Perception of Space through Representation Media: A Comparison between 2D Representation Techniques and 3D Virtual Environments

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ABSTRACT

For centuries, 2D drawing techniques such as plans, sections and elevations have been the main communication media for the profession of architecture. Addition to these techniques, for two decades, computer based representation techniques and 3D virtual environments (VE) have also entered to the profession of architecture. Effects of these computer based techniques on perception of space have always been interrogated by several researches. Although these researches generally regarded these computerized techniques as better and proper than conventional techniques, in some cases conventional techniques can be more effective to depict architectural space. Main aim of this thesis is to compare and evaluate the positive effects and shortcomings of 3D virtual environments and 2D conventional representation techniques in the context of perception of architectural space. Parallel to this objective, the thesis also aims to show the differentiation in perception of space with the change of representation media. To show these differences, a comparative method is used. As the main step of the application of this method, an experimental case study and survey has been constituted for comparing 2D conventional techniques and 3D computer based techniques. In this survey, 38 first year students from Izmir Institute of technology have taken place as test subject. According to the results of this comparative case study, contributions and shortcomings of 2D conventional representation techniques and 3D computer based techniques on improving the capability of architects on perception of the space have been determined.

ÖZ *

Plan, kesit, görünüs gibi iki boyutlu çizim teknikleri yüzyillardir mimarlik mesleginin ortak ve temel temsil dili olarak kullanilagelmistir. Son yirmi yildir ise, bu tekniklere ek olarak, bilgisayar tabanli temsil yöntemleri ve üç boyutlu sanal ortamlar da temsil araci olarak mimarlik dünyasina girmistir. Bilgisayar destekli bu çagdas temsil araçlarinin mekanin algilanmasina olan etkileri birçok arastirmaya konu olmustur. Bu çalismalarda genel olarak bilgisayar destekli temsil ve sunum yöntemlerinin geleneksel yöntemler üzerinde büyük bir üstünlügü oldugu düsünülmektedir, ancak bu üstünlük gerçekten bu kadar bariz bir sekilde var midir, ya da her durumda geçerli midir diye tartisilmasi ve üzerinde düsünülmesi gerekir. Bu tezin temel amaci; iki boyutlu geleneksel temsil yöntemleri ve üç boyutlu bilgisayar destekli temsil tekniklerinin mekanin algilanmasi baglaminda karsilastirilarak, avantajli olduklari ve eksik kaldiklari yönleri ortaya koymaktir. Bu amaca paralel olarak tez, ayrica mimari temsil ortaminin degismesine bagli olarak mekanin algilanmasinda meydana gelen farklilasmalari da inceler. Bu amaçlari gerçeklestirmek için bu tez, karsilastirmali bir yöntem izler; ve bu yöntemin en önemli noktasini da karsilastirmali alan çalismasi olusturur. Bu alan çalismasi, iki boyutlu geleneksel temsil yöntemleri ile üç boyutlu bilgisayar destekli yöntemlerini mimarlik 1. sinif ögrencileri üzerinde yapilan anketler yardimiyla, mekanin algilanmasi baglaminda karsilastirmaya çalisir. Bu alan çalismasinin sonucu olarak da, anketlerin degerlendirilmesi yapilip, geleneksel ve bilgisayar destekli yöntemlerin avantaj ve eksiklikleri ortaya koyulmustur.

*** Tezin Türkçe Adi:** Sunum Tekniklerinde Mekan Algisi: Iki Boyutlu Çizimler ve Üç Boyutlu Bilgisayar Ortami Arasinda Bir Karsilastirma

