accommodate certain functional and contextual conditions. The parameters of the project help to determine the focus of the design investigation. For example, a design exercise might focus primarily on structure and space, limiting the consideration of site, program, and other issues normally considered in a real world design project. Pedagogically this enables a design student to explore particular issues (e.g. structure and space) in depth in a relatively short time.

Wall-Plate-Frame is the name given to a series of exercises that explore three short span, structural system types and the space defining characteristics of each. In each exercise, 3D models in FormZ provide the means to create a range of analytical diagrams. One of the key features of a solid modeling program is control of the opacity (and its opposite: transparency) of the solid elements. Using this tool allows one to reverse solid and void representation in a design: interior spaces (voids) are rendered as solid masses, giving them tangible form and allowing them to be read through the structural matrix of solids. Secondary infill elements (habitable poche) can be introduced as a separate layer of solids and seen as an intermediary between primary spaces and structural solids. (Figure 7)

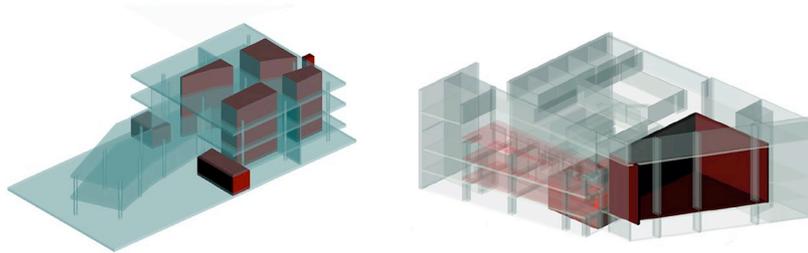


Figure 7. Two student design projects that use transparent structure to reveal the placement of non-structural solids (left) and principal spaces (right). Ahmed Al-Daqa and Waleed Hashim.

By simply switching layers on and off, the digital model can combine many different systems for comparison and study. (Figure 8)

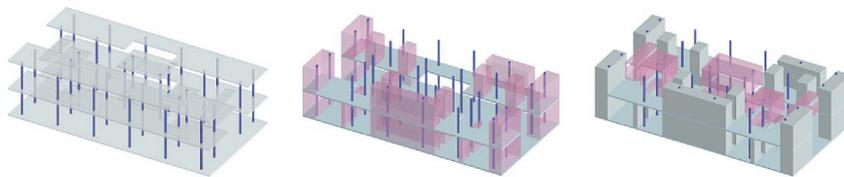


Figure 8. Three views of a Plate System Project: Structure, Structure + Infill, and Structure + Infill + Spaces. Project by Fatma Al-Sahlawi.

## 5. Creating Structural Form with Digital Modeling

New possibilities for creating structural form are emerging with the use of digital modeling. Although structural analysis applications are making it easier to verify performance, they are designed to aid in the synthesis of form. Created primarily to compute large structural frames with Cartesian geometries, they are less adaptable to the new wave of non-Euclidian *smooth* architectures. The structural forms that can support and provide armature for these curved and non-linear shapes are usually derived from architectural digital models whose coordinates are then imported into a structural application in which a finite element mesh is created to analysis the structure. Interestingly, the software most often used to model these forms is borrowed from related fields such as industrial design.

Product designers of objects ranging from toothbrushes to jet airliners have had to grapple with smooth, curved shapes whether because of ergonomics, physics, or just plain style. Their embrace of 3D modeling software preceded that of architects out of necessity. But now, as the current trend towards non-rectilinear shape grows, more architects are adopting various modeling software common to graphic artists, ship designers, and toolmakers to experiment with and to use in shaping complex form.

The role of the structural designer in this has become increasingly more challenging. Although a 3D model of an architectural form might exist, there must still be a design for the structure to accommodate the shape. That structure may be simply a three dimensional grid frame composed of linear elements whose overall shape follows the contour of the building. This describes the approach of Oosterhuis (2003), a leading designer on the forefront of what he calls an “E-motive architecture”. The genesis of the design is formally driven and the designer is confident that a suitable structural assembly can be devised.

This is not the same as an architectural form that is derived from structural invention. In that camp we would find a long line of engineer architects from the early masters like Nervi, Torroja, and Freyssinet, to present-day innovators such as Frei Otto and Calatrava. Most did not use the computer, relying instead on physical models to test performance. While the basic forms were not limited to rectilinear geometry, a mathematical relationship between shape and structural behavior was a guiding principle that might be seen as a kind of bridge between formal expression and computer analysis.

One technique that is currently being employed to define non-orthogonal shapes with a relationship to structural form is *parametric modeling*. Kolarevic (2003) explains how a parametric design is described not by its shape but rather by a set of values or parameters that can be varied in such a way as to produce complex, formally unconventional shapes. Using the example of Waterloo Station by Nicholas Grimshaw Architects, Kolarevic indicates that although parametrics are useful in generating a 3-D model of a complex building form, the success of the method requires that a well-conceived concept of structure that addresses basic tectonic issues must first be envisioned. For example, in Waterloo Station the scheme of a three-hinged trussed arch, asymmetrical about its axis, and varying in span, satisfies the site condition of a tapering rail terminal with differing height requirements from side to side. Based on this sectional concept, a parametric model could be defined to account for the incremental adjustments that would occur along the axis of the shed, resulting in 36 topologically identical trussed arches that vary from a maximum span of 48 m to a minimum of 35 m. (Figure 9)

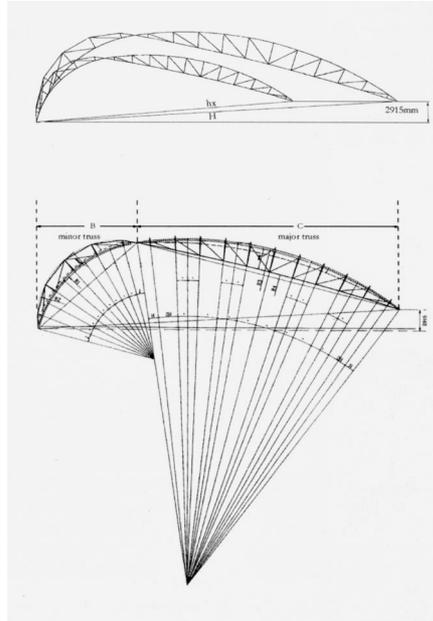


Figure 9. Waterloo Station, Nicholas Grimshaw Architects.

## 6. Summary

It may be obvious that applications of computer modeling in architectural education are numerous and diverse. For example, in the design of structures there are now many specialized applications that test performance through modeling and quantitative analysis. These applications are finding use in the teaching of structural behavior and in some instances, are being used in the design process. Yet the most benefit of digital modeling in architectural education today seems to be in enhanced visualization, that is, using the unique capabilities of the computer to make the manipulation of form easier and to construct new types of analytical views that reveal aspects of form (structural patterns in relation to other building systems, for example) that were previously too difficult produce. In the future CAD will play a decisive role in shifting our attitudes towards form. It will provide tools to increase our ability to create complex form and work with it in three dimensions. It should also continue to provide us with better techniques for investigating structure through the visualization of behavior and form.

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## ISLAMIC ARCHITECTURE AND DIGITAL DATABASES

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**Abstract.** Epigraphy in Islamic architecture represented an indispensable element in its conceptual design and structure. Our research investigates this unique role, which epigraphy played in Islamic architecture as a tool singularizing this architecture and the sensuality it inspires inside a building while bestowing on it its particular identity. This how SADEPIG came to being: it is a virtual database regrouping all the information about the monumental epigraphy which date from the Sa‘dian period in Morocco (1527-1660). The digital corpus of monumental Sa‘dian inscriptions provides also buildings plans, virtual tour within the monument, construction details, information about the identity of patron and builders.

### 1. Islamic Architecture

“Islamic architecture”, is a vast term which involves an immensely rich diversity of architectural traditions and ideologies; it’s exactly where resided always the geniality of this architecture. Islamic architecture engaged and reformulated many building traditions, practices and applications, which it then re-used with a new concept in a new context. Hence, in spite of the multiplicity of Islamic architectural styles and technical aspects according to the region, yet no eye can miss it is Islamic.

One of the most significant aspects of the Arabic Muslim architecture is the recourse to the use of calligraphy as an important decorative element. The erudite combination between the Arabic scripts and floral arabesques as well as geometric interlacing opens the gates wide open to infinite possibilities of compositions, which enchain a dialogue between the light and shade while insisting on subtleties of colours and forms (Khatibi, 1994, p.191).

The outstanding flexibility of Arabic letters, the rhythmic movement of its compositions in addition to the harmony of its signs bestow grace

and vigour to the entire edifice. Whether they would be capitals of columns, vaults, pillars, walls, or gates and windows, they are all endowed by epigraphic engravings; painted or sculpted they produce a seizing meditative effect (Khatibi, 1994, p.191).

## 2. Role of Epigraphy in Islamic Architecture

It is “*Mightier than the Sword*”<sup>i</sup>, our Arabic script featuring in our buildings, whether externally or internally, involves both the beauty of proportions and artistic execution as well as transmitting a profound meaning. That is to say that here the Islamic religion is introduced to provide both a sense of the beauty of the script and its spiritual context. Arabic calligraphy is an authentic Arabic Islamic art form and it associates the literary heritage of the Arabic language with the Islamic religion. From where emanates its extraordinary beauty, richness and power? Calligraphy means “beautiful handwriting,” and in Arabic tongue it also means “the geometry of the spirit.”

The idiom which states that “*The pen is mightier than the sword*” expresses a worldly widespread recognition of the power of the written word. Moreover, In Islamic culture, the particular importance accredited to writing found its roots in the fact that Arabic is both: the language of God's revelation to his Prophet Muhammad and subsequently the script in which it was written down. This is how the Arabic script has occupied a unique significance in Islam (Niewöhner, 2004, p. 574). The script has become a defining ideological feature of the material culture of the region we can broadly call Dar al-Islam; a vast area that one time has stretched from Spain in the west to the Malay states and Borneo at the farthest east (Hattstein, 2004, p. 9). The Arabic letters revealed a unified identity ideologically but diverse aesthetically, when we contemplate and read what's inscribed on various objects coming from the different corners of Dar al-Islam, we realize how the forms of Arabic letters change their shape according to epoch, region and material – whether it be a paper, a parchment, a coin, a tombstone, a metal bowl, a ceramic tile or a wooden frieze (see some examples in Table 1 below).

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<sup>i</sup> “Mightier than the sword: Arabic script beauty and meaning” was the title of a touring exhibition from the British Museum at The Ian Potter Museum of Art, Melbourne: 2003

TABLE 1. Examples of Islamic craft work embellished with Arabic calligraphy

 <p>Count Bobrinski cauldron, Herat 1163, Hermitage, St. Petersburg.</p>	 <p>Marble decorative panel, Ghazni, 12<sup>th</sup> century.</p>	 <p>Koranic Casket, Cairo early 14<sup>th</sup> century, Berlin Museum of Islamic Art.</p>	 <p>Glazed pottery plate, Iran or Transoxania, 10<sup>th</sup> century, The Louvre Museum, Paris.</p>
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This script didn't stop inside its local borders, but migrated to Europe for example, where the Arabic script as a pattern reflected the fascination in Europe for exotic objects coming from the Middle-East, so we see for instance how the Arabic script transformed into pattern in Renaissance painting and in pottery imported from Islamic Spain. As far as in China and Indonesia there were objects made for Muslims at the Ming Court, featuring both Chinese and Arabic calligraphy and all sorts of artistic testimonials on the remarkable synthesis that took place in the exchange between the local and imported styles. The chef-d'oeuvres of calligraphy became prestigious collection materials; they are preciously preserved, collected and negotiated at "astronomical prices" (Niewöhner, 2004, p. 574).

In Islamic Architectural History, textual decoration played a distinctive role. In façade decoration as in interior design programmes, epigraphy had always its place reserved in a conscious hierarchical decorative program within the different parts of a certain building. For example, in a mosque of a "T" plan, the textual decorative scheme would be sumptuous in this area of intersection between the transverse nave and the central axial nave of the prayer hall. That's because this intersection hosted the most sacred part of the sanctuary which is the *mihrāb* orienting the praying conglomeration towards the *qibla*; that's to say towards Mecca; the most sacred city of Islam. Consequently, specific Koranic verses were always chosen particularly for this place of the mosque to emphasize its function within. More specifically in the Moroccan and Andalusian medieval world, poetry was the summit of all

aspects of daily life. Hence we find it adorning all the palaces and houses; wooden ceilings, marble columns or fountains, stucco panels all tell us the story of the building and describe its beauty and architectural genie in poetic stanzas composed specifically for its several parts.

Reading the text is nothing but the first step on the way to establish the original context. The inscription has to be exposed to a “multipronged exegesis” in order to be able to reveal the circumstance when a certain quotation was cited. What must be taken in consideration is for instance: its location in the building, its role in the society, its place in contemporary cultural, popular, theological or even political arguments (Edwards, 1991, p.70). In Islamic architecture, indeed stone and brick delineate the building constructional structure, but it is the left to words to set up the ambience and sensational vibes. That’s how words cloaked in friezes of “architext”, became a constructive ingredient in the building that they embellish (Edwards, 1991, p.73).

The question is: can we set out a wider theoretical framework? Can a broad definition of Andalusian poetry and its *muwashahat* together with a demonstration of these poetic effects in architecture help in this aspect? The idea is to apply poetic ideas and their methods of thinking to architecture, asking what poetry in Islamic architecture is and how one can recognise the “poetic” in particular buildings or edifices.

### 3. Poetry and Islamic Architecture

Many western studies aimed to explicate poetry as a mode of thought and through the analysis of poetic thinking; they excelled in demonstrating the connections between poetry and architecture. Some studies managed to prove that the methods of poetry can illuminate architecture both theoretically and practically. The module explores the relations between these two corpuses of human knowledge and versions of sensual thought, poetry and architecture. Further studies applied techniques transferred from poetry to the understanding of architecture;-they stressed the usefulness of adopting various versions of rationality and irrationality for understanding design solutions.

Can we apply this to the understanding of medieval Islamic architecture? Two parallel threads of thinking are followed: on one hand, from the point of view of the poetry employed in this architecture, or rather composed and designed to ornament it, on the other hand, through tracing the relation between the poets and their poetry on the one hand and their influence on architects and their visions of design as well as the taste of the time on the other. To do this, the use of historical and cultural materials imaginatively in pursuing

such questions would be essential to construct a clear and forceful argument; and hence interpret prominently the cultural setting within which the architectural and the interior design took place.

Those architects whose reputations rest as firmly on their eloquent writings as on their designs and buildings can be traced through the evolution of the genre in Europe from the 15th to the 18th centuries; during this period many of the conventions that still guide architecture theorizing in the West were formulated. Many questions were asked about the relationships between writing and building, between theory and practice. Do the two creative forms illuminate, complement, or contradict one another?

Reading architecture as poetry, or poetry as architecture, leaves us in the particular position of reading poems that shall be taken as windows without limit. If we think of any poem, we shall dwell within that poem, persisting through space and time; moreover, we shall dwell at all times within, without giving up our standing outside. The same effect was meant to be achieved in two ways on the dweller through reading the poetic texts in the medieval Moroccan and Andalusian buildings; a non existing dimension was created through imagination, through metaphoric images and exaggerations in the poetic description of the standing edifice, in addition to the impact that was created within one's spirit imposed by the architectural designing language and tools.

Just as in architecture, poetry tends to organically regulate itself, as it ensures the balanced proportionality of all its components. Through exploring the vocabulary of Moroccan and Andalusian architecture and its ability to affect visual perceptions, our investigation is not merely confined to an analytical approach but invites the viewer of a Moroccan or an Andalusian monument to enjoy and indulge in the experience of poetic space and space of poetry.

Realizing the magnificent, unique role, epigraphy played in Islamic architecture as a tool singularizing this architecture and the sensuality it inspires inside a building while bestowing on it its particular identity within the earthly different types of architecture was what generated our work of research.

#### **4. Islamic Architecture and Modern Technology**

Technology is an indispensable necessity incorporated in every possible domain and aspect of our daily life now. Having a digital database gathering these architectural inscriptions would facilitate our knowledge process by having all necessary and precise information just by clicking a button on

computer screen. Not to mention the comparative means of research, hence visually accessible also on the screen.

Recently a lot of databases and special computer programs or software were developed and designed specifically to contribute to the modules of improvement of pedagogical tools of teaching and studying the Islamic art and architecture. Not to mention the crucial importance of documentation and information registration of Islamic monuments which have disappeared already or about to or even worse because they suffered from erroneous restorations which inhibit us for ever from contemplating the original status of a historical monument. So applying the modern technology to extensively advance and progress in our research of Islamic monumental epigraphy was a crucial necessity:

In the light of the progress of methodology of studying Arab epigraphy, the creation of our database for Moroccan Sa'dian and Andalusian Nasrid Monumental epigraphy was greatly inspired by an anterior great project held by a Tunisian team. This academic Tunisian team was the first to experience and experiment the Arabic computer program called *Epimac*.

**Epimac:** is a program figured out on the epigraphic plan by Mrs. Solange Ory, a professor at the French university of Provence, it was then interpreted in the computer language by 'Izz ad-Din Salah, a Tunisian doctor engineer of the Ecole Centrale de Nantes at Royan. This software was created to deal exhaustively with all the data which could possibly contain the Arabic inscriptions and put them under the disposition of the researchers of all disciplines. But it is too much hectically detailed because it contained a lot of dictionaries and language details and words roots which makes it nearer to calligraphic literary program rather than architectural epigraphic one. That's essentially, among others, what we carefully evaded in our SADEPIG which is much more architecturally oriented (Ory, 2001, p. 238).

## 5. SADEPIG

**Nomenclature:** The name chosen for this database derives simply from the mix of the first three letters of both words of "Sa'dian epigraphy".

**General idea:** When we first thought about the project, it was simply about designing a database to regroup all the information about the monumental epigraphy and written texts of buildings which date from the Sa'dian period in Morocco (1527-1660). Later the idea developed to invest in a user software, a simplified computer program, which would enable the researcher specialized in Islamic architecture or archaeology to browse easily between all the monumental epigraphy of all the

Moroccan architecture during the Sa'dian period in a first phase then those of Nasrid Andalusia in a second phase. Hence it's a sort of highly specialized program, a digital corpus of monumental Sa'dian inscriptions; every possible detail of this period buildings inscriptions is considered and included:

- The Arabic literary text of the inscription; Quranic, poetic or eulogist,
- The French as well English translation of these texts,
- The various analyses: Textual, Palaeographic and Artistic analysis,
- Techniques of execution,
- Supports used of different materials,
- Photos,
- Plans,
- Sections
- Maps
- Virtual tour of the building and its inscriptions.

Together with a team of four computer engineers: a programmer, a graphics designer, a database designer, a user Interface designer, we designed our SADEPIG database after having seen and studied most of the previous distinguished databases designed before to be used in the field of Islamic and Arabic monumental epigraphy. Among which was for instance the program of *epimac* mentioned above and used during the course of a Ph.D. thesis of a student from Aix-Marseille University. Another project "under publication" soon which I had the chance of watching is that of the Monumental inscriptions of Cairo, a project sponsored by department of Islamic art and architecture of the American University of Cairo. Other databases like *epi* also applied in German universities and finally in Spain now "in process" is a database aiming to gather all the monumental inscriptions of the Alhambra of Granada under the supervision of the Spanish architect and Professor Antonio Almagro sponsored by the school of Arabic studies in Granada. Having carefully studied the advantages and disadvantages of each, we designed the basic research criteria of this database for the Sa'dian epigraphy, in spite of the fact that this period of the end of medieval age is much less known and less estimated by a lot of Islamic art historians.

The importance of this project is that it will bring to being a new dazzling information about the Sa'dian epigraphy, one that would clear a lot of misunderstanding concerning the comprehension of this difficult and rather complex period of Islamic art and architecture. Our aim is to present to researchers a program designed specifically to gather all possible information about the monumental inscriptions of medieval Islamic monuments in Morocco and Andalusia between the 14<sup>th</sup> and 17<sup>th</sup> centuries, which was developed in the course of my PhD studies and

research at the Sorbonne University in Paris. We look forward to facilitate the task for future junior and senior scholars of Islamic architecture, where they can consult and fetch a huge amount of information by exploring a single virtual database that furthermore provides buildings plans, virtual tour within the monument, construction details, information about the identity of patron and builders. In addition to this the program incorporates a textual reading to monumental inscriptions of every building, since the epigraphy is a specificity of Islamic architecture which bestows on it its particular identity within other architectures of our planet. Moreover the texts are also translated to English and French languages, whether Quarnic or poetic texts, they provide ideological significance to these buildings and give information about their functions. The database offers also answers to questions like who composed these texts and why and techniques of execution on different materials such as marble, stucco, wood or stone or mosaics.

## 6. Technical Overview

*SADEPIG consists of two main parts:*

**Data Entry Program:** The data entry program is used mainly for the entry of data. It is oriented towards the process of data input and modification, and it relies on the user's knowledge and understanding of the data being input and the relations between its parts.

The data is divided into the four main categories that divide the Sa'dian architecture, and each category is divided into the corresponding subsections. These categories and subcategories are built into the program and cannot be changed, although with some work it can be modified into a more general categorization system.

The program database stores all the information related to the architecture at hand, including actual area maps and building/floor plans, with the ability to select where the specific monument resides in its corresponding map and where the specific inscription resides in the corresponding plan. This information is used in the second part of the program as means of visually browsing the database starting from a map of more than one building and down to a specific inscription.

This program's role comes at the beginning as all the research data is input either by the researcher or by a well-informed data entry person. After the data entry phase is over, the main focus is on the second, and more user-oriented, program.

**User Program / Data Research Program:** The user program was first planned as an integrated part of the data entry program, used by the researcher to retrieve the input data in a more user-oriented fashion. The idea was then extend to making a separate read-only program that can browse the database of architectural data provided by the original researcher and made available for other researchers of the field.

The program is mainly composed of different options for retrieving the stored data in an intelligent and easy way. Other than that, the program allows for different instances of data items to be opened at the same time, allowing the researcher to conduct a comparison between the information in the desired items.

The most straight-forward way for locating a certain item is to provide the index and retrieve a specifically-desired item. A more general way is to search for a value in a specific field, such as "Inscription Names" or "Monument Names" or "Patron Names", and a list of matching results would be produced. If a keyword search is required, a global search option is available that searches all the available fields and returns the results grouped by the respective result category; e.g.: Monuments, Inscriptions, Patrons, etc...

Another major feature of the program is the ability to browse through the database in a top-down manner. The user can start with the preferred criterion, be it Patrons, Monuments, Country/City, Category/Type, etc... and work all the way down through the items below this criterion. For example, a user might choose to list all the Monuments in a particular City, then list all the Inscriptions associated with a chosen Monument, and view the full details of a selected inscription and its monument. This provides means of exploring the program database for a user who is interested in knowing the amount of data stored in the database and under each criterion, and preview this data as desired.

One main highlight of the program, which had to be supported by the data entry program to provide the correct data, is the visual part. Given the visual area maps and building plans provided by the researcher at the time of data entry, the user has the ability to browse the database *visually*. The program provides a list of area maps (that were originally input using the data entry program) from which the user can select the desired area. The user can then click on a certain part of the map, provided that this part is associated with a specific Monument, to view the monument that resides at this area. The user is then presented with the stored information about this monument, along with a list of the visual plans that were stored in association to this monument. It is then possible to choose a certain plan and click on certain areas of this plan where one or more inscriptions are located and this inscription or a list of inscriptions is displayed. As such, whenever any item that has visual

data associated with it is opened, this visual image is shown alongside its data to allow the user to more visualize the whole architecture and, if desired, use this visual browsing system instead of the traditional one. This gives greater user interaction and a virtual feel of the architecture at hand.

## 7. The Program Application

1- When we click on the program's shortcut to open it, after the start up logo and the splash screen of program data (Figure1), the first screen we see is the interface with a tool bar offering us the control buttons leading us to choose between the four categories of Sa'dian architecture (Chrt.1, Figure 2):

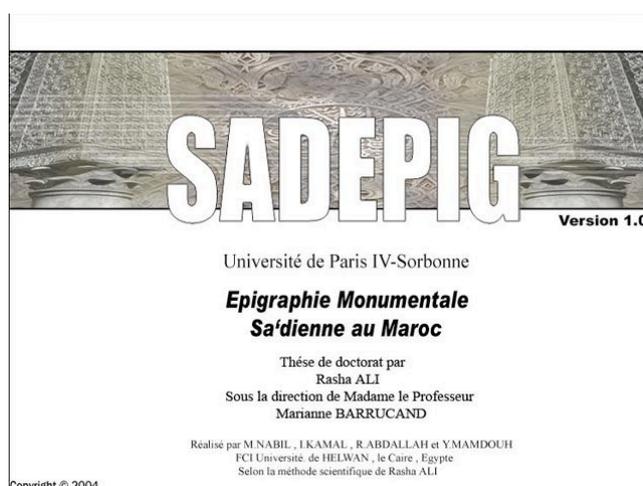


Figure 1. Screenshot of splash screen.  
SADEPIG - 1<sup>st</sup> version 2004.

CHART I. Sa'dian Architecture Category Choice.

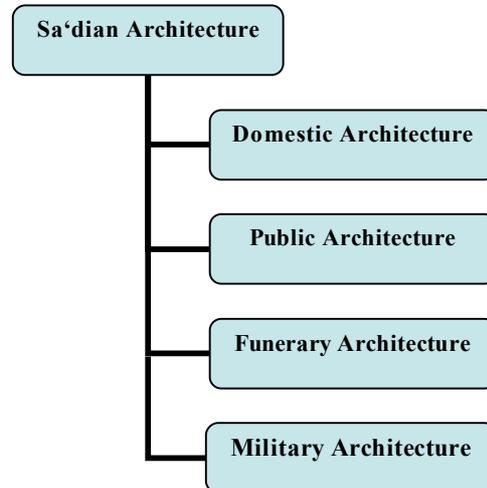


Figure 2. Screenshot of interface screen with tool bar of category choice.  
SADEPIG - 1<sup>st</sup> version 2004.

2- Once we click on any of these four categories, we open another window featuring the subsidiary categories enveloping the different types of buildings within the one category for example clicking on “domestic architecture” we choose between the palaces or the houses buttons. Or else if we click on the “public architecture” option, we have buttons marked with: mosques, *madrasas*, *zawiyyas*, fountains and *maristans*...etc (Figure 3).

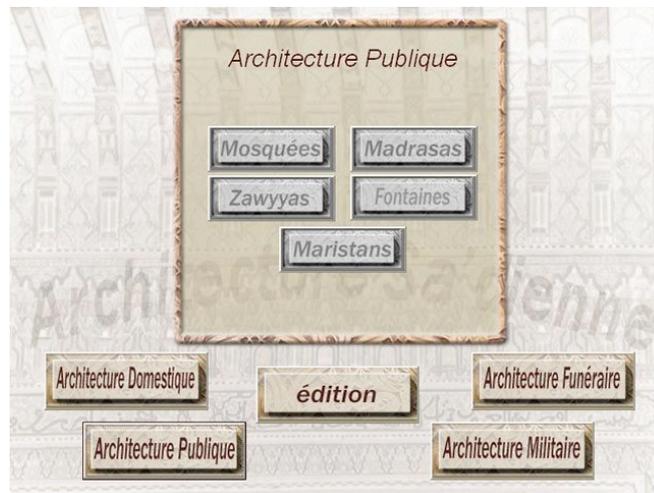
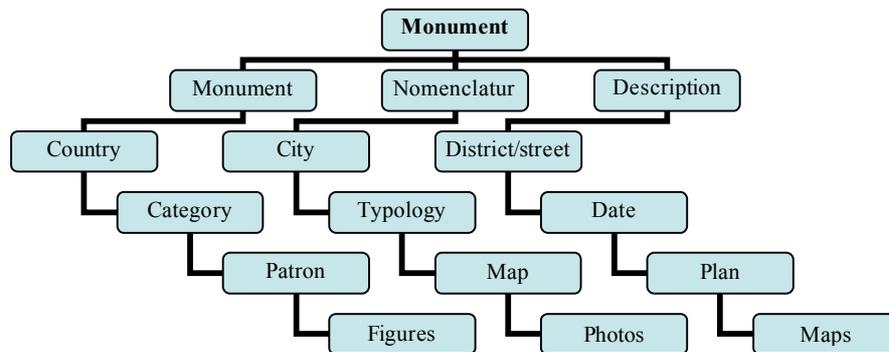


Figure 3. Screenshot of screen of subsidiary categories.  
SADEPIG - 1<sup>st</sup> version 2004.

