COMPUTER 3D VISUALIZATION TECHNOLOGY - A DYNAMIC DESIGN REPRESENTATION TOOL IN SOLVING DESIGN AND COMMUNICATION PROBLEMS IN THE EARLY PHASES OF THE ARCHITECTURAL DESIGN PROCESS

By

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COMPUTER 3D VISUALIZATION TECHNOLOGY - A DYNAMIC DESIGN
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Paralleling with development of computer technology, Computer-Aided Design (CAD) has been researched and introduced into industry since the 1960s. Until the mid-1980s, CAD means Computer-Aided Drafting in architectural field because the majority of practicing architects originally used computer as an electronic drafting tool to produce construction drawings. However, now computer 3D visualization technology as a design aided tool is impacting the architectural design process.

In this research, a review of architectural representation in the early design phases is given. Additionally, a literature review of CAD development is presented as well. As a focus of this research, computer 3D visualization technology has been
researched as a design aid. The emerging use of computer 3D visualization technology in some educational settings is also reviewed.

Within this research, three Case Studies are presented to provide insights of how computer 3D visualization technology may impact architectural design process, design service quality, and client-architect’s relationship.
DEDICATION

I would like to dedicate this research to my parents, Zongpin Jin and Yuxiang Qiao, and my wife Hongying Fan.
ACKNOWLEDGMENTS

The author expresses his sincere gratitude to the many people. Without whose selfless assistance this thesis could not have materialized. First of all, sincere thanks are due to Dr. Larry R. Barrow, my committee chairman, for his magnanimity in expending time and effort to guide and assist me throughout the intricacies of the program and the thesis process. Without his encourage and support in many aspects, it’s hard to imagine I could pass through this process. Expressed appreciation is also due to the other committee members, namely, Dean James L. West and Mr. Chris Arnold for the invaluable aid and direction provided by them. Additionally, I would like to thank Ms. Sarah Pittman. Thank her very kind and selfless help in many aspects. Finally, I would also like to thank all of my very friendly classmates, especially Xiang Wang and Han Li, and other faculties and staffs in School of Architecture who gave me their support during this period. Thank for their generous contributions.

A research thesis such as this owes much to those in the field of computer-aided design and other related discipline who have shared their knowledge and experience, both in their earlier writing, research and other kind of communications with me.
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DEFINITION OF KEYWORDS

ARCHITECT:
One who designs and supervises the construction of buildings or other large structures.

ARCHITECTURE:
The art and science of designing and erecting buildings.

ARCHITECTURAL DESIGN:
The process of planning out a building in systematic, usually graphic form.

DESIGN TOOL:
The tool is used for creating design ideas and assisting design development.

DRAFTING TOOL:
The tool is used for copying design documents.

FORM:
The shape and structure of an object. The essence of something.

CLIENT:
The patron who needs architectural design services and products, which includes other design disciplines and project owner.

TRADITIONAL DESIGN TOOL:
Physical manual tools which are not digital-based.

DIGITAL:
Expressed in digits, especially for use by a computer.

VIRTUAL:
Existing or resulting in essence or effect though not in actual fact, form, or name.
VIRTUAL REALITY:
A computer-generated digital world involving one or more human senses and generated in real-time by the participant’s actions.

MEDIA:
An intermediate agency, mean, instrumental channel.

EXTERNAL COGNITION:
To understand the intuition behind information visualization, it is useful to gain an appreciation for the important role of the external world in thought and reasoning.(Information Visualization, Stuart K. Card)

ARCHITECTURAL REPRESENTATION:
It’s the way that architects present their design concepts, display their design production (building design) and communicate with others such as project team members, project client and other related publics. It’s displayed in a certain symbol format.

COMPUTER 3D VISUALIZATION in ARCHITECTURE:
It’s to use computer applications to create 3-dimensional massing, space and simulating lighting condition and surface materials for architectural design review and presentation purposes.

COMPUTER 2D DRAFTING:
It’s to use computer applications to create 2-dimensional line-based drawings, such as floor plan, elevation and section etc for architectural design and presentation purpose.
CHAPTER I

INTRODUCTION

Architectural representation tools and techniques have played a central role in assisting architectural designers and their “thinking” for centuries; representation tools and techniques have been fundamental for the architect’s to bring their conceptual “ideas” to physical reality. Along with the development of architectural design, design representation tools and techniques have evolved as well. The current Computer-Aided Design (CAD) technology revolution now provides the architects with an expanded palette of visual design representation for design thinking and representation.

A Brief Background

Before the Renaissance, the master-builder played the role of building designer and contractor. The verbal design direction and instant on-site building layout are the major meanings of architectural representation and communication which leded by the master-builder at that time (Larry Barrow, 2000, P57-65). During the early Renaissance (1400 – 1500 AD), the function of master-builder decomposed into 1). theoretical-artist architect; 2). practicing architect; and 3). mason-builder (Larry Barrow, 2000, P66); in the meanwhile architectural design task and building construction task began to be
assigned to separate members – architectural designers & building constructors. Since then, architectural designers started to focus on building design tasks and design method/technique development in order to achieve the goal of creating new forms and spaces. In the late Renaissance (1500 – 1600 AD), when the architect started to draw out from construction site, a set of measurable drawings – plan, elevation, and section had become the main representation and communication tools between the architect and other design participants (Larry Barrow, 2000, P68). The architects draw 2D sketches like plans, elevations and sections etc. to review and present their ideas. Accompanying with the development of these two-dimensional drawings, some three-dimensional perspective techniques and physical modeling technique also had been invented to assist design development. In the past century, as a matter of fact, it is very common that many prominent architects always generated a lot of three-dimensional manual sketches and perspectives to guide their design ideas during initial design stages.

Since the early 1960’s, Computer-Aided Design technology has been introduced into engineering and architectural industries to solve design problem and improve design quality. In the 1980’s and 90’s, computer 2D drafting technique has became a premier tool for producing 2D construction documents throughout process of architectural design practice. Computer 3D modeling technique is widely accepted in design presentation generation as well. In the meantime, some pioneer architectural practitioners started trying to use computer 3D visualization technology in early design phases to solve visual design problems.
The Early Phases of Architectural Design Process

Generally, architectural design service for a new building erection starts from architect receiving client’s requirements. The early phases of the architectural design process discussed in this research include the following three phases:

1. Conceptual Design
2. Schematic Design
3. Early Design Development

In order to ensure a creative and functional design proposal, the continuous working cycle during above three design phases is the most important part within the whole design process.

Statement of Problem

Human civilization and technology have been developing at an accelerated rate which is resulting in an increasingly complex building design process. The emerging visual literacy of clients, and the public who wish to participate in the design process, offers additional challenges to architectural professionals. Concurrently, as societies access to information and digital media has increased, computer-Aided Design (CAD) technology has evolved and now provides architects an additional choice for design analysis, representation and presentation.

The practical problem in this research is described as follows:

The physical and functional complexity of modern architecture, growing visual literacy of architectural clients and the public, now
require increasingly powerful design and representation tools to assist the architect in solving visual design and communication problems in the early phases of the architectural design process.

The consequences of not dealing with the problem:

Lacking proper design and representation tools, architectural professionals will take the risks of making more design mistakes in the design development, construction documents, and construction phases resulting in increased cost to the owner; and/or inability to collaboratively communicate with design specialist, the owner, and other public project stakeholders in the early phases of design, which may result in client or public dissatisfaction, leading to the lose of the firms current client base.

The research problem in this research is as following:

Architectural professionals misunderstand the capability and limitations of current computer 3D visualization technology often results in either under or over estimating the value of the technology. This results in disruptive “frustrating” computing, and impedes the integration of computer 3D visualization technology as a design tool in architectural design process. The complex phenomena of the integration of traditional paper design processes and digital design processes is an emerging major factor
in the early phases of the design process and the practice of architecture is generally not understood.

Research Question, Hypothesis and Thesis

The research question in this research is as following:

*Does computer 3D visualization technology add value in solving visual design and communication problems in the early phases of the architectural design process?*

The research hypothesis is as following:

*Compared to traditional static manual paper 2D and 3D design techniques, it may now be more efficient to design using 3D digital design models in the early phases of the architectural design process.*

The thesis in this research is as following:

*Computer 3D visualization technology is impacting the early phases of the architectural design process, resulting in changing the nature of early phases of the architectural design process from a traditional manual “static” 2D and 3D design environment to a digital “dynamic” 3D design environment. This results in improved design output, in both quality and quantity, and hence greater client satisfaction and professional service.*
**Purpose of Research**

By analyzing the impact of computer 3D visualization technology in the early phases of the architectural design process, this research has provided an increasing understanding of the current and potential use of the technology in the early phases of architectural design. This will benefit the profession with avoiding misusing digital design tools and providing more and better design alternative solutions resulting in improved architectural design services.

**The Scope and Limitation of Research Study**

This thesis research has focused on architectural design representation tools and techniques with the following limitations:

1. To discuss the architectural design problems caused by lack of design/representation tools and techniques only, not others else like lack of creative design ideas, inappropriate management etc.

2. Architectural design phases covered in this research are conceptual design, schematic design, and early design development phases which are the early phases of the architectural design process.

3. As one of potential appropriate representation tools and techniques, computer 3D visualization technology is the main technique studied to solve visual design and communication problems in early phases of the architectural design process in this research.
4. CAD ‘simulation’ is an emerging design process factor, however, this is beyond the scope this ‘visualization’ representation research.

**Thesis Outline and Research Summary**

In this thesis, the research methodology has been qualitative-exploratory normative using the case study method. We discuss The development of Computer-Aided Design technology and its current situation in architectural practice field in Chapter III & IV, which is in order for reader better understanding the research problem. The role of representation in architectural design process as well as the development of representation tools and techniques is reviewed in Chapter V. In Chapter VI, all findings and analysis from the three case studies have been extracted out. The final conclusion has been given in Chapter VII. The three case studies of using computer 3D visualization in early phases of the architectural design process are provided as evidences to support the thesis conclusion in the APPENDICES.

From the three case studies reviewed in this research: 1). Envision Architects; 2). Pryor & Morrow Architects; 3). DRIL-Nissan Technology Center; beyond being a final design presentation tool which had been widely accepted in architectural profession, computer 3D visualization technology has been analyzed as a design representation tool in early design process in impacting design process and improving final design output. The effective methods of integrating computer 3D visualization technology in early design stages, the appropriate and inappropriate user conditions of such technique, the limitation of current computer 3D visualization technology are also
revealed in the research. In the meanwhile, the benefits of using computer 3D visualization technique as a design aid in early architectural design process are discussed as well.

The rapid development of computer technology and gradually matured Computer 3D visualization technology provide the architects more chances in improving architectural design service quality. Using as a design tool other than simple presentation tool, computer 3D visualization technique is gradually integrated into early architectural design process; it’s impacting the design process and mode of design from more 2D to more 3D, from more manual to more digital which resulting in more digital design environment as well as improving design service quality.
CHAPTER II

METHODOLOGY

This research has utilized the qualitative-exploratory Case Study research methodology as the primary means of research. The general literature review of development of Computer-Aided Design and role of representation in architectural design process is presented in the beginning of the research to give readers a general foundation of the research topic.

Three architectural firms/institute with three individual architectural design projects were selected for the case studies; each selected firm/institution for the case studies have displayed variegated propensity for the use of computer 3D visualization technology in the early phases of the architectural design process.

The data gathering from the three selected case studies is mostly drawn from the projects in which the author was personally involved. The author is a practical architect with ten years architectural working experience and six years experience in using computer 3D modeling and rendering in architectural design process having engaged the digital visualization tools in 1997 while practicing in Singapore. During this period, I have used AutoCAD R14 & 2000 and 3D Studio Max (Viz) as the primary CAD visualization programs. During my studies here at the MSU – Digital Research &
Imaging Lab, I have also learned several other main-stream CAD programs, like MicroStation Triforma, ArchiCAD, Revit, Form.Z and SketchUp. My background and personal knowledge of CAD has been essential to conduct this research. Additional information related to the case studies was collected from relevant architectural firms/institute and project team members through e-mail, phone and personal interview.

The research Findings and Analysis have been generated based on all the research findings as well as the three case studies. During the 2001 summer, I worked as an architectural computer 3D renderer and designer in Envision Architects, Albany, New York. The evidence drawn from my practical experience during that time strongly supports me to conduct this research. So does the study of the coursework, like Digital Design I during the last two years.

Table 2.01

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Firm/Institute</th>
<th>Contact</th>
<th>Location-Home Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Envision Architects, PC</td>
<td>Ted Mallin/Mark Yang</td>
<td>Albany, NY</td>
</tr>
<tr>
<td>2</td>
<td>Pryor &amp; Morrow Architects.</td>
<td>Sherry Berry/Larry Barrow</td>
<td>Columbus, MS</td>
</tr>
<tr>
<td>3</td>
<td>Digital Research &amp; Imaging Lab, MSU</td>
<td>Larry Barrow</td>
<td>Starkville, MS</td>
</tr>
</tbody>
</table>
In the following chapter, the history and background of Computer-Aided-Design technology in architecture is reviewed as a fundamental knowledge to understand this research paper.
CHAPTER III

HISTORY AND BACKGROUND

The qualitative-exploratory research methodology – case study has been introduced in the last chapter. In this chapter, we will review the development of Computer-Aided Design technology, and the impact of using this technology in changing the way of architectural profession during 1950s to the mid-1990s.

Introduction

In the past four decades, a major transformation has occurred in design and representation tools/techniques for the architectural profession. The use of computer assisted technology for drawing drafting and design visualization purposes gradually grew up and now the majority of construction drawings are produced by computer rather than traditional manual methods (See Figure 3.09 & 3.10). Many architectural firms use computer instead of manually to generate architectural perspective during design presentation (See Case Study I, II & III).

In the typical architect’s office during the 1970s, one would find many drawing boards, pencils, paper, squares and other drawing tools. If there was a computer in the office, probably it was only used for office administration purposes. However, by the
mid-1990s, the situation had changed dramatically. The computer hardware was now a significant component of the architect’s workplace and the traditional drawing board had disappeared or was kept for nostalgia purposes only (Daniela Bertol, 1997, P43-44).

**Computer-Aided Design Technology in History**

An approach with integrating computer technology into architectural practice is not a fresh idea as it was first proposed in the 1960s. At that time, the computer had much less power and was very expensive. Thus, most firms could not afford computer technology in their daily works.

The initial research and development of Computer-Aided Design technology was not initiated in the architectural field. Rather, in the 1950s, after World War II, the needs of the military intensified the development of the modern electronic computer. The first computer graphic system was developed at Massachusetts Institute of Technology's Lincoln Laboratory and used by the US Air Force's SAGE (*Semi Automatic Ground Environment*) air defense system (See Figure 3.01). This system involved the use of CRT (Cathode-Ray-Tube) displays to show computer-processed radar data and other information. The first light-pen was invented to draw and manipulate pictures on the screen in the system (See Figure 3.02). Following that in 1957, well known as "the Father of CADD/CAM" for his pioneering contributions to the field of computer-aided design and manufacturing, Dr. Patrick J. Hanratty developed PRONTO, the first commercial numerical-control programming system (Marian Bozdoc, 2001).
Figure 3.01  SAGE System
Source: Adapted from http://cad.about.com/cs/history

Figure 3.02  SAGE System: CRT Display and Light Pen
Source: Adapted from http://cad.about.com/cs/history
In the 1960s, encouraged by the success of computer technology applied in engineering industry and the promise of design methods movement, several individual pioneers begin to focus their researches on Computer-Aided Design. The research works done in MIT in the early 1960s (Ivan Sutherland, 1963; Coons, 1963) were looked upon as being the start of Computer-Aided Design applications related to architectural profession. The SKETCHPAD produced by Ivan Sutherland was accomplished in 1963. Within the system, a Lincoln TX2 computer was used to support a cathode-ray oscilloscope to allow graphical information to be displayed on a screen. Using a light pen, pictures could be drawn on the screen and then manipulated (See Figure 3.03).

Figure 3.03  Ivan Sutherland refreshable vector scope
Source: Adapted from http://cad.about.com/cs/history
In 1960, McDonnell Douglas Automation Company (McAuto) was founded. McAuto played the major role of CAD development and introduced a CAD program in 1965. In this first CAD program, the patterns of lines were displayed by using simple algorithms, first in 2D and then in 3D. Professor Charles Eastman at Carnegie-Mellon University at that time was the first pioneer researcher in this field (Marian Bozdoc, 2001). During the same period, similar research was being conducted in several other architectural institutions, like UCLA, Carnegie-Mellon University in United States; Edinburgh, Strathclyde, and Cambridge universities in the United Kingdom; and the university of Sydney in Australia. However, the low power of such applications and very high cost of computer equipment at that time impeded the progress of the architectural practitioner integrating the emerging technology in their daily work. In spite of these early architectural visionaries’ dreams, it would be 20 years or more before CAD would have an impact on most architectural practices in the 1980’s. In the late 1960s, the Computer-Aided Design systems released by several American vendors started to appear in the market. The Computervision Corporation released the first Computer-Aided Design system in 1969 (See Figure 3.04). This turnkey system was created for production drafting and sold to Xerox in same year. Some other firms like Colma and Applicon developed systems intended for the electronic engineering industry. Applicon was more of a research-oriented company. In the mid 80s it was acquired by Schlumberger and then merged with MDSI which Schlumberger had acquired earlier. Colma was originally a manufacturer of the digitizer used in mapping and integrated circuit manufacturing, in the 1980’s they started to move into the graphic
industry. In mid 80s Colma was acquired by General Electric and then sold to Prime Computer (Marian Bozdoc, 2001). By the end of 1960s, there were less than 200 CAD workstations in the United States, and most of these were used in the aerospace and automotive industries (David D. Bedworth, Mark R. Henderson, Philip M. Wolfe, 1991). Therefore, in the 1960s CAD is used only in very large companies who could afford expensive ‘one of a kind’ systems which were setup to their individual special needs. These systems were huge in size and space and cost millions of dollars (Sarah Denholm, 1999).