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LIST OF ABBREVIATIONS

2D: Two Dimensional

3D: Three Dimensional

CAAD: Computer Aided Architectural Design

CAD: Computer Aided Design

CAVE: Computer Aided Virtual Environment

DVE: Desktop Virtual Environments

HTML: Hyper Text Markup Language

IT: Information Technologies

IYTE: Izmir Institute of Technology

NC: Network Computer

PC: Personal Computer

QTVR: Quick Time Virtual Reality

SAGE: Semi Automatic Ground Environment

VE: Virtual Environments

VR: Virtual Reality

VRML: Virtual Reality Markup Language

IVE: Immersive Virtual Environments

HMD: Head Mounted Displays

Chapter 1
INTRODUCTION

1.1. Definition of the Problem

Main aim of architectural representations and drawings can be clarified as “to depict designed spaces and provide necessary perception of space for users or constructers”. For centuries, architects have been using 3D physical models and 2D drawings (plans, sections, elevations, perspectives, and axonometric drawings) to reach this aim. Although these drawing techniques can represent some characteristics of architectural spaces, it is apparent that they have some shortcomings in representation of certain characteristics of the space. For instance, these conventional drawing techniques can not definitely characterize three-dimensionality of spaces; and for this reason, users sometimes can not perceive the architect’s design absolutely.

By the developments of computer technologies, techniques such as computer aided design (CAD), virtual environments (VE) and virtual reality (VR) have entered to the profession of architecture. These computerized technologies have claimed to meet above mentioned shortcomings and limitations of conventional representation techniques. For searching the potentials of computer based representation techniques, researchers have applied some comparison based case studies. However, most of these researches generally compared conventional and computerized representation techniques only in the context of their ability on representation of physical, dimensional and formal properties. Thus, there was a necessity on comparison and evaluation of these two representation techniques in the context of perception of space and psychological effects created on human. Thus, in addition to the representation of physical properties, this study especially interests with the abilities of conventional and computerized representation techniques on “perception of architectural space”, and “perception and cognition of the present for the future creations”. In other words, this study does not only interest with the understanding of physical properties, but also with perception of the life and aura in architectural spaces.

1.2. Objectives of the Study

During the history, 3D physical models and 2D conventional drawings have always been the most important representation and communication media for profession of architecture. One of the aims of this study is to criticize these paper based conventional techniques in the context of their shortcomings on representation and perception of architectural space. In other words, this study plans to reveal shortcomings of the conventional representation methods in representation of 3D space.

Today, computer technologies are used as an important medium nearly in all phases of architectural processes such as design, presentation and application. Furthermore, these technologies and their concepts such as “virtual environments (VE)”, “cyberspace” and “computer aided design (CAD)” have been causing important and fundamental changes in understanding of architectural space. For instance, these concepts began to change architectural design habits, presentation techniques; briefly, the representation of space. Today, computer based 3D representations have nearly became as a necessity in all architectural processes. In other words, while architects were using only conventional 2D drawings and 3D physical models as representation medium of architecture in the past, today they began to use 3D computer models and virtual environments instead of conventional tools. Besides, although many researchers and users regard computer based 3D representation techniques as the proper techniques for the perception of architectural space, in some cases, conventional techniques can be more effective to depict architectural space according to these techniques. Parallel to these thoughts, **main objective of this study is to compare and evaluate the positive effects and shortcomings of 3D virtual environments and 2D conventional representation techniques in the context of perception of architectural space.**

In addition to this aim, this study aims to provide thinking on the following questions: What do virtual environments offer to architecture? What role will virtual environments play in architectural representations in the future? Can the experience that virtual environments offer, replace the conventional techniques and change the profession of architectural totally?

In the case study, the research makes comparisons between 2D conventional representation techniques and virtual environments as a representation medium. By this way, the study intends to reveal advantages and disadvantages of these methods to each other. Moreover, by the investigations and applied questionnaires, this study aims to criticize abilities of architectural representation techniques on expressing created spaces. By this way, this study constitutes the first step for developing new era's representation techniques' criteria, and answers the problem of "improving the perception of architectural space in architectural representation techniques".