3- Once a building has been chosen within the subsidiary categories, we have another screen with several list boxes providing the following data (Chrt.2, Figure 4):

CHART 2. Monument Data.





\* Finally a button marked **inscriptions**

Figure 4. Screenshot of screen of Monument data.  
SADEPIG - 1<sup>st</sup> version 2004.

4- Clicking on **inscriptions** we open another screen featuring (Chrt.3, Figure 5):

CHART 3. Inscription Data.

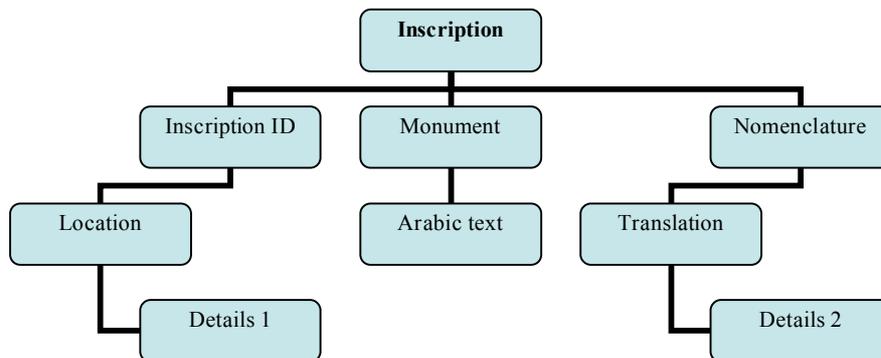
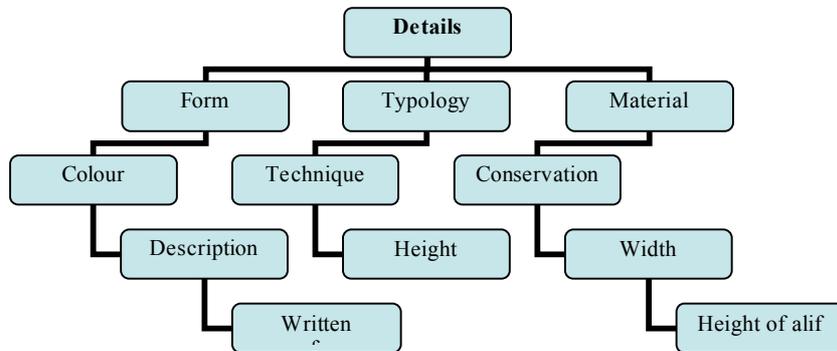




Figure 5. Screenshot of screen of Inscriptions data.  
SADEPIG - 1<sup>st</sup> version 2004.

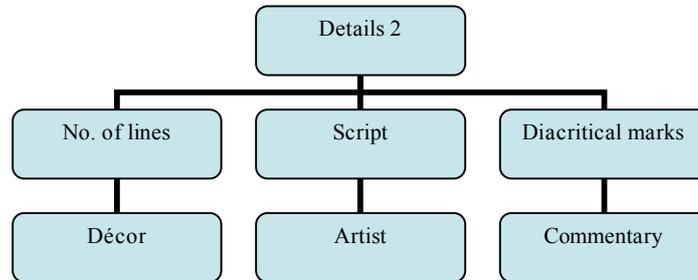
5- Then clicking on **details** we open a fifth screen providing further data (Chrt.4):

CHART 4. Inscription Details 1.



6- Then clicking on **details 2** we have (Chrt.5):

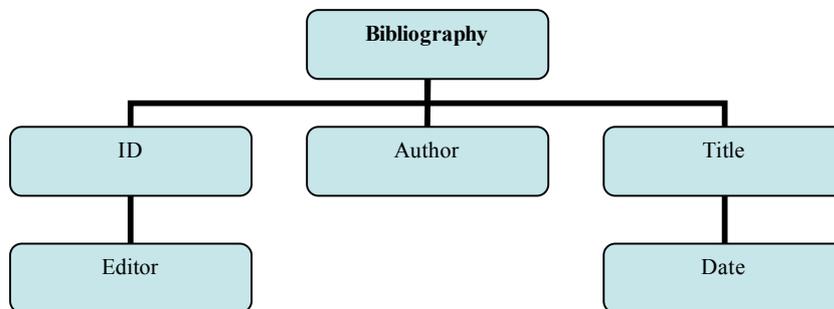
CHART 5. Inscription Details 2.



\* Finally a button marked **Bibliography**

7- Clicking on a button in screen of details 2 called **Bibliography** we have (Chrt.6):

CHART 6. Bibliographic Details.



8- Clicking on button of **photos** in same details 2 screen, we open another window (Chrt.7, Figure 6):

CHART 7. Photos.

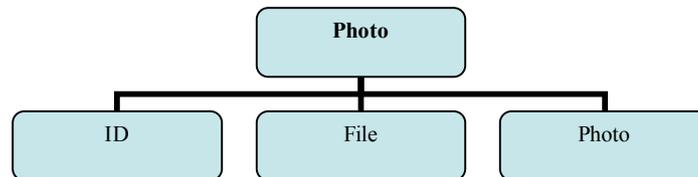
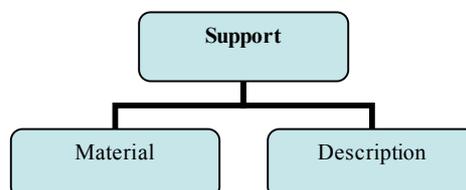


Figure 6. Screenshot of screen of Photos.  
SADEPIG - 1<sup>st</sup> version 2004.

9- Finally on same screen of details 2 we have button called **support** opening a window:

CHART 8. Structural Support of Inscription.



## 8. Conclusion

More than any thing the epigraphy in Muslim buildings signified their triumph, existence and distinguished identity. Nothing was ever left to hazard, writing never simply represented only décor in Islamic architecture, but rather an indispensable element in concept, design and structure. Texts, Quranic or poetic were carefully chosen or composed specifically for certain buildings with careful measurements to fit to walls and facades, they were afterwards confined to the workmanship who realized them beautifully and skilfully according to the different support which will receive them, whether it be stone, marble, wood, stucco or mosaic.

The script applied in monumental epigraphy was never the same used on paper or parchment or manuscripts. Furthermore, not any text was placed anywhere, the program destined for a *mihrab* was never that of a window or a door or a ceiling or a dome. The program designed for a house was far from that designed for a mosque or tomb or a *madrassa* or a hospital. This was the culmination expression of architecture in Islamic civilization, if it is a royal building commissioned by a sultan, the text composition was confined to *wazir al-qalam al-a'la* "the great vizir of supreme pen", beneath whom was a whole secretarial organization of a very refined and sophisticated level called *diwan al-insha'*, from where this is transferred to the *'arif* or architect of the time and his atelier of artists and *m'alilms*.

In order to progress in such a specialised study we had to turn in 2004 to the tools of our modern age. Certainly nowadays the computer incarnates our daily language and close companion par excellence. Our aim is to contribute to a technological march in the field of Islamic architecture and archaeology already started since at least a couple of decades. Our SADEPIG database is not the first and won't be the last. Our contribution targeted a virtual venue. We were not contented with the existent databases mainly occupied with the text and linguistic dictionaries in addition to other materialistic inscriptions details. That's what has driven us to develop our own with a focus more oriented on the architectural value of an epigraphy within a building. So we included plans and sections of buildings, maps to locate them within the quarters and their cities. Moreover in a later development in 2005, we added a virtual tour that would guide the consultant of this database within the building with emphasis on the placement of various inscriptions within an edifice or another. Our prospect is to continue ameliorating SADEPIG and equipping it with video and sound before it passes to be under the disposition of scholars and researchers of Islamic art, architecture and archaeology.

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## **DIGITAL RECTIFIED IMAGERY: A SURVEY METHOD FOR DESIGN AND CONSERVATION PROJECTS**

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**Abstract.** Faced with the need for understanding the physical context of the projects that come under their jurisdiction, architects, urban designers, and conservationists strive to secure congruent information. Practicing professionals are not set to carry out the collecting of information themselves. As information “users,” they reach out to information “providers,” including surveyors, photogrammetrists, and GIS specialists, to secure needed information. Information providers employ a gamut of methods to survey and document design project contexts, including land surveying techniques, stereo-photogrammetry, rectified imagery, laser scanning, and GIS. This study deals with digital rectified imagery (DRI) only and is aimed at creating an awareness of the method characteristics in the minds of the information users toward taking advantage of available DRI documentation opportunities offered by the information providers. As part of the methodology for this study, the authors have selected a subject building, captured a number of images through a digital camera, and processed the images using image processing software. The significance of this study resides in enabling the information users to understand RDI and to tap on its potential for consummating design, planning, and conservation projects.

### **1. Introduction**

Acquiring and analyzing information about the context of design projects remains a hallmark for any environmental design and planning activity. Faced with the need for understanding the context of the projects that come under their jurisdiction, architects, urban designers, and conservationists strive for ways to secure congruent information. This phenomenon arises with any proposed building project on a vacant land, a planning project for a city area, or a rehabilitation project of a historic structure. The purpose and

the scale of the project are in all cases dictating factors in characterizing the needed information.

Practicing professionals are generally aware of “what” and “how much” information is needed for the project in hand, but, with some exceptions, are not set to administer the collecting of information themselves. As information “users,” design professionals and public agency managers reach out to information “providers,” including surveyors, photogrammetrists, and GIS specialists, to secure needed information. Information providers employ a gamut of methods to survey and document design project contexts, including land surveying techniques, stereo-photogrammetry, rectified imagery, laser scanning, and Geographic Information Systems—all with relentlessly changing digital capabilities.

To make the best out of the needed information, it is appropriate for the information users (architects, urban designers, conservationists, and public agency managers) to be conversant with some methods of survey and documentation. Any method considered will, in its own way, add to the user’s knowledge in this area. Because of the multiplicity and application versatility of the methods, it was necessary to keep the investigation of this paper within manageable and meaningful scope; in this case, the digital rectified imagery (DRI). Further, the user-friendliness attributes of the DRI compared to, say, stereo-photogrammetry or laser scanning, makes it more approachable for the beginning user and thus germane for the purpose of investigation.

This study is aimed at creating an awareness of the DRI method characteristics in the minds of the information users toward taking advantage of available DRI documentation opportunities offered by the information providers. Digital rectified imagery is a member method of the field of photogrammetry—defined broadly as the art and science of measuring from photographs or images. Like all survey methods, digital rectified imagery goes through data acquisition and data processing functions. As part of the methodology for this study, the authors have selected a subject building, captured a number of images through a digital camera, and processed the images using image processing software.

## **2. The Study Subject and Data Collection**

The subject of the study was Hayes Hall, one of the main buildings on Bowling Green State University campus in Bowling Green, Ohio (Figure 1). Located at the center of the campus, and standing three stories tall, Hayes Hall assumes distinctive visual and historical prominence.

Built in 1931 as the Practical Arts Building and renovated in 1993 to house the Computer Science Department and computer related services,

Hayes Hall accommodated a variety of functions in between. The origin of the building is rooted in the exponential expansion of the Bowling Green State College, as the institution was then called, to meet the goals associated with elementary and secondary educator training (Center for Archival Collections, 2005). The changing functions the building assumed since attest to the historical development of the Bowling Green State University as a leading institution in Northwest part of the State. In 1959 the building was officially re-named after Rutherford B. Hayes, the 19th President of the United States, and his wife Lucy Webb Hayes of Fremont, Ohio.

The surface configurations of the main façade lent themselves well to this rectification exercise. For one, the essentially flat surfaces of the building provided a classic subject example for rectification. Additionally, the fact that the façade consists of three segments falling in two vertical planes provided an opportunity for examining the application of rectified imagery for surfaces at different depths—from the camera location. However, this complexity (of multiple façade segments) together with existing tree obstructions to photography on site posed challenges. For the latter, it was necessary to take photographs from multiple positions in front of façade and subsequently to deal with multiple images in the rectification process.



*Figure 1.* Hayes Hall: main façade looking west

The data collection function consisted of planning and taking a set of fourteen digital color images for the main façade of Hayes Hall. Some considerations were observed in planning and executing digital photography of the subject: first, the camera optical axis was pointing as orthogonal to the façade as possible; second, moving objects in front of the façade were avoided; third, as the capture of the whole façade was presumed, multiple

individual pictures were taken in order to get enough texture details; and fourth, image overlaps were guaranteed for building up mosaics.

Besides, an attempt was made to have all images taken under uniform day lighting conditions. This reduced the possibility for the captured images to have wide variations in their color and radiometric characteristics and, in turn, reduced the need for color and radiometric corrections forthcoming at a later stage of the rectification process. Such corrections help in maintaining color homogeneity throughout the composition.

### **3. Rectification Technique and Mosaic**

Rectified imagery is based on the concept of bringing the surface of an object, say a building façade, and the plane of the image (photograph) into a parallelism condition. Rectification is the process that creates such condition so that the resulting image is measurable. Thus, this method is most appropriate when the building surface is geometrically flat. However, buildings having multiple surfaces positioned in different vertical planes can be rectified separately and, subsequently, all brought to collapse in one reference plane through digital manipulation.

The image rectification procedure can be carried out either with or without surveying control points on the objects. The former procedure requires the knowledge of a minimum of four feature positions (x and y coordinates) in object space. The two projective transformation (Wolf and Dewitt, 2000; Lerma, 2002) is the ideal geometric transformation applied in order to geometrically correct the photography into a planar object space. This is true with no regard to lens distortion. We assume here working with either cameras with negligible lens distortion or calibrated cameras with known set of additional radial and tangential parameters.

The latter procedure, without surveying control points, also requires the application of a two projective transformation to correct the tilt inherent in the original imagery. This procedure can be carried out either interactively and visually with digital image processing software, or through correcting the image shape geometrically, i.e. transforming a quadrilateral into a rectangle.

Figure 2 shows an image and its rectified version after rectification using the Image Processing Toolbox in Matlab v. 7.0.



(a)



(b)

*Figure 2.* Imagery of the façade upper left part: (a) original; (b) rectified

The obtained rectified image is correct in proportion but is not to scale because the effects of the non-linear parameters were considered with the

calibration dataset or were negligible. Thus, Figure 2b needs to be made scalable in both axes. For this process, it is necessary to know at least two dimensions (preferably one horizontal and one vertical) on the monument in order to be able to measure accurately from the output (rectified) imagery.

There are occasions where the rectification procedure must be repeated for multiple images. This situation is typical when a) the monument is larger than the capturing image frame, b) the composition deals with several monuments and/or features, c) the need for accuracy mapping as well as the degree of detail is maximized and, d) when some outer features are placed in front of the target (for example, a tree or a streetlamp). Thus, a mosaic (or assembly of photographs forming a composite picture) is the result of multiple images. Applied to our subject, multiple image rectification resulted in a mosaic of rectified imagery.

Rectification becomes more challenging when the survey subject contains planar surfaces falling in more than one vertical plane. One vertical plane will be the “reference” surface, a surface where accurate measurements are meant to be taken. Features on surfaces in front of the reference surface and features on surfaces behind the reference surface will not be properly geometrically referenced. Hays Hall main façade contains planar surfaces falling in two vertical planes, one having the central part of the façade with the main entrance portal, and the second having two similar lateral segments flanking the entrance portal part. The second vertical plane was taken as the reference plane. The façade rectification procedure, at this juncture, continued as follows: a) completing rectification and mosaic for each of the three façade parts separately, and b) bringing the set of the three mosaics to form a collage by collapsing these mosaics into the reference vertical plane.

Figure 3 shows Hayes Hall’s façade imagery as a collage of the three sets of mosaic imagery. The total number of images used to this point was eight.



*Figure 3.* The façade after rectifying eight images

The image (Figure 3) so far produced through rectification, mosaic, and collage has some distractions arising from partial concealment of façade surfaces by trees and from heterogeneity (diversity) of the image colors. These distractions were corrected as described below (Figure 4). The façade areas concealed by trees in front of the building were cleared by taking four additional images from different locations and rectifying these images over the established image mosaics. The color correction of the twelve final rectified images was manually conducted through stretching and adapting the color image histograms to one neutral pre-selected image.



*Figure 4.* The façade after rectifying twelve images

A final step has completed the rectification effort. The mosaic of the central part of the façade was rescaled to come into a fit with the surrounding rectified mosaic sets (Fig. 5).



*Figure 5.* The façade's final rectified imagery subsequent to rescaling of the central part mosaic

The final rectified imagery obtained in Figure 5 can be considered a textured elevation plan, enriched with all the image texture provided by the different digital photographs.

#### **4. Applications, Advantages, and Use of Digital Rectified Imagery**

Characteristics of DRI underlie the method's applications and advantages. Capitalizing on the potential of the method's use, however, begins with understanding the nature and relationship between information users and providers.

Digital rectified imagery has several applications in the context of architectural, urban design, and conservation projects. These include: a) providing dimensional measurements of essentially flat surfaces, including interior elevations and ceiling surfaces; b) aiding in surface material condition evaluation, including color distinction; c) providing synchronized imagery of extended surfaces such as street corridor elevations that can be used in urban studies or strip conservation; and d) aiding in generating 3D modeling of building masses.

Similarly, rectified imagery has several advantages. It can be an economic and relatively quick method of producing a record of sufficient accuracy for most purposes (Andrews et al, 2003). Furthermore, it involves a limited number of images for the documentation task compared with other techniques, such as stereo photogrammetry. Additionally, it requires the use of common, not necessarily high-end, computer hardware; and, it benefits from the availability of commercial software with digital image processing capability.

As has been established, the rectification procedure can be used for correcting tilt and scale in photographs and, accordingly, it fits flat objects or objects that can be easily decomposed into planar segments. Would rectification be of benefit in cases where object surfaces depart from flat or planar surfaces, such as undulating surfaces? It would in an extended process called differential rectification; this process makes the backbone of "orthoimagery," another method of recording. Produced from digital photographs, orthoimagery eliminates image displacement not only due to tilt but also to object relief. Therefore, this method, through the embedded differential rectification process, assures that all the image patches are rectified to a common scale.

As an extension to rectified imagery, orthoimagery is a demanding method, however. Producing measurable orthoimages requires the knowledge of both camera interior and exterior orientation parameters as well as a digital surface model of the whole object. Its operation involves specialized equipment, software, and personnel. Such stringent requirements render orthoimagery appropriate for tasks that digital rectified imagery cannot perform adequately.

What categories of information users and providers are there? An architectural firm and a city planning department are instances of users. Each has interest in obtaining information regarding the existing physical

contexts in which their projects take place. The architectural firm receives commissions to renovate and add to extant buildings in its jurisdiction of practice. The city planning department deals with area planning and design on regular basis. Both organizations have reoccurring need for dimensional, condition, and polychromatic information on individual structures, urban cores, and historic areas.

Information providers hail from different documentation specialties. An interesting citation of these specialties comes to us from what becomes known as Recording, Documentation, and Information Management (RecorDIM) Initiative (a partnership between Getty Conservation Institute (GCI), International Council on Monuments and Sites (ICOMOS), and CIPA—joint Documentation Committee of ICOMOS and the International Society of Photogrammetry and Remote Sensing). Although addressing information needs primarily in the conservation field, the RecorDIM Initiative (GCI-ICOMOS-CIPA, 2002) identified a number of survey and documentation specialties that also apply to surveying of environment and objects in general: photography; photogrammetry (of which DRI is a constituent); surveying and GPS; 3D laser scanning; 3D modeling; geophysical prospection, etc.

As entities, information providers assume a number of organizational structures:

1. Documentation specialist groups: typically private enterprises that deal with survey and production of drawings and models of historic structures and sites using advanced digital technologies
2. Multi-purpose firms: design businesses that incorporate documentation and conservation studies together with other functions associated with architecture, interior design, landscape architecture, planning, and engineering
3. Conservation architects: professional architectural practices that specialize in historic architecture where survey and documentation are fundamental activities
4. Conservation-related public programs: typically large public programs with a mission to further documentation and conservation of historic resources (examples: the Historic American Building Survey of the U.S. Department of the Interior and the English Heritage sponsored by the Department of Culture, Media, and Sports)
5. University units: associated mostly with surveying or photogrammetry departments at engineering or technical schools

To cast a light on the nature of documentation information exchange, three projects involving the same information parties are summarized in Table 1. The provider party is the Department of Cartographic Engineering, Geodesy and Photogrammetry at the PolytechnicUniversity of Valencia,

Valencia, Spain; the user party is the Valencian Cultural Council. Rectification had been used in the three projects.

TABLE 1. Rectified imagery projects with project outcomes

<b>Project description</b>	<b>Place and year</b>	<b>Project Outcome</b>	<b>Documentation method used</b>
1. Documentation of two Neoclassic monastery inner-yards	City of Valencia, 1997	Scale drawings over rectified images; AutoCad hard copy drawings	Digital rectified imagery
2. Documentation of a Roman period floor mosaic	City of Enova, 2004	Scale drawings over rectified images; AutoCad hard copy drawings	Digital rectified imagery
3. Documentation of interior walls and ceiling of a train station space	City of Valencia, 2004	Scale drawings over rectified images; AutoCad hard copy drawings	Digital rectified imagery plus reflector-less total station

## 5. Conclusions

The objective of this study was to create an awareness of the DRI method characteristics in the minds of the information users toward taking advantage of available DRI documentation opportunities offered by the information providers. The principles, steps, and outcome of digital rectified imagery as discussed in the context of Hayes Hall documentation project provide a means of knowledge for architects, urban designers, conservationists, and agency managers—as information users. Not less important in this regard is the discussion's clarification of the applications and advantages of this method, and more pointedly, the categories of users and providers and the interaction between them.

The added knowledge to the design professionals' expertise will help not only in carrying out successful projects, but also in developing a decision making ability as to the appropriateness of using the method in the first place. Further, simple in structure but sufficiently telling, the DRI method, as discussed, is bound to turn the addressed audience's attention to the availability of other documentation approaches that can offer opportunities in their unique ways.

It is not unconceivable for certain user organizations, such as governmental conservation agencies or large architecture and engineering

firms, to deliberate the introduction of DRI or, for that matter, other survey method as an in-house documentation practice feature. The results of this study are bound to feed right into this kind of deliberation.

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## ADAPTIVE GENERATIVE PATTERNS

### *Design and Construction of Prague Biennale Pavilion*

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**Abstract.** This paper describes an experimental practice-based research project that considered design process, implementation and construction of a pavilion built to be part of the Performative Space section of the International Biennale of Contemporary Art, Prague 2005. The project was conceptualized as a time-bound performative situation with a parasite-like relationship to its host environment. Its design has emerged through an innovative iterative process that utilized digital simulative and procedural techniques and was formed in response to place-specific behavioral challenges. This paper presents the project as an in-depth case-study of digital methods in design, mass customization and unified methods of production. In particular, it considers the use of Voronoi patterns for production of structural elements providing detail on programming and construction techniques in relationship to design aspirations and practical constraints.

### **1. Project Background**

The project was developed in the Cambridge University Moving Image Studio (CUMIS) and Digital Studios of the Department of Architecture for the International Biennale of Contemporary Arts (13 June – 11 September 2005) organized under the auspices of the Czech National Gallery. The

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<sup>1</sup> The first two author surnames are listed in alphabetical order.

project was initiated in November 2004; production of the building elements began in the second half of May 2005 and together with construction continued until the end of June 2005. During the last months, the team worked in the *Veletržní Palace* (the Museum of Modern Art) in Prague. The last two weeks of work were done after the public was admitted to the exhibition so that the construction process has become integrated into the life of the Biennale as a performance in its own right.



Figure 1. View of the structure photographed during construction (a photograph).

*Veletržní Palace* is a 1920s functionalist structure made of reinforced concrete. It suffered badly in a massive fire in the 1970s. The lower-level spaces are still not fully restored and have a rough unfinished look. The pavilion was designed to fit into a stairwell (Figure 2) that connects the main exhibition hall located on the ground floor, the secondary entrance to the museum that becomes the primary entrance during the evening events and the performance/exhibition spaces of the lower level. The pavilion consisted of the purposely designed structure and of the interactive audio-visual system that was able to respond to the behaviour of the visitors.



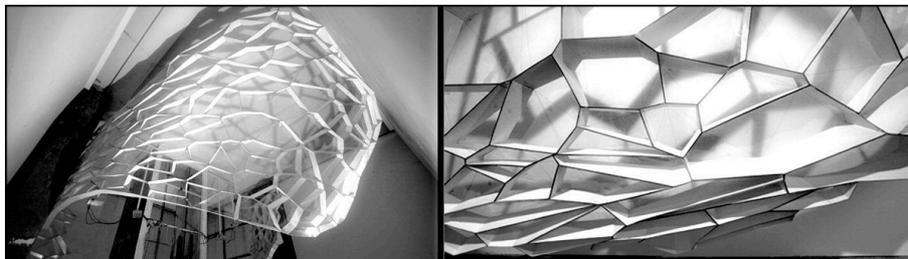
Figure 2. Three views of the stairwell space prepared for the construction (photographs).

The design process consisted of three parts. Firstly, dynamic simulation and time-based processes were used to produce two organic surfaces fitting into the stairwell space. Secondly, the computer-driven responsive audio-visual system was laid out in relationship to these surfaces. This system incorporated image-based computer vision and was able to create real-time

audio and video compositions in reaction to people's movement through the space. Interesting in their own right, the aforementioned parts of the design will be described in detail elsewhere. This paper focuses on the third part of the workflow describing how the two organic surfaces (Figure 3) produced during the first phase of the design process were materialized as building components. This description sets out a technical framework for the procedural production of a built structure under a variety of situational constraints and in response to the performative requirements of the audio-visual system.



*Figure 3.* A perspective into the stairwell (a digital rendering).



*Figure 4.* Structure installed in the stairwell and a fragment showing local curvature-dependant variations (photographs).

### 1.1 PAPER AS MATERIAL

Shigeru Ban (Shigeru Ban Architects, 2005) is perhaps the most established architect to have used paper and cardboard regularly in his practice. He uses paper tubes to replace beams and columns, or in arrays to form walls. A closer precedent is provided by Horst Kiechle (2004) who develops small ephemeral structures made of cardboard or paper at

architectural and object scales. In his work, the low-cost easy-to-manufacture paper-based materials are often used to define and reconfigure performance spaces. Kiechle uses flat, usually triangular elements to establish a curvilinear or irregular boundary between the regions of solid and void. His lamps provide a good example of relatively complex self-supporting paper structures.

Different utilization of paper can be seen in the use of honeycomb structures. Kraft- or aramid-paper honeycombs spacing two veneers are an established flat-board building material. The same principle of honeycomb sandwich is used for curvilinear and monocoque geometry in boats, airplanes and other situations where weight is an important consideration. The preliminary research has shown that paper and cardboard can be successfully used to design and build small-scale architectural installations featuring multi-parametric complex geometries under tight financial and temporal constraints.