Figure 3.04 Computervision Turnkey System
Source: Adapted from http://cad.about.com/cs/history
In the 1970s, mini-computers became available which were in a price range of 50k-200k. CAD really meant Computer-Aided Drafting at that time (Sarah Denholm, 1999) and the development of CAD mainly focused on automating 2D drafting. In the early 1970s, as the first company entered the AEC (architecture, engineering, and construction) market, Auto-trol emerged as a pioneer in the fledgling CAD industry by announcing Auto-Draft, one of the first turnkey graphics systems available. Auto-trol developed this system intended for plant design by large engineering companies. On the side of architectural profession, some large architectural firms like Skidmore, Owings, and Merrill in the United State and some large multi-disciplinary companies in Japan started to use their own developed Computer-Aided Drafting systems. But most of the architectural professionals were hesitant to venture outside the basic use of Computer-Aided Drafting and Design applications. However, contrastingly, Computer-Aided
Drafting and Design (CADD) vendors, researchers and architectural professionals in some academic environments showed great enthusiasm. Several organizations focusing on Computer-Aided Design had been formed, such as the Society for Computer Applications in Engineering, Planning, and Architecture (CEPA) in United States, the Construction Industry Computing Association (CICA) in Britain, and the Association for Computer-Aided Design (ACAD) in Australia (Antony Radford & Garry Stevens, 1985).

In the United State, a few CAD systems with small intelligence capability were developed during mid-1970s. However, most of these systems were still quite expensive, and thus, only affordable for a few large architectural firms.

Figure 3.06  Growth of Computer Work Station from 1960s to 1970s
Source:David D. Bedworth, Mark R. Henderson, Philip M. Wolfe, 1991
In United States, the number of work stations rose from less than 200 in the 1960s to about 12,000 in the 1970s (Figure 3.06). However, the 1970s was still the period of CAD experimentation and computer program ‘debugging’ in the architectural design and construction field (Kathleen Gibson, 1998). The use of computers in most architectural firms continued to focus on management and administration tasks. This was comprised of office daily administration, accounting, design description, specification writing, and cost estimating. Traditional manual methods remained in the early phases of the architectural design process and also for most of construction drawing phase.

During the 1970s, CAD was an academic dream; however, during the 1980s CAD was arrived in architectural practice. Many different CAD systems became available at that time. The development of 32 bit computers increased the power of CAD systems with higher computer speed and more memory capability. Solid modeling systems, rather than 2D drafting, were also emerging. Unigraphics introduced the first solid modeling system, Uni-Solids which was based on PADL-2 in 1981 (Michelle Pillers 1998). As a milestone, Autodesk was founded by John Walker in April 1982 in California. John Walker’s idea was to create a CAD program for a price of $1000 to can run on PC. Autodesk released AutoCAD 1.2 in April 1983, which was the first release of AutoCAD after Autodesk was founded (Marian Bozdoc, 2001).

During the 1980s, the forces of these improvements came from four aspects:

1) The success of computer technology application in engineering industries let architects re-recognize the role and capability of CAD:
comparing both of benefits and troubles brought by computer, the benefits now out weighted the cost. The computer could now be a practical tool and solve lots of practical problems easier than using traditional tools. Additionally, the computer could calculate complex geometry thus solving problems which were heretofore unsolvable.

Thus, the computer began to do many tedious technical tasks, increasing efficiency and allowing the architect more time to focus on creative design tasks.

2) Second, was the improvement of Computer-Aided Design technology. Many Computer-Aided Design systems were released onto the market and they were more mature for architectural practice than their ancestors in the 1970s.

3) The cost of using these technologies dropped dramatically so that CAD was affordable to even small architectural firms. Much of this transformation is contributed to the emergence of the Personal Computer (PC) and rapid development of the PC’s capability (See Figure 3.07, 3.08 & 3.10). However, in the 1980s, the PC platform CAD systems still had limited functions (2D) and the powerful CAD 3D systems only existed on the UNIX platform.

4) There were demands from some architectural service clients who started to force architectural professionals to use computer technology in for their design services.
Figure 3.07  Computer Processing Speed and Physical Size
Source: Dr. Larry Barrow, Dissertation 2000, Page 30-31

Figure 3.08  IBM 6090 Raster CAD/CAM Station
Source: Adapted from http://cad.about.com/cs/history
Based on the aforementioned factors, the “Use of Computer Accelerates” survey in 1982, we find the number of architectural firms who involved in using computer leaped from 30 percent in 1976 to 65 percent in 1981 (Antony Radford, Garry Stevens, 1987) (See Figure 3.09). The 2500 most active architectural and engineering firms in the United States were involved in this survey (Antony Radford, Garry Stevens, 1987). Following this survey, a 1985 survey (Wagner, 1985) showed “the suddenness of the upsurge in computer use among architects”. Figure 3.10 shows the result of how architects use the computer in that time period.

![Use of Computer in Architectural Office](image)

Figure 3.09 “Use of Computer Accelerates” survey in 1982
Source: Antony Radford & Garry Stevens, “Cadd Made Easy”, 1987
During the 1980s, from the above chart, we can see that computer usage in architectural design firms was still very technical; and thus, not inherently related to their core business nature — a creative thinking process. We see that, in fact, the use of the computer in the architectural firm is very close to the usage of the computer in non-design related businesses. This phenomenon tells us truth that architects had not yet taken up the challenge of computing and incorporated it as a design tool in the architectural design process (Antony Radford & Garry Stevens, 1987, p12). Another reason is simply that the CAD systems were not mature.

In first half of the 1990s, CAD 3D modeling capabilities made drastic improvements. In 1990, Spatial Technologies announced ACIS, a commercial solid
modeling system which provided a common database part that had the ability to be accessed & utilized in multiple environments, like part model, analysis model, assembly model, and manufacturing model (Michelle Pillers 1998). In the meantime, solid modeling on the low-end systems became available. Desktop ‘per person’ systems were emerging with much more new functionalities i.e. solid modeling, complex 3D geometry, parameterization, and constraints. Many companies, including architectural firms, started to choose one standard system for extended time periods of commitment. The cost of computer hardware and software continued to drop with powerful systems available for around US$ 3000 (Sarah Denholm, 1999). See Figure 3.11.

![Figure 3.11 Computer System Cost](source)

The early 1990s saw the development of computer technology that offered new potentials for architectural design and drafting forward at an accelerated rate. It became
possible that an architectural design could be pulled out directly in three dimensions, tested for shadows and light, color and massing, circulation and energy consumption. We can virtually review the design building before constructed it (Steven S. Ross, Architectural Record June 1993).

A survey of Architectural Record readers in early 1993, which was conducted by Architectural Record, showed that more than three-quarters of the respondents were using computer for design and drafting. The following are the key trends reflected in the survey:

1. Drafting work is highly computerized.
2. In order to help less-sophisticated clients visualize designs, the use of computer for design presentation has spread at the high end from large scale projects to the small projects.
3. More conceptual design was being done on computers.
4. The variety of hardware and software in use in architectural practices was increasing.
5. CAD software used in architecture became easier to use for simple tasks.
6. CAD training had emerged as a major cost.


However, the survey of Architectural Record in 1993 also indicated CAD tools were used by a very low percentage of the architectural practitioners in early design process (See Figure 3.12). But for construction drawing drafting, CAD tools were used in higher percentage (See Figure 3.13). In addition, the survey indicated “that the most
commonly used tools for 2D drafting and 3D modeling are not the same tools as those considered ‘most effective’ by practitioners who do 3D modeling in schematic design” (Thomas P. Conlon, 2000).

<table>
<thead>
<tr>
<th>CAD in Schematic Design</th>
<th>CAD in Construction Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manually: 30%</td>
<td>Manually: 17%</td>
</tr>
<tr>
<td>Digitally: 5%</td>
<td>Digitally: 25%</td>
</tr>
<tr>
<td>Others: 65%</td>
<td>Others: 58%</td>
</tr>
</tbody>
</table>

Note: Others means the mixture of manually and digitally in various percentage.

CAD as a design tool rather than just a drafting tool was researched and practiced extensively during the late 1980s and the 1990s. The majority of CAD pioneer researches were conducted by members of several organizations i.e. ACADIA (Association for Computer-Aided Design in Architecture), eCAADe (Education and research in Computer Aided Architectural Design in Europe), CAADRIA (Computer Aided Architectural Design Research In Asia), and CAAD Futures. The ACADIA was founded in 1981 which is dedicated to the promotion of communication and critical thinking regarding the use of computers in architecture, planning and building science.
The initial effort of ACADIA focused on architectural education and has remained so in
the past two decades. eCAADe was founded in 1983, which is a non-profit making
association of institutions and individuals with a common interest in integrating and
improving the use of computers in architectural education and other related professions
in Europe.

In the architectural practice arena, enlightened by the research development and
their own understanding of capabilities of Computer-Aided Design technology, some
pioneering architects started to pursue the assistance of computing technology in
solving their design problems. Typically, during the early 1990s, this was in the areas of
complex geometric forms which were quite hard, or impossible to solve, using
traditional methods. Architect Frank Gehry, well-known in the style of his creative and
free form design character, began using computer 3D visualization technology to better
visually present his ideas in design improvement and communicate his ideas to other
disciplines. His first actual build project was the “fish sculpture” for the 1992 Olympic
Village. The computer 3D digital design environment allowed Gehry to execute his
design effectively and get a high quality in representation accuracy and additionally,
this geometric data was transferable to the builder for construction as well (Kathleen
Gibson, 1998).

**Summary**

In this chapter, we have reviewed the development of Computer-Aided Design
technology in field of architecture as following:
1. The 1950s: CAD was researched and developed for the utilization of Military and Defense purposes.

2. The 1960s: CAD was focused on Engineering field, simple CAD systems were developed and mainly used in Aerospace and Automotive industries.

3. The 1970s: CAD started to integrate into architectural practice. The task of CAD is usually for administration and accounting purposes. A little 2D drafting work could be carried by CAD. Some large size architectural companies developed their own CAD systems.

4. The 1980s: Computer 2D drafting systems began to use widely for construction drawings in architectural office. Computer 3D solid modeling system was emerging.

5. The first half of 1990s: 2D drafting systems gradually replaced manual tools for working drawing production in later architectural design process; 3D modeling tools were accepted gradually for design presentation purpose; Design study and analysis in 3D digital environment was emerging.

In the past four decades, the environment of architectural design studio was changing, which resulted from Computer-Aided Design tools/techniques integrated into architectural design studio. Over 40 years ago, Ivan Sutherland contributed his first interactive CAD system – Sketchpad to the Industry. Since then, the computer assisted technology integrates into architectural discipline gradually, which from simple office administration work to 2D drafting, to 3D modeling, to design analysis.
Designing in digital environment was emerging, but the technology was not matured. In the meanwhile, most of the architectural professionals were not ready for the revolution of the digital design.

In this Chapter, we have reviewed the history and background of Computer-Aided Design technology in architecture. In the following chapter, the recent development of Computer-Aided Design technology in architecture is discussed in order to well understanding the current application situation of this technology in architecture.
CHAPTER IV
CURRENT CONTEXT OF COMPUTER-AIDED DESIGN IN ARCHITECTURE

The history and background of Computer-Aided Design in architecture is introduced in the last chapter. In this chapter, we will review the current situation of Computer-Aided Design technology in architecture, and the impact of using this technology in changing the way of architectural profession. The time period for which was affected is from mid-1990s to present.

Introduction

Today many architectural professions are benefiting from using Computer-Aided Design technology in their professional daily routine. The architectural CAD application has improved dramatically in function and convenience in recent years. The architectural CAD vendors are putting more efforts in both CAD technology development and their understanding the nature of architectural profession. CAD vendors are trying to overcome barriers-to-entry of digital technology in architecture. This effort is hampered due to earlier user experiences when attempting to engage technology in their design process, and/or frequent vendor overstatements regarding the
ease of use and potential of technology for the architect. “Meanwhile, philosophical battles were raging, architectural designers were continually trying to make the technology work for them, to fit technological developments to their own design practices, to make connections between disparate software developments in specialist areas.”(Peter Szalapaj, 2001)

However, in his book “CAD Principles for Architectural Design”, Peter Szalapaj also claimed that the experience drawn from architectural professionals in using CAD technology in their practices showed the strong evidence that CAD technology is entirely feasible to involve in architectural design process. And he believed “… it is now possible for diverse design practices to configure their own integrated CAD environments in response to the kind of architecture they want to produce, and the analytical procedures they need to make it happen.”(Peter Szalapaj, 2001).

**Current Context in Academia**

In recent years, several CAD research communities have researched new design methods which attempt to integrate CAD technology in the architectural design process. In the US, the primary research institution has been ACADIA (the Association for Computer-Aided Design in Architecture). The use of computers in design studios has been addressed as a topic several times at ACADIA conferences (-i.e. 1987, 1988, and 1998). From 1998's theme “Digital Design Studios: Does computers make a difference?”, we would find that many researchers showed their evidences to try to answer the question in their own ways. Clearly their evidence indicates that digital
design is no longer a question, but their question is how to most effectively conduct digital design studios as well as to develop new design techniques and even new software for studios of the future (Thomas Seebohm, Skip Van Wyk, ACADIA’98).

At the 1998 ACADIA conference, a valuable debate was raised regarding the Digital Design Studio, Sandy Stannard, the author of “Computer in Design: Exploring Light and Time,” indicated that the use of computer in design studio “… was not to replace traditional design methods but to complement and enhance them.” And “… the computer is simply that: just another tool for designers to use to explore and create architectural design. As just another tool, it is most strongly applied in conjunction with other more traditional design tools”(Sandy Stannard, 1998).

In the other hand, in his paper of A Proposal for Alternative Methodologies in Teaching Digital Design, John Marx believed that “Computers have the potential to radically change the process of architectural design, and match more closely the formal aspirations of contemporary designers”(John Marx, 1998). Marx pursued the idea of using digital modes to replace traditional modes rather than integrating these two modes together. To provide the evidences, he indicated using the 3D model in early design stages, and treating it as a basis for contract documents, had “proven cost effective especially with complex and curving forms.” In most cases he examined, the digital design process “… is quicker and more accurate than a non-digital process.” Among many other CAD researchers, the same argument is debated and discussed concurrently. This research paper also tries to answer the same question by our own experiences. As a matter of fact, some research pioneers revealed the design capability of CAD in a much
earlier time. In her book *Computer Visualization*, Kathleen Gibson wrote, “While many practitioners were trying to standardize computer-aided drafting, William Mitchell, and then professor of architecture at UCLA and presently professor of architecture at MIT, was recommending more innovation and technical development. Mitchell discovered that the power of CAD lay not in documentation, but in extending current methods of thinking about design.” (Kathleen Gibson, 1998, p03)

In the same direction, with carefully reviewed many case studies, Peter Szalapaj also suggested that CAD technology “… has moved on to a position in which far more than mere drafting is possible. CAD technology has progressed to a level in which it is possible to communicate design expressions representing early stage design ideas right through to detail drawings.” In the meanwhile, as a condition of using 3D CAD technology effectively, the user should be a architectural designer rather than a draftsman (Peter Szalapaj, 2001).

Generally, the research focus of CAD technology at present is focused on how to integrate CAD into the design process as an innovative design tool in lieu of just a replacement for traditional tools in design process.

**Current Context in CAD Software Development**

During the past five to ten years, CAD software has become much more sophisticated. Before the early 1990s, the CAD programs were mainly focused on automating standard drafting techniques, not on design testing or analysis. However, in today’s CAD market, many CAD softwares with many powerful functionalities are
available for architectural professions enhancing their design services. For example, the use of 3D library object driven software (SW), where the architect can automatically select and insert doors and windows is now possible. This type of SW provides a parametric 3D building model which allows quick editing features for the architect’s design and production process. Additionally, the 3D digital model allows collaborative work and remote team coordination. Compared to previous SW applications and/or versions, many major architectural CAD programs now have made major functional improvements for 2D drafting as well as 3D modeling.

Specifically, Graphisoft, of European origin, introduced ArchiCAD in 1985 and was the first object-based CAD system focused only on architecture; Autodesk introduced Architectural Desktop in 2000; Bentley Systems introduced MicroStation Triforma in 1996 which is claimed to be an “all-in-one” CAD system for architecture; Revit Technology introduced Revit in 2000, the first truly parametric 3D architectural CAD system. Most importantly, these SW applications range in cost from US $3,000-4,000. Considering their sophisticated functionality (i.e. 2D drafting, 3D modeling, team corporation, and project database management, etc) and their relatively affordability, even for sole practitioner, and these systems run on user friendly Personal Computers (PC); this is a remarkable event in the evolution of technology in architecture.

Additionally, as add-ons to the aforementioned “all-in-one” SW applications, specialized architectural CAD programs have been introduced as well. For instance, Autodesk Architectural Studio is a new conceptual design solution for sketching,
modeling, presenting and collaborating which is conducted in 3D digital design environment. Another CAD software focusing on the conceptual design stage is SketchUp by @Last Software. This SW is a deceptively simple, and quite powerful as a design tool for creating, viewing, and modifying design ideas within 3D digital environment in early architectural design process (See Figure 4.01). Due to their sophisticated 3D modeling and rendering functions, some general 3D modeling systems are also widely used by architectural designers for design study in early design process and design presentation in later design process, for example, 3D Studio Max (Viz) and Form.Z. Figure 4.02 is an interior space presentation executed by 3D Studio Max 3.0. So we now see architects have many more tools for their process in the early design phases for the use of 3D dynamic digital models in lieu of 2D static paper traditional graphics.

Figure 4.01  A Interface of SketchUp
Source: Jianying Jin, School of Architecture, MSU
As an effort to explore emerging digital design tools for the Digital Design Studio, the graduate program at the Mississippi State University, School of Architecture, has developed relevant courses such as Digital Design I (DDI) and Digital Design II (DDII). These courses focus on new design methodology and issues relating to input and output potential of emerging design technologies.