1.3. Domain of the Study

As it is mentioned above, main study area of the thesis is the comparison of conventional 2D and computer aided representation techniques' abilities in the context of spatial perception. As a beginning to this study, it will be suitable to define some terms and concepts mentioned in the thesis. One of these terms is the concept of "space". In the thesis, this term represents "architectural space". Related to the concept of space, the study only interests with the techniques for representing and depicting architectural space. Theoretical researches on the concept of space are not in the study area of the thesis.

The other important term for the thesis is the concept of "perception". Main research area of this study is the perception of space in the architectural representations. However, at this point it must be clarified that the theoretical researches on the concept of perception are not in the research area of this thesis. This study only interests with the representation of space in 2D drawings and 3D virtual environments; and perception of space in these representation media. **Perception of architectural space through representations is a visual process, so it can be thought that the term of perception refers to the "visual perception" in the thesis.** However, architectural representations are only symbolized versions of physical spaces and users try to perceive the represented spaces by these architectural representations. Thus, process of the perception of a physical space is similar to the process of perception of the representation of that space. When it is thought deeper in this context, it can be claimed that the term of perception sometimes refers to the "environmental perception and cognition" especially in the case study. At this point, it is necessary to investigate this concept deeper in the context of the thesis's research domain.

1.3.1.Concept of Perception in the Context of the Thesis

As it is mentioned above, in the thesis, concept of perception generally refers to the visual perception. However, for understanding some results of the case study, concepts of environmental perception and cognition must be explained. The process of environmental perception, and cognition or cognitive mapping (all of them refers the same thing) is defined as a process composed of series of psychological transformations by which an individual acquires codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in his spatial everyday environment (Altman, 1984, p.44). Similarly, Roger Downs describes cognitive map and cognitive mapping as follows: (Downs, 1977, pp. 6-7)

> *…A cognitive map is a product – a person's organized representation of some part of the spatial environment. Examples include a sketch map showing the route to your house; a list of the places downtown that you avoid because they are dangerous… and cognitive mapping is an abstraction covering those cognitive or mental abilities that enable us to collect, organize, store, recall and manipulate information about the spatial environment…*

After the definitions of the terms, it is the time to investigate the process of environmental perception and cognition. The basic question is "How do people acquire and process information about their environments?" Figure 1.1 depicts this process basically.

Obtaining Information	→	*Internal Processing of Information*	→	*Functions*
Acquisition and Sensing	→	Coding, Storing, Recalling and Decoding	→	Locations and Attributes of Environment

Figure 1.1. Elements of Environmental Perception and Cognition (Altman, 1984, p.45)

As it can be seen in the figure 1.1, first stage in coping with a new environment is to obtain information about it. Obviously this happens through the various sensory modalities such as vision, hearing, smell, touch, taste, etc. In other words, we acquire first information about a place by looking around; listen to things, smell or touch. These senses become part of our understanding of the environment. After this step, information processing begins. These information processing events include the coding and sorting of information into categories that fit our past experience or personality. In other words, information about the environment is grouped, organized and compared with similar or dissimilar past experiences environments. Because of the effects of past experiences, coding and sorting processes change according to the culture and experience of the users. For example, perception of a television changes for a person from a developed country or a man from a primitive tribe. Altman summarizes above mentioned processes as follows: (Altman, 1984, p.47)

> *Environmental cognitions are truly "psychological" in that we interpret the environment and we are selective and incomplete in our portrayal of it. We receive information about the environment from our senses, we process and organize it in ways that are represented in and carried about in our minds. What is meaningful, consistent and appropriate is, of course, heavily influenced by our cultural experiences.*

Above mentioned steps ("*Obtaining Information*" and "*Internal Processing of Information*") of the process of environmental cognition are generally related to the perception of the environment. Cognition of the environment generally begins with the perception of location of the environment.

Location generally deals with where things are by the help of the terms of *distance* and *direction*. Distance is often measured in linear units such as meters or feet. However, people generally describe distance very different such as 3 hours away, or 3 gallons of gas away, or 3 miles away. The other dimension of location is direction. Maps are usually oriented toward the cardinal directions of north, south, east, and west; and when traveling, we often rely on these directions. But in daily life, directions take many forms. In some instances, all directions are based on a well-known landmark, or a street etc. For example, two streets this side of the Güzelyali Park.