## 1.2 PATTERNS IN CONSTRUCTION

The spatial intervention was a significant part of the project. It intended to provide two kinds of impact. Firstly, the structure impinged on people's behavior such as movement through space or visual access with the intention to engender new social encounters. Secondly, the structure in combination with projected images created a visual field that could inform the visitors, redirect their attention and involve their bodies in the making of the dynamic visual form. Plant-cell microscopy images, urban-texture photographs and dance movies were processed so that their pattern-based nature was made apparent. The visual field consisted of the pattern-based spatial structure, pattern-based video imagery and the participant's bodily movement through the space. While static after construction, the structure was intended as a procedural response to the given environment. Its responsive nature called for a modular, component-based arrangement able to conform to geometrically complex surfaces and flexibly adapt to the changes in local conditions. These requirements led to the interest in honeycomb and similar structures.

Experimental work of A. Kudless (2005) explored the use of honeycomb structures for the construction of curvilinear geometry. One of the Biennale project's goals was to see if this approach could be taken further with the use of non-periodic patterns capable of local change. The pattern adopted after preliminary research was a Voronoi diagram (Figure 10, C) defined as "the partitioning of a plane with  $n$  points into convex polygons such that each polygon contains exactly one generating point and every point in a given polygon is closer to its generating point than to any other" (Weisstein, 2005).

Voronoi patterns are in wide use in various applications in computer science. In architecture, Thomas Wingate (2005) used Voronoi diagram to determine the form for the decorative ice-blocks used in a flat vertical wall of the Ice Hotel, Sweden.

### 1.3 DIGITAL TOOLS

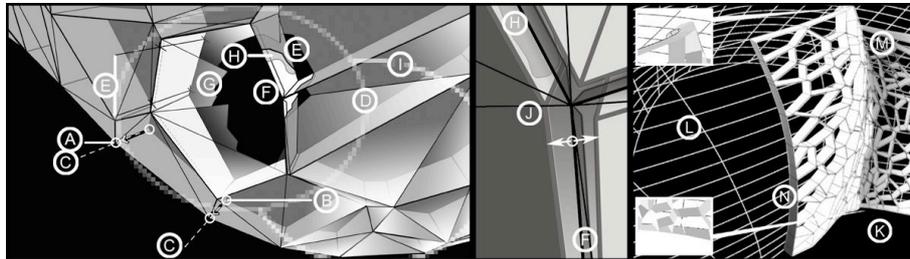
The project's methodology is a first step towards an approach that incorporates architectural form-finding, multi-media design and fabrication of building components as parts of a unified performative process. In the foundation of this process are the protocols for the cross-platform data exchange. Currently, all of the three areas utilize digital tools that are capable of programmable data-wrangling. The unified digital-fabrication workflow offers other benefits apart from convenience. Design via parameter-readjustment allows for work with relational diagrams. During development, the designer is able to, and in fact has to, move up and down the branches of the process tree, reviewing the feedback and readjusting the inputs. Even though everything in the computer system is ultimately solvable, the designer waives the right to control results explicitly and instead guides the process with multiple indirect measures. The sacrifice of arbitrary control leads to gains in the capacity to deal with complex systems as systems, without reducing them to basic components. The bifurcations of the process with which the designer becomes intimately involved often lead to solutions that could not have been pre-specified from the start as spatial layouts or even as design goals. The feedback is often real-time or comparatively fast. The ability to tweak different components of the process allows the designer to learn about system relationships via experimentation. It becomes possible to plot alternative design paths in terms of multiple sequential versions. This process of probing and recoiling is exploratory by nature. The design process acquires a character of an investigative tool rather than that of a method with which a wilful author promotes his or her worldview. Significantly, the design suggestions derived from the procedural design process can be very different from those intuited at the beginning. Insights gained in this way can both educate the designer and lead to innovative solutions.

It is often said that specification of the problem is part of the solution. Thus, educating the designer is a significant goal. Within this project, the educated designer is providing a vital link between the solvable system and the fuzzy reality of the in-world situation. The designer is aware of many practical circumstances such as constraints on resources, materials, money, time and knowledge or multiple design goals related to various peers groups. The design process begins when on-site observations are expressed in the digital domain in terms of virtual forces impacting upon geometric systems and proceeds as interactions between these systems and the designer.

For the first stage of the design process we needed an integrated multi-faceted programmable software environment capable of animation and dynamic simulation. In response to these requirements, Alias Maya (Alias, 2005) was chosen for its capabilities to deal with complex geometries. With Maya we were able to establish form-finding design-processes incorporating a number of techniques such as layered randomization, particle simulation and force simulation using dynamic curves and fields. These techniques were combined into an active diagram able to support versioning and prototype breeding. Maya was also used on-site to layout the suspension system.

In order to develop the building components, we needed a programmable environment able to support unfolding and construction-oriented content organization. Rhinoceros 3D (Robert McNeel & Associates, 2005) was used for Voronoi tile-generation, cell-structure generation, unfolding of cell-walls and nesting of the cell-skins and cell-walls. FormZ (Auto-Des-Sys, Inc., 2005) was used to unfold polygonal geometry of the cell-skins. Finally, MAX/MSP/Jitter (Cycling '74, 2005) programming environment was used for the design of digital audio-visual responsive system.

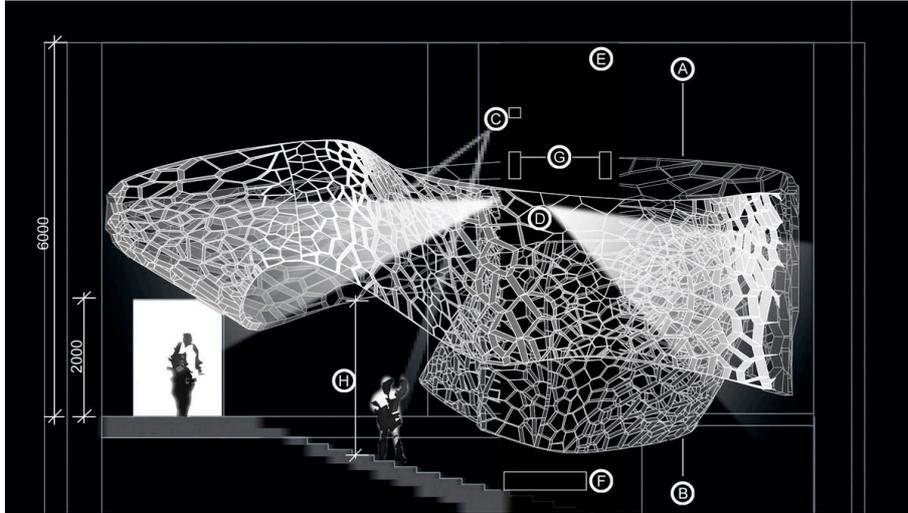
## 2. Scripted Production



*Figure 6.* Terminology and the structure of the cells. A) Offset point, shown circled. B) Base point, shown circled. C) Direction of offset along the normals, shown as dashed lines. D) Cell. E) Cell-wall with varying width. F) Cell-skin flaps. G) Cell-skin. H) Glue. I) Non-planarity of cell-walls and cell-skins, shown as shading changes. J) Cell-wall insets. K) Outer shell. L) Input surface. M) Generated cells. N) Shell seam. (digital renderings)

The first stage of the procedural-design process, run in Maya, produced two organic, topologically cylindrical NURBS-surfaces. The ready surfaces were then exported as IGES files and transferred into Rhino where the generation of the building elements was conducted.

Production of building elements was automated and the technical procedure was encapsulated in two scripts<sup>2</sup> that were run one after the other. The first script governs the distribution of points on a given NURBS surface. The second script uses these points as input for the generation of a Voronoi pattern and building elements based on it.



*Figure 7.* Side view as designed. The height of the stairwell in the supplied documentation was underestimated; the actual height was 10.000mm. A) Outer shell. B) Inner shell. C) Approximate area observed by the computer-vision system. D) Video projections. E) Disused lift. F) Computers and the sound system. G) Speakers. H) Free passage is left unobstructed all the way along the stairwell. (a digital rendering)

<sup>2</sup> RhinoScript is a VBScript-based scripting language.

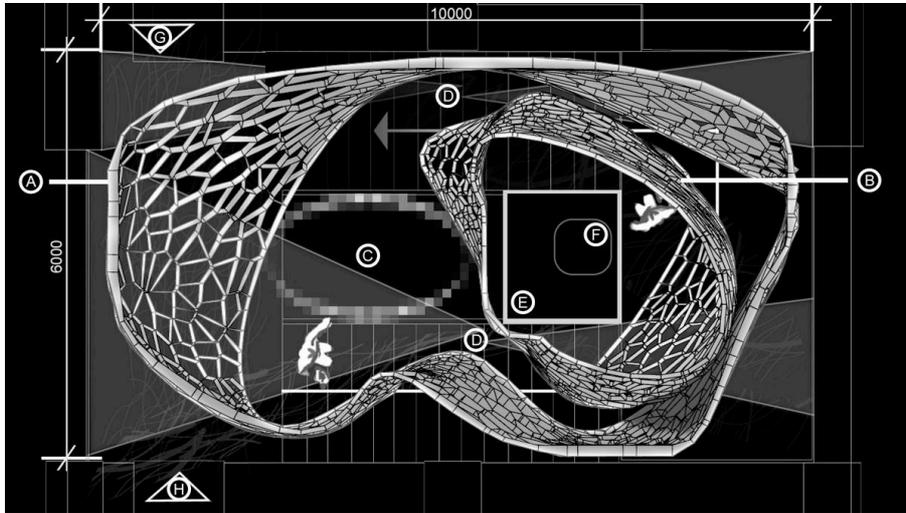


Figure 8. Plan view as designed. The major form was driven by dynamic curves. The flattened areas along the walls were produced by particle systems. The outer shell had curvature-based cell-wall width differences obvious along the top rim. The inner shell had a constant cell-wall width. A) Outer shell. B) Inner shell. C) Approximation of the area observed by the computer-vision system. D) Video projections. E) Disused lift. F) Computers and the sound system. G) Doors to the Main Hall. H) Street entrance. (a digital rendering)

## 2.1. DISTRIBUTION OF POINTS

As the first step, the script asks the designer to specify a NURBS surface to be used as input. Next, the designer is given an opportunity to specify the number of points to be created. The points can be distributed according to one of three methods as described below:

**Constant.** This method attempts to distribute the given number of points on a given surface uniformly so that the resulting distances between neighboring points are close to equal. The method begins with a rough estimation of the minimum possible distance between points for a given surface and a given number of points where the points are distributed uniformly.

$$D_{\text{emin}} = \sqrt{\frac{2 S_{\text{surf}}}{N_{\text{pts}} \partial}} \quad (1)$$

Where  $D_{\text{emin}}$  is the estimate of the minimum distance between points,  $S_{\text{surf}}$  is the surface area of the input surface and  $N_{\text{pts}}$  is the number of points on the surface.

The result of the estimation is suggested as the default designer-input for the minimum distance between points  $D_{\min}$ . Input values smaller than the estimation will produce less evenly spread distributions while the values significantly larger than the estimate will force the program into an infinite cycle as the script will struggle to find suitable point locations. This behavior is due to the nature of the procedure that attempts to add one point at a time looking to satisfy the condition  $D_{\text{cur}} \geq D_{\min}$  where  $D_{\text{cur}}$  is the distance between the currently tested point and its nearest neighbor. If  $D_{\text{cur}} \geq D_{\min}$  is true, a new point is created, otherwise a new point is attempted and the procedure goes into a cycle until the condition is satisfied.

**Curvature.** This method relates the point density to the amount of surface curvature so that the higher the surface curvature the higher the point density. This relationship is established in two steps. First, the given surface is sampled and the curvature data is collected into a sorted array. The number of sampling points can be explicitly specified by the designer allowing for crude-force acceleration during test runs. The designer is then given the opportunity to specify  $D_{\min}$  and  $D_{\max}$  with the latter being the maximum allowable distance between points.  $D_{\text{cur}}$  is then found as follows:

$$D_{\text{cur}} = \left( \frac{\frac{1}{|C_{\text{pmax}}|} - \frac{1}{C_{\text{smax}}}}{\frac{1}{C_{\text{smin}}} - \frac{1}{C_{\text{smax}}}} (D_{\text{max}} - D_{\text{min}}) \right) + D_{\text{min}} \quad (2)$$

Where in addition to the aforementioned definitions  $C_{\text{pmax}}$  is the maximum principal curvature at the attempted point,  $C_{\text{smax}}$  is the maximum sampled curvature for the given surface and  $C_{\text{smin}}$  is the minimum sampled curvature for the given surface.

In practice, this kind of calculation means that even though  $D_{\text{max}}$  is collected as the designer input and used in calculations, it is not directly constraining the maximum distances between points so that if  $N_{\text{pts}}$  and  $D_{\min}$  are both relatively low, the resulting distribution can contain areas with  $D_{\text{cur}}$  values far greater than  $D_{\text{max}}$  as input by the designer. Such gaps can produce the cells that are too large to be structurally sound.

**Inverse Curvature.** This method is similar to the *Curvature* method but the relationship of curvature to density is inversed with the areas of higher curvature containing lower point-densities. The use of the *Inverse Curvature* method has implications similar to that of the *Curvature* method.

$$D_{\text{cur}} = \left( \frac{|C_{\text{pmax}}| - C_{\text{smax}}}{C_{\text{smin}} - C_{\text{smax}}} (D_{\text{max}} - D_{\text{min}}) \right) + D_{\text{min}} \quad (3)$$

Several such methods can be combined to produce the final point-cloud. If this technique is used, each method is run separately with the desired settings and the resulting point-clouds are added together.

The project utilized the total of 1560 points and an equal number of corresponding cells. 700 points and *Curvature* method were used to generate the point-cloud for the inner shell. The point-cloud for the outer shell was made with 860 points using a combination of *Curvature* and *Constant* methods. The combination of the two methods made it possible to enforce the desired  $D_{\max}$  threshold on the distances between points. This was achieved by running the script with *Constant* method using 250 points and the default  $D_{\min}$  estimate provided by the script. This caused the points to be near-uniformly distributed across the surface during the first run. The second run of the script used 610 points distributed by *Curvature* method with desired  $D_{\min}$  and  $D_{\max}$  values estimated given the geometry of the shell surfaces and the structural properties of the cardboard. The numbers of points in all cases were found via multiple readjustments of parameters in the generation chain.

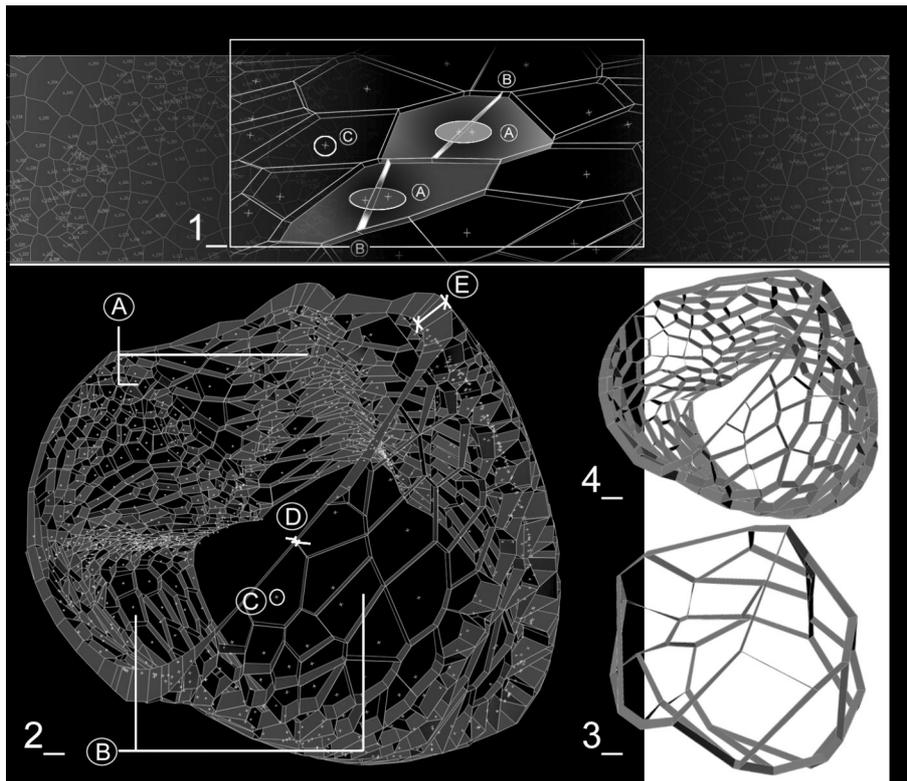


Figure 9. Variations in shell structure, inner shell. 1\_) Fragment showing the structural consequences after a point-cloud is added to another point-cloud. 1\_A) The minimal distances between points were controlled during the distribution of points for each point-cloud.

However, when one cloud was placed over the other, the distances between some point-pairs could be well within these thresholds. 1\_B) An extra cell-wall inserted between the two points. 1\_C) A point in a cloud. 2\_) An image showing structural variations. Settings: two point-clouds used, 1<sup>st</sup> cloud – Constant method, 150 points; 2<sup>nd</sup> cloud – Curvature method, 700 points; curvature-dependant cell-wall height, minimum cell-wall height – 50mm, maximum cell-wall height – 250mm. 2\_A) “Rivers” of high density at high-curvature areas. 2\_B) Low-curvature areas. 2\_C) A point. 2\_D) High cell-wall. 2\_E) Low cell-wall. 3\_) One point-cloud used – Constant method, 20 points; Constant method for cell-wall height, 150mm. 4\_) One point-cloud used – Constant method, 200 points; Constant method for cell-wall height, 150mm. (digital renderings).

The results had to satisfy a number of structural and experiential criteria. The most fundamental of these are cell sizes and proportions. A related negotiable criterion was the degree with which the cell-walls and cell-skins were able to conform to the curvilinearity of the input surfaces. As cell-walls and cell-skins are defined by straight edges, tighter tessellations result in better conformity. Another significant criterion is cell geometry. All cell-walls and cell-skins are non-planar surfaces (Figure 6, I). This non-planarity adds to structural rigidity but can also make it more difficult to match the cells in the assembly and even cause breakage in the material. Therefore, high non-planarity had to be avoided. Cell quantity, together with other parameters, would have a direct impact on the weight of the structure and the number of operations required for its production.

Experientially, the iterative process looked to uncover the effects on visual density and variety of surface texture, visual permeability along varying view lines and production of shadow patterns.

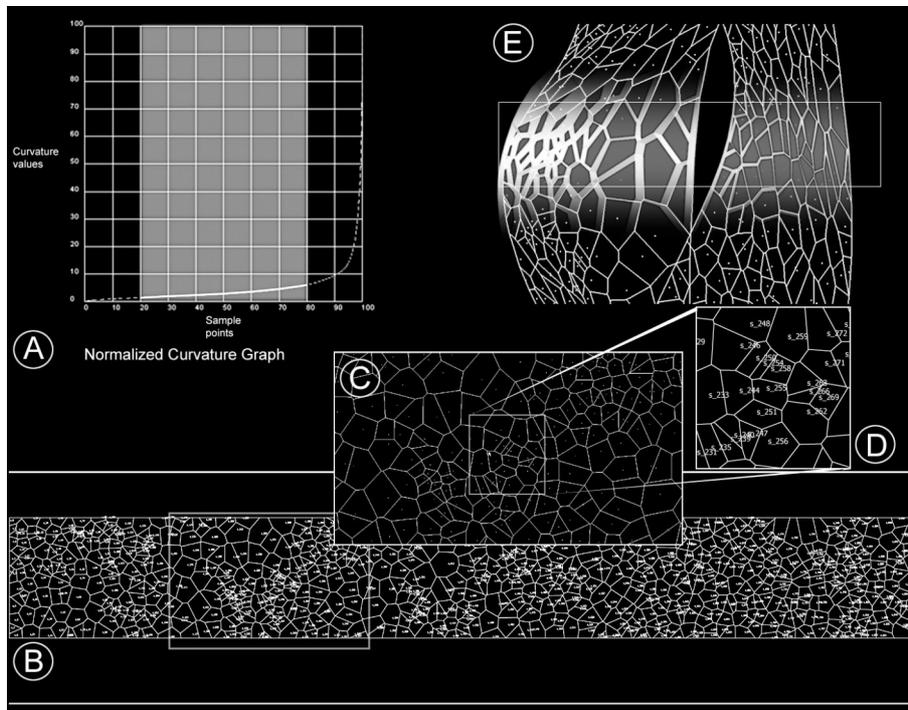


Figure 10. A) A graph showing sampled curvature-values and clamping of the curvature range. B) Inner-shell Voronoi pattern in XYZ space. C) A fragment showing variable densities. D) A fragment showing local variations produced when one of the two point-clouds is added to the other; see the narrow cell in the central area. E) Voronoi tiles in the UV space.

The relationship between curvature and point density as established by *Curvature* and *Inverse Curvature* methods can be adversely affected by the surfaces that include areas with extremely high or extremely low curvature. If the whole array of sampled curvature values was used for the test calculations, the script tended to produce confined areas with high density while distributing the points on the rest of the surface almost uniformly. Thus, it was necessary to introduce the facility that would allow the designer to visualize the sampled curvature values and to clamp the value range if necessary. To achieve this, the given array of curvature values was first normalized to fit the 0-to-100 range and then displayed as a graph (Figure 10, A). At this stage, the designer was offered an option to clip the lower and/or higher portions of the range discarding part of the data. This detail of the process might appear to be a trivial problem intrinsic to the specific implementation. However, the experience of designing the structures for this project demonstrated that such “problems” should rather be seen as opportunities fundamental to the process because their impact is far from “trivial” in terms of methodological formalisms and practical choices. While

the in-depth theoretical discussion is beyond the boundaries of this paper, this clamping procedure is mentioned here as a typical example of a feedback-loop relationship between the designer and the model. Instead of the much-criticized rigidity that is seen as a typical property of digital tools, this relationship is not dissimilar to that between a designer and a paper sketch. Through multiple iterations and refinement, the voluntary input is calibrated against the meaning already invested into the system. Thus, calculable numeric data acquires the exploratory suggestive capacity that sets up a dialogical relationship between multiple versions generated in response to modified input and sets the ground for the discovery of new form.

Adding the product of the two methods together produced structurally interesting variations in point distribution. When two point-clouds were combined into one, the  $D_{\min}$  threshold was not enforced and some of the points in the resulting point-cloud were positioned very close to each other (Fig. 1, 1\_A; Fig. 10, D). Instances of such tight positioning occurred across the whole surface introducing another layer of complexity into the structure with the visual impact being more prominent in the areas with low curvatures where  $D_{\min}$  thresholds was at their largest.

The type of a method, the weighting of a method (i.e. what percentage of the total number of points is controlled by the given method) and the number of methods used constitute input gateways that accept data specified by the designer or supplied by another procedure (refer to Fig. 9 for examples). The designer input can be established by running multiple iterations of the routine and the certain versions can be judged as more suitable based on the number of criteria to do with human behavior or construction logic.

The curvature/density relationship as implemented in the script exemplifies the adaptive capacity of the approach. Other procedural relationships of this kind can be established and the controlling input can be provided via on-site observations or computational methods. The examples of such data might include isovists/viewsheds, light-level and body-movement measurements or simulative AI routines. The parameters of the structure that might be driven by such data include fenestration; cell-skin and cell-wall transparency, color, light reflectance, light transmittance and other material properties; cell-wall widths, cell-wall orientation, cell density, cell uniformity and the like. For example, the project featured experiments linking the orientation of the cell-walls to the positions of the video projectors. Such linking enables the structure to guide the moving-image formation by opening or blocking light cones, controlling shadow distributions, framing views and articulating the sculptural properties of the structure. Further experimentation along these lines will be conducted in the future. At the present stage, the project's approach to form-finding and the production of building elements seeks to establish the methodological

backbone for the open and flexible process able to respond to multiple complex data inputs.

## 2.2 GENERATION OF CELLS

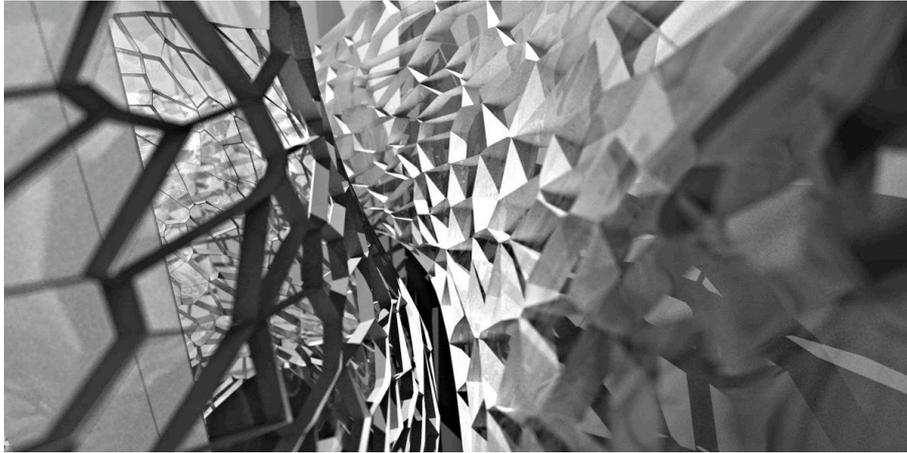


Figure 11. A perspective along the direction of the inter-shell canyon (a digital rendering).

The cell-generation script used *Constant*, *Curvature* and *Inverse Curvature* methods that are similar to those implemented in the point-distribution script (see the description earlier in the text). In the cell-generation script, the curvature data was used to determine cell-wall widths.

The second script began with the request for the designer to pick a NURBS surface and a point-cloud (as produced by the point-distribution script described above). The designer was also asked to specify the name prefix for the cells to be created. After these steps, the designer was given a number of options that controlled the building elements about to be created and specified their attributes.

- Should the cell-skins be created? If the answer was “yes”, should they be created at inner edges of cell-walls, outer edges or both?
- Should the insets to compensate for material thickness be created? If the answer is “yes”, the designer had to specify the width by which the insets should be offset from the original cell-walls.
- Should the cell-walls be unfolded?
- Which method should be used to establish the width of cell-walls? *Constant*, *Curvature* or *Inverse Curvature*? If *Constant* was chosen, the designer was requested to specify the cell-wall width. If *Curvature* or *Inverse Curvature* was chosen, the designer was requested to specify the minimum and maximum cell-wall widths.

- For point-clouds containing more than 20 points the designer was requested to specify an optimization factor constraining the number of points taken into consideration during calculations.
- If the unfolding procedure was activated earlier in option selection, the designer was requested to specify the location where the log file was to be saved. The log file contained a record of the process with error reports and precision warnings for each cell.

This section describes the flow of the script used to generate the cells and the skins for the outer shell. The script began by unwrapping the NURBS surface and the point-cloud from the UV space into the XYZ model-space such that the resulting rectangle of the NURBS surface was resting on the horizontal XY plane. The points in the 2D point-cloud were then sorted in the ascending order. When the points are sorted in this way, it becomes easier to locate them and their associated cells in digital models, during manufacturing and during construction. The sorted point-cloud was then transferred back onto the 3D surface and each point of this point-cloud was later used as an anchor for textual cell-labels. Next, the surface was sampled at each point of the point-cloud and the curvature data was stored, ready to be used by the *Curvature* method that was chosen to establish cell-wall widths. The script then drew a curvature graph to allow the designer to clip the areas with extreme curvatures.

After that, the script ran a looped routine generating Voronoi tiles within the unwrapped NURBS rectangle (Fig. 10, B) using a method the first version of which was written by David Rutten (2005) and further developed by Thomas Wingate (2005) and Andrew Kudless (2005).

This method uses Rhino's functions and commands to perform the necessary calculations. The method creates one tile at a time by first establishing the positions for and creating the vertex points, then drawing border lines through the points and finally trimming the tile curve with the surface boundary using Boolean curve subtraction. This method worked well in our case. However, it was comparatively slow because the process created new geometry at every step - a purely numerical approach would work much faster. Additionally, large point-clouds force the script to consider too many points when drawing tiles thus slowing down the performance dramatically. To avoid this problem an aggressive acceleration threshold was implemented via an introduction of a designer-specified optimization factor constraining the number of points taken into consideration to an arbitrary number. This measure was highly effective but can potentially be error-prone if the designer-specified threshold forces the algorithm to miss significant points.