In the Fall of 2001 Digital Design I course class, seven students of varied educational levels, disciplines, and user experience were challenged to understand new opportunities, and current limitations of SW applications relevant to their discipline and career goals. Six of the students had a professional degree in architecture, with various levels of practice experience, and one student was an acting archeologist.
requirement of the class, each student was asked to rate themselves on a scale of 1-10 for 8 of the most relevant SW applications in architecture. After class review, the students were not allowed to use a SW application with which they had prior user knowledge. Rather, they were asked to use a SW which they did NOT know for engagement and modeling for the first half of the semester. The students were given the task of modeling the existing MSU School of Architecture building (Giles Hall). This was done by the instructor, Dr. Larry Barrow, in an attempt to focus the student on learning the SW verses “design decisions.” Additionally, each student tracked and reported their learning experience to their fellow classmates relative to ease of use, features, limitations, and potential. This offered a collaborative learning environment which resulted in knowledge building class discussions where students compared the capability and usability of each program. The group member’s existing knowledge level for each CAD programs was evaluated at the beginning of the class (See Table 4.01). From this evaluation, the fact found is only knowledge of knowing AutoCAD R14 and 3D Studio Max is above the average. It also reflect another fact which Autodesk’s products dominate the majority of CAD market (See Figure 4.03).
Table 4.01  Evaluation of Existing CAD knowledge Among DDI’s Students, Fall 2001
Source: Digital Design I, Fall 2001, School of Architecture, MSU

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>RI4</th>
<th>Desktop</th>
<th>Inventor</th>
<th>Archi. Studio</th>
<th>3D Studio Max</th>
<th>Triforma</th>
<th>ArchiCAD</th>
<th>Revit</th>
<th>FormZ</th>
<th>Rhino</th>
<th>Maya</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jin</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>Kai</td>
<td>8</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>Xiang</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Han</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>Meeta</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>Nethra</td>
<td>7.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7.5</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>Kevin</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
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<td>14</td>
<td>2</td>
<td>0</td>
<td>35.5</td>
<td>4</td>
<td>10</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>8</td>
<td>134</td>
</tr>
</tbody>
</table>

NOTE: Enter a rating of 0--10  -----> 0 = no knowledge  -----> 10 = Expert

Figure 4.03  Group Existing Knowledge level of CAD Programs, DDI, Fall 2001
Source: Digital Design I, Fall 2001, School of Architecture, MSU
At mid-term, each student presented their digital model and gave a general report of functionality and capability of the CAD program in use of architectural design process. The diagram of such evaluation is given here (See Table 4.02 & Figure 4.04). This evaluation will be very helpful when we integrating CAD techniques into our architectural practice. It can give us a general direction on what CAD program we will use, how to use, when to use and who is the best person to use it.

<table>
<thead>
<tr>
<th>No.</th>
<th>Software</th>
<th>Student Investigator</th>
<th>Architectural Modeling</th>
<th>General Modeling</th>
<th>Freeform Modeling</th>
<th>Ease of Use for Market Niche</th>
<th>Object Libraries</th>
<th>Rendering</th>
<th>Animation</th>
<th>Parametric</th>
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<tr>
<td>0</td>
<td>Architectural Desktop</td>
<td></td>
<td>9</td>
<td>8</td>
<td>6.5</td>
<td>5</td>
<td>8</td>
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<td>5</td>
<td>8</td>
</tr>
<tr>
<td>1</td>
<td>3D Studio Max</td>
<td>Kai Pan</td>
<td>6.5</td>
<td>10</td>
<td>9</td>
<td>6</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Rhino</td>
<td>Xiang Wang</td>
<td>6.5</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>FormZ</td>
<td>Kevin McMahon</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>7</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
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<td>Jianying Jin</td>
<td>10</td>
<td>5</td>
<td>1</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
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<td>Nethra Ram Mohan</td>
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<td>10</td>
<td>4</td>
<td>0</td>
<td>10</td>
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<td>9</td>
</tr>
<tr>
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<td>Han Li</td>
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<td>1</td>
<td>9</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Revit</td>
<td>Meeta Shingne</td>
<td>10</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td></td>
<td>8.1</td>
<td>7.8</td>
<td>6.4</td>
<td>7.4</td>
<td>4.4</td>
<td>7.0</td>
<td>6.4</td>
<td>5.4</td>
</tr>
</tbody>
</table>

NOTE: Enter a rating of 0 --10 ( 1 = poor ----> 10 = Excellent ); *With Plug-ins
<table>
<thead>
<tr>
<th>No.</th>
<th>Software</th>
<th>Student Investigator</th>
<th>Construction Drawings</th>
<th>Cost Estimating</th>
<th>Project Management</th>
<th>2D Output</th>
<th>3D Output CAD/CAM</th>
<th>Customer Support</th>
<th>Average</th>
<th>Retail Cost ($)</th>
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<tbody>
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<td>10</td>
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</tr>
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<td>10</td>
<td>5.0</td>
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<td>0</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>4.3</td>
<td>900</td>
</tr>
<tr>
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<td>FormZ</td>
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<td>0</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>5.3</td>
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</tr>
<tr>
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<td>Microstation TriForma</td>
<td>Jianying Jin</td>
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<td>10</td>
<td>10</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>7.7</td>
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<tr>
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<td>Maya</td>
<td>Nethra Ram Mohan</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>6</td>
<td>5.3</td>
<td>7,000</td>
</tr>
<tr>
<td>6</td>
<td>ArchiCAD</td>
<td>Han Li</td>
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<td>10</td>
<td>7</td>
<td>10</td>
<td>3</td>
<td>8</td>
<td>7.4</td>
<td>3,500</td>
</tr>
<tr>
<td>7</td>
<td>Revit</td>
<td>Meeta Shingne</td>
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<td>8</td>
<td>10</td>
<td>10</td>
<td>3</td>
<td>10</td>
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<td>TOTAL</td>
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<td>3.5</td>
<td>3.4</td>
<td>5.1</td>
<td>7.4</td>
<td>9.1</td>
<td>6.2</td>
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</tbody>
</table>

NOTE: Enter a rating of 0 – 10 (1 = poor ----> 10 = Excellent ); *With Plug-ins
Figure 4.04  Rating of CAD Programs Used in Digital Design I
Source: Digital Design I, Fall 2001, School of Architecture, MSU

Figure 4.05 is a working sample of using 3D Studio Max 3.0 in DDI class, Fall 2001. 3D Studio Max (& Viz) is a sophisticated 3D modeling, animation and rendering program, and it’s now being extensively used in architectural visual design testing, analysis and design presentation by architectural professionals. In order to produce reasonable and meaningful 3D modeling and rendering, the learning curve of 3D Studio Max (or Viz) is much higher than 2D drafting programs.
Maya from Alias/Wavefront, owned by Silicon Graphics Inc. is the current king-of-the-hill in high-end 3D animation software, and over the past few years has become the leading package for character animation in feature films. It’s another program tested in DDI class, Fall 2001 by Nethra Ram Mohan. From Nethra’s comments, Maya is a really powerful modeling, rendering and animation package. However, due to its high software cost, and demanding learning curve, as well as not providing accurate measurable geometries it is not very suitable for architecture. Figure 4.06 is a working sample of using Maya program in DDI class, Fall 2001.
Revit from Revit Technology Corporation is the first parametric building modeler developed for AEC industry. Revit's advanced parametric technology offers unprecedented ease of use in a product that has been designed to enable architects, engineers, owner/operators and construction professionals to transform the entire process by which buildings are designed, constructed and operated over their lifecycle. (Source from Meeta Shingne, DDI class presentation, Fall 2001) Figure 4.07 & 4.08 are working samples of using Revit program in DDI class, Fall 2001.
Figure 4.07  A Working Sample of Using Revit with DDI’s Project Model  
(Before Rendering)  
Source: Meeta Shingne, School of Architecture, MSU, 2001

Figure 4.08  A Working Sample of Using Revit with DDI’s Project Model  
(After Rendering)  
Source: Meeta Shingne, School of Architecture, MSU, 2001
MicroStation Triforma was also reviewed in the Fall 2001 DDI class. This is a major architectural CAD application which is mainly used by large architectural design firms. Introduced by Bentley Systems, Incorporated, MicroStation TriForma is an application for the building design, management and construction industry. It’s based on Single Building Model concept. MicroStation TriForma provides the necessary tools to design projects in 3D and at the same time keep track of materials, quantities, cost reports and specification texts, simply by modifying the 3D model. The plans, cut views, elevations, bill of materials, quantity reports and specification book are documents generated from the model. All the required information is stored in or linked to the 3D model. As a result, the modifications have to be made only once in the model and derivative documents are automatically modified (Source from Bentley Systems, Incorporated, 2001). Figure 4.09 is a working sample of using MicroStation Triforma in DDI class, Fall 2001.
Current Context in Architectural Practice

In architectural practice, currently Computer-Aided Drafting tools have completely replaced manual paper tools for the production of construction working drawing during the later architectural design process and construction plans. The use of digital tools in the later phases of design is well accepted by most practicing professionals in architecture, construction, and related engineering fields. Concurrently, computer 3D visualization technology has been widely used for final architectural
design presentation since the mid-1990s. The realistic, easy editing, and multiple views available make this technique a favorite tool for final design presentations. The research survey of The Use of 3D CAD by Geopraxis, Inc. in 2000 indicated that the most sophisticated 3D modeling tools are used more for final design presentation of marketing purpose to create a photo realistic rendering or animated walkthrough rather than for building design (Thomas P. Conlon, 2000). The majority of responders were relatively active 3D users. Over 50% of them use 3D software at least three days per week and less than 20% of them use it fewer than once a month (Thomas P. Conlon, 2000). The survey of Use 3D CAD conducted on DesignCommunity.Com from October through December of 1999 shows some detailed information of Use 3D CAD in architectural design presentation. See Figure 4.10 & 4.11.

Figure 4.10  Projects of 3D CAD Assisted Presentation
Source: Thomas P. Conlon, ArchitectureWeek June 2000
A recent survey of interviews with managers in 256 UK AEC companies was conducted by Business Advantage Group Plc. (CADspaghetti, January 2002 Issue). The result shows that 39% of the UK companies are using a 3D modeling program to some degree, but the majority of users (61%) are still working with 2D CAD only.

However, many architectural firms have already benefited from using 3D CAD technology in their practice, especially when they are faced with critical and complicate designs.

Using 3D CAD technology enhances the architectural designers’ capability to create complex forms, to provide a clear communication with their design partners and their clients. The very famous architectural firm in USA, NBBJ, has successfully integrated digital 3D techniques into their architectural design process. According to Michael Hallmark AIA, Principle of NBBJ Sports and Entertainment, digital 3D models
are effective for understanding design ideas. Digital 3D models provide the designers a tool to evaluate space, form and as well as design details. Additionally, the use of color and textures scanned from materials intended for the project, for mapping to the digital 3D model provide a valuable tool to valuate material choices (Mark Von Wodtke, 2000). Paul Q. Davis, a senior project designer for NBBJ, indicated that some building forms would be very difficult to design and build without using a digital 3D model (Mark Von Wodtke, 2000). During the period of designing the Paul Brown Stadium, digital 3D model was extensively used to investigate architecture. “Sight lines optimizing the view from each seat in the stadium help to develop the complex form of the bowl and intricate geometry involved in the roof. “It is like a boat hull design.” … “Every bay changes.” … “Computer 3D models provide a way to understand the design.” These architects use digital 3D models as part of pre-schematic design proposal to win client contracts, for the preliminary and design development, as well as construction documents to help work out fabrication.” (Mark Von Wodtke, 2000). A work flow of using digital 3D model in NBBJ is shown in Figure 4.12.
Beyond the scope of this research, the computer 3D CAD technology is also used in some systematic specific quantitative design analysis during architectural design, like structural analysis, lighting analysis, acoustic analysis, thermal analysis and bioclimatic analysis etc. Relatively early, in 1993, Nicholas Grimshaw & Partner designed the Waterloo International Terminal in London, UK using 3D CAD technology to solve the technical issues of a 400-metre-long curved glass roof. Using a specialized SW application for structural analysis, 3D CAD technology was used to represent parametric relationships, making it possible to handle the complexity and variation in the size and shape of the structural elements involved in the curved glass roof (Peter Szalapaj, 2001). According to Kirkland from Nicholas Grimshaw and Partners, “These tools are enabling designers to achieve these goals practically and cost effectively. Such
resources are likely to lead to the emergence of new architectural forms no longer confined by cost efficiencies of planar form. This kind of design tool will enable principal designers to quickly produce a variety of ideas, and make these accessible to other team members in a general, re-usable, executable, and extensible form.” (Source from AEC Magazine, November, 2002). Figure 4.13 is a view of the digital 3D environment used in the design process for the Waterloo International Station, London, UK.

![Figure 4.13 Digital 3D View of Train Platforms from Concourse of Existing Train Station](source)

Summary

Computer-Aided Design technology is impacting architectural design activities and transforming the design process from a manual to a digital process. The need for effective and efficient communication and representation tools/techniques for solving practical design problems, as well as new form innovation, is forcing the architectural professions to engage the digital design environment. However, in spite of the emergence of highly sophisticated 3D modeling SW, the majority of design in the early phases of architecture remains in the traditional paper based method.

The rapid development of Computer-Aided Design technology in the past two decades has made computer as a main construction documentation drafting tool in architectural practice. But, CAD, Computer-Aided Design, as its name implies has not reached maturity in the current architectural design process. Based on the reality, it’s quite suitable to interpret CAD as Computer-Aided-Drafting before the 1990s. As Daniela Bertol described, “. . . the efficiency of electronic drafting by itself does not give a legitimate reason to state the computer is used in the design process.” And “The reality is that, in the majority of practices, while drafting is highly automated, the hand sketch is still the primary medium in the exploration of design alternatives.” (1997, p51). How to improve this situation and take advantage of computer technology to increase ability of our creative design thinking and productive efficiency is under extensive practice and discussion recently.

In Chapter III and IV, we have reviewed the development of Computer-Aided Design technology in architecture. In the next chapter, the development of architectural
representation technique and its role in design process are discussed in an effort to understand how computer 3D visualization technology can be a design representation tool in architectural design process.
CHAPTER V

REPRESENTATION IN EARLY PHASES OF THE
ARCHITECTURAL DESIGN PROCESS

In the last chapter, we have reviewed the current situation of Computer-Aided Design technology in architecture, and the impact of using this technology in changing the way of architectural profession. In this chapter, we will discuss the nature of representation, the role of representation in early phases of the architectural design process, the development of representation. A brief relationship of different type of representation with different design phases is given as well. The purpose of this chapter is to establish the appropriate capabilities that design representation tools and techniques used in early phases of the architectural design process should have in order for the architect selecting and using them efficiently and effectively.

General Architectural Representation

In architectural practice, the architects utilize some certain kinds of physical and digital representation of their proposed design to simulate the future living reality. The representation is the bridge of generation of architect’s creativity and the future living reality. The role of architectural representation is very crucial during the design process
because it is the only way architects use to explore partial and final result of their design and communicate to others (J. Peter Jordan, 1997). The process of early phases of the architectural design actually is a series of interactive reactions between the architect’s internal envision and external design representation (See Figure 5.02).

As long as architectural design existed, generating design representation has been one of the fundamental skills expected of architects. In fact, an architect is really constructing a virtual building during the architectural design process to simulate what his construction cohorts will build ultimately as a physical building. This *virtual building* can only be made known through its *representation* for the architect himself reviewing, his colleagues critiquing, the owner approving, and a constructor building (See Figure 5.01). As a perfect representation requires high level professional knowledge and more practical experiences to recognize, “It should be no surprise that skill in producing these *representational* artifacts can be mistaken for the skill required to design a building.” (J. Peter Jordan, ACADIA 97, p01)

![Diagram](image-url)

*Figure 5.01  Architectural design communication – Representation*
The nature and purpose of representation:

We always talk about representation when the architects communicate with each other. But what does representation mean? In many dictionaries, we may find out the definition of the word ‘representation’. But we may get a clearer meaning from Omer Akin’s paper Representation and Architecture as he explained:

*My Random House Dictionary gives two definitions for the verb “to represent”; a) “to express or designate by some term, character, symbol or the like,” and b) “to present or picture to the mind.” Then we can define representation circularly, as the “product of the act of representing.”*

In the meanwhile, Omer Akin has pointed out there are two conditions for a representation. First, representation must correspond to a real object, state, action or their implications because representation should be a symbol. Next, it must be attributed to the corresponding reality through some shared human convention or understanding in order for a representation to picture to human viewers mind. (Omer Akin, 1982, p01)

Therefore, now we know a representation in the design field should have three continuous steps to complete it in order to achieve its purpose (See figure 5.02). First, an architect has some ideas in mind, in order for others to receive and understand the presented ideas properly, the architect should express his ideas out of his mind to an external symbol format (Form of representation). Then the receivers will absorb the architect’s ideas into their mind and interpret it by viewing this representation. In the meanwhile, the architect will also study and improve his ideas by reviewing the previous design representation. So, a representation is really a central connection
within the design process. Without this connection, the whole design process could never be completed.

![Diagram](image)

Figure 5.02 Architectural Representation Process

In architecture, for example, when an architect begins to design, he may grab a certain kind of design tool, like a pencil and a piece of paper, or even sit down in front of a computer, then start to draw something. "In fact he is representing a thought or a partial design idea to himself. This representation is a symbol that his mind will absorb, re-form, and react to" (Omer Akin, 1982, p03). As the design process continues, this process will be cycled until the architect works out an appropriate design proposal. In addition, the early phases of the architectural design process also consist of a series of representations within that the representation information bounces between the architect and other project stakeholders to include engineering consultants, the client, the public, and in the emerging project delivery environment, this process often includes the builder and other respective construction industry participants. This representational process is engaged in order to improve design quality by gaining input and advice from other team experts as well as the client. The following depicts the path of representation information flow (see Figure 5.03).
Therefore, *representation* is critical to the design process. But we know that many architects use many different types of representation throughout whole design process to conduct their design activities, like drawings (2D & 3D), physical models, computer digital models, written materials, as well as body gestures and verbal descriptions during Person-Person presentations. Then we may ask ourselves “Are all types of representation equal in every aspects?” (Also, what types of representation are appropriate for different times, audiences and needs). Omer Akin pointed out three aspects:

*An appropriate representation, then, is one that contains all the information at a level of abstraction suitable for its intended purpose.* (1982, p07)

*An appropriate representation, then, is one that presents its contents in a way that is compatible with the expectations resulting from the mental representations of the perceiver.* (1982, p09)
An appropriate representation, then, is one that is consistent with the reality that it is intended to refer to. (1982, p11)

Therefore, the architect must understand the nature and purpose of representation in the early phases of architectural design process if they are to appropriately solve design problems. In order to complete the whole process of representation, we need tools to carry and convey our thinking throughout the design process (see Figure 5.03). We often call the tool “media.” In this term, representation is a method and process of representing our thinking (i.e. the cargo) and media is a conveyor of our thinking (i.e. the vehicle).

Media, in the Oxford Dictionary, is defined as “an intermediate agency, mean, instrumental channel.” From this definition, we may get a hint why the media can be a tool between the user and the message which the user “created, received, stored, manipulated, or disseminated.” Further more, media is more than just a “tool” and it is also “an environment” (McCullough, 1996). In the architectural design process, media such as paper drawings, physical models, or computer models can be treated as a representation tool and/or environment for an architect presenting, reviewing and refining the design ideas. By employing a certain kind of media, externalizing and evaluating the architect’s design ideas become possible. Therefore, we realize that “Media” can have a tremendous influence on the design process. In the meanwhile, the limitation and improperness of the media applied in design process may result in the limitation and improperness in design decision-making. (Osman Ataman, Julio Benmudez, ACADIA’s 1999, Page xii)
Architectural design representation tools and techniques involved in early phases of architectural design process should have capabilities as follows:

1. An ability to present lines to form building profile and shapes.
2. An ability to present 3D massing to simulate building form and space.
3. An ability to present color and texture to simulate building material, lighting and other surrounding environment elements.
4. An ability to easily manipulate the architects “design-thinking” to increase design efficiency and effectiveness.
5. An ability to generate an efficient and effective final design presentation.

**Architectural Representation Typologies**

As we have discussed, architectural representation is the central thread running through the early phases of the architectural design process. So, well understanding the capability of different type of representation is essential for architectural design activity.

Prior to the Renaissance, the architect as a master-builder played the role of building designer and contractor. The verbal design direction and instant on-site building layout sketches are the major meanings of architectural representation and communication which leaded by the master-builder at that time (Larry Barrow, 2000, P57-65). Architectural drawings like 2D plans, sections, and elevations have been concerned as one of main representation formats in architectural design process since their inventions during the Renaissance in Europe. Based on the inherent nature of different drawing types, different types of drawing should be utilized at different
architectural design stages. For example, due to its’ intuitive, convenient, and easier
generation, free-hand sketch is widely used in early phases of architectural design
process, like conceptual design and schematic design phases (See Figure 5.04).

Figure 5.04  A free-hand sketch – Nissan Technology Center, MS
Source: Dr. Larry Barrow, School of Architecture, MSU

In their book *Architectural Representation*, Robert Greenstreet and James W.
Shields pointed out: “If a particular drawing convention affects in some way the user’s
perception of space and form, it will ultimately impact upon the design and any debate
thereby generated. Consequently, it is important for the designer to be fully aware of the
available range of drawing types, their effects, applications, and appropriateness to
certain projects to ensure a compatible match between the tool and product, thereby
maximizing the potential for a successful outcome to the scheme (1988, p04).”
The types of representation are reviewed as following order:

1. Orthographic projection: plan, section and elevation;
2. Paraline Projection: Axonometric and Oblique Drawing;
3. Perspective Drawing;
4. Physical 3D Model;
5. Computer 3D Modeling;

The Plan, Section, and Elevation:

The orthographic projection type of drawing like plan, section, and elevation is the most commonly used in architectural discipline since this representation technique had been introduced into architectural design practice during the Renaissance (circa 1500 AD). The characteristic of this type of representation is converting three-dimensional space form into a two-dimensional plane format. This type of representation is mostly used in construction documentation phase in which the documents are produced for conveyed accurate and measurable building design information to others (see Figure 5.05 & 5.06). Due to its nature, the lack of spatial and qualitative character may be considered to limit the use of orthographic drawings in early design stages. Other than that, the greater advantages of this type of representation make the plan, section, and elevation very successful as a major media in conveying design information (Robert Greenstreet, James W. Shields, 1988).
Figure 5.05  A part of full detailed floor plan, Furniture Research Lab, MSU
Source: Pryor & Morrow Architects,

Figure 5.06  Floor plan, elevation and section
Source: Adopted from Robert Greenstreet & James W. Shields-“Architectural Representation”
Paraline Projection: Axonometric and Oblique Drawing

Axonometric and oblique drawings have been widely used as a representation technique in twentieth-century architecture. This representation technique creates a sensation of three-dimensional space by projecting parallel lines from an orthographic projection and these drawings are quite easy to understand by both architect and layman (Paul Laseau, 2000).
Compared to 2D orthographic projection drawings, paraline drawings provide the viewer with much more information in a single drawing. It can show at least two elevations (sometimes a plan layout too), building space, and some rough surrounding site information at same time (see Figure 5.07) (Robert Greenstreet, James W. Shields, 1988, p48). Comparing with perspective drawing, this type of representation is easy to create, requires less technical skill and less experience. The aforementioned advantages have made this drawing type a favorite for architects as a design tool. However, like any single representation tool, paraline projection drawing has its disadvantages. Therefore, when we decide to utilize it, we should consider Robert Greenstreet and James W. Shields’s suggestions, “It is reasonable to infer, therefore, that the use of paraline drawing tends to favor objects over space, and excessive reliance on the technique may result in less consideration of the spatial aspects of a design. For this reason, it is important to use axonometric and oblique in conjunction with other drawing types or other tools – computer imaging – animations, etc to ensure that all aspects of a scheme are fully explored” (Robert Greenstreet, James W. Shields, 1988, p49, 50).

**Perspective Drawing:**

Leon Battista Alberti was the first person describing a practical method for employing perspective in his work (Daniela Bertol, 1997). In the fifteenth century, the development of the perspective drawing methods provided architects a new way for solving visual design problems. This visualization phenomena provided an entirely new method for observing and recording reality. Perspective drawings, compared to all
traditional drawing formats, have much more capabilities in representing the three-dimensional world. Therefore, an architect or layperson can understand perspectives much more readily than other kinds of drawings (Robert Greenstreet, James W. Shields, 1988, p68). Figure 5.08 is a two-point perspective shown a very complex architectural space which is quite hard to present clearly by only two-dimensional plans and elevations.

![Figure 5.08 A two-point perspective](image)

Produced by Michael Doyle, Felt pen. Lloyd Center Food Court. Communication Arts, Inc.

Generally, detailed perspectives drawings are generated after the design concept is fixed. The audiences of this representation type are primarily clients and the public.
Usually, detailed perspectives drawings are generated by a representation specialist. Due to the nature of this type of representation, perspective drawings are more intuitive and effective than 2D drawings in representing the relationships of 3D physical components. Perspective drawings allow the layman to understand the design concept easily and totally. But perspectives require more time, presentation skill, and technical knowledge than other drawing types.

However, the nature of design has its own rules, which may not follow the architects’ desire. Like theatrical designer Tim Palkovic expressed,

“The most desirable approach to design drawing begins with a perspective sketch that is easily translated into a floor plan. This insures that perceptual problems are considered from the conception of the design and not discovered later.”

In history, we find that many prominent architectural designers, such as Bramante and Frank Lloyd Wright, have perceived perspective as integral part of their early phases of design. Basically, there are One-Point (Parallel) perspective, Two-Point (Angular) perspective, and Bird-Eye View perspective. The simplest and also first developed, one-point perspective was extensively used during the Renaissance era. It’s effectively suited to explain a building design “which are composed and experienced axially and frontally” (See Figure 5.09). Two-point perspectives are much more realistic than one-point perspectives and can be introduced into almost every type of building designs without much distortion (See Figure 5.10). But more capabilities require more energy and knowledge input. Introduced into the architectural discipline by Leonardo da
Vinci, bird’s-eye view perspectives have very strong capabilities to present complex information regarding the three-dimensional objects in a single view. Using a high and distant vantage point, the two sides and the top of any cubical solid can be seen in one time, the scale and detailed information may be sacrificed for conceptual information as the viewpoint is quite far away from presented building (See Figure 5.11). But accompanying with its strong capability, the difficulty of generation is higher than almost all other drawing types. Careful and selectively used bird’s eye view perspective can be a very powerful design tool to communicate with others (sometimes even the designer himself).

Figure 5.09  Vredeman de Vries: One-point perspective rendering
Source: Daniela Bertol with David Foell, Designing Digital Space, 1997
Figure 5.10 A two-point perspective

Figure 5.11 A Bird’s Eye Perspective – Xianhai Spots, China
Source: Design Link Architects, Singapore. Computer rendering by: Yuenhui Shao, Jianying Jin
Physical 3D Model:

Physical models are used as a tool in visualizing and interpreting abstract design information. They are more powerful visual communicators than two-dimensional drawings and perspectives. Unlike separate two-dimensional (2D) plans, elevations, and sections, physical models combine the plan layout, external appearances (elevation’s information) and three-dimensional space and form; thus, presenting the design concept as a whole (see Figure 5.12). The nature of physical models makes them much more closely related to the final design product and physical building. Therefore, this allows clients a much easier interpretation of the design information. Compared with static vanishing points of perspective drawings, the 3D physical model offers tactility and limitless angle views of the building design for both the architect and owner. Therefore, physical models are used extensively by the architects in conceptual design and final design presentation phases as “a useful alternative or supplement to basic drawing techniques” (Robert Greenstreet, James W. Shields, 1988, p120). Another benefit of physical models is the relationship analysis of single building and its surrounding condition if the physical models contain not only the single building, but also the surrounding site situation.

However, physical model has its weak points as well. Due to its unreal scaled situation, physical model is generally only appreciated in an aerial viewpoint representation. However, the actual ground plane human experiential reality is lost. Also, physical models fail to express a closed interior space and detailed information of
material and lighting conditions. Therefore, sometimes, these experiential observations limitations may lead the viewers to wrong directions and design decision making.

**Figure 5.12** A concept model made by hardwood

**Computer 3D Modeling:**

In the past decade, computer 3D modeling has become accepted as a presentation and design tool for architect’s design “thinking, visualizing, communicating, and predicting” (Wei Dong, 1998). Computer 3D models are being used for many purposes as conceptual models, schematic design study models, and presentation models.

Unlike traditional 2D drawings which are limited to the “X and Y” Cartesian axis, computer 3D model provides the designers with a third space direction in the “Z
axis.” This phenomena allows the design environment to much more closely resemble reality. In this 3D virtual design environment, the designer doesn’t just work on each plan, section, and elevation separately; but rather, an entire 3D building. In different design stages, computer 3D models may vary in details. In conceptual design stage, computer 3D models represent the physical relationship of building massing, space planning, and space scale. In schematic stage, computer 3D models may have more refinement in scaled detail and other building physical elements like material pattern, color, and lighting conditions. At their highest level of development, computer generated 3D models are used for presentation purposes and rival realism. This level of computer 3D model is often called “photo-realistic” representation and often contains details of the surrounding environment (See Figure 5.13).

Figure 5.13 Interior view of Saint Madeleine Sophie Church, Albany, NY
Architect: Envision Architects, PC; Computer renderer: Jianying Jin
Compared to physical 3D modeling, computer 3D modeling is much easier in manipulating and modifying fine detailed building components, building finishes materials, and interior lighting conditions. Additionally, the external human’s eye level view and interior view(s) of the design proposal can be easily represented as well (See Figure 5.14).

Figure 5.14  Secondary Drop-off Point, HBD Punggol Apartment
Architect: Design Link Architects, Singapore; Computer Renderer: Jianying Jin
Current Visual Representation Techniques in Early Phases
of The Architectural Design Process

Unlike other disciplines, today’s architectural practice still utilizes traditional representation tools and techniques which have been developed for several hundred years since the Renaissance. Relatively recently, with the development of (CAD) technology, new techniques and tools continue to emerge to assist architects in visual design representation during early phases of the architectural design process.

Orthographic projection – specifically like plan, elevation and section is still the most common type of representation in architectural practice today. From concept design to construction drawing phase, architects mainly use plans, sections and elevations to develop their ideas, communicate with their professional fellows and clients. Especially in construction drawing stage, this two-dimensional drawing format is almost the only type of design representation for the architects to conduct design and construction tasks.

Contrastingly to the traditional way of generating drawings, the majority of US firms now generate their construction drawings using the computer. Easy editing, convenient and fast duplication, ease of data transmittal through the internet, and ease of storage has made CAD the favorite architectural drafting tools over the last two decades. The 1997 AIA Firm Survey report shows that 68% of architectural firms used CAD 2D tools in their design process. See Figure 5.15.
Figure 5.15  Percentage of Architectural Firm Applied CAD 2D in Design Process
Source: The AIA Survey Report 1997

Figure 5.16  Percentage of Architectural Firm Applied CAD 3D in Design Process
Source: The AIA Survey Report 1997
The skill of producing free-hand perspective sketches as a very powerful communication tool has been taught in modern architectural schools. Ease of use, convenient, and intuitive nature of this drawing format makes it the favorite representation type in early phases of architectural design process.

Computer generated perspective sketches have recently appeared in architectural practice. Similar to two-dimensional drafted drawings, three-dimensional computer modeling sketches offer many advantages which can not be provided by traditional free-hand sketches. These advantages include easy editing, fast duplication, limitless different angle views and capability of reflecting accurate building components which are crucial to solving visual design problems in the early design stages.

Similar to the use of perspective representation in traditional methodology, computer generated fine-detailed perspective drawings have been typically utilized in the final design presentation. The purpose of this approach is to convey the architects design information, communicate with clients and convince them to approve the design.

Computer 3D modeling as a design environment has been studied by CAD pioneers for a long time and this digital design environment concept begin to be accepted and emerge in architectural practice in recent years. Now the rapid development of CAD provides architectural professionals a chance of designing in digital 3D environment initially. Computer 3D models with a variety of detail level can be used for various purposes throughout architectural design process. Conceptual models, schematic models, and presentation models service a continuous design and representation functions in design process. However, in order to achieve the effective
and efficient result, a certain conditions should be met during using computer 3D visualization tools. The AIA Survey Report 1997 indicated that there is 44% of architectural firms applied CAD 3D technique during the design process which includes using computer to generate final perspective and to assist design. See Figure 5.16.

Due to its immature status, Virtual Reality (VR) is not typically used in most current architectural design practices and VR is beyond the scope of this research. However, a brief overview is as follows.

Studied and developed since the 1970s, Virtual Reality has begun to permeate the architectural profession in academic research units. In Daniela Bertol’s word, “Virtual reality is a computer-generated world involving one or more human senses and generated in real-time by the participant’s actions. The real-time responsiveness of the computer to the participant’s action distinguishes VR from other kinds of computer-generated simulations. The participant in a VR environment is the perceiver and creator at the same time, in a world where the object of perception is created by actions” (1997, p67). In order to integrate VR into architectural design practice, further research should be conducted.

**Summary**

In their book, *Architectural Representation*, Robert Greenstreet and James Shields described the general relationship between representation technique and purpose of use:
Graphic representation can serve a number of roles in relation to architectural design. The most obvious is the clarification and communication of ideas from the designer to a client or, eventually, to a contractor. In these roles the purpose, and therefore the nature, of the graphic product is different. Drawings for clients, for example, are intended not merely to communicate but also to persuade, convince, or impress. Communications to contractors need only transmit detailed technical information to ensure the correct construction of the project. Obviously, the graphic techniques used for these two purposes are likely to be different, and misuse in either case could lead to confusion or misunderstanding. (1988, p 02)

Representation by itself has its own rules. The different type of representation has different functions and it may match certain purpose properly. In order to give a full play of certain representation, the tools, representation purpose and its audience should be carefully matched.

First, the type of representation should be planned with the type of its audience and purpose accordingly. Like, if the audiences are a group of layperson who are lacks of general architectural professional knowledge, the representation may contain far more explanatory data for their better understanding. But if the audiences are a group of professional exports, the representation may be far sophisticated and complex than the
former. Therefore, in order to achieve the best result of representation, the designer should bear in mind the methods of representation and the conditions tied with it in any time.

Second, different design representation tools/techniques have different capabilities. Certain type of tools/techniques may suit certain representations better than others. In addition, no single design representation tool/technique can fit into whole design process. Different phases and different purposes may request using different tools/techniques to achieve the goal. For example, the perspective sketches used for design study in early design stages will quite different with the perspective drawings used for final design presentation in later time. The tools/technique applied on those representations may be different as well.

Third, we must pay more attention in using new tools/techniques. Developing and exploring a possibility of new tool/technique is not simply trying to replace its traditional counterpart (at least in the beginning, but replacement may happen in the future when the new tool/technique become fully mature), the main purpose of it is to give architectural professionals more choices in their design representation to achieve their design goal rather than trying to discard the traditional one.

The nature of early architectural design process is to generate, explore, review and modify a design concept rather than provide a precise design plan. From this point of view, 3D design representation shows more advantages in solving visual design problems like massing, spacing, coloring and lighting than 2D design representation. Comparing manual and digital 3D representation techniques, the current computer 3D
visualization technique provides the architects more convenient ways than traditional manual techniques, like easy editing, quick duplicate similar ideas, more precise and so on.