After all the tiles were generated, the points that define the tile vertices were transferred from the 2D plane onto the 3D input surface using their UV coordinates (Figure 10, E). For each on-surface point, a lofted point was found along a vector normal to the surface and at a distance determined by

the *Curvature* method. Polyline boundaries of the tiles were then drawn through the base set of points and through the newly created set of points offset along the direction of the surface normal (Figure 6, C).

A polygonal cell-skin (Figure 6, G) was generated at base using the base polyline and then a cell-wall (Figure 6, E) was generated as a loft between the base and the offset polylines. A unique textual label was then positioned at the centre of the cell.

Cells were generated so that the vertices of the adjacent sides shared the same coordinates. This geometrically precise solution did not take into account the thickness of the cell-wall material, the thickness of the cell-skin flap and the thickness of the glue. This introduced an error that accumulated to a significant amount. There were 76 touching cell-walls along the top edge of the outer shell. Assuming that each doubled cell-wall had a thickness of 6mm it is possible to approximate that the length of the top edge of the shell as constructed would be by 456mm longer than of that modeled digitally. This is a significant amount and the script attempted to compensate for it by creating copies of cell-walls that were inset towards the centre of the cell, along the cell-wall normals, by a designer-specified amount (Figure 6, J).

Cell-skin was then named and exported as a .DXF file into a specifically created directory. Rhino does not support unfolding for polygonal geometry and this task was accomplished in FormZ. FormZ 3.9 that was available for the project did not support scripting and the unfolding of the cell-skins was accomplished manually. This process could be automated in a later version of the software. In addition to unfolding, flaps for gluing (Figure 6, F) were manually added to each unfolded cell-skin even though this procedure could potentially also be encapsulated into a custom script.

Next, the script unfolded the cell-wall and laid it out on the horizontal plane, positioning it alongside the other unfolded strips and assigning to it a textual label. The textual output of the `UnrollSrf` command used for unfolding was written into a log file. This was a necessary quality-control measure. Each side of a cell-wall produced by this process is a non-planar surface and this non-planarity can reach high degrees if the cell-wall sides are long and the local surface-curvature is high. In some cases, the `UnrollSrf` command can fail completely or generate a warning if it registers that the area of the resulting unfolded surface varies significantly from the area of the original surface. The log file provided the facility to catch and treat these problem cases.

All types of objects created by the script were automatically sorted into the relevant layers and named where appropriate to facilitate manual inspection and manipulation. Being able to quickly identify and/or track each detail is crucial when dealing with many uniquely parameterized but topologically identical elements. The content, size, position and orientation

of the labels were all taken into account when managing components. Several project-specific auxiliary scripts were written to aid the tasks of selection and manipulation.

Writing an entry for the unfolded cell-wall into the log file and assigning a random color to the newly created elements for easy visual identification completed one iteration of the loop. The same sequence was repeated for each cell. After all of the cells were created, the script closed the log file, set up the viewports as appropriate, turned off auxiliary layers and exited.

We failed to find the software that would be able to successfully automate the nesting of the unfolded components. Therefore, the unfolded cell-walls were manually nested to fit the dimensions of the cardboard sheets (see Table 2) and the size of the laser-cutter table (1850mm x 920mm). Some longer cell-wall strips had to be split in two and in rare cases three parts, which again emphasized the importance of consistent content management.

TABLE 1. Summary of shell properties.

<i>Parameter</i>	<i>Unit</i>	<i>Inner shell</i>	<i>Outer shell</i>
Number of cells	No.	700	860
Point-distribution method	name	Curvature	Curvature
$D_{\min}$	mm	100	100
$D_{\max}$	mm	600	800
Cell-width method	name	Constant	Curvature
Cell-width range	mm	70	70 - 160
Total area of cell-walls	$m^2$	48	101
Total area of cell-skins	$m^2$	37	59
Average number of sides per cell	No.	5.8	5.8
Cell-wall cardboard caliper	$\mu m$	3000	2000
Total weight of cell-walls	kg	94	138

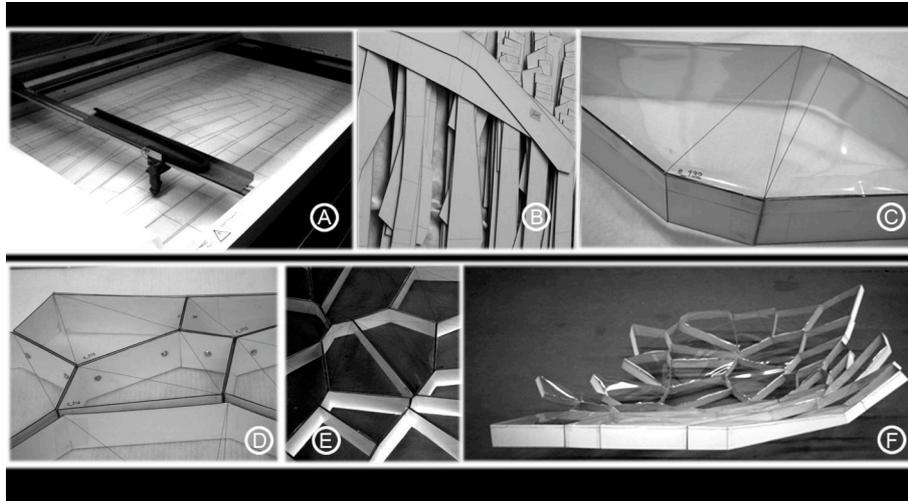
### 3. Manufacturing and Construction

The files containing the data for plotting and cutting of the components were prepared in an appropriate format to be sent to the manufacturer. This was a labour-intensive and mostly manual process.

Cell-walls were pre-manufactured on a laser-cutting table (Figure 12, A). The cutting machine was calibrated to create two types of cuts: a near-full cut to separate the detail from the rest of the material and a partial cut to establish fold-lines. The details were never fully cut out because it was expected that the whole sheets would be easier to transport and the details would be easy to punch out on the site of assembly. However, this introduced badly-cut cell-wall boundaries in places where the card was not fully flat on the surface of the cutting table and the separation of details

proved a time-consuming process. Cell-skins were first plotted on transparent film and then hand-cut to shape and the gluing flaps were pre-folded. The logistics were a major challenge. Large numbers of similar-looking but uniquely-shaped elements required stringent procedures in naming, sorting, transporting and assembling. This part of work was conducted in Cambridge and the ready components were then transported to Prague.

In Prague, the first step in element preparation included the removal of the pre-cut cell-wall strips from the cardboard sheets (Figure 12, B), folding end-to-end and joining with reinforced adhesive tape. Then, the cell-skin was attached to the corresponding cell-wall with hot-melt glue making up a complete cell (Figure 12, C). Assignment, positioning and orientation of labels were crucial at this stage. Thereafter, the assembly of patches (Figure 12, F) consisting of a group of adjacent cells was undertaken in the areas that provided easy access and sufficient flat-floor area. The adjacent cell-walls were also attached with hot-melt glue. The assembly was considered to be an engaging performance in its own right worthy of access by the volunteers and the visiting public. The assembly of components directly in the stairwell would also be a practical impossibility because that space was poorly lit, confined, did not have large enough areas of flat floor and was in constant use during the days. The cell patches had to be made to specific dimensions so that it would be possible to move and mount them without specialised machinery and so that they would fit into doors and freight lifts of the museum. For this purpose the outer shell was arbitrarily split into 14 vertical patches of approximately the same size, each with an individual suspension point. The practice has shown the selected method to be far from perfect as it was difficult to assemble curvilinear patches on the flat floor and even more difficult to suspend and match their seams in the dangerous heights of the stairwell space.



*Figure 12.* Strips, cells and patches. A) A cardboard sheet cut and scored by a laser-cutter and sorted for assembly. B) Cardboard strips to be assembled into cell-walls. C) A cell with a cell-skin attached. D) Cells assembled with hot-melt glue and reinforced with nuts and bolts. E) A fragment of a cell-patch. F) A cell-patch. (photographs)

The next stage included the installation of the suspension structure in the stairwell and mounting of the assembled cell patches. As anticipated, problems were occurring at the fold lines of the cells-walls where the cardboard was weakened by score-lines. The structural load had to extend through the cells and wire ropes towards the ceiling. The wires were fixed to the touching cell-walls of the upper rim. The locations of the suspension point had a significant impact on the deformation of the shells. The cell walls below the suspension points were in tension and that could lead to bending while the parts of the structure between the suspension points would attempt to sag. The structure was very light but given the thicknesses of the cell-walls and the dimensions of the cells the stresses were significant. Structural continuity around the corner-areas of the cells was crucial. The cells adjacent to suspension points were reinforced with extra tape and the nearby cells were joined with metal bolts in addition to glue (Figure 12, D).

The final stage of the construction was the suspension of the cell patches in the stairwell. Each shell could only assume the final form when fully assembled. Before the patches were joined together, nothing was forcing them into their ultimate form and they would distort under the influence of gravity and pull/push forces applied during assembly. Forcing the patches into the designated shapes in an eight-meter-high confined space was a considerable challenge. A full scaffolding system had to be constructed and subsequently gradually lowered and disassembled as the patches were put into place (Figure 1; Figure 2, right). Given this technique it would likely to be

beneficial to sub-split and assemble the shells in smaller horizontal rather than vertical sections.

Several possible layouts of the attachment to the existing stairwell structure were considered. Because of the bad condition of the ceiling and the difficulty in reaching it, it was decided to position several wire ropes horizontally, fastening them to the walls. These ropes meant to provide a grid-like basis for the secondary ropes extending to the suspension points. Temporary synthetic ropes were used to hoist the patches into place and orient them correctly. Two adjacent patches suspended and positioned as appropriate were then connected along the shared seam with bolts and nuts.

Suspending patches one at a time temporarily overloaded some cells as the patches deformed under gravity. This exposed problems in cell attachments introduced by poor quality matching and gluing. Again, nuts, bolts and washers were used to reinforce the problematic connections.

Three dedicated computers running custom-written MAX/MSP/Jitter code were installed in the disused lift and connected to the camera, speakers and projectors (Fig. 7; Fig. 8). This ensured that the audio-visual system was in operation during construction and could be readjusted in response to the emergent situations.

### 3.1 MATERIALS

Grey-centered cardboard with two-side white lamination and transparent film coated on one side and suitable for use in A0 ink-jet plotters were used to make cell-walls and cell-skins respectively. The project utilized 3000 $\mu$ m cardboard for the outer shell cell-walls and 2000 $\mu$ m cardboard for the inner shell cell-walls. A number of tests were carried out with honeycombs and other cellular structures and the details of the implementation were discussed with engineers. The inverse relationship between the cell-wall width and the size of the cells was intended to provide near-uniform structural strength at different curvature levels while saving material, minimizing weight and avoiding highly non-planar component surfaces. As the cells were joined side-by-side, all the walls apart from upper and lower rims had double thickness. The rims were additionally reinforced with an extra layer of cardboard.

Being multi-vertex polygons with flexible joints, the cells did not automatically assume their intended form. This made them structurally weak and difficult to identify and fit. Cell-skins, made from thin and light but rigid and strong plastic film, locked each cell into shape and greatly contributed to the structural strength of the structure.

TABLE 2. Principal materials.

<i>Material</i>	<i>No.</i>	<i>Size (mm)</i>	<i>Caliper (<math>\mu</math>m)</i>	<i>Substance (g/m<sup>2</sup>)</i>	<i>Stiffness, Resonanz method (ISO 5629) (mNm) (md)</i>	
						<i>(cd)</i>
Kappa-Attica Displayline Board	35	1600 x 1200	3000	1950	5700	2885
James Cropper PLC display board	70	1850 x 1250	2000	1375	3175	1010
HP acetate film	3	914 x 45000	125	N/A	N/A	N/A

### 3.2 TIME AND COST

The project was under development for more than 6 months with 6 people involved in the design and fabrication processes on a regular basis and more helping in the later stages. The on-site assembly was particularly labor-intensive with more than 30 people involved in various kinds of work for no less than 20 days. Cardboard is a relatively inexpensive material. However, the production costs are not insignificant. Altogether, there were 1560 cells, each cell had an average of 5.8 sides, and each side required a series of discrete operations, the total amounting to tens of thousands of individual operations. The demands on time and cost would be significantly reduced through automation of the manufacturing stage and rationalization of the logistics but the development of a cost-effective building process would take its own time and further investment.

As a very rough estimate, it is possible to predict that with the described workflow the full structure as designed could be completed in 70 working days by a team of 10 people at a cost of £70.000 if full commercial rates were used.

## 4. Conclusion

This paper described a series of experimental techniques for procedural design using as a case-study a practical project developed and constructed for a large public event. The primary research aspiration behind this work was a desire to develop the backbone process that could illuminate the significant theoretical and practical issues and serve as a basis for future work. The experimentation has confirmed that adaptive non-periodic patterns such as Voronoi can be implemented into a procedural design workflow. This integration provided the first steps towards a unified design approach that considered place-specific form-finding together with custom-built audio-visual design. It was shown how structure uniformity and

density, cell orientation, cell depth, and parameters of cell-skin can be procedurally fine-tuned as interrelated system components.

Future work might look at two areas: the use of patterns other than Voronoi and more intelligent generation of patterns. For example, Cambridge University's Department of Plant Sciences (2005) works on computational simulative models that strive to uncover the way plant-cells specialize, grow, adapt and make up complex structures via cell-to-cell interactions under the influence of local conditions. While this kind of research seeks to understand and modify the growth of plants it can also provide techniques and insights to inform the architectural design of adaptive structures able to host responsive performative situations. Morphogenetic models of growth and cell division can be adopted to and around a unified system able to satisfy multiple spatio-mechanical, functional and performative factors of a complex design situation.

### Acknowledgements

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## **I<sup>3</sup> - EYE-CUBE**

*Interactive intuitive mixed-reality interface for Virtual Architecture*

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**Abstract.** This paper introduces a new tangible interface for navigating through immersive virtual Architecture. It replaces the common mouse or glove with a set of tangible cubes. It includes physical architectural floor plans as contextual haptic constraints for the cubes to ensure better object manipulation compared to free space. The position and orientation of the cubes relative to the floor plan is tracked by web cameras and a newly developed program translates this into the 6-dof of the virtual camera generating a 3D view for the immersive projection of virtual architecture. This easy to use tangible interface mixes common 2D dimensional (real) with 3D immersive representation (virtual) of Architecture to overcome the problem of ‘Getting lost in Cyberspace’.

### **1. Introduction – Immersive Presentation of Architecture**

In this paper we focus on selected aspects of architecture namely on the organization of space and representation of scale. Consequently, computational visualizations of architecture need to enable proper visual perception of space and scale. Hence visualizations of architecture on small computer screens and interaction devices such as mouse or keyboard are

deemed to be not sufficient. Fortunately the advances of technology and development of Virtual Reality have brought about large screen visualizations with stereoscopic immersive projections that ‘wrap’ the 3d space around a user eventually making him believe that he is inside the virtual world rather than looking at it from outside. This is indeed a very positive development towards better visual perception of architecture, but we still feel that the navigation is too difficult to appropriately explore architectural space.

## **2. Problem Statement – Lost in Cyberspace**

Common navigation devices still require the user to wear a position and orientation tracker systems, whereby the movements of the viewer in the real space are synchronized with the virtual architecture. Now imagine a viewer has to explore a virtual corridor, how would he interact with the space? Intuitively one would start moving in real space, and expect the system to translate this into walking along the virtual corridor, well, until the user hits the projection screen. A regular mishap when layperson walks through virtual space for the first time.

Another persistent problem is that users tend to loose orientation exploring virtual worlds. They don’t know if they are still heading in the same direction, is the room where they came from towards the left or right, etc. This sense of orientation is very important in the exploration of architectural space. A lack of orientation is crucial, quite characteristic and is commonly results in what is referred to as ‘Getting lost in Cyberspace’.

## **3. Project brief – A new Tangible and Mixed Reality Interface**

The objective of the project was to overcome this problem by approaching it from two directions. The first is more from the human-computer-interface point of view and concerns the user’s ability to navigate through space intuitively. An easy control of the 6 degrees-of-freedom (x,y,z, yaw, pitch, roll) is not given by a common mouse (2-dof) and gloves are too technical to use, although they allow for 6-dof. The second problem comes from an architectural point of view and expresses the concern that the 2D representations as printed floor plans, section, elevations are still common when dealing with architecture and should thus not be excluded. Hence the objective was to propose a navigation interface that links both the 3d-immersive and 2d-drawing representation.

A first brief mapped the key features of such a system which foresees a table which holds 2d drawings and a moveable tangible object that

represents the camera. The object shall become a non-wired easy to grasp interface which translates all 6-dof to the virtual camera. And the object resting on the floor plan, should establish a 3<sup>rd</sup> person view that tells the positions of user or rather virtual camera. The navigation interface should furthermore be independent of the displayed architecture, meaning it should work with other floor plans of even different scale and architecture. The procedure to synchronize the coordinate origin between the floor plans and 3d model and the extents in all three directions must be an easy procedure to be performed quickly by a standard user.

#### **4. Mixed Reality Lab (Department of Engineering)**

Current research in developing human-computer-interfaces tries to overcome these problems by developing interface devices that represent themselves less technical and are easy to handle and respond intuitively. We refer to Augmented or Mixed Reality when the three dimensional computer generated virtual space (or architecture in our case) augments the visual cues of the real work we are in, so that basically both worlds a) the Virtual and b) the Real can be seen at the same time (Milgram, Takemura, Utsumi, and Kishino, 1994). At the same time two major transitions happen to replace the traditional input and output devices. So called multimodal interfaces extend the range of possible user input by gesture, sound, speech, touch etc. (Schomaker, Nijstmans, and Camurri, 1995). The usual glove for interacting in virtual worlds is for instance such an interface which allows the user to communicate with the system by gestures expressed through finger positions or movements.

On the other hand usual output devices such as monitor screens are replaced by surrounding stereoscopic projections environments which make the user feel inside a space rather than looking at it through a window (Cruz-Neira, Sandin, and DeFanti, 1993). Wearable display systems such as Head-Mounted-Displays (HMD) are other developments in this area. One of the authors has developed several combinations of multimodal and mixed reality interfaces with one combination customized for this particular architectural usage (Zhou, 2004). Physical cubes are used as tangible user interface to interact with Augmented Reality (Ishii and Ullmer, 1997).

#### **5. Digital Space Lab (Department of Architecture)**

The interface is supposed to be integrated into the Digital Space Lab (DSL) of the Department of Architecture (Wittkopf, 2004)]. The DSL comprises of three systems. The commercial VR Software *EON Professional* is used to

import 3D-CAD models and render stereoscopic images of high resolution in real-time. The rendering is distributed over two high-performance graphic PC-workstations. The display system then blends both images together resulting in a total pixel resolution of 2304x1024. Four bright projectors beam the images from the back onto a translucent flat screen of 2m by 4.5m size. Each pair is projecting one view, meaning the left and right image overlap. This is then turned into a 3d image in the eye of the user by wearing simple polarized glasses. Figure 1 shows the PC-workstations and projection screen. For a presentations viewer would just stand or sit in front of the screen while a expert user sitting in front of the PC-workstations navigates them through the space. Alternatively the user can use a wireless mouse while directly looking at the projection screen.

This large, stereoscopic, bright image of high resolution allows users to view Architecture from within to judge on scale, space and visual connections as can be seen in Figure 2. The immersive visualization of architecture can be augmented with interactive features which eventually establish a laboratory for architectural design studies, a lab of particular importance for teaching and learning by experimenting.



*Figure 1.* Working session inside the Digital Space Lab showing the PC-workstations on the right hand side and the back-projection screen behind the user

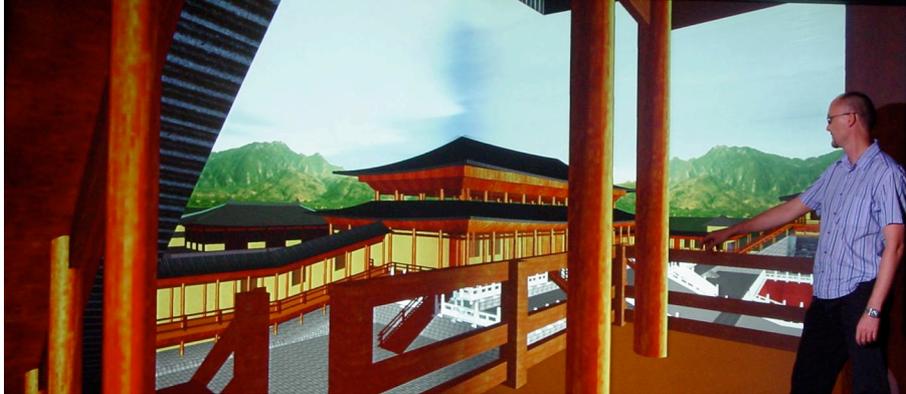


Figure 2. User experiencing the projected architecture in almost 1:1 scale

The current navigation devices include a 2-dof and 6-dof mouse but experience has shown that the following movements are relative difficult:

- Going back/forth or left/right while looking around
- Panning vertically and horizontally along a façade
- Locking a certain angle (looking up) while panning or walking
- Jumping to one view without traveling

Two or three button mice only allow modifying two or three degrees of freedom (dof), which have to be identified upfront. The keyboard can help to activate the other dof's but all 6-dof at the same time can not be performed. The standard setting for instance would allow the user only to walk towards the view, which is quite in-natural since we look around while walking. This forces a user to learn a new confusing way to navigate which is different from the natural and henceforth not intuitive.

Space mouse or 5-6-dof mice on the other hand are very touch sensitive and require additional push of buttons to switch between different dof and provide very little haptic feedback. Gloves require the user to learn a certain language of finger gestures before one can easily navigate through space. So in short, a natural navigation is characterized by movements in space (6-dof) but the supporting interfaces are not very intuitive.

## 5. The Interface

### 5.1 SYSTEM DESIGN

We name this interface system as the Eye-Cube, abbreviated as  $I^3$  to represent an *interactive intuitive interface*. In most cases, the main function of first cube is to become a virtual eye of the user in virtual space, creating an immersive experience for him during the architecture visualization process. The second cube on the other hand serves as a multi-function interface device to allow the user to interact with the virtual environment in an intuitive manner, depending on how it was pre-programmed by the designer.

The core of this system lies in two cubes (7cm x 7cm x 7cm) with different patterns printed on each and every face of both cubes. We found the possible reasons for choosing cubes/blocks lie mainly in two aspects:

- As compared to a ball or other artifact in complex shapes, a cube/block has stable physical equilibriums (resting on one of its surfaces) which make it relatively easier to track/sense. In this sample system, we define the states of the cube by these physical equilibriums.
- Cubes when piled together form a compact and stable structure. This could reduce scatter on the interactive workspace.

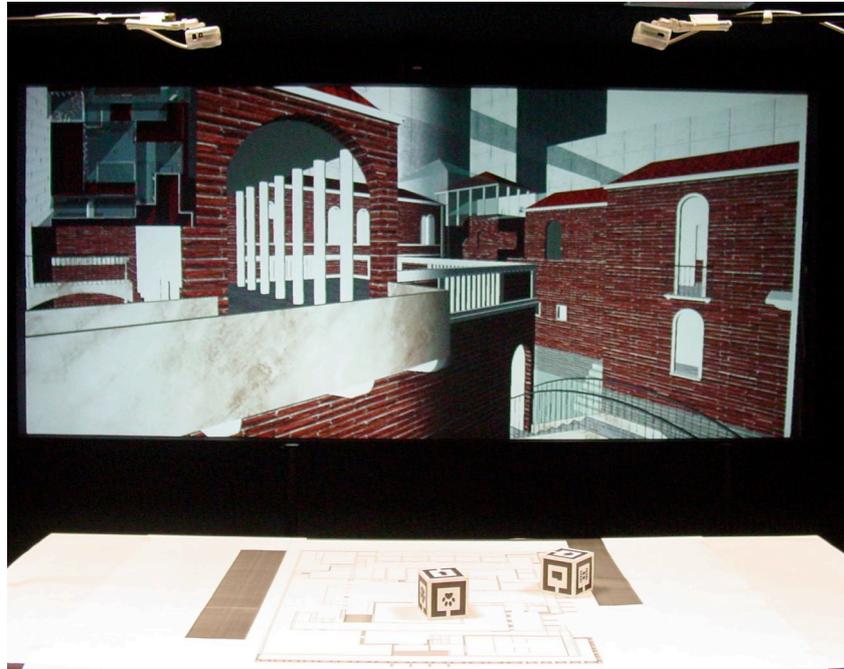
In addition to the above mentioned, the cube is an intuitive and simple object that we are familiar with since childhood. This graspable object allows us to take advantage our keen spatial reasoning and leverages off our prehensile behaviors for physical object manipulations.

The cubes can be made of any solid and hard but relatively lightweight materials such as plastic or wood, In this case, we choose acrylic for it is easily available. The size of the cubes is chosen in such way so that it can be easily held in average adult users' hands. There are neither wires attached nor circuitry embedded in the cubes; they are just plain solid cubes with patterns.

A table large enough to allow a floor-plan of A0 size (1189mm x 81 mm) to be placed on top of it is located 5m in front of a 4.5m by 2.5m rear projection screen. Two desktops computers are responsible for running the *EON Professional* visualization software to render the virtual environment the user desires to see and project it on the screen through 4 bright high-resolution projectors.

Figure 3 shows the components of the interface as part of the Digital Space Lab of the Department of Architecture. The foreground shows a table

with a floor plan on which the floor plan is mounted. Two web cameras are tracking the cubes position from above.



*Figure 3.* Cubes resting on a physical drawing, vision tracked by two web cameras to generate the 3d view on the large projection screen.

The table thus becomes the platform for the user of which he can interact with the virtual environment projected. As pointed out, this physical table surface will provide contextual haptic constraints to ensure better object manipulation compared to free space (Wang and Mac Kenzie, 2000). Based on the user's manipulation of the cubes with respect to the floor-plan laid on the table, the virtual environment is directly influenced and affected. By this means, the tangible cubes have become a handle to interact with the physical and virtual world simultaneously. By referencing to the physical layouts, the designer will be well-instructed their location and orientations in the virtual world, hence he will not get lost in the virtual design space.

Figure 4 shows a user controlling the view with the cube showing the arrow on top, and saving the view through a rotation of the other cube. The cube size is actually depending on the resolution of the camera and its distance to the table.

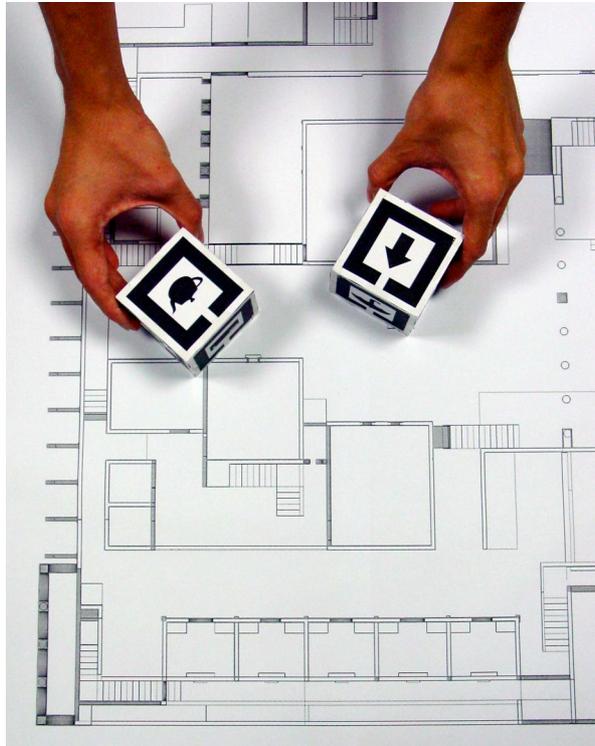


Figure 4. User controlling the view with the cube showing the arrow on top and saving the view with a rotation of the other cube.