In this chapter, we discussed and review the nature and purpose of representation in early phases of architectural design process, the relationship of representation, the tools/techniques applied on it, and audience of representation. In the following chapter, my ANALYSIS AND FINDINGS will be extracted from all the evidence presented to include the three selected case studies which can be reviewed in the Appendices is presented.
CHAPTER VI

ANALYSIS AND FINDINGS

“Sure, PC empowerment is a grandiose concept. After all, the PC is used much for playing games and telling multimedia stories as for finding cures for cancer. But most of it about solving problems, enabling you to learn and augmenting your impact on the world by giving you powerful tools.”

--- Bill Gates, 1996

RESEARCH QUESTION:

In order to answer the research question, “Does computer 3D visualization technique as a design representation tool add value in solving visual design and communication problems in the early phases of the architectural design process?”, three architectural firms/institute with three individual practical projects were selected as case studies under this research. Within these three case studies, computer 3D visualization technology as a design representation tool was involved in early design process. These three exploratory case studies provide us with primary research data, augmented with the secondary research data presented in the earlier chapters, will be
utilized for this chapters ANALYSIS AND FINDINGS. A list of the three case studies is as follows (Table 6.01):

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Firm/Institute</th>
<th>Office Location</th>
<th>Staff</th>
<th>Contact Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Envision Architects</td>
<td>Albany, NY</td>
<td>45</td>
<td>Ted Mallin/ Mark Yang</td>
</tr>
<tr>
<td>II</td>
<td>Pryor &amp; Morrow</td>
<td>Columbus, MS</td>
<td>27</td>
<td>Sherry Berry/ Larry Barrow</td>
</tr>
<tr>
<td>III</td>
<td>Digital Research &amp; Imaging Lab, MSU</td>
<td>Mississippi State</td>
<td>10</td>
<td>Larry Barrow</td>
</tr>
</tbody>
</table>

**RESEARCH HYPOTHESIS:**

The following research hypothesis was tested throughout the three case studies:

*Compared to traditional static manual paper 2D and 3D design techniques, it may now be more efficient to design using 3D digital design models in the early phases of the architectural design process.*

**THESIS STATEMENT:**

From the tested hypothesis, the research thesis is concluded as the following:

*Computer 3D visualization technology is impacting the early phases of the architectural design process, resulting in changing the nature of early phases of the architectural design process from a traditional manual “static” 2D and 3D design environment to a*
digital “dynamic” 3D design environment. This results in improved design output, in both quality and quantity, and hence greater client satisfaction and professional service.

PROOF STATEMENTS:

In order to qualify Thesis Statement, the following facts offered as proof:

1. DESIGN ALTERNATIVES: The capability of testing and comparing more design alternatives is enhanced by using computer 3D visualization technology as a design tool in the early phases of the architectural design process. Similar to the effort of using 2D digital drafting tools, at the outset, creating the digital building model may take more time. However, the capability of unlimited views, and the ease of manipulating the digital building model with different lighting conditions, surface finishes, and ease of editing allows architects to make quick design alternatives. See case study I and III.

2. COMPRESSED DESIGN CYCLE: In some architectural practices, using computer 3D visualization technique as early as possible in early design stages enables the architect to design more naturally in 3D (manual and digital) which avoids some unnecessary interim 2D representation process. As a result, the time frame for the early design stages can be compressed and some hard copy printing for output can be avoided. See case study I and III.
3. VISUAL COMMUNICATION AMONG DESIGN TEAM MEMBERS: Currently, using digital 3D design environments allows the architects to easily convey design information in early design phases, especially in the late schematic design and early design development stages. Professional knowledge required for representation perceivers of both project team members and clients to interpret such design information is reduced. Representation perceivers can easily obtain design information with less risks of misunderstanding. See case study I-III.

4. ARCHITECT-CLIENT’S RELATIONSHIP: Digital 3D output produces clear visual imagery thus allowing the client to be more comfortable and confident in making further decisions. As we know, “Anxiety from miscommunication is highest at key decision points in the design process – the client is concerned about agreeing to a design they may not fully understand;” (Paul Eshelman, Kesia Tatchill, Human Ecology, Winter92, Vol. 20 Issue 1, p15). Therefore, 3D digital output helps alleviate this problem, and this is especially true when the clients lack architectural knowledge or prior experience working with architects and the design process. Additionally, more explicit visual communication by the architect to the owner offers a higher quality service which leads an improvement in architect-client’s relationship. See case study I - III.

5. DESIGN TOOL: In some architectural design firms, computer 3D visualization technology is now being used as a design tool during the early design phases.
This 3D digital design process takes advantage of computer 3D visualization technology to improve design service quality in term of providing more design solutions and reducing design time. Traditional manual sketching techniques are still utilized, however, even in these cases, the use of 3D digital technologies offer an augmentative and supplemental tool to these traditional methods. See case study I-III.

6. PRESENTATION TOOL: In many architectural design firms, computer 3D visualization technology is being used widely as a presentation tool during the final design presentation stage. This type of presentation can be very photorealistic and conveys more accurate design information. See case study I-III.

7. DESIGNER VS. VISUALIZATION SPECIALIST: During the early phases of the architectural design process, a few emerging architects act as both designer and computer 3D visualization specialist. This is the ideal situation of integrating computer 3D visualization tool into design process to give a full interface between the digital tools and “design thinking” This approach is in direct contrast to the more prevalent scenario where the design is completed and then passed off to a visualization expert in a separate department. However, it requires the architect has both architectural professional knowledge and
computer 3D visualization skill and this is still rare in the profession at the current time. See case study I-III.

8. DIGITAL 3D DESIGN ENVIRONMENT: Due to the increasing complexity of modern architecture, and the concurrent rapid development of Computer-Aided Design technology (which includes computer 3D visualization technology), we now see more digital designing occurring in the early phases of the architectural design process in some architectural practices. See case study I and III.

CASE STUDY ANALYSIS

Extracted research evidence from the three case studies, will be presented based on each individual proof statement.

Case Study I: Envision Architects, PC

Doyle Middle School/Troy High School Additions

The Envision Architects is a mid-size architectural design firm. Mid-size, and small firms, comprise the majority of the architectural design business in North America. The evaluation of this type of firm regarding computer 3D visualization technology offers universal significance to the architectural profession. The author was an intern student worked for Envision during the summer 2001 and worked on the project which was selected to evaluate in this research paper. The selected project in this case study is the Doyle Middle School/Troy High School Additions. The initial
design phase used traditional paper techniques and computer 3D visualization tool was just used as a presentation tool. After disappointing feedback from the client at the initial design presentation, the second design concept and process used computer 3D visualization system as both a design tool, to assist design analysis and modification, and a presentation tool for the final design presentation.

1). DESIGN ALTERNATIVES:

During the second design cycle, computer 3D visualization technology was used in the schematic design and early design development stages by an intern architect who was also a design team member. A digital 3D building model was produced concurrently as the design concept developed. Following this, several proposals of color schemes and surface materials, building spaces, and building facades were studied quickly by manipulating the digital 3D model. Thus, computer 3D visualization technology showed increased capability for design concept comparison and modification than traditional manual techniques.

2). COMPRESSED DESIGN CYCLE:

The design time required for concept comparison and modification was reduced by using the digital 3D model. The digital design team members worked closely and they discussed and reviewed design ideas by directly using a digital 3D model. Design alternatives were tested very quickly. No manual paper drawing or computer printing
were required. The traditional paper drawing step for design proposal analysis was completely avoided.

3). VISUAL COMMUNICATION AMONG DESIGN TEAM MEMBERS:

Traditional 2D floor plans, elevations and sections were generated from the computer 3D model. This allowed the ENVISION’s architects to communicate with each other using 3D and 2D graphics simultaneously. The digital 3D format representation allowed ENVISION architects to communicate more intuitively and conveniently. Also, communication was more efficient and there was less risk of interpretative design mistakes.

4). ARCHITECT-CLIENT’S RELATIONSHIP:

During the later schematic design and early design development stages, ENVISION studied and tested a number of design proposals using a computer 3D model. The digital design proposals were reviewed with the client using images to gain the clients input interactively during the development of the design. The color perspective digital images offered a clear means of design interpretation by the clients. Resultantly, the clients very appreciated that they had an increased involvement in the design evolution for their project. The architect-client’s mutual trust was enhanced dramatically over the first “traditional” paper design process.
5). PRESENTATION TOOL:

Computer 3D visualization images were used to produce architectural perspectives for the first and second design presentations.

6). DESIGNER VS. COMPUTER VISUALIZATION SPECIALIST:

For Doyle Middle School/Troy High School Additions project, there were two persons in charge of the digital 3D model. In the first design phase effort, the computer team member was not utilized until design was complete. In this case, the computer specialist was not a design team member. He was used only as a computer 3D modeler for presentation purposes after the design was complete. In the second design effort, Jin (the Author) was in charge of the second design presentation. I was also a design team member involved the design process from the outset of conceptual thinking. As noted earlier, I am acknowledgeable architect with years of experience as a designer and architectural digital design and computer 3D visualization system. For this project, a software which I am very familiar with was utilized, 3D Studio Viz.

8). DIGITAL 3D DESIGN ENVIRONMENT:

After the first design presentation, a digital 3D building model based on the revised design proposal was set up quickly. The visual design development was conducted extensively in this digital 3D environment, for example, design alternatives comparison, design review and discussion.
### Table 6.02  Part 1: Case Study I - Design Representation Analysis

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Design Tool</th>
<th>Presentation Tool</th>
<th>Design Communication Method</th>
<th>Designer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;. Design Presentation</td>
<td></td>
<td>2D &amp; 3D Digital</td>
<td></td>
<td>Senior Architect</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;. Design Presentation</td>
<td></td>
<td>2D &amp; 3D Digital</td>
<td></td>
<td>Senior Architect &amp; Intern Architect (Jin)</td>
</tr>
</tbody>
</table>

### Table 6.02  Part 2: Case Study I - Design Representation Analysis

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Computer Modeler</th>
<th>Modeler’s Experience</th>
<th>3D CAD Software Used</th>
<th>Client’s Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;. Design Concept</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;. Design Presentation</td>
<td>Intern Architect</td>
<td>One Year</td>
<td>3D Studio VIZ R3</td>
<td>Low</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;. Design Concept</td>
<td>Intern Architect (Jin)</td>
<td>Six Years</td>
<td>3D Studio VIZ R3</td>
<td>High</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;. Design Presentation</td>
<td>Intern Architect (Jin)</td>
<td>Six Years</td>
<td>3D Studio VIZ R3</td>
<td>High</td>
</tr>
</tbody>
</table>
The representation samples related to different design phases could be found in Appendix A1 – Case Study I from Page 112 to 139.

Case Study II: Pryor & Morrow Architects

Furniture Research Institute Laboratory, MSU

This case study is chosen as a counter-evidence to support the research thesis. Pryor & Morrow is a traditional medium size architectural firm located in Columbus, Mississippi. They use very traditional design and representation methods and use digital 2D drafting for construction documents. The selected project was the Furniture Research Institute Laboratory for Mississippi State University. Based on the client’s need for fund raising activities Pryor & Morrow hired an “outsource” computer consultant to generate computer 3D model images after completion of the design development phase. However, the owner was not satisfied with the quality of the digital image output. Hence, a second computer 3D visualization consultant was engaged – the Digital Research & Imaging Lab (DRIL) at the MSU School of Architecture.

1). DESIGN ALTERNATIVES:

During the conceptual and schematic design phases, a few drafted design alternatives were produced by 2D manual sketches.
2). COMPRESSED DESIGN CYCLE:

The design process in early design phases was very traditional and standard. The traditional design cycle involved manual sketching, 2D computer drafting, paper printing drawings, manual revising, 2D drafting and printing again was the methodology.

3). VISUAL COMMUNICATION AMONG DESIGN TEAM MEMBERS:

Manual 2D sketching and drafting technique is the main visual communication tool used in early design process. A few of very rough manual 3D sketches was generated for design study.

4). ARCHITECT-CLIENT’S RELATIONSHIP:

The architect-client’s design communication was not as an optimum quality level due to improper design presentation methods involved in the early design process. Additional issues, beyond the scope of this research, included unstable administrative staffing based on key MSU staff leaving during critical phases of the project process beyond the control of the architect. As mentioned earlier, following design development, when the design was fixed and construction documents were nearing completion, the architect contacted the MSU Digital Research & Imaging Lab (DRIL), to seek help. Thereafter, a higher quality 3D model was generated which offered more reliable architectural perspectives. This allowed the owner to see the design much more
clearly and an opportunity to question some design decisions as well as meet their needs of fund raising.

5). DESIGN TOOL:

The traditional manual 2D sketching and drafting tools were used to execute design development throughout design process.

6). PRESENTATION TOOL:

Combining with manual 2D and computer 2D tools, computer 3D visualization tool was used for design presentation.

7). DESIGNER VS. COMPUTER VISUALIZATION SPECIALIST:

The user of computer 3D visualization personnel involved in this project stood as a perspective rendering specialist alone, not a design team member.

8). DIGITAL 3D DESIGN ENVIRONMENT:

Digital 3D design environment didn’t occur in this project. The design process was solely conducted in manual design environment.
### Table 6.03  Part 1: Case Study II - Design Representation Analysis

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Design Tool</th>
<th>Presentation Tool</th>
<th>Design Communication Method</th>
<th>Designer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Presentation</td>
<td></td>
<td>Digital</td>
<td></td>
<td>Intern Architect</td>
</tr>
<tr>
<td>2nd. Design Presentation</td>
<td></td>
<td>Digital</td>
<td></td>
<td>Computer 3D Consultant/Architect (DRIL)</td>
</tr>
</tbody>
</table>

### Table 6.03  Part 2: Case Study II - Design Representation Analysis

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Computer Modeler</th>
<th>Modeler’s Experience</th>
<th>3D CAD Software Used</th>
<th>Client’s Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Concept</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Presentation</td>
<td>Computer 3D Consultant/Architect (Tracy)</td>
<td>Three Years</td>
<td>Form.Z</td>
<td>Low</td>
</tr>
<tr>
<td>Design Development</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd. Design Presentation</td>
<td>Computer 3D Consultant/Architect (DRIL)</td>
<td>Three - Six Years</td>
<td>3D Studio Max</td>
<td>High</td>
</tr>
</tbody>
</table>
From this case study, a critical factor regarding technology has three folds:

1) Hardware - DRIL had high end dual processing machines with high end graphic cards.

2) Software - DRIL had higher end software with much higher rendering capability.

3) Brainware (Skillful Personnel) - DRIL had some skillful and experienced professionals with well understanding both architecture and computer 3D visualization technology.

The representation samples related to different design phases could be found in Appendix A2 – Case Study II from Page 140 to 157.

Case Study III: Digital Research & Imaging Lab (DRIL), MSU

Nissan Technology Research Center, Mississippi

This case study provides a primary source of computer 3D visualization technology as a premier design tool in early phases of the architectural design process. This project was the result of the President of MSU, Dr. Malcom Potera engaging the MSU School of Architecture to assist him and the Mississippi Development Authority (MDA) with a conceptual design presentation for the Nissan Corporation. The proposed facility was the Nissan Technology Research Center to be located in Canton, MS. According to this specific situation, the design representation method and technique used in this project were quite different with normal architectural design studio, which contains a few manual sketches and digital 3D modeling/animation. The DRIL Director,
Dr. Larry R. Barrow, AIA, setup a collaborative digital design team at the project outset.

1). DESIGN ALTERNATIVES:

Along with the initial design concept generated by Dr. Larry Barrow with a few manual sketches which was based on client’s very rough idea, the computer 3D building modeling environment was set up. After that, the design alternatives were tested and studied very quickly within the digital 3D modeling environment.

2). COMPRESSED DESIGN CYCLE:

During the early design stages, design concept development was conducted mainly in digital 3D environment. No paper drawing and printing were produced. The design review and discussion between design team members was just executed by direct viewing digital 3D building model and verbal communication.

3). VISUAL COMMUNICATION AMONG DESIGN TEAM MEMBERS:

The very schematic design “idea” was generated using a few manual sketches. Thereafter, the visual communication tool was the computer monitor and a collaborative team digital web site.
4). ARCHITECT-CLIENT’S RELATIONSHIP:

The weekly design result and development status were presented to the client by using the internet project web site. This type of communication allowed the client seamless tracking of the design process. This frequent architect-client communication ensured the design was in agreement with the early design decisions.

5). DESIGN TOOL:

A computer 3D visualization technique was used extensively as a design tool to assist design development during the design process. The computer 3D visualization systems used in this project were Form.Z and 3D Studio Max software applications and the project website.

6). PRESENTATION TOOL:

The final design presentation was a by-product of the Computer 3D modeling images which were generated as an integral component of the design process. For the final output, computer 3D visualizations were generated to present the final design presentation perspectives via a fly-over and fly-through animation. A multi-media final presentation was generated in the DRIL’s video suite using Media 100.

7). DESIGNER VS. COMPUTER VISUALIZATION SPECIALIST:

Among three design team members who are in charge of producing computer 3D modeling environment, two of them are architectural professional background with
skillful computer 3D visualization knowledge. The other team member, who was in charge of the site model, was a media specialist with skillful digital 3D visualization knowledge as well. This collaborative team of knowledgeable digital design members allowed the digital 3D design process to proceed smoothly and successfully.

8). DIGITAL 3D DESIGN ENVIRONMENT:

The design process was mainly executed in digital 3D environment after initial design concepts generated by a few manual sketches.