To track the movements and states of the cubes, two *Unibrain* IEEE1394 cameras are required to overlook the table from the top. The necessity of two cameras arises due to the limited field of view of the camera lenses to encompass the whole A0 size floor-plan. With two cameras, a volume space of A0 size by the height of 30cm can be covered with two cameras looking down from the height of 1.4 m, allowing users to move the cubes freely in such a space. Both cameras have a slight overlap vision of about 20% at the centre.

The video which has the cubes in it is captured from the camera are fed to the desktop computers via a 10m IEEE394 cable, where it will be processed by a program. This will be. Figure 5 shows how the developed program recognizes the cubes and translates this into meaningful data such as position and orientation to be channeled directly to the *EON Professional* visualization software in real-time.

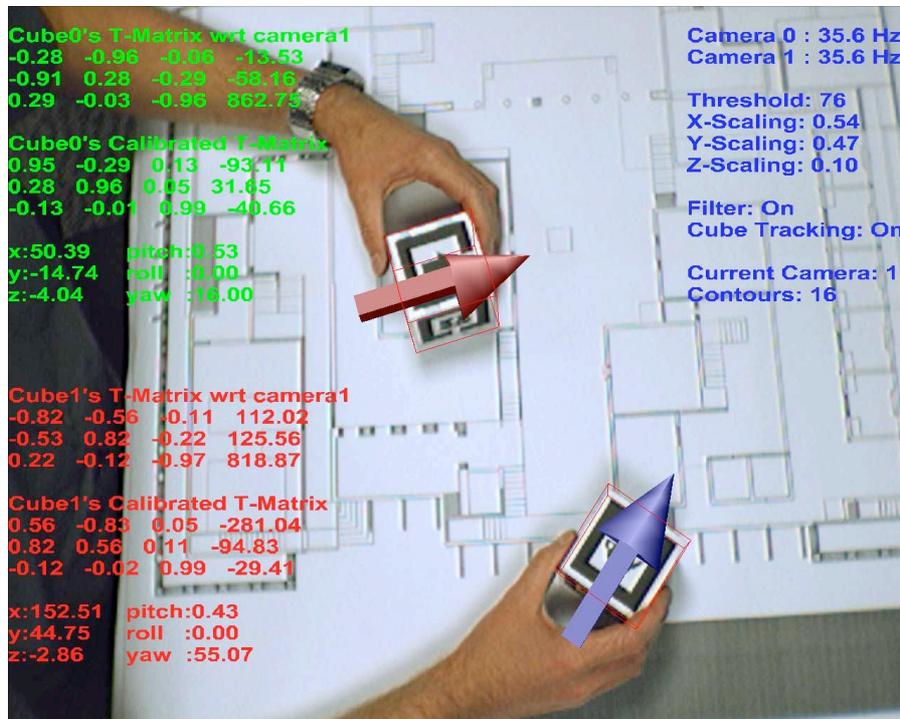


Figure 5. The developed software recognizes the cube and translates the data as position and orientation of the virtual camera

In short, the whole system forms a close-loop feedback system, where the user's physical input (cube manipulation) is affecting the output (virtual environment video projected on screen) and then back to the user as a feedback, allowing him to relate what he does with the cubes and what he sees on the screen. This system is shown in Figure 6. The complex communication and tedious computation process that lies underneath are completely invisible to the end-user. More importantly, the gap between the physical and virtual world become blurred and the user interacts with both worlds simultaneously and intuitively.

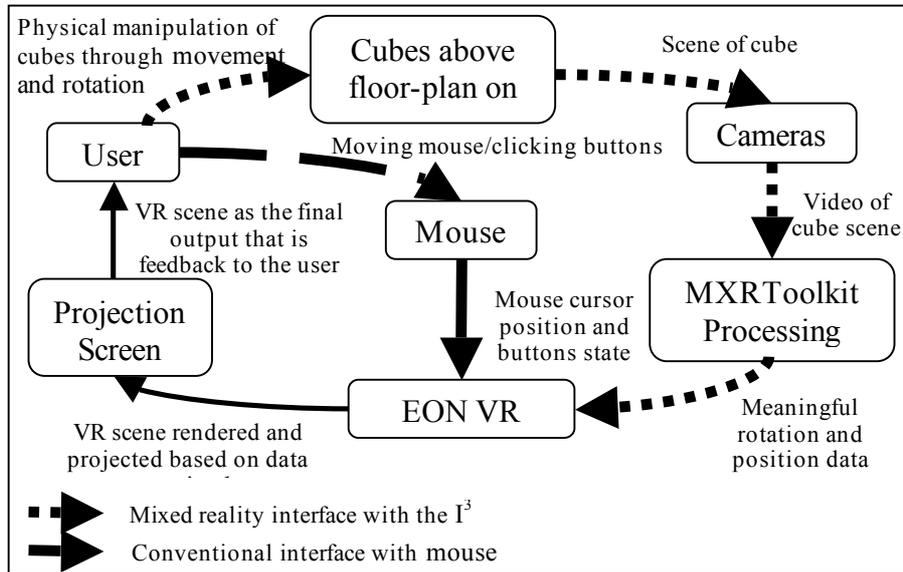


Figure 6: The top level system design of the I3 system

## 5.2. TECHNOLOGY

### 5.2.1. Tracking

The primary technology behind the I<sup>3</sup> system lies in the field of vision tracking. As our task involves the tracking of 3D objects, we considered using *ARToolkit* for tracking of 3D objects (Billinghurst and Kato, 1999). However, the latest stable version of the *ARToolkit* runs on Linux platform, whereas our current visualization software, *EON Professional* runs on the *Windows XP* platform. Hence we used the *MXRToolkit*, a similar open source library package that runs Windows platform.

*MXRToolkit* works on the principle of tracking the position of the 2D marker with reference to the camera. However, 2D cards are relatively hard to grasp and the tracking will be difficult if our hands occlude the markers when manipulating cards. To surmount these problems, we designed an algorithm to track our 3D cube which has six different markers on each of its surfaces. The position of each marker relative to one another is known and fixed. Thus, to identify where the cube is, the minimum requirement is to track any of the six markers. This idea is similar to ‘multiple marker tracking’ in *MXRToolkit*. However, instead of putting multiple markers on the same card, we extend and apply this idea to 3D artifact-cube (Zhou, 2004). Our algorithm ensures continuous tracking when our Figures happen to occlude different parts of cube during interaction, which is very likely to

happen. It allows an intuitive and direct handing of the cubes with very little constraints in manipulation whatsoever. This effectively bridges the gulf between the designers and the users of the I<sup>3</sup> system.

#### 5.2.2. Processing and Calibration

The tracking program is able to run at the frequency of 30Hz, allowing sufficient real-time update in the visualization program. A software average filter is also implemented in the program to smoothen the tracking data so as to reduce jittery that might arise from various factors such as unstable lighting which affects the video captured.

Ultimately, the *MXRToolkit* will decipher the video captured into meaningful data to be used in the visualization software. By tracking the marker cube in the image of each video frame, the transformation matrix of each cube (if seen/tracked) with respect to the camera will be obtained through a series of calculation. This of course is not enough, because what we need is a relative position and orientation with respect to the floor-plan which the cubes are rested upon.

In order to achieve this, calibration is needed in the pre-programming process, so that the centre and boundary volume of the floor-plan is known by the program that computes the data. This calibration process is done by simply placing and marking the cube (in software using keyboard) on the centre and extreme edges of the floor-plan provided that the camera and the floor-plan remain fixed to each other, the calibration process need to be executed once and the data will be saved.

In essence, we only need to track each cube's position and orientation, a total 6 degrees of freedom. However, for simplification we ignore the roll component so as to preserve the horizon and to restrict user to rotating the cube about the two other angles. Accidental rotation about the y-axis will be ignored by the program.

#### 5.2.3. Communication

In order to feed the positions and orientations of the two cubes into the visualization software, we created a TCP/IP server-client for networking communication of the data. Using the *EON Professional* Software Development Kit, we are able to implement the client structure to connect and retrieve data on the server that we implement on the *MXRToolkit* processing program. Hence the designer user would just need to link up the positions/orientation data to the relevant section of the visualization program, for example the virtual camera. An overview of the communication flow is given in Figure 7.

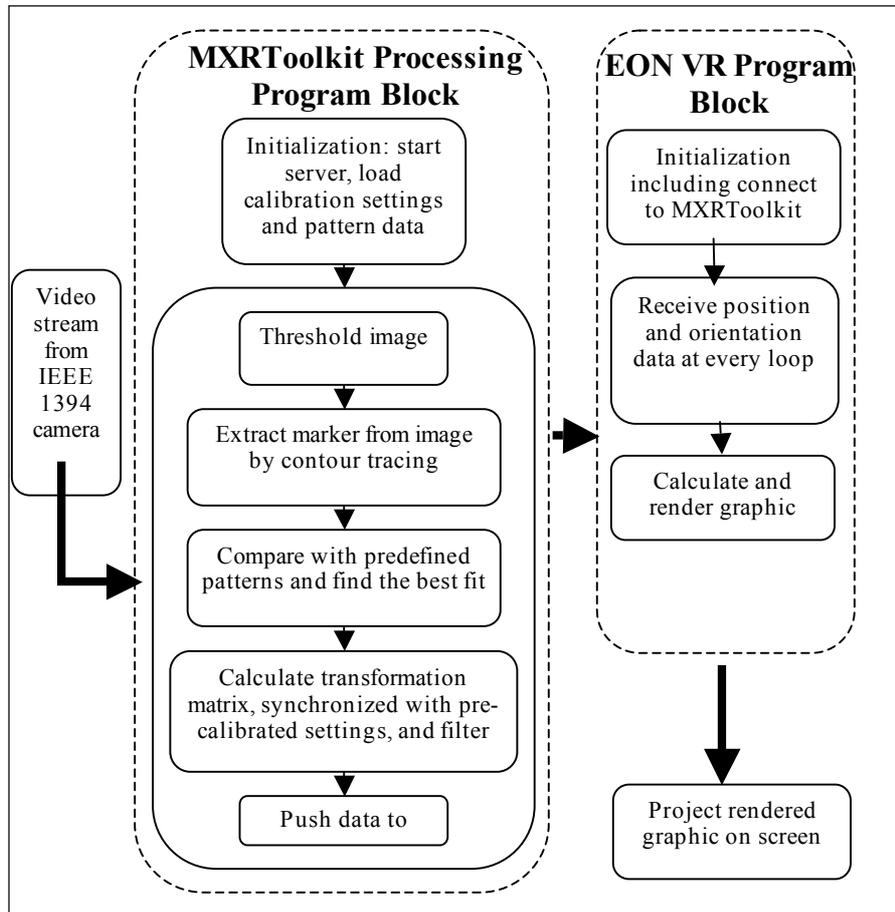


Figure 7. The core processing units' work flow of the of the I3 system

### 5.3. USAGE

In this section we will look in depth on the how the I<sup>3</sup> system is being applied effectively as an interactive interface for architecture visualization process. We will look at three primary usages of the cubes that not only as a substitution but also in achieving features that are not possible before this using the conventional interfaces such as keyboard and mouse.

#### 5.3.1. The Third Eye

As mentioned earlier, the primary application of the first cube is to be the user's third eye in the virtual environment. What is novel here is not so much of how the cube represents the first person perspective of the user (as

can be done with keyboard and mouse), but how the cube actually translates the user's action into a virtual viewfinder. Mouse and keyboard, while allowing user to roam around in virtual environment, do not provide an absolute reference frame for the user. A keyboard is static; a mouse movement is tracked based on the difference of current position with respect to previous position which is not continuous in time as the user often has to lift the mouse back to the original position. The lack of such a physical absolute reference frame often leads to user to lose his sense of position and orientation in the virtual environment, especially in instance where the surrounding looks almost the same everywhere such as inside a forest or an empty room.

A cube, on the other hand, solves this problem intuitively and elegantly. When the user moves and rotates the cube on top of the floor-plan, the first person view shown in the projection screen is directly reflected. For example, if the cube is placed facing west in the lobby of the floor-plan, the corresponding first-person view projected would be simply facing west in the lobby as well. Hence the floor-plan now becomes the absolute reference frame and the cube physical position and orientation mirrors directly what should be seen from that spot in the virtual environment. Any confusion can be cleared by just checking between what is being projected on the screen and where is the cube.

However, the advantages of using the cube interface do not stop here. Instead of using (and memorizing) different mouse button to change positions or rotations, the cube interface could not have been simpler; moving and rotating the cube in physical space corresponds directly to the movement and rotation of the view in virtual space. The mouse interface only provides freedom of movement in a 2 dimension plane, whereas the cube actually offers all the 6 degrees of freedom to the user. Text display on the screen is also possible to show the camera's current absolute position and orientation relative to the current frame.

Of course, we should also notice that too much choices of freedom might sometimes confuse the user too. For example, the user might not be too comfortable holding and maintaining a cube in the mid air to view a building from the bird's eyes view, but still he wishes to move around to see the every parts of the building from the current height and angle. To solve this problem, we can use the second cube to "lock" the desired position and orientation. In this case, by rotating the second cube 90 degrees clockwise about the vertical axis, the z-position and pitch angle of the first cube can be locked virtually, and thus the user can rest the cube back on the floor-plan to vary only the x-y positions and yaw.

Users can also predefine and recall up to 20 individual views for any virtual scene. In the predefinition-mode, the user would have to use the first cube to pinpoint the desired saving point. Once selected, the second cube

will be rotated clockwise for about 15 degrees to save that very point, with text display on the screen to serve as prompt. In the recall-mode, the user would just need the second cube and rotate in the same direction to cycle through the views saved earlier. To extend this further, the points can be interpolated to form a guided tour playback for the user to watch. The switching of different modes (predefinition, recall and guided tour) can be achieved by moving the cube to different quadrant of the floor-plan.

### *5.3.3. Third Person View*

Sometimes first person view perspective might not give the best information or idea how the place might actually look like. For example, the user is now in office block somewhere in the middle of a tall building, and he wishes to see himself from a third person perspective, something like a X-ray vision that cuts through the building to see where he is exactly standing.

This can be done simply with two cubes. Using the second cube, we can specify a certain rotation; say 90 degrees anticlockwise with respect to the vertical axis to switch between the original first person view or the third person view. Once we are in the third person view mode, what we are actually doing is to give an offset to the original view we were in, with the angle pointing to our original point, instead of where we were looking in the first person view. In other words, our view is now locked towards our earlier point at a certain distance which we now can vary through the rotation of the first cube.

Rotating the first cube to zoom might not be sufficient to view where we are, our representation in the virtual space could be occluded by wall or other objects. Hence we deploy the second cube rotation about the horizontal axis to vary the near cutting plane, assuming the far cutting plane is much further behind, thus giving the user the ability to see through walls.

For a simpler third person viewing mode, an overhead bird eyes view that looks directly downwards might be sufficient and intuitive enough to give a clear picture.

### *5.3.4. Future applications - Customization of Objects*

The application of the cubes for customization of objects yet another interactive and intuitive way of sending commands from the user to the virtual environment. Using one cube, the user could specify what he wishes to customize, for example, color, texture, lighting condition or size through a combination of movement or rotation. In order not to burden the user to memorize different combination, the pattern printed on the cube should be easily recognized for each mode, for example a painting brush pattern representing switching color mode. Text and graphical denotations are also

displayed on the screen to act as additional aid to remind the user to switch between different modes.

The second cube is now in charge of varying the parameters of the attribute selected by the first cube. If the user selects the color attribute, moving in the x, y and rotating about the vertical axis could each independently influence the red, green and blue component of the color preferred. Or if the user wishes to change the external condition of a building, the second cube can now be treated as a virtual sun to shine on the building from different positions and angle and intensity. The options and possibilities for customization of objects that can be achieved with the two cubes are theoretically endless, although system complexity becomes a real problem when user gets confused about too many choices.

## **6. Conclusion**

The paper introduced a new tangible interface for easy navigation through immersive Virtual Architecture to overcome the common problem of 'Getting lost in Cyberspace'. It has conceptually been developed for general applications and was further developed and extended to meet the special requirements for easy navigation within Virtual Architecture. The integration of the 2D floor plans as contextual reference and constrains resulted in positive feedback particularly from new users, who usually would have problems operating with the limited 2-dof mouse or too complex glove. Operating the cubes to control the camera, set slanted references planes, save and recall views, and display a third person's top view was also found to be easy and intuitive. This is important since the cubes are the key to access many combinations hosting different features. Features such as object modification or browsing through additional media such as still pictures and video are planned for the future. Having integrated this interface into the Digital Space Lab of the Department of Architecture will enable more non-expert users benefit from immersive visualization of virtual architectural space.

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**Section VI: Environmental Quality  
Modelling and Evaluation**

## USING SPACE SYNTAX SOFTWARE IN EXPLAINING CRIME

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**Abstract.** Space syntax provides methods for analyzing spaces using recent developments in computer programs. This paper reports a study that was undertaken to investigate the role of space syntax in identifying geographical patterns of crime in Ypsilanti, Michigan. All the spaces in the city were analyzed using the *Spatialist*, a computer program developed by Georgia Tech. The *Spatialist* computes the accessibility level of all the spaces in a spatial system. Sociodemographic variables such as median income, racial composition, youth concentration and level of education were available from the U.S. Census. The crime report was obtained from the Ypsilanti Police Department and Eastern Michigan University. It includes data on four types of crime at an address level with the exact date and time. Both sociodemographic variables and crime data were merged with the *Spatialist* map using ArcGIS. The data was analyzed using SAS, an advanced statistical package. Findings showed strong relationships between attributes of space and crime locations.

### 1. Introduction

A considerable body of literature now exists on the impact of spatial configuration on human behavior. Wayfinding performance, for example, decreases in buildings characterized with high number of hallway intersections (Best, 1970) and with more complex relations between choice points (O'Neill, 1991). On an urban scale, some studies have given some weight to assertions that curvilinear street networks, T-intersections, and spatial relationships influence walking and bicycling (Frank and Engelke, 2001; Southworth and Owens, 1993.). Much of these researches, however, were not able to illuminate the extent to which spatial configuration influences human behavior. Additionally, it was difficult to derive an objective methodology that can reliably demonstrate a statistical relationship between environment and behavior.

Only recently, some researchers have begun to give more attention to the properties of spatial configuration and their effect on human behavior using *Space Syntax* techniques. Space syntax, a group of theories that examine the social use of space, was developed in the late 60s by Hillier and Hanson (1984). Briefly, this theory is based on breaking all the spaces in a plan into long lines of sight. For example, all the hallways in a building plan will be flood-filled by long lines of sight. Similarly, all the streets in a city will be broken into interconnected long lines of sight. According to space syntax, these lines are known as axial lines.

Gradually and over the years, several space syntax measures were developed based on the relation between each axial line and all the lines in the system (e.g. in a building plan or in a city). This research will focus on two of these measures: Integration and Connectivity. To elaborate on these two measures, Connectivity gives the number of lines that are directly connected to a specific line. Integration, on the other hand, is an indicator of how easily a line is reached from all other lines in the spatial area. Mathematically speaking, it is the average number of spaces that one needs to pass through to reach a specific line from all other axial lines in the system. In other words, integration values suggest the extent to which a selected space in the system is more *integrated* (can be easily reached from other spaces), or more *segregated* (one has to travel through many spaces in order to reach that selected space). Two additional measures were also derived from integration measure: 1) global integration measures the relationship between a specific line and all the other lines in a system, and 2) local integration measures the accessibility of the line from lines that are few steps away as specified by the researcher.

Several computer programs have been developed to compute these measures. Most of these programs produce two types of output: alphanumeric data with spatial parameters assigned to each axial line and graphic data with a map that has colored lines where red indicates the most integrated or connected line to indigo for the most segregated or least connected line. Simply put, looking at the resulting map one will enable the researcher to make inferences about streets, areas or neighborhoods in a city. Examples of these programs include the *Spatialist*, developed by Peponis and Wineman at Georgia Tech; *Depthmap*, developed by Turner at University College London; and *Omnivista*, developed by Dalton and Dalton at University College London.

As a result of advancement in computer technologies, several studies have looked at the implications of space syntax measures on human behavior. For example, we investigated the effects of spatial behaviors and layout attributes on individual's perception of psychosocial constructs in four U.S. federal office settings (Rashid et al., 2005). Using space syntax techniques, questionnaire surveys and behavioral mappings, we found that

measures like integration and connectivity had significant effects on individual's perception of psychosocial constructs in office settings.

On an urban scale, several studies found strong correlations between space syntax measures and walking behavior. Reid (1999), for example, found that Deutch neighborhoods with higher mean connectivities and integration had higher movement rates with a correlation coefficient of 0.829. Similarly, Nubani (2003) confirmed similar results in three cities in Southeastern Michigan. Correlations between integration and walking were strong.

The objective of this paper is to use similar computer technologies in understanding geographical distribution of crime as a behavioral outcome. It examines the relationship between measures of space syntax and certain types of crime in order to address the question of 'opportunity.' Specifically the research applies the techniques of space syntax to explore the characteristics of streets that might contribute to the reduction of opportunities for criminal acts. In addition to examining street characteristics, the paper also addresses theories related to crime as set forth by criminologists.

## **2. Background Literature**

Generally, most of the 'design for crime prevention' work has been grounded in three theories related to crime: the rational offender theory (also known as rational choice theory), the behavioral geography theory and the routine activities theory (Taylor, 2002). The rational offender theory stemmed from the classical school of criminology founded by Cesare Beccaria. He believed that people have the will to act freely and that crime is controllable by means of punishment. However, this perspective declined by mid-twentieth century as the positivist criminology argued that crimes are the results of genetic, social and psychological factors rather than personal choice and decision-making (Siegel, 2002). In 1970s, the rational choice theory supported the thoughts called by the classical school of criminology and assumed that the benefits of crime influence patterns of offenses. In other words, criminals are rational actors who weigh the potential costs of crime and the consequences of their actions (Siegel, 2002). Their decision process considers both their personal needs such as money and excitement and situational factors such as the likelihood of being caught and surveillance.

The behavioral geography theory, on the other hand, considers the fact that places that are closer to where offenders work or reside are at higher risk of being burglarized than places that are not within the offenders' regular

route. One may infer that this theory suggests that crime rate is linked to easy accessibility (Taylor, 2002).

The routine activities theory looks at the interaction of three everyday variables: 1) the availability of attractive targets such as unlocked homes and attractive valuables; 2) the absence of guardians such as neighbors, homeowners or police; and 3) the presence of motivated offenders such as teenagers and unemployed people (Reid, 2002; Siegel, 2002). If targets are exposed to all three variables, they are at higher risk of being victimized.

It is worth mentioning that the rational offender theory provided the basis for the situational crime prevention program (Bennett, 1989). It is targeted at reducing the opportunities to commit burglaries based on the belief that offenders freely and actively commit crimes as a response to immediate circumstances and depending on costs and rewards.

Based on the review provided by Bennett (1989), situational measures operate at three levels. First, at an individual level, situational measures call for target hardening and installing alarms and surveillance cameras. The time it takes to overcome such obstacles is perceived as a risk by offenders. Secondly, at a community level, neighborhood watch programs have been implemented to involve residents in reporting suspicious activities. Research to date has not shown whether this had a perceived risk among offenders or not. Thirdly, at a physical environment level, situational measures are based on Jacobs and Newman's concepts of controlling pedestrian and traffic flows, territoriality and natural surveillance. Jacobs believed that through the occupation and use of space, residents come to consider a particular space as theirs and exert control over it (Jacobs, 1961).

To a certain degree, it can be deduced from the afore-mentioned theories and prevention programs that offenders share four general concerns: how quickly it takes to get to the target, how quickly it takes to run away, how much value the target possibly has, and, how likely the offender is to be caught while committing the crime or leaving the scene (Taylor, 2002; Rengert, 1980).

Previous literature has also shown that the three basic elements necessary for someone to commit a crime are ability, opportunity and motive (Stollard, 1991). Thus, if it could be shown using space syntax techniques which streets offer the opportunity to commit a crime, then it becomes easier for police to know which streets to increase patrolling

### **3. Space Syntax and Crime**

Building on the idea that neighborhood layouts provide opportunities and access to commit a crime, Shu and Huang (2003) studied the influence of spatial configuration on the distribution of burglary in 121 residential

neighborhoods. In the first part of their analysis, they controlled for social factors by looking at three districts in Northern Taiwan inhabited by different social classes. Police crime data was gathered for an 8 month period; there were total number of 241 crime incidents. Through correlational analyses, a strong connection was found between global integration and burglary rates in low-income neighborhoods. Further findings indicated that there were correlations between local integration and burglary rates in middle-income neighborhoods. The authors proposed that globally and locally integrated middle-income neighborhoods are safer than segregated ones. In addition, the authors found no correlation between global or local integration and burglary rates in high-income neighborhoods. This is possibly explained by the fact that “target hardening” features are more common within high income neighborhoods.

Similar to previous work by Shu and Huang, Jones & Fanek (1997) looked at the effect of spatial configuration on crime in Austin, Texas. They selected four pairs of tracts in which each pair had similar income, poverty rates, population and racial composition. Using Axman software, developed at University College London, their findings showed that pairs with higher integration values were associated with lower crime rates. The authors explained that more connected streets will attract higher pedestrian movement, and thus more eyes on the street.

As a result of promising findings using Space Syntax for identifying the spatial distribution of crime, Gosnells, a city in Western Australia consulted the Space Syntax laboratory at University College London and Murdoch University to identify the spatial distribution of crime (Australia’s National Government Newspaper, 2003). The Space Syntax Lab compared the movement of pedestrians and vehicles to crime statistics and space syntax measures. The results were consistent with previous findings and showed a strong link between spatial configuration and burglary and theft.

Farooq (1999) looked at crime in Metro Atlanta in his doctoral dissertation. He investigated spatial and sociodemographic measures in different types housing settings using similar computer programs. Contrary to previous research, his findings showed that in private rental housing and public housing, crimes against property and persons were higher in integrated areas. The author suggests that this is explained by the fact that these buildings were located on vehicular routes that offered an easy escape to offenders.

#### **4. Types of Crime and Description of Case Study**

Generally, different types of crime have been found to be associated with different types of land use and social characteristics (Dunn, 1980). Personal

attack crimes, for example, occur more often in lower class neighborhoods, while property crimes occur more often in neighborhoods that are accessible or close to other land uses, or in neighborhoods with higher percentages of underemployed or single residents. Arsons, robberies and burglaries share monetary gain objectives and are more likely to occur in middle- and high-class neighborhoods (Rengert, 1980). For these reasons, we excluded non-residential neighborhoods from this study. We also excluded organized crimes or crimes that involve acquaintances or for the purpose of revenge such as assaults and murder. Specifically, we focused on four stranger-to-stranger types of crime. These are larceny, motor vehicle theft, breaking and entering, and robbery.

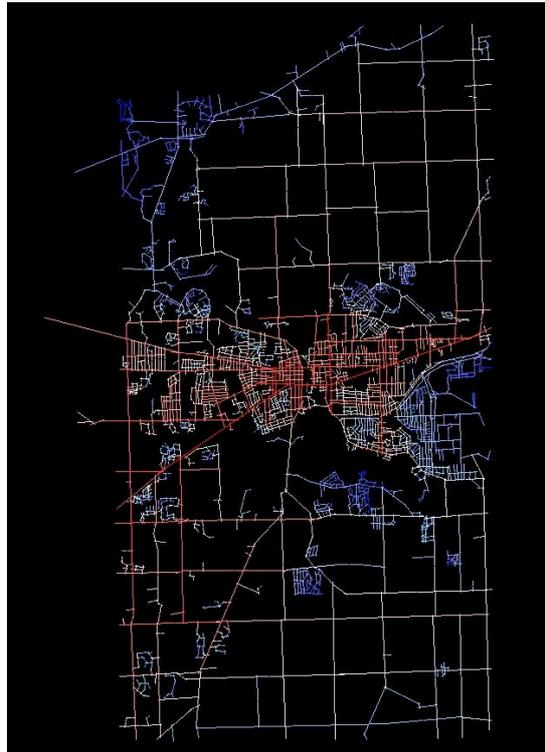
According to the FBI Uniform Report (1998), larceny, motor vehicle theft and breaking and entering are considered property crimes where the object of the offense is the taking of property without any threat involved. More precisely, larceny is taking away property from the possession of another. Purse-snatching and shoplifting are good examples of larceny. Motor vehicle theft is the stealing of a truck, automobile, motorcycles, and any other vehicle. Breaking and entering is defined as the unlawful entry into a property without putting people under threat (Hill, 1995). Robbery on the other hand is a violent crime that involves putting victims under threat. It includes taking anything of value from persons (FBI Uniform Report, 1998).

In this study, we looked at Ypsilanti, a city located within the Metropolitan Detroit area of Michigan. With a population of approximately 22,362, 1273 crime incidents were reported in year 2003. Crime types in this figure include larceny, breaking and entering, robbery and motor vehicle theft. According to FBI Crime Reports, the crime level in Ypsilanti is worse than the national average particularly for burglaries, robberies, and thefts (FBI Crime Reports, 2002). The crime report was obtained from the Ypsilanti Police Department and Eastern Michigan University. It includes data on the four types of crime at an address level with the exact date and time.

## 5. The Axial Map Analysis

A street map of Ypsilanti was imported into the Spatialist program. All the streets were then broken into long lines of sight that if two people stand at each end of the line, they should be able to see each other. These lines are also known as *axial lines*. Ypsilanti comprised of an average of 2000 axial lines. Analyzing the relationship among these lines is impossible to calculate manually. The Spatialist assigned an ID to each axial line and appended three space syntax measures to each line. These measures were

connectivity, local integration and global integration. The Spatialist also produced a colored graphic representation of these values on the map of Ypsilanti (see Figure 1). The colors range from red indicating highly accessible routes (high values) to indigo indicating the least accessible routes (low values). Accessibility is explained in terms of the average number of turns one needs to make to get to any part of a street from any point in the city. As explained in the next section, a glance at this map tells the researcher which of the streets offered escape route to criminals.



*Figure 1.* The Spatialist output of the Ypsilanti Axial Map.

Since the unit of analysis is the axial line (or the street space), it was necessary to append sociodemographic data along with crime data to each line. Therefore, a street map of Ypsilanti was prepared showing 30 block groups using ArcGIS. Data on population density, youth concentration, level of education, percentage of owners, age distribution and racial composition were available from U.S. Census and were appended to each block group in Ypsilanti. The report on crime at an address level was semi-manually entered into the same database. Moreover, the original axial map

that was prepared using Spatialist was later converted into an appropriate format and was given accurate geographic coordinates for Ypsilanti, allowing us to match the Spatialist axial map with the ArcGIS Ypsilanti road map (Figure 2), and to merge our two databases.



*Figure 2:* Crime locations plotted on Ypsilanti Axial Map. Line weight indicates level of connectivity where thick lines represent highly connected spaces and thin lines represents spaces with low number of connections

## 6. Results and Analysis

The GENMODE Procedure in SAS (Version 9) was used in these analyses. Because of the clustered nature of the data, axial lines were clustered within randomly selected block groups, random intercepts and random spatial measures effects associated with the randomly sampled block groups were also included, to test the hypothesis that the crime counts and effects of spatial measures on crime counts tend to randomly vary from one block group to another.

Since space syntax measures were highly correlated with each other, it was necessary to look at the effect of each measure on crime in a separate model. Each model also contained sociodemographic variables. When connectivity was entered in the model, it was positively correlated with larceny ( $p < 0.0001$ ), breaking and entering ( $p < 0.0001$ ), motor vehicle theft ( $p < 0.0001$ ), but not with robbery. However, additional findings showed that the effect of connectivity on different types of crime was moderated by

levels of home ownership at the block group level. In the model, the product of both connectivity and home ownership on larceny was negative and was significant at  $p < .0001$ . These results suggest that the higher the percentage of people who own their residences at a block group level, the more negative the relationship between connectivity and larceny (see Table 1). Similarly, models that looked at other crime types revealed that there were interactions between the two variables connectivity and level of home ownership.

TABLE 1: Results of the model showing the effect of sociodemographic measures and connectivity on larceny

Analysis Of GEE Parameter Estimates						
Empirical Standard Error Estimates						
Parameter	Standard Estimate	95% Confidence Error	Limits	Z	Pr >  Z	
Intercept	1.4933	0.5934	0.3304	2.6563	2.52	0.0118
Connectivity	1.0976	0.2234	0.6598	1.5354	4.91	<.0001
PEROWNER	-1.4959	0.6367	-2.7438	-0.2480	-2.35	0.0188
YOUTH	-2.4470	3.7417	-9.7805	4.8865	-0.65	0.5131
DENSITY	0.0000	0.0001	-0.0001	0.0001	0.51	0.6099
EDUC2PER	-1.5182	1.6517	-4.7554	1.7190	-0.92	0.3580
conn*PEROWNER	-1.0815	0.1675	-1.4098	-0.7533	-6.46	<.0001
conn*YOUTH	0.0815	0.9203	-1.7223	1.8852	0.09	0.9295

The sample plots in Figure 2 illustrate the nature of these interactions. Home ownership is displayed on the X-Axis and crime count is plotted along the Y-Axis. Three regression slopes were plotted to predict larceny at different levels of home ownership and connectivity. The unstandardized regression coefficients were examined and were used in the model. For example, the estimated model that was used to assess the effect of the two independent variables (home ownership “X” and connectivity “Z”) on larceny “Y” is as follows:

$$\text{Larceny (Y)} = -3.519 + 1.933 (Z) + 4.062 (X) - 2.040 (Z*X)$$

The methodology described here has been recommended by Aiken and West (1991).

Perhaps these results can be related to the effects of ‘eyes on the street.’ If there are higher levels of home ownership (indicating a more stable

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population), under conditions of high and moderate levels of connectivity (supporting neighboring and 'eyes on the street'), larceny is significantly lower, while under conditions of low connectivity, larceny is significantly higher. Similarly, when other crime types were examined, high levels of home ownership in the neighborhood with high levels of connectivity (supporting neighboring and 'eyes on the street'), are associated with lower levels of breaking and entering, motor vehicle theft, and robbery.

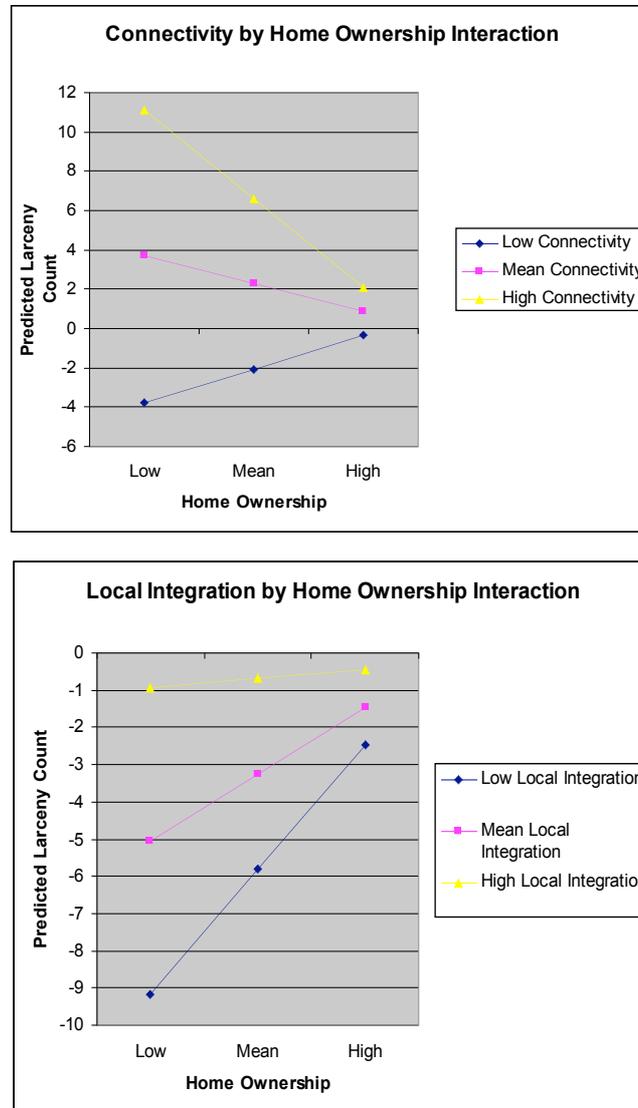


Figure 2: Plots of interaction effects of connectivity and integration by home ownership on larcenies

The analysis also looked at the association of global integration and local integration with crime types and demographic measures. Global integration was not related to any of the crime types. Local integration on the other hand was positively linked with higher breaking and entering ( $p < 0.0001$ ), higher motor vehicle theft ( $p = 0.0139$ ), but not to robbery. There were also significant interactions between local integration and home ownership

with all types of crimes. For example, motor vehicle theft, breaking and entering, and robbery are positively associated with higher levels of home ownership along low to moderately accessible routes. There are several factors that may affect these results. It is perhaps less likely to be caught along more segregated routes. Home ownership may indicate a higher level of valuables and thus a more attractive target to criminals. Highly integrated routes had no effects on these crimes. Larceny, on the other hand, tends to increase with higher levels of home ownership along less integrated routes. Fewer larcenies appeared in integrated areas with higher levels of home ownership. A careful examination is needed to compare both sets of interaction plots.

## 7. Conclusions

Results of the analysis showed that two space syntax measures, local integration and connectivity, were highly associated with different crime types through interactions with levels of home ownership in different block groups. In other words, the number of intersections a route has and the average number of turns one needs to reach it from any route in the city objectively express the nature of its accessibility. Other factors such as median income, youth concentration, density, racial composition and global integration did not feature in the model. It is interesting to note that although criminals have different motives for committing a crime whether it is to burglarize a property or snatch a purse on the street (Davidson, 1993), the effect of spatial measures was consistent in all types of crimes except for larceny. Unlike other crimes types, larceny increases slightly with the increase of levels of home ownership along highly accessible routes. According to Brantingham (1984), if a criminal is searching for a target with all things being equal, the closest target will be chosen. In the case of larcenies, the effect of home ownership is weaker because larcenies are crimes that occur to people in the streets rather in their homes. However, if that route had more intersections, larcenies tend to dramatically drop with higher levels of home ownership indicating higher potential movement and eyes on the street.

To conclude, recent developments in space syntax computer software and methodologies appear to add a promising new tool to examine the implications of spatial layout characteristics on crime outcomes as well as other behavioral outcomes. In this study, for example, we were able to identify the type of streets that offered escape routes to criminals simply by comparing the topological relationships among all the streets within a city to actual crime counts. People usually select routes intuitively without the aid of a map or without having an understanding of how that route is connected

to all the routes in the city. However, space syntax software enabled researchers to understand how people behave in urban environments and offered predictions about the streets that are more likely to be occupied by people and the streets that are more likely to be vulnerable to crime. It is also interesting to know that the resulting colored map may capture at a glance the accessibility level of streets. This in turn may prove to be valuable for police as it helps them understand where they should increase their patrolling.

In sum, space syntax relies on advancement of computer technology to map out spatial interrelationships and thereby allowing the researcher to understand the structure of the city and how it is related to behavioral outcome. It represents the physical complexity of the city as systems of spaces created between and within buildings. This objective method is proven powerful as it allows cities of different forms and structures to be compared in terms of spatial interrelationships. Additionally, new urban developments could also be tested in terms of how space will be used.

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## VISUALIZATION MANAGEMENT AND INSPECTION FOR PLUMBING CONSTRUCTION QUALITY CONTROL

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**Abstract.** This research compares the working process at a construction site with the shop drawings made by a plumbing inspector for installed pipes. This study compared the 2D plumbing shop drawings with the 3D point cloud of the toilet in a campus building. A long-range 3D scanner was used to retrieve the point cloud records of pipes to build a visualization management system. The visual comparison was used to locate pipes at the construction site. We found the differences could be identified easily between the point cloud and shop drawings. The presence of point clouds created a new method to inspect plumbing locations, as a way to verify construction quality.

## 1. Introduction

In general, building construction operations are conducted in accordance with an architect's shop drawing. Construction contents proceed to integrate with the arrangement of shop drawings for related production work without causing conflicts and contradictions with each other. A construction company frequently has to coordinate with professional M&E (mechanical and electrical) and HVAC (heating, ventilating, and air conditioning) technicians. At a building construction site, there are many conditions that are coordinated insufficiently with the rest of the production or regulate construction contents, in accordance with actual construction situation (Ambrose, 1992, p.64). Sometimes, construction contents may not conform to original design shop drawings, by being influenced by the client or the building management process. In addition, the user just needs to change the plans (Al-Momani, 2000, p.51; Cox et al., 1999, p.427), or discover design mistakes that have to be corrected (Mokhtar et al., 1998, p.82). Therefore, the final result will differ from the original design shop drawings. From the beginning of construction to the finished building at the final stage, building design may be changed many times. Related plumbing also needs to be modified because of these changes. Other major changes may be instigated by management, which changes the function of whole building in the future. Therefore, it is very important to review design changes constantly and follow-up construction quality.

When the construction is finished, the architect would draw as-built shop drawings in accordance with the actual condition of the finished building in order to provide a referable drawing and to receive a certified occupancy permit. However, the whole construction period are made of many stages that proceed grouting or other construction operations that causes the plans to be never confirmed again in the future. For example, pipes and toilet drains in the wall cannot be described accurately after the concrete grouting is poured. The sealed layout makes it hard to measure the final location of the pipes or drain, so it cannot be clearly recorded or correctly redrawn for shop drawings.

During the construction process, the construction inspectors use a camera to record operations every time. Photographs just record the images of the construction site, it is still difficult to inspect the scale and dimension of works only from the pictures. Almost all the as-built shop drawings display as-seen information only seen by the naked eyes at the construction site when design change is made. The photos cannot be used as a kind of reference to draw as-built shop drawings.

In virtual reality (VR), visual effects are created to represent the real environment. The VR screen feels like being in a real construction site. Therefore, VR technology can be used to inspect construction projects

(Savioja et al., 2004, p.85), to check the detail of a construction component's configuration using a virtual reality model (Sampaio et al., 2004, p.141), and to reconstruct a 3D model to simulate and inspect possible problems during the design stage (Li et al., 2004, p.288). VR technology can be used to study and to check the construction situation from an off site location easily. The possible uses can be unlimited at a construction site with regards to problem inspection from an on-site or off-site computer screen.

This study believes that builders encounter many design changes, both large and small, during the construction. Its influence is as critical as shop drawings and building management. In order to retrieve information for later use, we use a 3D scanner to record plumbing information to visualize plumbing point clouds during construction process. The visualization of 3D point clouds has the same spatial information as the actual environment, so it can record the interrelationships of the three-dimensional plumbing in spaces. It not only can ensure the plumbing location in the plan, but also can present the three-dimensional plumbing space in accordance with construction quality inspection with point cloud records. This research uses known shop drawings to compare with the 3D point cloud scans of a construction site. The differences between the shop drawings and point cloud can be quickly checked, and the original shop drawings can be corrected as complete and accurate as possible to serve the needs of as-built final drawings.

## 2. 3D Scan

A long-range 3D laser scanner can retrieve the surface geometries of remote objects as point clouds. The 3D scan of small objects at short range has been widely applied to the industrial design as part of the reverse engineering process. Previous industrial applications were not suitable for data retrieval of large objects like buildings until recent when the long-range laser scanner is developed. This study used a Cyrax 2500 to scan a building site as a way to record construction status. Originally, construction recorded with text, photos, and videos and was a tedious process. The 3D scan data could be used as a type of supplementary record in the analysis and evaluation of construction quality and quantity.

The scans provide finished records that include the configuration of the plumbing that is visible to the scanner. These records are useful for checking working quality. Since the clouds consist of x-, y-, and z-coordinates, as-built geometric information can be compared with 2D original shop drawings. Its plan can be brought up on a computer screen to verify any possible difference in between (Shih and Wang, 2002, p.338; 2004, p.98).

A matrix of 999 points in width and 999 points in length was used to figure the shapes of the object surfaces that exposed to the scanner. If it can be recorded completely, it will be scanned from different orientations to create an omni view. This research scanned to record the plumbing locations from more than four orientations in each room. This system allows modifications of scan density and the juxtaposing of multiple scans in one scanworld. Scans can be registered using reference points shared by adjacent scans. The size and boundary of the scanworld is virtually unlimited.

Scanned data are stored in Cyclone .imp format, which is translated into .xyz or .dxf files to be used by other applications, such as AutoCAD and MicroStation. CloudWorx and MicroStation TriForma were also used in this study (Figure 1).

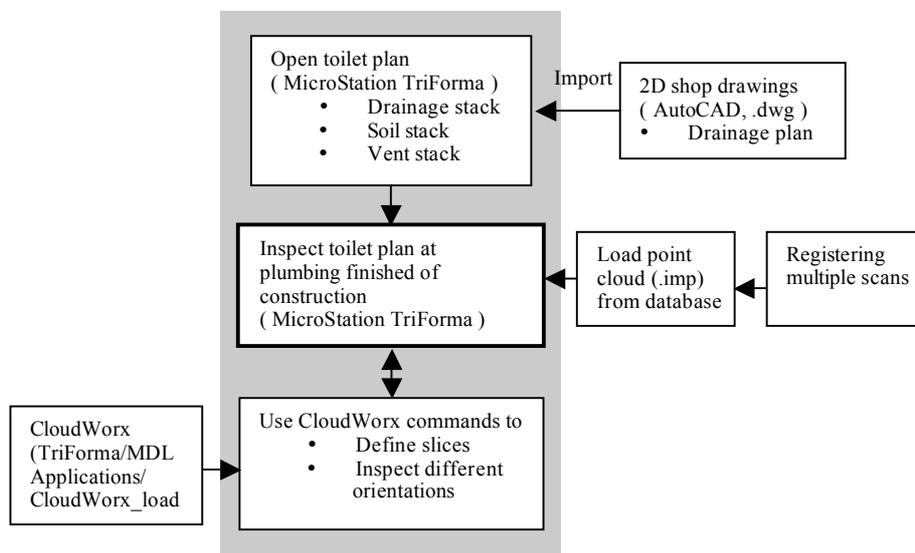


Figure 1. Information flow

In MicroStation TriForma, CloudWorx is loaded to import point cloud file. When scanning is finished, many unnecessary dots from the point cloud of plumbing will be cancelled. Use command "Defined slices" to cancel other point clouds, but just keep plumbing point cloud. This research combines 2D shop drawing of drainage plan and 3D point cloud of plumbing; it can display the difference between them.

### **3. The Operation Condition of the Shop Drawings at the Construction Site**

In the operation process at the building construction site, every type of work in production is depending on relational shop drawings from the architect. Only the operation by shop drawings can reduce construction conflicts and mistakes. Although the architect supplies diagram information for the shop drawings, they can produce construction conflict, or are not possible to use on the construction site. It usually needs an architect or contractor to coordinate construction so that every type of work in production can proceed smoothly despite coordination or design changes.

At the construction site, the construction and administrative department proceeds to build from and review the shop drawings. The architect is supposed to review the shop drawings as well. But the plumbing shop drawings are usually drawn separately and are never integrated with the other drawings. In fact, it is not permitted to integrate shop drawings with complete plumbing drawings. The pipes must be considered a three-dimensional environment with their pipe diameter and sluicing gradient (Stein and Reynolds, 1992, p.643), which makes reading the drawings difficult. On the construction site, it is only possible to check single construction items and very difficult to review plumbing shop drawings. If a conflict arises, the architect is consulted and there is usually a formal record for follow-up, review, and acceptance. However, in the plumbing of a building under construction, shop drawings are used to present the plumbing lay out. It is used to as the basis for inspection and acceptance. So the shop drawings cannot describe clearly the plumbing's location and passing route. Operation of the construction site is usually in accordance with personal construction experience. Although its function is the same as the original shop drawings, its configuration is different completely from the shop drawings or original design concept.

The owner of the building must understand that the completed building will be different from the architect's built shop drawings. When the building is finished, the architect draws built shop drawings to match the condition of the finished building, however, the plumbing could be concealed by the concrete in building structure, or placed in the ceiling. If the architect wants to redraw the built shop drawings, he must not only expend time and risk not being able to complete the plans. There are many problems with plumbing during building construction.

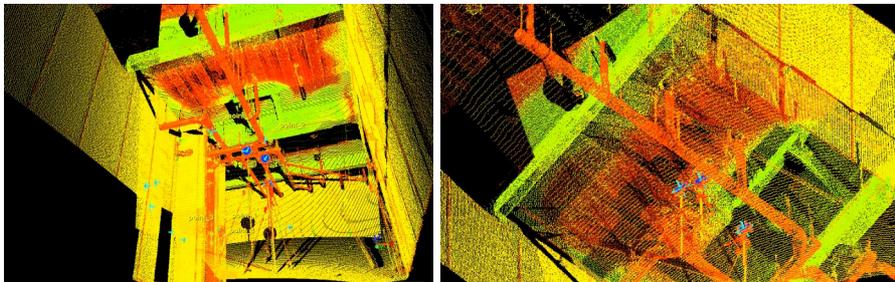
Plumbing has always been a major concern for construction companies according to our interviews. The main reasons for this are regulated locations and the plumbing function in the shop drawings. Many plumbing layouts and passing routes must consider the condition of the construction site. Problems include missing construction items and other components. It

must go by an alternative route or a substitutive plan has to be created. They also understand the follow-up necessary to maintain the work since when the building is finished; it will not be familiar and difficult to navigate. The new owner must expend much more time to test or build new pipes in order to avoid interfering or negatively influencing the original plumbing system.

This research believes that the plumbing construction process period at present, outwardly is constructed from shop drawings, but is actually very different between actual conditions and the shop drawings. Since built shop drawings are drawn incomplete, this indicates the real configuration of the plumbing and leads to difficulty in doing follow-up jobs by building management.

#### **4. Use 3D Point Cloud to Obtain Accurate VR Construction Information from a Construction Site**

After the finished plumbing was laid out on a construction site, this research used a 3D scanner to record the spatial information of the plumbing (Figure 2). The 3D scanner has a three-dimensional recording function, so it is easy to transform the scan into 3D point cloud information to relay the spatial location of the plumbing. The 3D scanner can view and review the work from the visualization point cloud, and understand clearly the finished plumbing condition during different periods of construction.



*Figure 2.* Point cloud of plumbing (at male toilet)

There are limits to the scanning range of the 3D scanner. If the 3D scanner is recording interior spatial pipes, than it must register multiple scans, however, it may record clearly, and completely single spatial pipe information. At spatial reference points, it must consider which location to scan. This is an important factor for spatial scanning and registering. We must also consider the problems of registering since it must consider the overlapping of different scanning information. When it must decrease the number of scans and increase scan efficiency, part of the overlap will

possibly compress. So the reference points should be centralized and it must combine three or more reference points. When these reference points are too centralized, it could result in inaccurate registering.

When this research was scanning the construction piping, the scanner's movement was decreased as well as the register times of the scan. This was due to its spatial limits and scanning range. For this toilet plumbing research, we need four to five scans to register in order to present clear relationships and locations between the pipes and shaft.

This research uses pipes point clouds and Cyclone to analyze each section of the building, the relationship and location of the pipes, and measure correlative data, like pipe size, gradient, and distance to ceiling. Moreover, it helps to understand the different points between construction conditions and original shop drawings.

## 5. Inspection with Original Shop Drawings

Beside the above-mentioned analysis of the relational pipes of the construction site, this research compared the scanning and original shop drawings with the pipes in the construction site. The research also reviewed the construction status of the shop drawings, or the difference between status information and original shop drawings. The point cloud information registering process can control some detail (Figure 3, Figure 4).

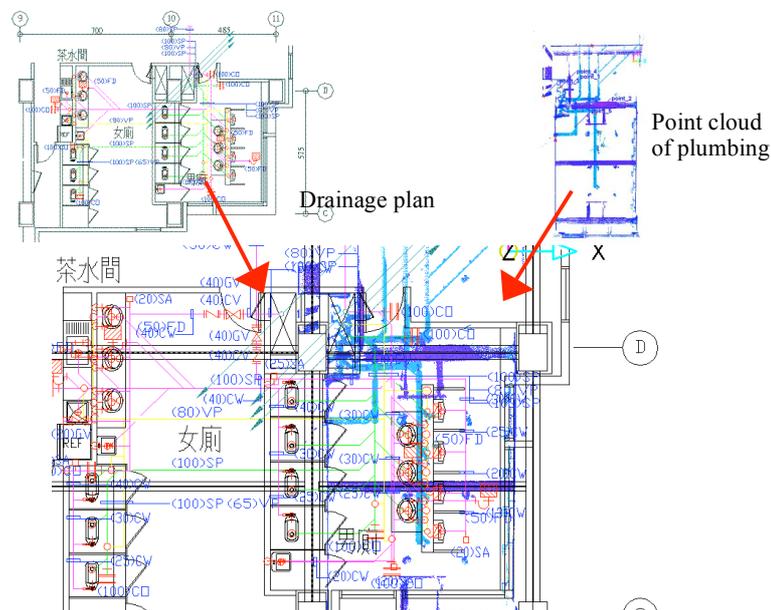


Figure 3. Point cloud of male toilet with pile of toilet plan

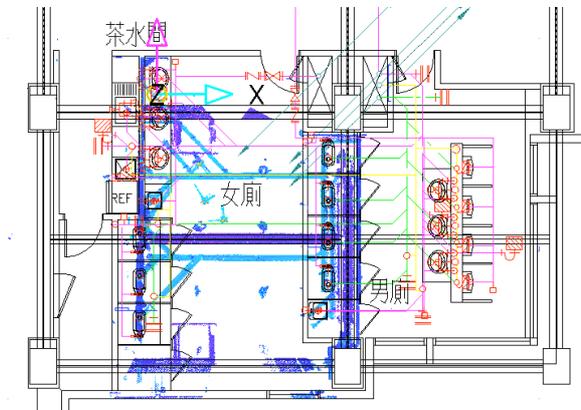


Figure 4. Point cloud of female toilet with pile of toilet plan

For example, building construction of the ninth floor involved plumbing in the ceiling; this research found that there was a great difference between the pipe layout status and the original shop drawings.

- a. The location change of sewage drainage pipes: their actual location was different from the original shop drawings. This was discovered through the status layout. The length of the sewage drainage pipes is shorter than the original shop drawings. We do not know if it was done to save pipe material. But this affirms that the pipes' layout status has a decreased strong point discharging distance by the water closet of men's toilet. It produces three points of sewage drainage pipe turn which is an increase of one point more than the original shop drawings. This could influence sewage drainage efficiency in the future.
- b. Part of the drainage location changed at the men's toilet: the drainage is not in the location described in the original shop drawings. Later inquiries show that this was a design change. The partition toilet's wall was moved since the function of space beside the men's toilet was changed.
- c. Vent stacks not yet set up: in accordance with point cloud information at that time, the research found that the original design vent stacks were not yet to set up. For a multifarious construction item, this is hard to leave out. In the past, some construction sites had 45° Y drainage fitting not yet set up after construction was finished. This caused overflow from the column of the building. It takes much effort to knock down the column and maintain the drainage pipe.
- d. Increase one branch of soil stack beside the partition wall: since the final design change has not been determined, the builders do not understand clearly, where the soil stack goes. However, the builder can control the location and direction of the pipes in advance, and take this as a basis for construction in the future.