Table 6.04 Part 1: Case Study III - Design Representation Analysis

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Design Tool</th>
<th>Presentation Tool</th>
<th>Design Communication Method</th>
<th>Designer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3D Digital</td>
<td>3D Digital</td>
<td></td>
</tr>
<tr>
<td>Design Presentation</td>
<td>3D Digital</td>
<td>3D Digital</td>
<td>3D Digital</td>
<td>Dr. Larry Barrow</td>
</tr>
</tbody>
</table>
Table 6.04 Part 2: Case Study III - Design Representation Analysis

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Computer Modeler</th>
<th>Modeler’s Experience</th>
<th>3D CAD Software Used</th>
<th>Client’s Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Concept</td>
<td>Peter Graves</td>
<td>Five Years</td>
<td>Form.Z</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Joe Hagerman</td>
<td>Five Years</td>
<td>Form.Z</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jianying Jin</td>
<td>Six Years</td>
<td>3D Studio Max</td>
<td></td>
</tr>
<tr>
<td>Design Presentation</td>
<td>Peter Graves</td>
<td>Five Years</td>
<td>Form.Z</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Joe Hagerman</td>
<td>Five Years</td>
<td>Form.Z</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jianying Jin</td>
<td>Six Years</td>
<td>3D Studio Max</td>
<td></td>
</tr>
</tbody>
</table>

GENERAL FINDINGS

Table 6.05 Proof Statements – Case Study Correlation

<table>
<thead>
<tr>
<th>PROOF STATEMENTS</th>
<th>CS I</th>
<th>CS II</th>
<th>CS III</th>
</tr>
</thead>
<tbody>
<tr>
<td>1). Design Alternatives</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2). Compressed Design Cycle</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3). Visual Communication</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4). Architect-Client’s Relationship</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5). Design Tool</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6). Presentation Tool</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7). Designer VS. Computer Visualization Specialist</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8). Digital 3D Design Environment</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Three case studies are analyzed in using computer 3D visualization technology in early design phases. The benefits of using computer 3D visualization technology in early design phases are as following:
1. **Productivity:** Comparing with traditional more manual 2D and 3D design environment, using more digital 3D design environment to solve visual design problems in early phases of design process can reduce some traditional interim paper-base representation steps. As a result, the design cycle (time) for early design phases is reduced. See case study I & III.

2. **Design quality:** Using computer 3D visualization technology in schematic design and early design development stages increased the opportunities in exploring more design alternatives in solving visual design problems within limited design time frame. In digital 3D design environment, design alternatives are tested and studied very easily and quickly after the initial set of design model is built up. Within the limit design time frame, more design solutions are studied, the more chances to gain better design quality. See case study I.

3. **Architect-client’s relationship:** More design solutions can be presented to the client very quickly and conveniently by using computer 3D design environment. The client will feel not being excluded outside the design process. The architect-client’s relationship gets closed. This will result in the architects gaining more market share (or at least not lose current market share) in the future. See case study I & III.
4. Communication efficiency: In computer 3D design environment, the communication among design team and among designers-clients is more intuitive and time efficient. More virtual 3D imagery format communication requires less representation interpretation steps and ensures less risk of misinterpreting design ideas. See case study I & III.

5. Design collaboration: In computer 3D design environment, design works could be smoothly divided and assigned to team members who may use their own specific digital tool to work. Collaboration efficiency can be achieved easily. See Case study III.

Beyond the above benefits, some other general findings are presented here:

1. Production cost: Using computer 3D visualization technique in architectural design process requires personnel skillful. If architectural firms do not have such personnel in house, hiring either temporary staff with such skill or individual special consultant is required. As a result, the production cost may rise. See case study I & III.

2. Architect with computer 3D visualization skill: Design task and creating computer 3D design environment is integrated one part. The ideal situation for using computer 3D visualization technology in early design phases is designers with manipulating computer 3D visualization system skill. Assigning design
task and 3D visualization task to separated persons will take high risk of misusing computer 3D visualization technique and may create some communication problems during the design process. See case study I & III.

3. Current computer 3D visualization system: The more powerful and functional current computer 3D visualization systems used in architectural design process have one common feature: they require considerable time and effort to master them before they can be used productively. This is a result from their complex functional command chain and very non-intuitive interface. This has really harmed architectural practitioner’s enthusiasm in integrating computer 3D visualization technology into their design process. Currently, the lack of appropriate architecture-related computer 3D visualization systems continues to frustrate many architectural practitioners. See case study I & II.

4. Key architectural profession generation: current principles and senior architectural professionals are not educated in digital technologies, and most only know the traditional manual design methods. The lack of general knowledge of computer 3D visualization technology causes some of them to make erroneous decisions regarding staff, equipment and HW/SW; or in some cases, ignoring 3D digital modeling technology as a strategic tool in their design process and practice. See case study I & II.
SUMMARY

The impact of computer 3D visualization technology in early phases of the architectural design process is reviewed throughout the three case studies. From the Findings and Analysis, we find that Computer 3D Visualization Technology is impacting our architectural profession activities in terms of design procedure and mode of design environment as well as improving design service quality.

This research indicates architectural design professionals are increasingly using digital technology in the early design phases. This is a result of the complexity of modern architecture and the rapid development of computer 3D visualization technology. This trend is expected to continue in the future.

In addition, we should pay more attention to “technology”. Just like Zeleny and Dr. Larry R. Barrow said in his Harvard Doctorate Dissertation in 2000: technology is the combination of Hardware, Software, and Brainware (people with the knowledge of hardware and software). If anyone of them is missing or lacking in capability, technology will be frustrating and less than satisfactory. Furthermore, within these three factors, brainware is more crucial than HW/SW. The three case studies all show the offer evidence which confirm in these points.
CHAPTER VII

CONCLUSION

Computer 3D visualization technology is impacting the early phases of the architectural design process, resulting in changing the nature of early phases of the architectural design process from a traditional manual “static” 2D and 3D design environment to a digital “dynamic” 3D design environment. This results in improved design output, in both quality and quantity, and hence greater client satisfaction and professional service.

In recent years, architectural design process in early phases is being more impacted by computer 3D visualization technology. Easy editing, capabilities of easy handling accuracy of building elements like lighting condition, surface material and relationship of building elements in 3D space make computer 3D visualization technology a powerful design tool in early design process. In later schematic design and early design development phases, more visual design elements and factors are involved into architectural design consideration. The relationship of these visual design elements becomes more complex which requires more architectural knowledge and years of architectural practical experience to handle. Using computer 3D visualization technique
can take advantages of its virtual visual features in solving these problems easily in this design period.

As an ideal condition, using computer 3D visualization technology as design aided tool in early phases of architectural design process requires the users should have both architectural professional knowledge and computer 3D visualization technical skills. Lack of either one will lower the power of such tool or even misusing it to create more problems.

Some benefits of using computer 3D visualization technique as design assist in early design stages are revealed in this paper:

1). The designers can present, review and communicate their design ideas in digital 3D space clearly. It lowered the risk of making design mistakes, comparing with traditional manual method;

2). Some traditional mid-steps of manual and paper works are eliminated. It shortened the design turnover and design production cost is reduced.

3). The clients have more opportunities to review design proposal and communicate with designers with clear understanding of designer’s ideas. It satisfied the clients in higher level.

In the other hand, although computer 3D visualization technology as a design aid showed some powers in architectural design process and these powers may grow in the future, the research indicated that the combination of traditional manual design techniques and computer 3D design technique is still the preferable choice for architectural practitioners used in early design process in recent years. The balance of
this combination really depends on how well the design firm understands computer 3D visualization technique applied on architectural design and how good they manipulate this tool. Traditional manual sketching technique is still a useful tool in generating initial design ideas because of its intuitive, comfortable and convenient features for most of current architectural professional generation. The current computer 3D visualization technique is not very mature at this point.

Some further research areas are indicated as following:

1. How to improve architectural professional capability with handling emerging CAD technology. Current experienced architectural profession generation is in lack of computer-literacy educational background and on-site computer skill training. As their basic architectural education training is based on manual mode, most of they seriously believe that computer mechanism would not fit into design process. This opinion seriously impeded integration of Computer-Aided Design technology into architectural design process.

2. How to improve computer 3D visualization technology in understanding architectural profession. The lack of appreciated architectural 3D visualization system is another reason why many architectural practitioners ignoring this technique.

3. How to improve the intuitive and convenient features of computer 3D visualization programs. Due to its hard learning-curve, not-intuitive human-computer interface of current computer 3D visualization systems,
many architectural practitioners complain the usability of such technology used in architectural design process.

4. Virtual Reality is being research in many academic institutes. How to improve this technology and find a suitable position as a design aided tool in early architectural design process is needed.

As a result of this research, computer 3D visualization technology is being a serious design aided tool in early architectural design process to show its great value. The nature of computer 3D visualization technology closely matches to the requirement of being a design tool in early process of architectural design. With using this technique, architectural professionals could much easier to improve their professional service quality than ever before and remain their market share value stable as well. In the meanwhile, the rapid development of computer technology gradually empowers computer 3D visualization system being a design aided tool in more respects and in a deep degree. Computer 3D visualization technology is definitely impacting architectural profession in certain respects and it will continue to impact and change our architectural professional life.
The following selection of book titles, journals, and reviews lists the various sources of information that this thesis directly and indirectly draws from and utilized for reference.


5. CAD spaghetti, January 2002 issue, “3D AEC Intelligence Quest”


33. Scott Johnson, “What’s in a Representation, Why Do We Care, and What Does It Mean? Examining the Evidence from Psychology”. ACADIA 1997, Page 05-15


APPENDIX – A1

CASE STUDY I - TROY HIGH SCHOOL/DOYLE MIDDLE SCHOOL ADDITIONS, ENVISION ARCHITECTS, PC, ALBANY, NY
Firm Overview:

Founded in 1983, by Mr. Ted W. Mallin in Albany, New York, a few years later, Mr. Benjamin Mendel Jr. joined the firm as Managing Principle to enhance marketing force, ENVISION ARCHITECTS is a highly skilled, creative and versatile architectural firm. The number of staff grows stably from the beginning of 9 persons to recent 45 (December, 2001). The firm provides a full range of architectural service from design to construction management. Ms. Sandra Baptie joined the firm in 1994 who graduated from an architectural professional master program in Harvard Design School as enhancement of design capability. In 2000, as Mr. Benjamin Mendel Jr. decided to retired in soon later, Mr. Michael Poost, a registered architect who has fifteen years architectural practicing experience, was invited to join the firm in later 2000. Now, under the leadership of principals Ted W. Mallin, Sandra Baptie and Michael Poost, ENVISION ARCHITECTS practices in a style which places their client's needs at the forefront of the endeavors, recognizing that their goal to improve and expand upon their
regional reputation for excellence can only be met through the continual satisfaction of those whom they serve.

**Scope of services and major type of project:**

ENVISION ARCHITECTS provides services in the following areas: architectural design, master planning, historic preservation, strategic facilities planning, and building renovations. The major types of project highly involved in the firm are educational and religious buildings.

**Professional resources:**

ENVISION is a firm of approximately forty-five staff, including sixteen registered architects. The firm also offers in-house construction management services with dedicated CM staffs. They serve a clientele comprised largely of institutions from the healthcare and education sectors, churches and community organizations. Their award-winning design skill is fostered in an atmosphere of collaboration, thoroughness and the pursuit of appropriate creativity in formulating their response to the client’s challenges.

Unique to ENVISION is the distinguished role of Design Counsel held by Benjamin Mendel Jr., Noushin Ehsan and Lawrence Linder. These colleagues serve the firm as design leaders at a principal level of responsibility and authority for specialized consultation on specific projects.
Business Strategies:

ENVISION is committed to a practice that is centered upon the direct and active leadership of the firm's principals in all aspects of the work. They believe that this approach assures their clients that they are at all times receiving the highest and best level of talent and experience which they are capable of offering, and that the resources of the firm are at their dispose to meet the ongoing challenges of the project.

At ENVISION they operate in collaborative teams where everyone is cross-trained to support team needs as they range from planning to construction administration, and small projects to large. Each architectural staff is skilled in a variety of computer applications (not includes computer 3D visualization systems), the tools by which nearly all of their work is accomplished (See Table A1.01).

<table>
<thead>
<tr>
<th>CAD Applications In Office</th>
<th>AutoCAD 2000</th>
<th>Power Point</th>
<th>Adobe Photoshop</th>
<th>Adobe Indesign</th>
<th>Adobe Illustrator</th>
<th>Form.Z</th>
<th>Sketch Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of architectural stuffs using</td>
<td>100%</td>
<td>100%</td>
<td>50%</td>
<td>40%</td>
<td>20%</td>
<td>None</td>
<td>One Stuff</td>
</tr>
</tbody>
</table>

Note: Total number of architectural stuffs in Albany Office is 16

Collaboration assures an open and balanced perspective, which values the input of all members of the project planning process. Thoroughness in the acquisition and documentation of data and design detail assures completeness in their work, so that all of the client’s requirements are understood and incorporated in their planning, and
documented comprehensively so that they can effectively be accomplished in the construction process. Appropriate creativity assures that they will endeavor to distinguish each client’s project in an appropriate manner, which serves their client’s mission, program, site and budget.

**CAD history:**

ENVISION started to invest in CAD (Computer-Aided Design) in 1995, when the company grew very quickly. In order to improve the design productivity and gain competitive advantage, ENVISION began to use computer to produce construction drawings at that time. The Computer drafting system used at that time is AutoCAD R13. From then, the majority of construction drawings were produced by computer rather than manual. Now Computer-Aided Drafting tool has totally replaced manual tool in later design process for drawing production.

Digital scanners and digital cameras are used widely during design process due to their convenient advantages. Several computer visualization and presentation programs have been used throughout design process, such as AutoCAD, Adobe Photoshop, Premier, InDesign, Illustrator and PowerPoint etc.

**The Problem**

Using computer 3D visualization system as a design and presentation tool started from recent three years. The firm’s principles recognized the capabilities and advantages of computer as a design assistant; they decided to invest this technology.
The first computer 3D visualization system ENVISION used is Form.Z, and later the 3D Studio VIZ (After May 2001). However, the lack of personnel with both computer 3D modeling skill and architectural knowledge impeded the company in using such technology in design process at that time. Mr. Ted said: “we try to invite some appropriate manpower to join our team in order to take advantage of this technique, but the result always made us disappointed.” The main reason is that the person they hired didn’t have enough knowledge and skill in both architectural design and computer 3D visualization technique. The personnel they hired usually is knowledgeable in either architecture or computer 3D visualization only. As a result, ENVISION still don’t have a full-time personnel to take care of this duty. “If we need this kind of specialist, we will look for help outside the firm temporarily. Sometime we really struggled in between of using this technique or not.” Mr. Ted said.

In order to increase the efficiency of architect’s creative design activities in initial design process, ENVISION is looking for some easy-used, convenient 3D sketching systems recently. When Mr. Mike Miller, one of firm’s associates, played with SKETCHUP which is a very new developed computer 3D sketching system, he was very exciting about its functionalities based on its simple interface and easy learning features. Continually looking for appropriate computer sketching tools and encourage their staffs to improve computer 3D visualization skill is the next step for ENVISION in the near future.
**Troy High School/Doyle Middle School (THS/DMS) Additions**

In this case study, we will review the process of Troy High School/Doyle Middle School Additions (THS/DMS Additions in following content) design and discuss using computer 3D visualization system as a design assistant in concept design to early design development stages, such as when computer 3D visualization systems had been used in the design process, why to use it, how to use it, and who used it.

**Project background:**

In May of 2000, the public overwhelmingly passed a referendum to improve Troy city schools. Each school building in the District will receive substantial capital investment to make much needed improvements related to life safety, accessibility, energy use and deferred maintenance.

The Troy High School/Doyle Middle School (THS/DMS) also benefited from these academic program enhancements where several new facilities are being constructed. The Doyle Music Department is being reconstructed and expanded and, at the High School work will include a new Library and Media Center, a reconstructed and expanded Math and Science Department, a reconstructed and expanded Guidance Department, a new adaptive physical education Gym and several new classrooms. Figure A1.01 is a rear view of existing THS/DMS. Beige color building is THS and brown color building is DMS.
A few crucial factors architects encountered during the design process:

1. As the project is a few additions of two existing school buildings, the relationship of the additions and the existing buildings is a key design issue under architects’ design concept development. What kind of representation technique to be used to discover the relationship will seriously influence the design output.

2. This project involved a few large interior spaces like new Troy High School lobby, new library, extension of science project hall for which the clients required the architect to present them in some convenient manner other than traditional two-dimensional plans, elevations, and sections in order for them better visualizing and easier making further decisions. How to achieve the client’s expects is the next challenge for ENVISION.
3. Following No. 2, for architect himself, how to resolve interior space design problems in which lighting conditions, material selections, and color patterns schemes are heavily involved is another challenge.

4. As this project is a public project, and the client’s representatives are school board members and superintendents, which are a group of public people with diverse backgrounds. The key issue here is that almost every representative is seriously in lack of general architectural knowledge. How to communicate with them effectively and efficiently in order that they could better understand design concept and make a right decision based on their understanding was challenging the architects throughout the design process especially in initial design process.

**Process of design development:**

The principal architect for THS/DMS Additions is Mr. Ted Mallin, the managing principal of ENVISION. He controlled the overall design process, included general design concept and project time schedule. The actual design activities were conducted by a few Envision’s architects based on Mr. Ted’s oral comments.

The process of THS/DMS Additions from design concept to design development phase actually consisted of two periods: first design development period and second design development period. The first design presentation was held on November 29, 2000. The second design presentation was held on July 24, 2001.
In the first period, from May 2000 to November 2000, design activities conducted with traditional design methods. It means that designers generated the initial design ideas with manual tools, like pen, pencil and paper. The design ideas were expressed as manually two-dimensional sketches. When initial design ideas were worked out, these design data were imported into computer as a 2D digital format. Then the architects used both 2D manual sketches and computer printed 2D drawings to communicate with each other, or themselves (See Table A1.02). The design study and development was based on these representation formats as well. These design steps iterated until first design presentation. Before first design presentation, a part-time staff was hired to produce computer 3D model and generate architectural perspectives for design presentation purpose only. A massing physical model is a part of final presentation package as well.

Table A1.02-Part I  Case Study I - Design Representation Analysis

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Design Tool</th>
<th>Presentation Tool</th>
<th>Design Communication Method</th>
<th>Designer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st. Design Presentation</td>
<td>2D &amp; 3D Digital</td>
<td></td>
<td></td>
<td>Senior Architect</td>
</tr>
<tr>
<td>2nd. Design Presentation</td>
<td>2D &amp; 3D Digital</td>
<td></td>
<td></td>
<td>Senior Architect &amp; Intern Architect (Jin)</td>
</tr>
</tbody>
</table>
Table A1.02-Part II  Case Study I - Design Representation Analysis

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Computer Modeler</th>
<th>Modeler’s Experience</th>
<th>3D CAD Software Used</th>
<th>Client’s Satisfaction</th>
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</thead>
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<tr>
<td>1st. Design Concept</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st. Design Presentation</td>
<td>Intern Architect</td>
<td>One Year</td>
<td>3D Studio VIZ R3</td>
<td>Low</td>
</tr>
<tr>
<td>2nd. Design Concept</td>
<td>Intern Architect (Jin)</td>
<td>Six Years</td>
<td>3D Studio VIZ R3</td>
<td>High</td>
</tr>
<tr>
<td>2nd. Design Presentation</td>
<td>Intern Architect (Jin)</td>
<td>Six Years</td>
<td>3D Studio VIZ R3</td>
<td>High</td>
</tr>
</tbody>
</table>

As THS/DMS additions consist of a few large interior spaces like new library, science project hall, creating a “bright, warm, and friendly study environment with full of natural light” is a core task in the design process and choosing interior finishes material and color scheme is the main step to achieve the design goal, Mr. Ted Mallin mentioned. The method of choosing interior finishes material and color scheme in this project is very traditional during first round design development. The several material samples and color samples which the architects supposed to use was placed in front of them, they compared them with different combinations and then chose the best result based on their years experiences. The first design presentation drawing package contained basic computer 2D drawings (floor plans, elevations and sections) and several computer 3D generated perspectives. The following images (Figure A1.02 to A1.12) are several samples presented in the first design presentation.
Figure A1.02  Site Plan
Source: Envision Architects, PC

Figure A1.03  Computer 3D model of THS
Source: Envision Architects, PC

Figure A1.04  A Proposed First Floor Plan of THS
Source: Envision Architects, PC

Figure A1.05  A Proposed Entry Façade of THS
Source: Envision Architects, PC
Figure A1.06  A Proposed External View of Library, THS
Source: Envision Architects, PC

Figure A1.07  A Interior View of New Lobby, THS
Source: Envision Architects, PC

Figure A1.08  A Interior View of Library Entry
Source: Envision Architects, PC

Figure A1.09  A Proposed Elevation, THS
Source: Envision Architects, PC
The feedback from the clients was not satisfied after first design presentation. This resulted from both of the design proposal and the quality of design presentation. The main complain from the clients is that the visual presentation didn’t reflect the design concepts which the architect orally explained. Therefore, the clients considered
this result may come from two aspects. One is design itself didn’t reach the level as the architects explained to them (Design problem). Another is the design presentation didn’t reach the level design should have (Presentation problem).

How to clarify this situation with their clients is really challenging ENVISION at that time.

At beginning of second round design development, after Mr. Ted Mallin and the design team analyzed and summarized the reasons why first design presentation was not satisfied by their clients, they decided to enhance their design strength and presentation capability by using more three-dimensional representation format. After making such decision, they started to compare both manual method and digital method in generating 3D representation based on existing in-house capability, production cost, production time, and strength of each method. Finally they chose digital tools. The major digital programs included 3D Studio VIZ 3i, Adobe Premier and AutoCAD 2000. At the time being, the existing in-house professional resources couldn’t provide such a specific technical skill, therefore, they decided to hire a specialist temporarily for that time period. Due to this situation, Jianying Jin (the author) joined the firm as a computer 3D visualization specialist and designer. Jin was a graduate student in an architectural digital design program. Before entered the program, he was an architect with ten over years working experience. He also had computer 3D visualization knowledge and skill with several years’ practical experience. This time period was under his summer intern program.
When Mr. Ted talked about the role of the computer 3D visualization specialist, he said, “We don’t simply hire a computer 3D visualization specialist who doesn’t have architectural knowledge, it against our initial principle of combining design and presentation within one role. We try to find out every possibility and potential of this role in order for us drawing lessons from it.” One day, after Jin joined the firm, during the conversation between Mr. Ted and him, Mr. Ted said: “We’re quite frustrated by the lack of appropriate representation tools for visual representation in initial design development stages and client-architect’s communication. However these two matters are definitely the essential part of our design process. Like in the last time presentation, actually, I have a very ambitious design idea for this project. But I found it was very hard represent it clearly and effectively because we just used verbal, writing, and traditional two-dimensional drawings and some improper visual images. Our clients were hard to get an understandable picture of our design concept too.” Due to the above reasons, once Mr. Jin joined the team, he also participated into the design process as a design team member rather than a perspective illustrator only. Because he was also an architect with years architectural design practicing experiences.
Computer 3D visualization tools were used extensively during the design concept study and design development after first design presentation. Based on the existing design information (from initial to first design presentation), a computer 3D building model with surrounding condition was quickly built up (See figure A1.13). This computer 3D model was used as a digital 3D design environment extensively during second round design development. Mr. Jin worked closely with other design team members in order to avoid unnecessary design representation steps during the design study. When design development had a major and minor modification considered by chief designer, sometimes a few manual sketches were generated quickly and passed to Jin, or sometimes the chief designer just came to Jin’s place and sit down with him, let him make a modification in digital 3D modeling environment and
reviewed the result immediately. Most of minor design studies were executed in this digital design space without manual sketches generate.

A number of perspective sketches both rough and detailed were generated by using computer 3D visualization system for different design schemes’ comparison and discussion, color scheme study, and building finishes material selections. “We are very excited that this tool can assist us studying design alternatives so quickly. It gives us more opportunities to improve our design output and saved us more time.” said Mr. Ted, when he reviewed the process of using this technology. Figure A1.14, A1.15, A1.16, and A1.17 are some samples of design options for Music Department addition during the design study. Figure A1.18 and A1.19 are the comparison of color schemes for Additional gym.
Due to the very tight time schedule, when interior design had started to be considered, Jin worked with interior designer Ms. Paulina Calderon together, in same place, in same time. According to Chief architect, Mr. Ted’s design concepts, Paulina
generated a set of 2D manual sketches which contained core design ideas only. Because at the time being, the 3D building model had been produced. The digital 3D interior space perspectives which mainly considered lighting conditions, surface material pattern and color were generated quickly based on the sketches and discussion among Jin, Paulina, and Ted. The works for producing interior model were just manipulating different assigned materials, lighting conditions and camera view angles. Design ideas and alternatives were tested and studied very quickly by viewing digital 3D sketches. Figure A1.20 is the proposed new library floor layout. Figure A1.21, A1.22, A1.23 and A1.24 are the comparison samples of library proposals with and without furniture.

Figure A1.20   Proposed New Library Floor Plan
Source: Envision Architects, PC
As another function of computer 3D model, the draft and detailed computer generated perspectives also dramatically extended the designers’ temporary working memory which is a crucial knowledge resource to influence design output. So, with the result, the architects now were very confident with their design output.
The second design presentation was strongly enhanced by using computer 3D visualization system. In addition to traditional presentation contents, a series of computer generated perspectives shown the design alternatives and different views of design spaces were provided in the presentation package. Those perspective drawings were very costly, time consumed, and almost impossible to achieve within the design time frame if using traditional manual methods. A one-minute fly-over animation was also provided for the clients better understanding the overall design concept. A hand built physical massing model had been included into final presentation package as well. The following images are some sample perspectives shown in the second design presentation on July 24, 2001.

Figure A1.25  Proposed New Lobby, THS
Source: Envision Architects, PC; 3D Model by Jianying Jin

Figure A1.26  Proposed New Lobby, THS
Source: Envision Architects, PC; 3D Model by Jianying Jin
Figure A1.27  Proposed New Science Hall, THS
Source: Envision Architects, PC; 3D Model by Jianying Jin

Figure A1.28  Proposed New Science Hall, THS
Source: Envision Architects, PC; 3D Model by Jianying Jin

Figure A1.29  Proposed New Entrance, THS.
Brick Color Scheme.
Source: Envision Architects, PC; 3D Model by Jianying Jin

Figure A1.30  Proposed New Entrance, THS.
Blue Color Scheme.
Source: Envision Architects, PC; 3D Model by Jianying Jin
During the second architect-client design presentation conference, unlike the last presentation, the clients only asked some building code related questions after Mr. Ted presenting the design proposal. The clients very appreciated that ENVISION’s architects could present the design in such a more realistic manner than before and also provide them more design alternatives for their choosing. “I felt the presentation was very informative and I very appreciated what was being presented here by ENVISION.” Mr. Clem Zotto, the School Board President, explained after design presentation.

**Role of computer 3D visualization system in the design process:**

1). Design visualizing tool: In Schematic design and design development stages, computer 3D visualization system was used as communication and evaluation tool for designers themselves.
2). Intermediate design presentation tool: Both draft and detailed design perspectives had presented to clients for seeking their comments and suggestions frequently during the design process.

3). Final design presentation tool: A dozen of computer-generated perspectives and a one-minute fly-over animation had been provided in final design presentation package. This is impossible to achieve if using traditional manual methods in the very tight time schedule.

**Reason of using computer 3D visualization system:**

Design needs: During late schematic design phase and early design development phase, in order to review the design ideas outside designer’s mind clearly, the architects started to look for computer 3D visualization tool as a design aid other than traditional manual tools. This is due to lack of appropriate power of those traditional tools in interaction between designer and representative media during this design period. Time input and accurate presenting output are the main concerns of the architects in this stage.

Client’s expectation: as the clients are a group of people drawn from diverse background and the majority of them are in the lack of basic architectural knowledge, therefore, they very appreciated that the architect could present the design result in a general knowledge basis other than very traditional architectural professional style. That means architects should consider some wide-acceptable general visual format in their
presentation rather than simply writing description, verbal explanation, and two-dimensional line-based drawings (like plans, elevations, and sections).

Process of using computer 3D visualization system:

In first design proposal cycle, computer 3D visualization tool was used as presentation tool in final design presentation during the first architect-client conference. The tool didn’t involve in design concept development process.

In second proposal cycle, computer 3D visualization tool was used from beginning of design revision to final design presentation. During in-house design, it was used for reviewing design ideas for designers themselves, for communication between junior designers and principals, for seeking suggestions from the clients. In the final design presentation, it was used for producing detailed realistic perspectives and interactive animation for client’s better understanding design concept and convincing them to accept designer’s ideas as much as possible.

SUMMARY:

By test using computer 3D visualization technology as a design aid in early phases of architectural design process, ENVISION tasted some fruit of it. Using computer 3D visualization tool solved many critical visual design problems in this project which are difficult to handle in traditional design environment. It secured their market share in the future. However, due to both not very convenient current computer
3D visualization system used in architectural design and the lack of computer 3D skillful architectural personnel, ENVISION will have to continue struggling.

**Case Study Discussion Questions**

1. How does computer 3D visualization tool be used as a design tool but not a presentation tool only?

2. Does computer 3D visualization tool used as a design tool improve the design quality?

3. How does computer 3D visualization tool impact early architectural design process? In what degree and with what result?

4. What is the relationship the computer 3D visualization user with other design team member? And how does this relationship affect design output?
<table>
<thead>
<tr>
<th>Envision Architects</th>
<th>Case Study I – Summation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Keywords:</strong></td>
<td>Early design phases; Computer 3D visualization technology; Design tool; Presentation tool;</td>
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<td><strong>Protagonist:</strong></td>
<td>Ted Mallin</td>
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<tr>
<td><strong>Objectives:</strong></td>
<td>Impact of computer 3D visualization technology as a design tool in early phases of architectural design process</td>
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<tr>
<td><strong>Decisions:</strong></td>
<td>Why use computer 3D visualization technology in early phases of architectural design process, how to use it and who uses it</td>
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<td><strong>Time Period:</strong></td>
<td>2000 - 2001</td>
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<tr>
<td><strong>Revision</strong></td>
<td>Summary: Mid-size local firm in urban area.</td>
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<td></td>
<td>Projects Reviewed: Troy High School/Doyle Middle School, Troy, NY</td>
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</tbody>
</table>
| **Main Issues:**    | 1). Firm size and location;  
|                     | 2). Early phases of architectural design process  
|                     | 3). Design tool;  
|                     | 4). Presentation tool;  
|                     | 5). Architect vs. visualization specialist;  
|                     | 6). Architect-client’s relationship;  
|                     | 7). Type of communication among design team;  
|                     | 8). 2D representation;  
|                     | 9). 3D representation; |
| **Innovations:**    | 1). Use computer 3D visualization technology as presentation tool in design presentation;  
|                     | 2). Use computer visualization technology as a design tool during schematic early design development stage; |

Figure A1.33  Case Study I - Summation
APPENDIX A2

CASE STUDY II - FURNITURE RESEARCH INSTITUTE
LABORATORY, MSU, PRYOR & MORROW
ARCHITECTS, COLUMBUS, MS
FIRM OVERVIEW:

Established in 1985, Pryor & Morrow Architects is a growing architecture and engineering firm located on the prairie between Columbus and Starkville. Their practice is as diverse as their clientele - their work includes schools, commercial developments, hospitals, detention centers, churches, and many other building types. The design service covers the northern half of Mississippi and west central Alabama. Pryor & Morrow has projects in Jackson, Carthage, Tunica, Oxford, Tupelo, Iuka, Fulton, Amory, Philadelphia, Tuscaloosa, and many places in between.

Design excellence has been the trademark of Pryor & Morrow Architects since the firm's inception in 1985. Some of their most successful work includes a series of continuing projects for Old Waverly Golf Club. Each project - including the clubhouse, the pro shop, the pool and tennis complex, townhouses, a series of villas, and Scotland Yard Condominiums - works with the other projects to create a cohesive sense of community. The Mississippi Chapter of the American Institute of Architects recognized
Pryor & Morrow's success with an honor award for Old Waverly. This accomplishment was enhanced by Old Waverly's selection as the site of the 1999 U.S. Women’s Open.

Both of the firm partners grew up in construction families, a fact that is partly responsible for their unique relationship with the construction industry. Pryor & Morrow attempts to work with and to learn from contractors, vendors, and manufacturers as much as possible. The firm’s "hands on" approach to design leads to a higher quality product and, quite often, significant cost savings.

Pryor & Morrow’s in-house engineering staff is an important component of the practice. On many of the smaller projects, the firm does both mechanical and electrical engineering in-house. And, when a project requires consulting engineers, they have personnel on staff who understands the consultants' needs.

In Pryor & Morrow, the design methods in early design phases are very traditional. The manual 2D sketches and printed drawings are the main communication format among design team and between designer & client. Sometimes, a few manual 3D sketches are produced as a design study and for architect-client communication. Computer 3D visualization tool is never used for design purpose in the past. As the project architect Ms. Sherry Berry mentioned, only two projects used computer 3D visualization system to generate perspective drawings for presentation purpose in the past in Pryor & Morrow. The reasons of that came from two aspects: first, almost no project clients requested to produce high quality architectural perspective. Second, the architects didn’t realize this requirement due to the lack of such skill in house as well as cost constraints.
Until now, AutoCAD 2002 is the only CAD system in Pryor & Morrow. It is used as computer 2D drafting tool only. Recently, Pryor & Morrow starts to recognize that AutoCAD 2002 has pretty good 3D modeling function when some design staffs browsing the system manual and trying it, as Sherry Berry described. Usually, if design requires to produce computer 3D models, the individual computer 3D visualization consultant will be invited to handle the task; but 3D visualization has rarely been utilized.

**Furniture Research Institute Laboratory, Mississippi State University**

**Project Brief:**

The Furniture Research Institute Laboratory is a 35,500 square foot furniture research facility proposed by School of Forestry, Mississippi State University. It is to support a comprehensive furniture research, testing and technical assistance program. This facility has been named the Franklin Furniture Manufacturing and Management Center and will house the Director of the Institute of Furniture Manufacturing and Management. A key function of this facility will be to display and demonstrate the collective programs and outcomes of all units within the Institute and to showcase the furniture industry in Mississippi. The building will house the current furniture research and testing program. It will include the following features:

1. Quality Testing Laboratory
2. Machinability Laboratory
3. Engineering and Automation Laboratory
4. Product Design Laboratory
5. Auditorium/Distance Learning Classroom to Seat 75
6. Computer Classroom to Seat 20
7. Large Conference Room to Seat 25
8. Graduate Offices with 12 Work Stations
9. 2,500 square foot Lobby/Display Area
10. 11 Faculty Offices
11. 3 Research Assistant Suites with Total of 12 Work Stations
12. Receptionist's Area
13. Secretary's Office
14. Director's Office

Design Methods:

The whole design process in early design stages for this project is very traditional. When Pryor & Morrow was invited as the architect for this project by MSU, several architect-client’s meeting were held. The building functions, client’s requirements, and architect’s initial ideas were discussed during the meetings. The site analysis and project’s programming were executed by Pryor & Morrow at the same time. The building functional space analysis and very rough design concepts were studied and discussed among the architects and the client. The representation format was manual 2D drawings which include line-base pencil sketches, simple color diagram of building space analysis.
The design representation methods applied onto conceptual design to design development is mostly traditional manual techniques, and represented in two-dimensional format. The manual 2D sketches were used to generate initial design concepts. Then, these design data were imported into computer by AutoCAD drafting. The following design study and discussion were executed based on the printed 2D drafting drawings. Some 2D manual sketches were generated again. These design steps iterate several time until satisfied design results produced. During these period, the communication among design team and between architect-client was conducted by using these 2D drawings as well.