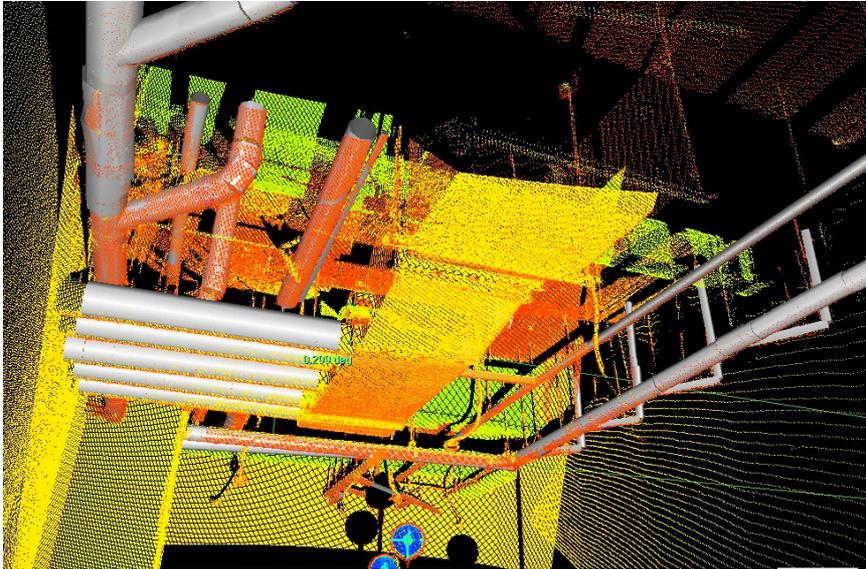


Figure 6. Measure sluicing gradient of pipe model

Since the pipe scan is limited by location of the scanner and registering scan, there will be dead space that cannot present clearly the whole contents of the pipes. This research sets scan density at  $600 \times 600$ , if it wants to display thin pipe, it will set up higher density of point cloud. When the diameter of the pipe is too small, like a water supply pipe, the scanner cannot present a clearly specific representation of the pipe. This influences the decision of pipes. Therefore, this research is limited to drainage pipes.

## 6. The Influence of Building use Management in the Future

In building plumbing construction, one of the most important considerations is function. If function can conform to need of use, then the construction location can be changed as well as the pipe-passing route if it is acceptable to the end users. However, many pipe locations are lost as soon as grouting or other operation procedures are completed. So the built shop drawings cannot reflect their actual location. This would result in losing accurate plumbing information in the future for building use and maintenance management and increase trouble, time wasted, and maintenance costs.

This study's focus is to use a 3D scanner to record the true location of the pipes and transform the point cloud information when the plumbing is finished. Through the inspection process, it can control quality and quantity of construction to determine whether the original shop drawings are the

same, and the architect can use this point cloud record to change the built shop drawings.

Users can use the point cloud information to determine the pipes three-dimensional location in the building. It is not only different than the two-dimensional diagram information from the past, but also records clearly any direction in which these pipes are laid. This allows for convenient pipe management. In addition, point cloud information can be transformed into built shop drawings that present correct pipe location. There would be no more "hints" of where the pipes maybe located any more thereby producing convenient pipe management for the future.

## 7. Conclusion

This research used a pipes scanning process to find many construction behaviors based on construction schedule and the user's need to change. This information is useful for any builder who wants to know of and control status change as quickly as possible. However, for the user or builder, it cannot be easy to control. Specialized building drawings and diagrams are hard to understand for the user. If it can use visualization 3D point cloud information to convey the actual construction's general situation on site, it will help the user to understand the construction scheduled progress and quality.

Point cloud information will make construction inspection more convenient. This research found, via a point cloud and shop drawings inspection process, that it makes design changes easier since there is better correlation between the design diagrams and construction site. It takes the point cloud information as a reference for the finished building as built shop drawings. Its greatest help will involve follow-up issues for building management and building tenants.

It cannot be denied that the weight of the 3D scanner and the scanning method will influence the result of the scanning. So it must consider construction schedule progress and construction process influence. For large-scale building construction, if it creates information for a complete set of pipes, it must need to rely on much labor power and material resources. Behind scanning, the check work will be another item from the original construction organization.

The greatest relationship for scan precision regards small pipes. Pipes with small diameter are hard to determine in a spatial point cloud, so it must set higher density of matrix to scan. Because vision dead space is a problem for scanning, the set up and lay out of the scanner must be planned in advance. Moreover, interior visual angle problems must be accounted for

with multiple scans and registering. This will allow it to present a more complete point cloud information and a better overall picture.

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## EVALUATION OF A HIGHER EDUCATION SELF-LEARNING INTERFACE

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**Abstract:** This paper is a follow-up to a previous paper published in ASCAAD 2004 (A. Bennadji et al 2005). The latter reported on CASD (Computer Aided Sustainable Design) a self-learning educational interface which assists the various building's actors in their design with a particular attention to the aspect of energy saving.

This paper focuses on the importance of software evaluation and how the testing is done to achieve a better human-machine interaction.

The paper will go through the summative evaluation of CASD, presents the output of this evaluation and addresses the challenge facing software developers: how to make an interface accessible to all users and specifically students in higher education.

### 1. Introduction

Computational tools have the potential to provide an effective means to support design decision makers. Thereby, the most important factor is not software acquisition, but the effort needed for learning and using it. "The extent of required time and effort is believed to be one of the main hindrances toward the pervasive use of computational building performance assessment tools by designers: Currently, modelling applications are mostly used, if at all, in the later stages of design and by specialists, rather than architects" (Ardeshir Mahdavi et al, 2004).

Few studies have explicitly dealt with the ascertainment and quantification of the actual effort needed to understand, master, and apply computational building evaluation tools.

In this paper, we report on the collaborative work that took place between the School of Architecture at The Robert Gordon University in Scotland and the Institute of Architecture at The Mohammed Khider University in Algeria. The collaborative idea was to build bridges between developed and developing countries in terms of Information Technology and how to apply it in an effective and economical way.

The project's aim was to develop an (online) interface, called Computer Aided Sustainable Design (CASD) that will guide the user through a series of input screens to allow him/her to describe the building and select various environmental options. The interface is to be accessed by students at the School of Architecture to allow them to integrate environmental aspects in their designs.

A selection of building specifications from a database is used to generate numerical information that will be used by a calculation engine that uses sophisticated thermal models (Brown, J. and Palmer, J.: 1991).

One of the project's main objectives was to develop a tool that assists in reducing the number of design cycles (revisions). This fits with government policy to improve the effectiveness of the design process and to make procurement of buildings cheaper and more efficient (A. Bennadji et al ,2002).

In the past, people have resisted the use of such simulation programs for a number of different reasons. They felt that it was time consuming to input the necessary data and that the program was not user friendly enough. The team aimed to reduce the amount of input required for each building with the use of extensive, intelligent defaults. To make the program more user friendly, an implementation of a pictorial based input system was used with a minimal amount of data required to describe a building. Users also felt that programs could not be trusted, perhaps because of their complexity and the fact that they could not understand them.

The idea of this project at industrial level was developed in a previous project "EnergySave" (D.Bouchlaghem et al, 2005). At this later stage, CASD software is developed for purely educational purposes as we thought useful to allow students in architecture and building-related courses to understand the extent of environmental issues while designing a building.

As the effort and time required to learn and understand a software is extensive (A. Mahdavi, et al, 2003. and K.P. Lam, 1999), we opted for HTML as it seemed to be the most popular, not only at university level where all students are used to the Internet but also at professional level as most daily common needs are now achieved by using the Internet.

Therefore, the interface for CASD software will be in HTML format, and all the evaluation study will be based on this specific format and platform.

### 1.1 PROJECT'S OUTCOMES

The project attempts to produce an interface for students in architecture and tries to give guidance for interface developers in terms of assessment and user's appreciation of the implemented version. CASD was an attempt to the development of fully working software that can simulate buildings' energy consumption and CO<sub>2</sub> emission. CASD was then used, in this collaboration with developing countries, as an educational program where students can enter their building's specification and then compare their design with a benchmark building of a similar description and specification. The comparison will be purely in terms of sustainability. The student will then be able to study in details the specifications of the benchmark building, so that he can improve his/her design in order to reach a better environmental impact. This version of CASD will not include any simulation by a third-party calculation engine, but only a comparison from a background database of buildings' performances.

### 1.2 PAPER'S OBJECTIVES

The paper aims to address software evaluation at its different development stages. It is essential for software designers to reach users' desires. As a scientifically recognised research method, the final product is not necessarily the same as what the designer planned it to be, but rather what the users feel more comfortable with and more adapted to their needs. The question: "why are we evaluating?" becomes more obvious after the failure of many software projects which didn't receive a great welcome from users. The simple answer to this question is: to help improve the system. The system function will not be addressed in this paper. Generally it is the IT expert who deals with the technical side of software development. Thus, the paper will focus on the software's usability.

## 2. CASD

CASD has been developed using HTML in the Macromedia Dreamweaver MX environment. ASP (Active Server Pages) code was used to link the Web pages with a MS Access Database containing all the data entered by the user, and other default (standard) values related to the building regulations as well as benchmark projects. ASP allows one to dynamically edit, change or add any content of a Web page, respond to user queries or data submitted from HTML forms, access any data in the database and return the results to the

web browser. CASD (see Figure 1) is comprised of a sequence of screens (Web pages) in which the user can freely move forward or backward.

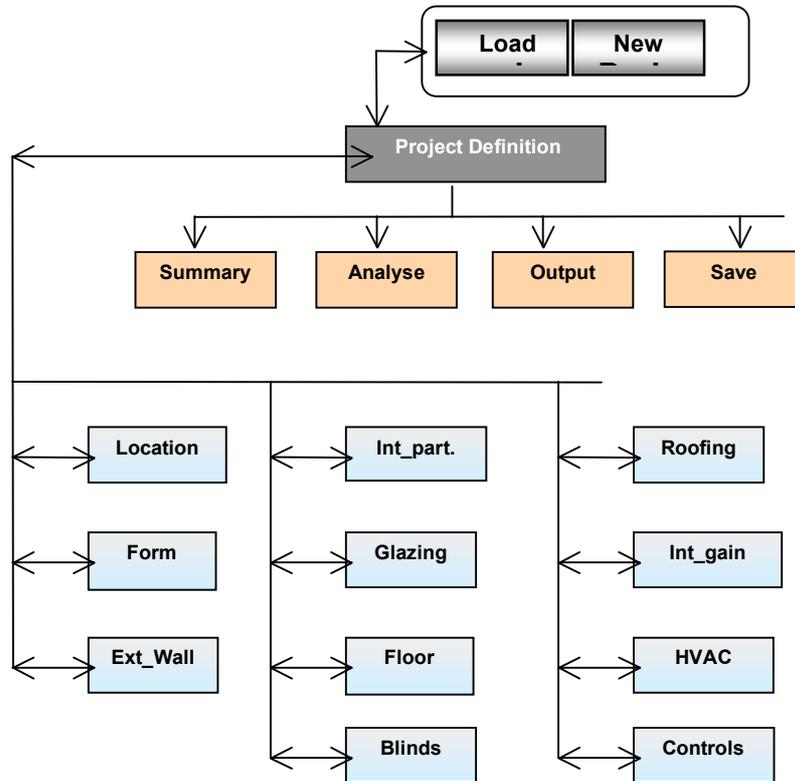


Figure 1. CASD interface

The user is free to start from any screen after completing the first one which relates to the project description. The user can stop at any stage, save his/her work and resume at some other time. Figure 2 shows an example screen.

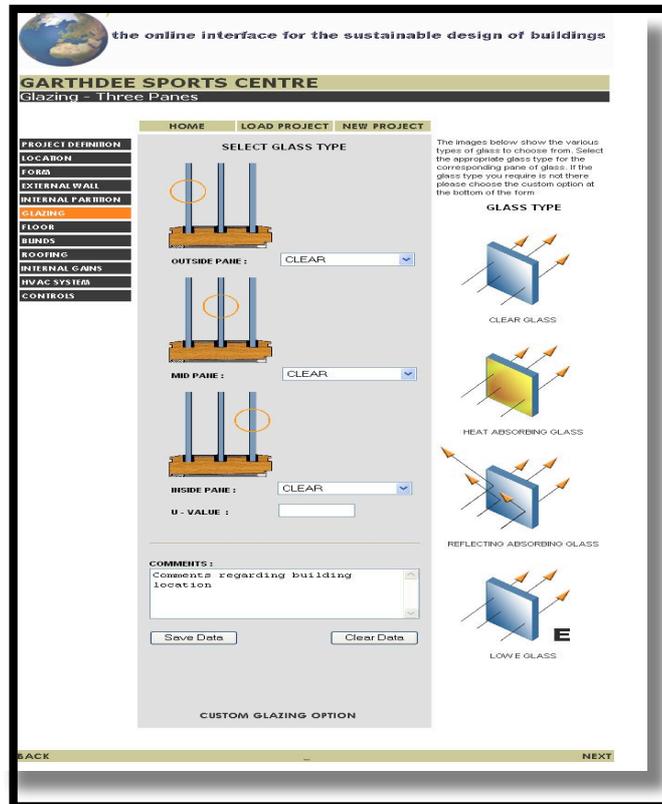


Figure 2. A typical CASD screen

### 3. Evaluation Methodology

Evaluation theories and methods were widely disseminated for different research areas for decades. However, not enough attention was given to software evaluation research methodologies. The fact that software development is a new exploration might be an explanation of this lack of research in this area (Molich, R., et al., 1990. Nielsen, J., et al, 1993. Nielsen, J. 1992. and Nielsen, J., 1994).

We were not deeply engaged in the evaluation while designing the software, as it is for students use only and we worked on similar software intended for professional users where a proper evaluation by professionals was done (D. Bouchlaghem., 2005). It appears after a first try by students, that we are dealing with a different type of users, who are not necessarily IT users.

Therefore, we found ourselves obliged to evaluate the software in 3 steps if we want a great welcome of CASD by the students' community.

The diagram in Figure 3 summarises the evaluation methods from which our methodology of evaluation is inspired. It gives an overview of different types and stages of evaluation. Our evaluation stages were based on the interpolation of this method to the use of CASD for teaching and learning. This strategy circumplex is drawn from (McGrath, 2000).

#### **4. Background to the Method's Application**

Due to the conference character and the attendees' backgrounds, we thought it would be wise to give an overview of systems' evaluation methods and how a specific method was applied to CASD.

Many methods for software evaluation have been developed in the last 3 decades. Three main levels are used, Formative, Summative and Integrative levels<sup>3</sup>:

- Formative: For the designer of the system
- Summative: For the customer of the system
- Integrative (Draper, S. W., et al. 1996): For neither directly – intended to help embed a system effectively.

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<sup>3</sup> The distinction between formative and Summative evaluation is due to the philosopher Michael Scriven. It is a theme which runs right through this paper.

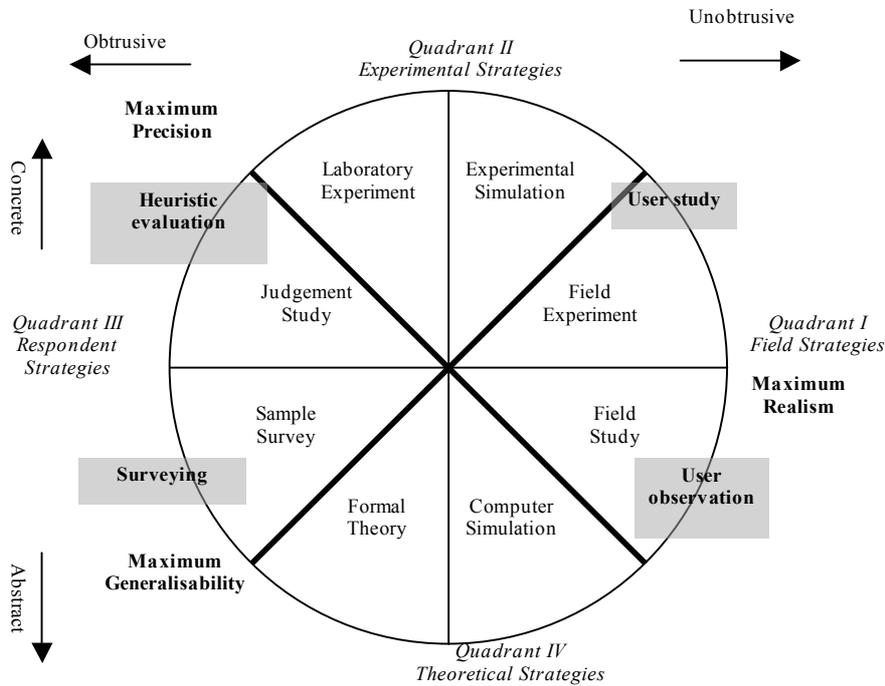


Figure 3. The strategy circumplex

Within these various levels of evaluation; different methods are available to test software's effectiveness. Due to the specific character<sup>4</sup> of the software to be evaluated, three methods of evaluation will be used:

- Experiments: user testing.
- Observation: protocol analysis.
- Surveying: questionnaire.

#### 4.1 FORMATIVE EVALUATION

Formative evaluation took place at different realisation stages:

1. Before interface design: The design is iterative, and design decisions are tested at key development stages. This step will influence the final product as feedback during conceptual stage will assist design decisions.
2. Early design stages: this evaluation is based on task completion times to determine the most effective method for each operation. This early stage can be long or short depending on the software aim and utilisation and outcomes.

<sup>4</sup> In architecture education a huge emphasis is given to the visual representation of objects, and students refer to their visual memory to understand phenomena by analogy.

3. Later design stages: at a final design stage the evaluation focuses on identifying user difficulties with the interface and aims to address essential questions such as,
  - Are users able to control the interface?
  - Do they understand the interface's feedback?

#### 4.2 SUMMATIVE EVALUATION

The summative evaluation takes place after the software completion. It can be considered as a final evaluation, as feedback at this stage can be positive and the software can start to be used. Unfortunately this doesn't happen very often and other steps of evaluation may be needed.

The characteristics of this evaluation step are:

1. The summative evaluation is not generally iterative and is used to verify the software success.
2. Based on usability metrics: e.g., time to complete benchmark tasks, existence of documentation.
3. Tests for proper functioning of system:
  - Often uses quantitative measures
  - Conducted after design completion

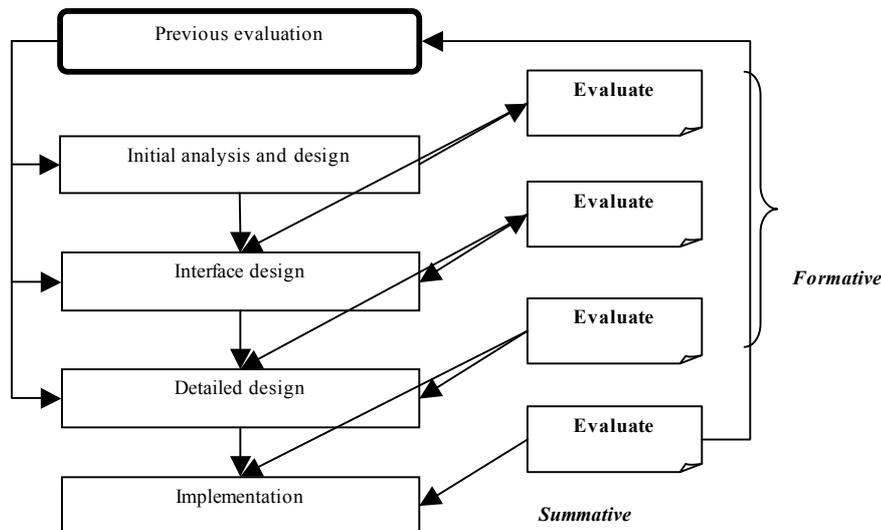


Figure 4. Evaluation as part of the design process



As the heuristic evaluation method is difficult for a single individual to do because one person will never be able to find all the usability problems in an interface, we have used 10 students from higher stages to evaluate CASD. Figure 5 shows 10 evaluators who found 12 usability problems. Each of the black squares indicates the finding of one of the usability problems by one of the evaluators. The Figure clearly shows that there is a substantial amount of non overlap between the sets of usability problems found by different evaluators. It is certainly true that some usability problems are so easy to find that they are found by almost everybody, but there are also some problems that are found by very few evaluators. Furthermore, one cannot just identify the best evaluator and rely solely on that person's findings. First, it is not necessarily true that the same person will be the best evaluator every time. Second, some of the hardest-to-find usability problems (represented by the leftmost columns in Figure 5) are found by evaluators who do not otherwise find many usability problems. Therefore, it was necessary to involve multiple evaluators in this heuristic evaluation.

## 5.2 SURVEY

A survey was carried out, but the students were from early stages; and hence different from expert students used for the heuristic evaluation. Only students from first year were discarded due to their lack of computer use in their design. CASD was installed on the university's server as well as the questionnaire. Web-based surveying is seen to be more effective as it reduces cost and time of data entry

### 5.2.1 *The Questionnaire*

The questionnaire (see Table 1) was comprised of 17 closed questions and 1 open question. Closed questions were used in order to be analysed statistically. They were ordered in such a way that the key criteria come first. The last open question was there to allow the questionnaire-takers to give general comments on CASD's usability.

TABLE 1: Questionnaire submitted to students

Criterion	Rating
1. Is it easy to start the program?	Yes/No
2. Is the use of interface easy to understand? (For example, is the screen layout clear and easy to interpret?)	Yes/No
3. Is the visual message clear enough on all pages globally?	Yes/No
4. Is it easy to navigate through the program?	Yes/No
5. Are the icons used to assist navigation (e.g. back to previous pages or main page, exit) clear and intelligible?	Yes/No
6. Is it always clear to you which point you have reached in the program?	Yes/No
7. Are the included pictures, relevant, and aid understanding?	Yes/No
8. Are the choices given to you helpful?	Yes/No
9. Does the interface look more serious compared to any ordinary website?	Yes/No
10. Is it worth having feedback if you get something wrong?	Yes/No
11. Do you like the fact that some of the spaces that you have to fill in are filled automatically for you?	Yes/No
12. Do you like the neutral background of the interface?	Yes/No
13. Can the user easily quit something that is beyond his/her ability?	Yes/No
14. Do you prefer to fill only the part that you are expert on and leave the rest to other experts?	Yes/No
15. Do you feel able to navigate it you start from other than the 1 <sup>st</sup> page?	Yes/No
16. Does the site contain what you expected, e.g. as indicated in its title or URL?	Yes/No
17. Is the interface logo communicative enough?	Yes/No
18. Please write in few comments that can improve the software.	

### 5.2.2 Analysis of Survey Results:

The results of the survey are summarised in Figure 6 and are self-explanatory<sup>5</sup>. The diagonal in Figure 6, shows a limit between the best and worst scenarios.

<sup>5</sup> Note that the answer yes for question 18 represents the number of users who have given comments.

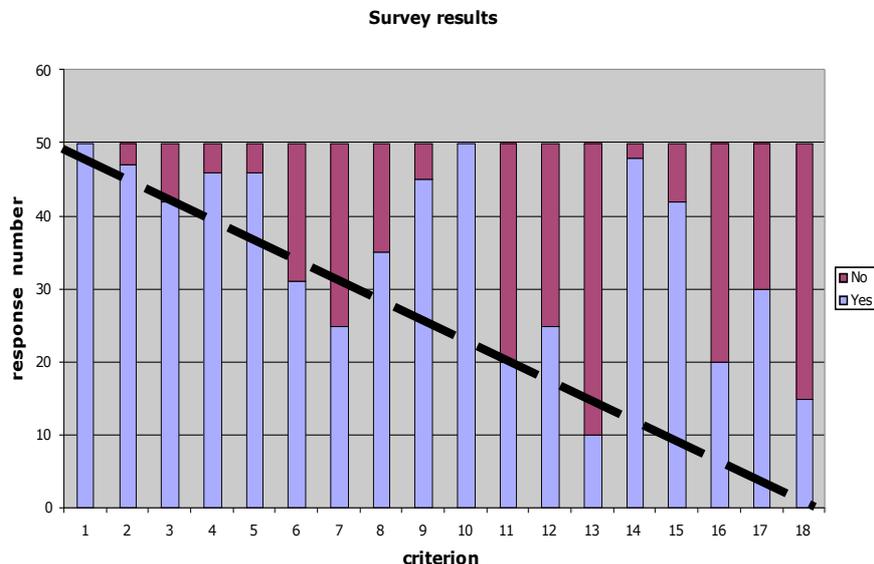


Figure 6: Questionnaire's results

Figure 6 shows that a majority of evaluators rated the key criteria (from 1 to 10) positively, as shown by the diagonal. The survey's verdict was satisfactory overall, and allowed us to pin point areas of further improvement. In that sense it was complementary to the heuristical evaluation.

## 6. Conclusion

Designing software interfaces has become a very challenging and competitive area. Clients do not only look for software that does the job, but they also want it to be widely accessible. The only way to reach this objective is to design a user friendly interface that maximises the user's acceptance of the software.

As such, Computer-based learning packages are no different, and extreme care should be devoted to evaluating their usability. In this paper, we focused on how such an evaluation can be conducted using well established methodologies and techniques in the field of software evaluation.

The aim is to have an impact on teaching methodologies where the computer is increasingly playing a big role. The tendency now is towards encouraging students to be more independent and to take more responsibility for their learning experience, and this can only be achieved if user-friendly self-learning computer packages are made available to them.

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## **A REAL-TIME SIMULATION TOOL FOR FAULT DETECTION AND DIAGNOSIS OF HVAC SYSTEMS**

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**Abstract.** In this study, a real-time simulation tool was developed for online monitoring, control and diagnosis of HVAC systems. A two-zone variable air volume terminal reheat (VAV-TRH) HVAC system is considered. The developed program can be used in offline and online environments. The offline environment allows the operators to examine optimal control strategies, and to investigate problems associated with improper size of components which could be the root cause of the fault. The online environment is useful for monitoring, control and diagnosis of HVAC systems. A set of expert rules were applied to identify the faults. Simulation results show that the developed tool is able to correctly identify the fault patterns and therefore can be used for improving operating performance of HVAC systems.

### **1. Introduction**

As a complex electromechanical system, the heating, ventilating and air conditioning (HVAC) system experiences faults virtually everywhere. Faults in HVAC systems comprise a wide range of problems, such as poor tuning of controllers, stuck or leaky dampers and valves, broken sensors or actuators. Faults can cause increased energy consumption, worn equipment, and less comfortable conditions. In other words, faults tend to degrade the performance of HVAC systems. Accordingly, it is very important to develop fault detection and diagnosis (FDD) tools for HVAC systems.

In recent years, real-time systems have been widely applied to detect and diagnose faults in HVAC systems. Several researchers have contributed to the development of real-time FDD systems. Anderson et al. (1989) developed a quasi-real-time expert system for diagnostic analysis of an industrial HVAC system. The system consisted of a statistical analysis

preprocessor and a rule-based expert system. Peitsman and Soethout (1997) applied auto aggressive (ARX) models in real-time model-based diagnosis. The system model was used to detect faults based on performance degradation. After a fault was detected, the component models were used to locate the defective component. Dodier et al. (1998) described automated fault detection and diagnosis scheme in which Bayer's classifier was used to predict the state of operation of a fan-powered VAV box. Han et al. (1999) presented a model-based fault detection and diagnosis tool for HVAC systems.

In this study, a real-time simulation tool will be developed for online monitoring, control and diagnosis of HVAC systems. In order to achieve this objective, a two-zone variable air volume terminal reheat (VAV-TRH) HVAC system will be utilized as a platform.