Both manual and digital detailed perspectives were not generated for design study purpose. During the early design development phase, when the architectural design was almost confirmed, the client requested Pryor & Morrow to provide a set of detailed computer generated perspectives for the building fund raising purposes. At that time, Pryor & Morrow didn’t have such technical personnel in house. Therefore they hired a temporary computer 3D modeler, Ms. Tracy Etheridge who just graduated from her undergraduate architecture program three years ago, to help them on this task. Tracy generated those perspectives based on the information provided by Pryor & Morrow. Because the architectural design had been confirmed and construction drawing was being produced, the role of Tracy was just to represent the design information in another format. The communication between Pryor & Morrow and Tracy is remote as Tracy sited in Florida, far away from Pryor & Morrow Architects.
For the computer 3D model, some interesting facts were mentioned by Ms. Sherry Berry. Although the computer 3D model was produced in quite late phase, it still played a role of design aid unconsciously in some aspects. Pryor & Morrow’s architects found some very unpractical design elements in their 2D architectural drawings by viewing the computer 3D model, which they didn’t recognize before. For example, the proposed connection between new laboratory building and adjoining neighborhood building is not very suit into that location. These design weaknesses were quickly fixed before being presented to the client.

Figure A2.01  An Interior View of Furniture Exhibition Room
Source: Pryor & Morrow’s Architects
Some design factors like building color pattern, material used, interior lighting condition, and some space functions were studied and discussed by Pryor & Morrow by viewing the computer 3D model as well. Figure A2.01 and A2.02 are interior views of furniture exhibition room of different design options, provided by Pryor & Morrow.

**Practical Problem:**

However, when received these set of perspective drawings, from the perspectives, the client found out some improper design visions which they didn’t imagine before. The design output shown in the perspectives was not the imagination result they respected before, they quite disappointed. The client did not satisfy the
perspectives quality as well. In addition, the client thought that they might have more difficulties if they use this set of perspectives for rising building funding due to the digital media representation and image output quality.

**Some Design Modification Solutions:**

In an effort to satisfy the client’s needs for their fund raising and promotion efforts, the architects contacted the Digital Research and Imaging Lab (DRIL) in School of Architecture, at Mississippi State University. This decision was made after carefully considered the situation that Pryor & Morrow doesn’t have digital 3D visualization capability in house.

The Digital Research and Imaging Lab is a multi-platform visualization laboratory for inter-disciplinary research work conducted by the School of Architecture. The lab contains UNIX (SGI and Sun), WindowsNT, and MAC OS workstations running a variety of latest modeling, rendering, animation, CAD, web authoring and multi-media softwares.

Research and project types engaged in the DRIL encompass a wide array of issues in architecture and related fields. Digital modeling, animation and web design problems are engaged using the latest hardware, software applications and programming languages. Research often includes a multi-disciplinary team where the student engages research in both material and virtual architecture.

At the beginning of DRIL involved in this project, the role of DRIL as a computer 3D visualization specialist is to help Pryor & Morrow Architects to re-
generate a set of computer 3D perspectives. According to the client’s requirements, Digital Research and Imaging Lab (DRIL) re-generated a set of perspective drawings which as exact as possible followed design information provided in the working drawings by Pryor & Morrow. This is for the client visioning their future property accurately and better understanding the current design situation. It also helped the client to figure out the root of previous problems.

Figure A2.03  An interior view of conference room  
Source : Pryor & Morrow’s Architects

Figure A2.04  An interior view of conference room  
Source : Digital Research & Imaging Lab, MSU

Figure A2.03 is original interior perspective of conference room produced by Tracy Etheridge. The representation information in this drawing almost followed the working drawings provided by Pryor & Morrow without any change.

In contrast, Figure A2.04 is the same room interior perspective generated by DRIL. This is the result that DRIL carefully studied the working drawings about room layout, lighting condition and surface finishes (material color and pattern), consulted the
furniture supplier about furniture types in this room. Some modifications of finishes color and material were suggested by DRIL in this perspective.

In order for the client better understanding the capabilities and limitations of computer 3D visualization tool in affecting architectural design output, DRIL went to little further. Used as a sample, the conference room’s interior design was modified by DRIL to give the client a vision how well the room could be. The ceiling structure, wall pattern, lighting fixture, floor carpet pattern and furniture style were modified accordingly to an alternative design solution. Figure A2.05 is a perspective view of modified conference room design proposed by DRIL.

![Figure A2.05: An interior view of conference room](source: Digital Research & Imaging Lab, MSU)
As the client didn’t have a chance to make a further design decision in the initial design stages by viewing more design solutions in such an easy understandable way, DRIL tried to give them such chance at this time. Figure A2.06 is the alternative design solutions for the auditorium interior provided by DRIL, according to per interior perspective provided by Pryor & Morrow. Before generated these interior design solutions, DRIL carefully consulted furniture suppliers and visited similar existing forestry school’s facilities.

![An Interior View of Auditorium](source)

Figure A2.06  An Interior View of Auditorium  
Source: Digital Research & Imaging Lab

Figure A2.07 is the interior perspective of auditorium designed by Pryor and Morrow and generated by Tracy Etheridge.
The Furniture Exhibition Hall (showroom) is the largest and most important space in the building. To make every building items (space, color and lighting condition etc.) of this space fitting into exhibition category is highly appreciated by the client. Figure A2.08 is the interior perspective of showroom generated by DRIL after DRIL carefully studied Pryor & Morrow’s construction documents and client’s comments.
Figure A2.08 An Interior View of Furniture Showroom  
Source: Digital Research & Imaging Lab

Figure A2.09 is the perspective of showroom interior designed by Pryor & Morrow and generated by Ms. Tracy Etheridge.

Figure A2.09 An Interior View of Furniture Showroom  
Source: Pryor & Morrow’s Architects.
During the process of generating Furniture Showroom perspective, DRIL also analyzed the options for the client. As a design suggestion, one more interior perspective view of this space had been produced which removed the two columns at the center of this space for the client’s consideration (see Figure A2.10).

Figure A2.10 An additional Interior View of Furniture Showroom
Source: Digital Research & Imaging Lab

Role of Computer 3D Visualization Tool in Early Design Phases:

In the design period conducted by Pryor & Morrow Architects, computer 3D visualization tool is used for final design presentation initially. However, this tool still affected their design solution objectively after they applied it, even they didn’t recognize it before. The computer 3D visualization tool was also applied as a presentation tool by DRIL according to the client’s requirement. In the meanwhile, in
order to provide the client some additional solutions, DRIL used computer 3D visualization tool as a design tool as well.

**Main Purposes:**

This case study is trying to analyze whether the traditional representation techniques applied onto initial design stage are sufficient in assisting architects to create and develop design concept. Another purpose is try to find whether the different role of computer visualization tool user with different level of understanding computer 3D visualization tool in design process can affect design process and design output quality differently.

At this writing, this project is in the bid-phase. The client continues to ponder possible design modifications after reviewing the perspective drawings provided by DRIL.

**SUMMARY:**

Located in Mississippi’s rural area, Pryor & Morrow’s architects remains quite traditional design style in early design process, like manual 2D & 3D sketching, computer 2D drafting. Rarely requested by their clients makes Pryor & Morrow less considering computer 3D visualization technique in their design process in the past. However, current client’s demands in using computer 3D visualization tool to achieve better design communication are increasing. The situation of client’s requirement and lack capability of handling computer 3D visualization technique in house definitely
forced Pryor & Morrow to re-evaluate their competitive ability in the architectural professional service market. This project indicates that the digital modeling and rendering can contribute to the design process in the earlier phases of design for both the owner and architect. (Thank you so much, Dr. Barrow)

**Case Study Discussion Questions**

1. In current architectural practice, is it really sufficient by using only traditional manual design tool in early design stages?

2. Does computer 3D visualization tool used as a presentation tool impact the design output?

3. What is the relationship the computer 3D visualization user with other design team member? And how does this relationship affect design output?
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<th>Pryor &amp; Morrow</th>
<th>Case Study II – Summation</th>
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<td>Sherry Berry</td>
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<td>Decisions:</td>
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<td>Time Period:</td>
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<tr>
<td>Summary:</td>
<td>Mid-size firm in Mississippi</td>
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<td>Projects Reviewed:</td>
<td>Furniture Research Institute Laboratory, MSU</td>
</tr>
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</table>
| Main Issues:   | 1). Firm size and location  
2). Early phases of architectural design process  
3). Design tool;  
4). Presentation tool;  
5). Architect vs. visualization specialist;  
6). Architect-client’s relationship;  
7). Type of communication among design team;  
8). 2D representation;  
9). 3D representation; |
| Innovations:   | 1). Use computer 3D visualization technology as presentation tool in design presentation;  
2). Use computer visualization technology as a partial design tool during early design development stage; |
APPENDIX A3

CASE STUDY III\(^1\) - PROPOSED NISSAN TECHNOLOGY
RESEARCH CENTER, CANTON, MISSISSIPPI

The Project

The Proposed Nissan Technology Research Center at Mississippi is a schematic design feasibility proposal presentation requested by the joint venture of Nissan Corporation and the Mississippi Development Authority (MDA). The main building functional spaces include: 1). Administrative Offices and Engineering Design Complex; 2). Prototyping and Experimental Areas; 3). Educational Complex. Dr. Malcom Potera, former president of Mississippi State University (president of Mississippi State University at that time) is the representative of Mississippi Development Authority, who supervised the design process. The actual project design was executed by Digital Research & Imaging Lab (DRIL) in School of Architecture (SARC), Mississippi State University.

\(^1\) Candidate for the Master of Science in Architecture Degree, Jianying Jin prepared this Case Study under the supervision of Dr. Larry R. Barrow — AIA, as a basis for class discussion rather than to illustrate either effective or ineffective handling of information technology and professional practice.

Copyright © 2002 by the Mississippi State University, School of Architecture – Digital Research and Imaging Lab (DRIL). No part of this publication may be reproduced, stored in a retrieval system, used in a spreadsheet, or transmitted in any form or by any means - electronic, mechanical, photocopying, recording, or otherwise - without the permission of the Mississippi State University - School of Architecture - Digital Research and Imaging Lab (DRIL).
The project conducted by Digital Research & Imaging Lab is just to develop a design concept for the client’s overall planning purpose. Due to this specific situation, the chief designer, Dr. Larry Borrow – Director of DRIL decided to take advantage of DRIL’s research and facilities to achieve the design goal rather than traditional paper-based design process.

**The Digital Research & Imaging Lab**

The Digital Research and Imaging Lab is a multi-platform visualization laboratory for inter-disciplinary research work conducted by the School of Architecture. The lab contains high-end computers on which run a variety of modeling, rendering, animation, CAD, web authoring and multi-media software.

Research and project types engaged in the DRIL encompass a wide array of issues in architecture and related fields. Digital modeling, animation and web design problems are engaged using the latest hardware, software applications and programming languages. Research often includes a multi-disciplinary team where the student engages research in both material and virtual architecture. Students are encouraged to pursue research problems and explore the potential technology applications in architecture or their related field of study.

**Design Team Brief**

The design team for this project included four team members throughout the design process. Director of DRIL, Dr. Larry Barrow is the project manager and chief
designer, who is responsible for design concept development. There are other three junior design team members assisting Dr. Barrow to make digital design environment by using computer 3D visualization tools.

Dr. Larry Barrow is a practicing architect as well as an academian. Before entered Harvard Design School to pursue his doctoral degree, he practiced architectural design profession for seventeen years. Both architectural practical experience and advanced CAD knowledge makes him very comfortable trying to use new digital technology and creating new design method in architectural design process.

The other team members are Joe Hageman, Peter Graves and Jianying Jin. The common ground for these three persons is knowledgeable and skillful in architectural computer 3D visualization technology. Mr. Joe Hageman and Jin have architectural professional background. Peter Graves has a degree in Bachelor’s degree in Education and a Masters of Science degree with an emphasis on technology and visualization from the School of Architecture, Mississippi State University. Joe was in charged of the initial 3D conceptual modeling of the buildings. The site ground model with detailed ground information like roads, parking lot, topographical condition and lake was made by Peter Graves. Mr. Jianying Jin was responsible for the final presentation producing the building 3D digital model refinements, rendering, animation and final output images.
The Design Method

As requested by the clients, the design output is a conceptual design and feasibility proposal presentation. Due to the different situation between DRIL and normal architectural design studio, Dr. Larry Barrow decided to treat this project as both practical and research project. Therefore, the design method used is quite different with the tradition. Receiving general design requirements and a very rough idea from Dr. Malcom Potera with a simple sketch, Dr. Barrow generated the initial design concepts by using a few manual sketches. After that, Joe began to create computer 3D building modeling as much as possible based on the sketches and Dr. Barrow’s oral explanation. Once this digital 3D modeling design environment had been set up, the design study and modification was conducted totally in this digital environment. Figure A3.01 is the very rough sketch generated by Dr. Malcom Potera during the initial design conversation with Dr. Barrow.

Figure A3.01  A Manual Sketch of Site Layout
Source: Dr. Larry Barrow; Sketched by: Dr. Malcom Potera
Design Process Brief

The design process in this only concept design stage is mainly involved with a few manual sketches and computer 3D visualization technique. When the initial design ideas were created by Dr. Barrow, several manual sketches generated by Dr. Barrow had been passed to Joe Hageman (see figure A3.02 to A3.06). Joe Hageman started to produce digital 3D building model based on these several manual sketches and the discussion with Dr. Barrow. In the meanwhile, Peter Graves began to work on the site ground model. Starting from this point, the design process was executed in digital 3D environment without any manual paper sketches and manual drawing generated for design purpose. The computer 3D visualization program used by Joe Hageman and Peter Graves is Form.Z, a very mature 3D modeling system with a capability of 2D drafting.

Figure A3.02  A sketch of Initial Design Concept
Source: Dr. Larry Barrow;
Figure A3.03  A Sketch of Elevation at Atrium
Source: Dr. Larry Barrow;

Figure A3.04  A Sketch of Roof Plan at Atrium
Source: Dr. Larry Barrow;

Figure A3.05  A Sketch of Cross Section at Atrium
Source: Dr. Larry Barrow;
During the digital 3D model generating, both Dr. Barrow and Joe Hageman worked together to produce digital 3D model, and modified design concept according to the digital 3D model format representation. This procedure iterated several times until the design concept matured. Dr. Barrow indicated, “sometimes when I looked at the computer 3D model, I could immediately find proper scale and form representation clearly, in lieu of the manual sketches due to the very accurate character of the digital model.” Thus we find the digital 3D visualization tool can assist in assessing mental images and freehand sketches in the early phases of design.

The initial digital 3D model was quite simple at the beginning without consideration of color, material and lighting condition. But along with the design
concept development going into depth, the modeling content became more detailed.

In order to seek the client’s suggestion and confirmation, during the different micro-design stages, the different level’s perspectives rendered from computer 3D visualization system had been used as communication media for client-architect’s communication. Usually one to two weeks, the computer rendered perspectives which reflected the design development status were presented to the client by web-base format. This type of presentation made the client easier and quicker reviewing the project development. This step had been repeated several times due to the design modifications and development. The following images (Figure A3.07, A3.08 & A3.09) are some samples which were used for design discussion and presented to the client during the design process.

Figure A3.07  An Interior View of Proposed Entrance Lobby
Source: Digital Research & Imaging Lab
Figure A3.08  An Interior View of Research Workshop Space  
Source: Digital Research & Imaging Lab

Figure A3.09  A Rear View of Proposed Nissan Tech. Research Center  
Source: Digital Research & Imaging Lab
Design Output Brief:

The final design output delivered to the client is a series of computer generated perspectives and a two-minute video presentation. These design information has been put On-line for the client’s review. The following images are some samples of presentation perspectives.

Figure A3.10  Site Plan of Proposed Nissan Tech. Research Center
Source: Digital Research & Imaging Lab
Figure A3.11  Rear View of Proposed Nissan Tech. Research Center
Source: Digital Research & Imaging Lab

Figure A3.12  Site Entrance of Proposed Nissan Tech. Research Center
Source: Digital Research & Imaging Lab
Figure A3.13  Entry Driveway View of Proposed Nissan Tech. Research Center  
Source: Digital Research & Imaging Lab

Figure A3.14  Front Entry View of Proposed Nissan Tech. Research Center  
Source: Digital Research & Imaging Lab
Figure A3.15  Front View of Proposed Nissan Tech. Research Center  
Source: Digital Research & Imaging Lab

Figure A3.16  Rear View of Proposed Nissan Tech. Research Center (Night Scene)  
Source: Digital Research & Imaging Lab
SUMMARY:

As a result of this case study, computer 3D visualization technique showed a great capability and potential as architectural design aided tool. Designing in digital 3D environment is being possible. However, the most of current computer 3D visualization program request long time learning curve to master their complicated functional interface before users skillfully manipulating them to achieve the design goals. Therefore, in order to give a full play of computer 3D visualization technology as design aid in early design phases, the appreciated personnel with both architectural profession knowledge and computer 3D visualization skill is highly required.

Case Study Discussion Questions

1. How does computer 3D visualization tool be used as a design tool but not a presentation tool only?
2. Does computer 3D visualization tool used as a design tool improve the design productivity and design quality?
3. How does computer 3D visualization tool impact early architectural design process? In what degree and with what result?
4. What is the relationship the computer 3D visualization user with other design team member? And how does this relationship affect design output?
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<td>Early design phases; Computer 3D visualization technology; Design tool; Presentation tool;</td>
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<td><strong>Protagonist:</strong></td>
<td>Dr. Larry Barrow, Director of DRIL</td>
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<td><strong>Objectives:</strong></td>
<td>Impact of computer 3D visualization technology in early phases of architectural design process</td>
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<td>Why use computer 3D visualization technology in early phases of architectural design process, how to use it and who uses it</td>
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<td><strong>Summary:</strong></td>
<td>Architectural Digital Design Research Center in a Research Institutional Environment.</td>
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<td>Nissan Technology Research Center, Mississippi</td>
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<tr>
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