## **2. Two-zone VAV-TRH System**

### 2.1. PHYSICAL MODEL

The two-zone VAV-TRH HVAC system analyzed in this study is shown in Figure 1. The major components of the system are (1) two environmental zones, (2) a supply fan, (3) a return fan, (4) a cooling and dehumidifying coil, (5) two VAV boxes with reheat coils, and (6) ductwork. In the modeled system, outdoor air (OA) enters the system and is mixed with recirculated air (RA). After being conditioned in the cooling coil and the reheat coil (if required), the mixed air is supplied to zones. In response to demand for cooling from zone thermostats, volume flow rates of supply air (SA) to Zones 1 and 2 vary by modulating the VAV dampers, which are maneuvered by the two controllers – C1 and C2. The controller C3 modulates positions of outdoor air, recirculated air, and exhaust air dampers to minimize the requirements for mechanical cooling energy. The controller C4 is used to maintain discharge air temperature at a varying set point by adjusting the chilled water valve. In addition a supervisory Energy Management and Control System (EMCS) is used to determine the set point values of zone temperatures and discharge air temperature which are then supplied to the four controllers as inputs.

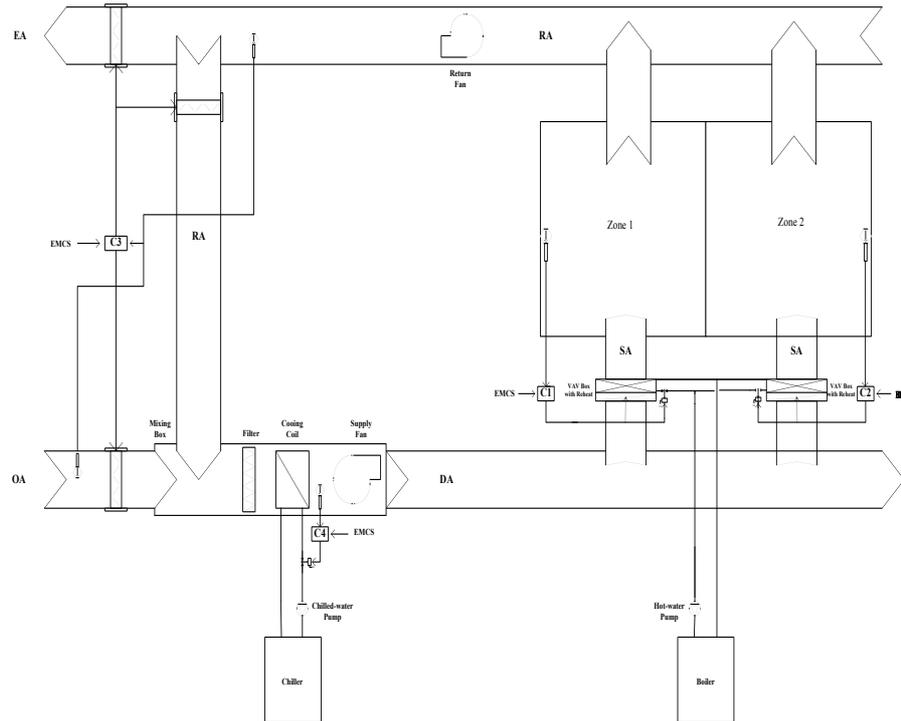
### 2.2. DYNAMIC MODEL

#### *2.2.1. Zone Model*

A detailed zone model is too complex and is not suitable for on-line applications (Zhang and Nelson 1992, p.46). Assuming uniform temperature

and neglecting air infiltration, the model can be expressed by the following equation:

$$k\rho_a c_{pa} V_z \frac{dT_z(t)}{dt} = \dot{m}_{sa} c_{pa} [T_{sa}(t) - T_z(t)] + q_s \quad (1)$$



OA	Outside Air	RA	Return/recirculated Air
DA	Discharge Air	EA	Exhaust Air
EMCS	Energy Management and Control System		

Figure 1. Schematic diagram of a two-zone VAV-TRH HVAC system.

### 2.2.2. Coil Model

The coil is the most important interface between the primary plant (e.g., chiller or boiler) and the secondary air distribution system. In this study, the coil model is described by the following equations (Clark, 1985, p.54&55):

$$\frac{dT_{ao}}{dt} = \frac{T_{aoss} - T_{ao}}{\tau} \quad (2)$$

$$\frac{dT_{wo}}{dt} = \frac{T_{woss} - T_{wo}}{\tau} \tag{3}$$

$$\tau = \frac{C_m}{U_o A_o} \tag{4}$$

$$T_{aoss} = T_{ai} + \frac{\varepsilon C_{\min}}{C_a} (T_{wi} - T_{ai}) \tag{5}$$

$$T_{woss} = T_{wi} - \frac{C_a}{C_w} (T_{aoss} - T_{ai}) \tag{6}$$

$$\varepsilon = 1 - \exp\left\{\frac{\exp[-Rn(NTU)] - 1}{Rn}\right\} \tag{7}$$

$$n = (NTU)^{-0.22} \tag{8}$$

$$R = \frac{C_{\min}}{C_{\max}} \tag{9}$$

### 2.3. SIMULATIONS OF CONTROL STRATEGIES

For the modeled system, two control strategies were designed – an optimal control strategy and a reheat control strategy. A reheat control strategy is one in which the discharge air temperature set point is determined such that the supply airflow rate is minimized. An optimal control strategy is one where the total cost of operation is minimized while maintaining comfort conditions.

Figures 2 and 3 depict the dynamic performance of the modeled HVAC system when a reheat control strategy and an optimal control strategy are used. It is noted that temperature of Zone 2 ( $T_{z2}$ ) was fluctuating, centered on the set point value when the reheat control strategy was in effect. This was because the corresponding reheat coil was activated and the hot water valve was maneuvered by a two-position controller.

A comparison of the two control strategies shows that under the same operating conditions, the optimal control strategy results in a saving of 16% input energy required by the chiller relative to the reheat control strategy by raising the discharge air temperature set point. Also, the optimal control strategy reduces the need for reheat (Wulfinghoff 1999, p. 264). Therefore, the optimal control strategy is an ideal solution to energy conservation.

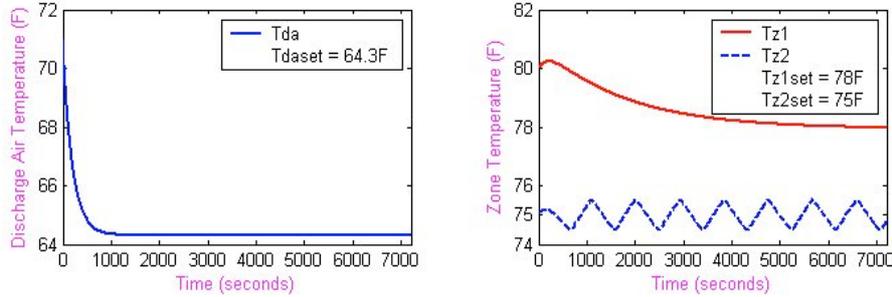


Figure 2. Response of temperatures (Reheat Control).

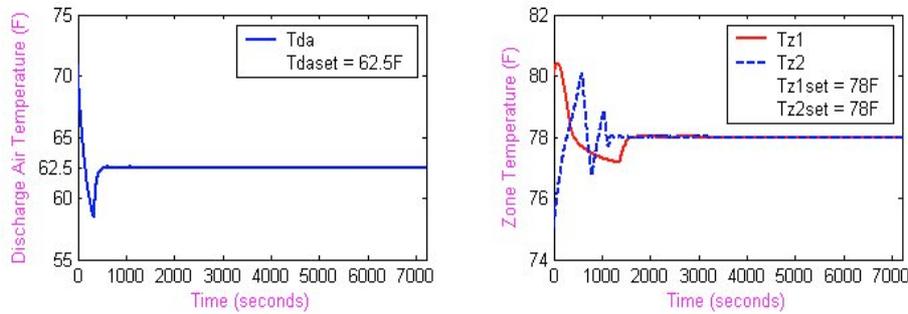


Figure 3. Response of temperatures (Optimal Control).

### 3. Real-time Software Development

#### 3.1. DEVELOPMENT ENVIRONMENT

The software is implemented in Matlab/Simulink environment. It supports linear and nonlinear systems and can be modeled in continuous time, sampled time, or a hybrid of the two. Furthermore, Matlab/Simulink provides a graphical user interface (GUI) for building models as block diagrams.

#### 3.2. SOFTWARE REQUIREMENTS

The developed tool, which is referred to as HVAC Simulator in this study, is a simulation system using a two-zone VAV-TRH HVAC system as platform. The use-case driven approach (Jacobson et al., 1992) was used to analyze requirements of the software. Table 1 depicts a typical use case for determining optimal set points.

TABLE 2. Description of use case.

Description	System determines the optimal set of control variables
Status	Detailed Description
Actors	HVAC operator, Weather forecast website, Load predictor, Energy management and control system
Pre-Conditions	<ol style="list-style-type: none"> <li>1. System must be loaded</li> <li>2. Weather forecast website outputs outdoor air temperature</li> <li>3. Load predictors outputs building loads</li> </ol>
Flow of Events	
Basic Scenario	<ol style="list-style-type: none"> <li>1. A dialog box prompts HVAC operator to enter outdoor air temperature and building loads</li> <li>2. HVAC operator enters the required data</li> <li>3. System determines the optimal set of control variables</li> <li>4. System displays the optimal set of control variables</li> </ol>
Alternative Scenario	<p>Step 3a: System cannot determine the optimal set of control variables based on the given information</p> <p>Step 4a: System displays the message that the optimal set is not available and the reheat control strategy should be used.</p>
Post-Conditions	System displays the optimal set of control variables
Related Use Cases	
Used Use Cases	None
Extending Use Cases	None

HVAC Simulator has two running modes: offline simulation and online (i.e. real-time) application. The offline environment allows the operators to test control strategies, and to investigate problems caused by incorrect sizing of HVAC components. The function can be implemented through predicting the dynamic behavior of the modeled HVAC system. Also, the user can create a real-time application to let the system run while synchronized to a real-time clock. This allows the system to control or interact with an external system. The software program has several user interface windows which facilitate running the program interactively. One such user interface is shown in Figure 4.

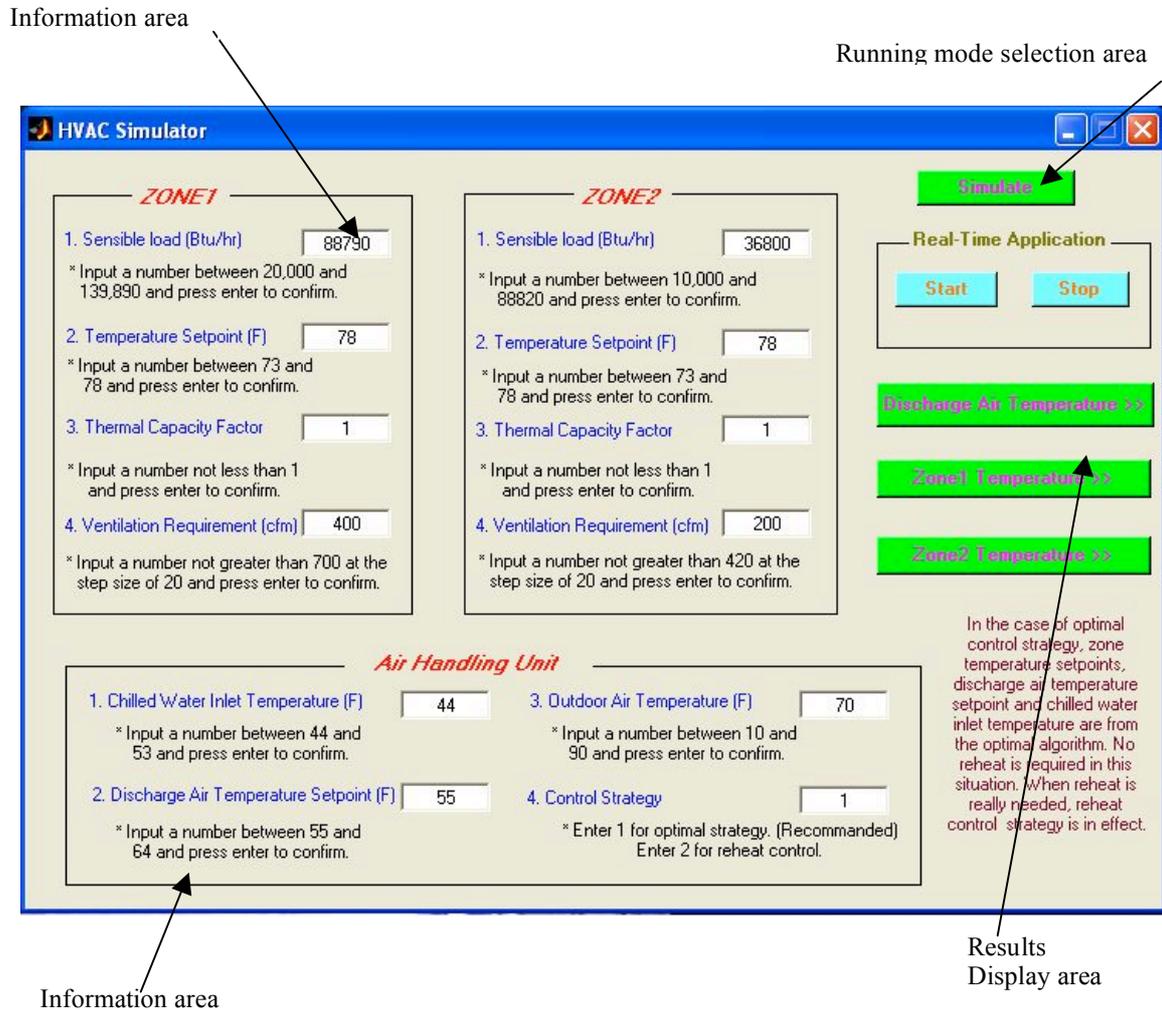


Figure 4. Graphical user interface

#### 4. Expert FDD Rules

In general, expert rules are formulated based on the knowledge of HVAC experts. In this study, some expert rules are adapted from the literature (House et al. 2003). The expert rules are categorized according to the operation modes of the air handling unit (AHU): (1) mechanical cooling with minimum outdoor air intake (Mode#1), (2) mechanical or natural cooling with 100% outdoor air (Mode#2), and (3) natural cooling with outdoor air (Mode#3). Among these rules, those common for at least two

operation modes are referred to as common rules (Table 2) while others are specific rules. All rules are written such that a fault will be indicated if the equation defining the fault is satisfied.

TABLE 2. Common expert rules.

Rule #	Content	Rule #	Content
1	$T_{da} > T_{ma} + \Delta T_{sf} + \epsilon_t$	7	$T_{sa} \leq T_{da} - \epsilon_t$
2	$T_{da} > T_{ra} - \Delta T_{sf} + \epsilon_t$	8	$T_{sa} = const$
3	$T_{da} \geq T_{daset} + \epsilon_t$	9	$T_z \geq T_{zset} + \epsilon_t$
4	$T_{da} \leq T_{daset} - \epsilon_t$	10	$T_z \leq T_{zset} - \epsilon_t$
5	$T_{da} \neq const$	11	$T_z \neq const$
6	$T_{sa} \geq T_{da} + \epsilon_t$	12	$U_{wact} > U_{wexp}$

4.1. RULES FOR MODE#1

In Mode#1, the cooling coil valve is modulated to satisfy the discharge air temperature set point value, and the mixing box dampers are set for minimum outdoor air intake.

Two rules for Mode#1 are listed as follows:

Rule 13  $T_{oa} < T_{ra} - \epsilon_t$

Rule 14  $R_{osact} \neq R_{os exp}$

4.2. RULES FOR MODE#2

In Mode#2, the mixing box dampers are set for 100% outdoor air, 0% return air, and 100% exhaust air. When the outdoor air temperature is greater than the discharge air temperature set point, the cooling coil valve is modulated to satisfy the discharge air temperature set point. When the values of the above two temperatures are the same, the cooling coil valve is closed and natural cooling is utilized.

Four rules for Mode#2 are listed as follows:

$$\text{Rule 15} \quad T_{oa} < T_{daset} - \Delta T_{sf} - \varepsilon_t$$

$$\text{Rule 16} \quad T_{oa} > T_{ra} + \varepsilon_t$$

$$\text{Rule 17} \quad T_{oa} \geq T_{ma} + \varepsilon_t$$

$$\text{Rule 18} \quad T_{oa} \leq T_{ma} - \varepsilon_t$$

#### 4.3 RULES FOR MODE#3

In Mode#3, the mixing box dampers are controlled to maintain the discharge air temperature at the set point value and no mechanical energy is required.

Two rules for Mode#3 are listed as follows:

$$\text{Rule 19} \quad T_{oa} > T_{daset} - \Delta T_{sf} + \varepsilon_t$$

$$\text{Rule 20} \quad T_{da} < T_{ma} + \Delta T_{sf} - \varepsilon_t$$

## 5. Applications

The validity and robustness of the expert rules were tested by embedding a fault in the model to simulate a faulty HVAC system and conducting real-time simulations. A sampling interval of 3-second was chosen. Only single fault cases were investigated. Results from two test cases are described.

### 5.1. CASE 1 – A STUCK COOLING COIL VALVE

Since the control signal to the cooling coil valve modulates to maintain the discharge air temperature at its associated set point, this fault will eventually cause the control signal to saturate at one of its limit.

Two tests were performed to simulate these two situations, where the discharge air temperature set point value was 55F (i.e.,  $T_{daset} = 55\text{F}$ ). Test 1 was simulated by causing the cooling coil valve to stick at  $t = 519\text{s}$  at 30% open position. In the meantime, design loads were acting on the system. As shown in Figure 5, the discharge air temperature was 64.3F (i.e.,  $T_{da} = 64.3\text{F}$ ), much higher than the set point value. It should also be noted that zone temperatures ( $T_{z1} = 84.5\text{F}$  and  $T_{z2} = 84.1\text{F}$ ) were greater than the set point values. This was because design loads could not be satisfied even though VAV damper control signals had saturated. Test 2 was simulated by causing the cooling coil valve to stick at  $t = 2,208\text{s}$  at 70% open position. In the meantime, the system was undergoing relatively small partial loads. As shown in Figure 6, the discharge air temperature was 50.3F (i.e.,  $T_{da} = 50.3\text{F}$ ), much less than the set point. However, unlike Test 1, both zone

temperature set points were reached. This was because this fault could be compensated by decreasing VAV damper control signals.

From the results, it is found that zone temperatures will not necessarily be affected when the cooling coil valve is stuck. The fact that the discharge air temperature cannot be reached is the primary symptom of this fault. Accordingly, the fault – cooling coil valve stuck – can be confirmed due to satisfaction of Rules 3 and 4.

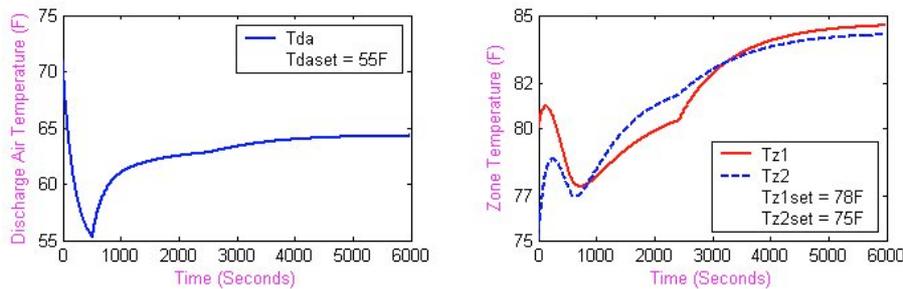


Figure 5. Response of temperatures.

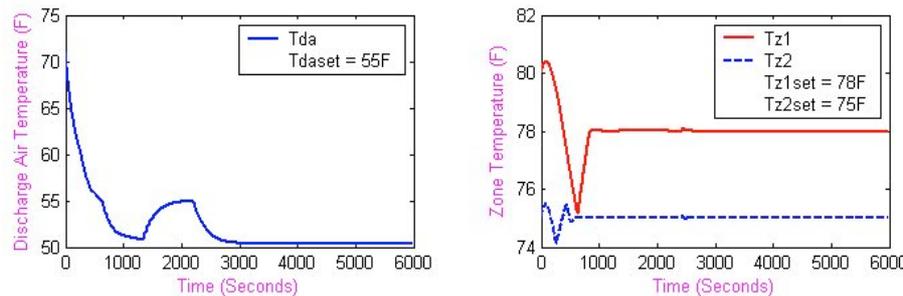


Figure 6. Response of temperatures.

### 5.3. CASE 2 – A STUCK OUTDOOR AIR DAMPER

This fault belongs to economizer cycle and occurs due to failure of a linkage in the mixing box dampers, which include outdoor air damper, recirculated air damper, and exhaust air damper. It presents three different symptoms under three different AHU operation modes.

Three tests were performed to simulate the fault corresponding to the AHU operation modes. Test 1 was for Mode#1 and simulated by causing the outdoor air damper to stick at 8% open position at  $t = 1,266s$ . As shown in Figure 7, the actual ratio of outdoor air intake to supply airflow rate was 0.14 (i.e.,  $R_{osact} = 0.14$ ), which was less than the expected ratio (i.e.,  $R_{osexp} = 0.18$ ). Test 2 was for Mode#2 and simulated by causing the outdoor air damper to stick at 60% open position at  $t = 1,230s$ . As shown in Figure 8, Zone 1 temperature was 84F (i.e.,  $T_{z1} = 84F$ ). Test 3 was for Mode#3 and simulated by causing the outdoor air damper to stick at 30% open position at  $t = 1,413s$ . As shown in Figure 9, the discharge air temperature was 57.7F (i.e.,

$T_{da} = 57.7$  F), being greater than the set point as a result of the fact that less outdoor air was drawn into the system. From the above tests, it is concluded that the fault – outdoor air damper stuck – occurred due to satisfaction of Rule 3 in Mode#1, Rule 9 in Mode#2, and Rule 14 in Mode#3.

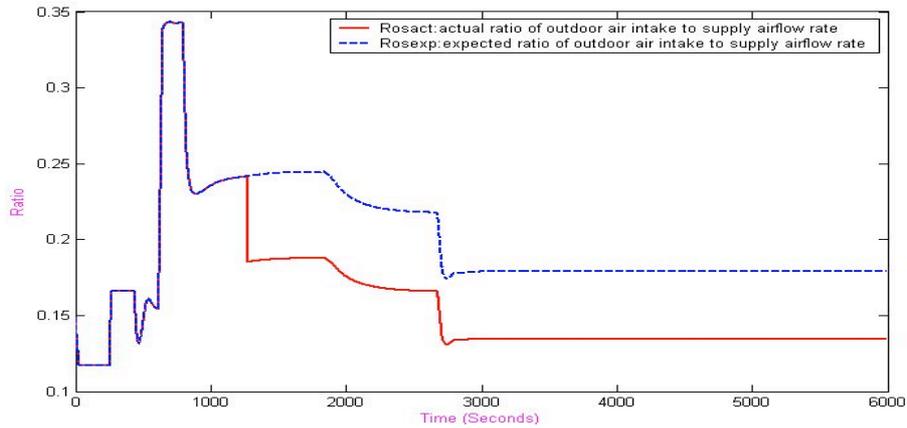


Figure 7. Ratio of outdoor air intake to supply airflow rate.

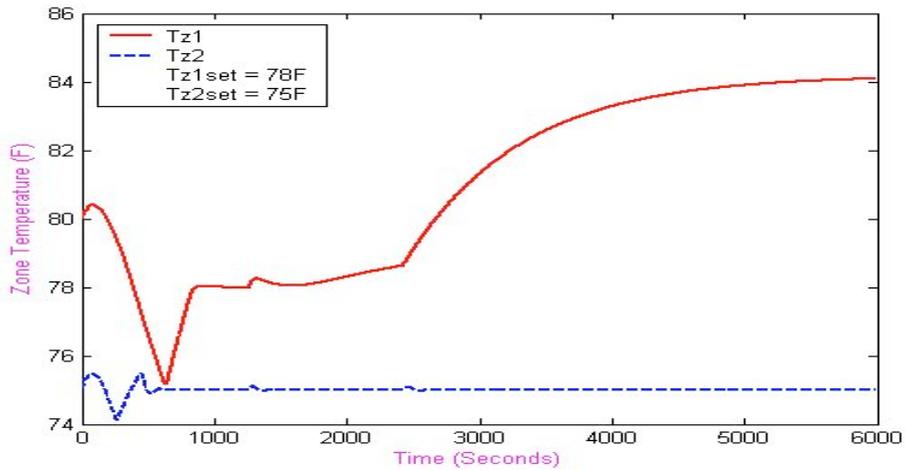


Figure 8. Response of zone temperatures.

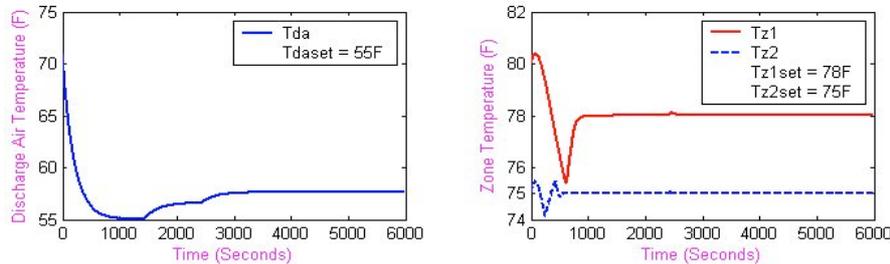


Figure 9. Response of temperatures.

## 6. Conclusions

In this paper, a real-time simulation tool has been developed for online monitoring, control and diagnosis of HVAC systems. This program runs in two modes: offline mode and online mode. When it is running in offline mode, it facilitates HVAC operators examine control strategies, and investigate problems caused by improper sizing of HVAC components. When it is running in online mode, real-time simulations can be implemented. Non real-time simulations have shown that the optimal control strategy is advantageous to the reheat control strategy. Real-time simulations have demonstrated that the developed tool is effective in identifying the fault patterns.

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### Nomenclature

$C_a$	air capacitance rate (Btu/hr-F)
$C_m$	total thermal capacitance of coil material (Btu/hr-F)
$C_{\max}$	maximum of $C_a$ and $C_w$ (Btu/hr-F)
$C_{\min}$	minimum of $C_a$ and $C_w$ (Btu/hr-F)
$c_{pa}$	specific heat of air (Btu/lbm-F)
$C_w$	water capacitance rate (Btu/hr-F)
$k$	factor describing the thermal capacity of zone
$\dot{m}_{sa}$	supply air mass flow rate (lbm/hr)
$q_s$	instantaneous sensible load (Kw or Btu/hr)
$R$	ratio of minimum to maximum capacitance
$R_{osact}$	actual ratio of outdoor air to supply airflow rate
$R_{osexp}$	expected ratio of outdoor air to supply airflow rate
$T_{ai}$	entering coil air temperature (F)
$T_{ao}$	air dynamic outlet temperature (F)
$T_{aoss}$	steady state air outlet temperature (F)
$T_{da}$	discharge air temperature (F)
$T_{daset}$	discharge air temperature set point (F)
$T_{ma}$	mixed air temperature (F)
$T_{oa}$	outdoor air temperature (F or °C)
$T_{ra}$	return air temperature (F)
$T_{sa}$	supply air temperature (F)
$T_z$	zone temperature (F or °C)

$T_{zset}$	zone temperature set point (F)
$T_{wi}$	inlet water temperature (F)
$T_{wo}$	water dynamic outlet temperature (F)
$T_{woss}$	steady state water outlet temperature (F)
$t$	time (hour)
$U_{wact}$	actual control signal to the cooling coil valve
$U_{wexp}$	expected control signal to the cooling coil valve
$V_z$	zone air volume (ft <sup>3</sup> )
$\Delta T_d$	temperature rise in ducts (°C)
$\Delta T_f$	temperature rise across fan (F or °C)