Until now, above mentioned paragraphs have described the general process of how people orient to environmental attributes and locations; and now it is the time to define 5 dimensions to construct a mental image of a space. These dimensions are *paths*, *edges*, *districts*, *nodes* and *landmarks*. Paths are channels along which the observer customarily, occasionally or potentially moves. Edges are boundaries between two phases. Districts can be defined as the large sections of the space which are recognizable and have some common identifying characters. Nodes can be defined as the strategic spots of a space. Finally the landmarks are the unique and memorable points of the space (Altman, 1984, pp.50-54).

1.3.2.Other Domains of the Study

After the definition of important terms and concepts mentioned in the thesis, it is the time to clarify other domains of the thesis. In general, this study investigates all architectural representation methods that are being used in architecture today. These representation methods are generally thought in two groups in the study: First group is conventional techniques such as drawings and 3D physical models; and second group is computer based contemporary methods such as all kinds of virtual environments. Although the thesis mentions about the history and aims of these two methods; main investigations are made only in the context of these representation techniques' capacity on representing architectural space and providing sufficient perception on architectural space.

One of the main aims of the architects during the history has always been to prepare the most realistic presentations and representations. Parallel to the study's general domain, while the thesis studies on the conventional representation techniques (first group), these attempts to reach "reality" in architectural presentations and representations are deeply mentioned. As a result of this investigation, it is seen that architects and designers always try to reach "real" in their presentations, but their tools and media changes according to the technology. For example, they were using handmade perspective drawings and paintings in the history; but today they use computer renders instead of these conventional tools.

Also, in investigation of computer based representation techniques (second group), representation and perception of space is the main point. Parallel to this situation, in the case study; which is based on a comparison between conventional methods and computerized methods; the study uses only basic virtual environment systems (Desktop Virtual Environments) as computerized representation medium. This group of virtual environments (VE) is chosen because of its cheaper hardware requirements, easy and widespread use according to complex systems. All Personal computer (PC) systems with multimedia equipments and a graphic display card can be used as a Desktop Virtual Environment (DVE) media. A detailed explanation about DVE systems will be given in Chapter 3.

1.4. Method of the Study

To achieve the above mentioned objectives, the thesis used comparison as the main method. The study has constructed a comparison between 2D conventional representation techniques (plan, section and elevation) and computer based 3D representation techniques (DVE systems) through a questionnaire and survey. This survey has been applied in two steps to the 38 first year students of Izmir Institute of Technology, Department of Architecture. The method of comparison used in the case study is explained in detail in Chapter 5.2, page 72 and 73.

To achieve the aim of the study, following flow chart has been developed. The steps in the flow chart can be enumerated as follows:

1. Problem definition
2. Discussing the deficiencies and contributions of conventional and computer aided representation methods on spatial perception.
3. Literature survey on effects of conventional representation techniques on perception of architectural space.
4. Literature survey on the effects of computer technologies on perception of architectural space.
5. Literature survey on the concepts of computer and computer aided design (CAD) technologies in architecture.
6. Investigating available computer models and softwares for the case study.
7. Definition of the method for the case study
8. Selecting suitable buildings for the case study.
9. Preparation of the computer models and conventional drawings of the selected buildings for the applications of the case study.
10. Application of phase 1 of the case study (Effects of conventional representation techniques on perception of architectural space).
11. Evaluating the results of the inquiries based on conventional representation techniques.
12. Application of phase 2 of the case study (Effects of Computerized representation techniques on perception of architectural space).
13. Evaluating the results of the inquiries based on computer aided representation techniques.
14. Comparing and evaluating the results of both inquiries.

In the following figure (Figure 1.2), the studies mentioned above in list to accomplish the thesis will be showed in a scheme and explained briefly.

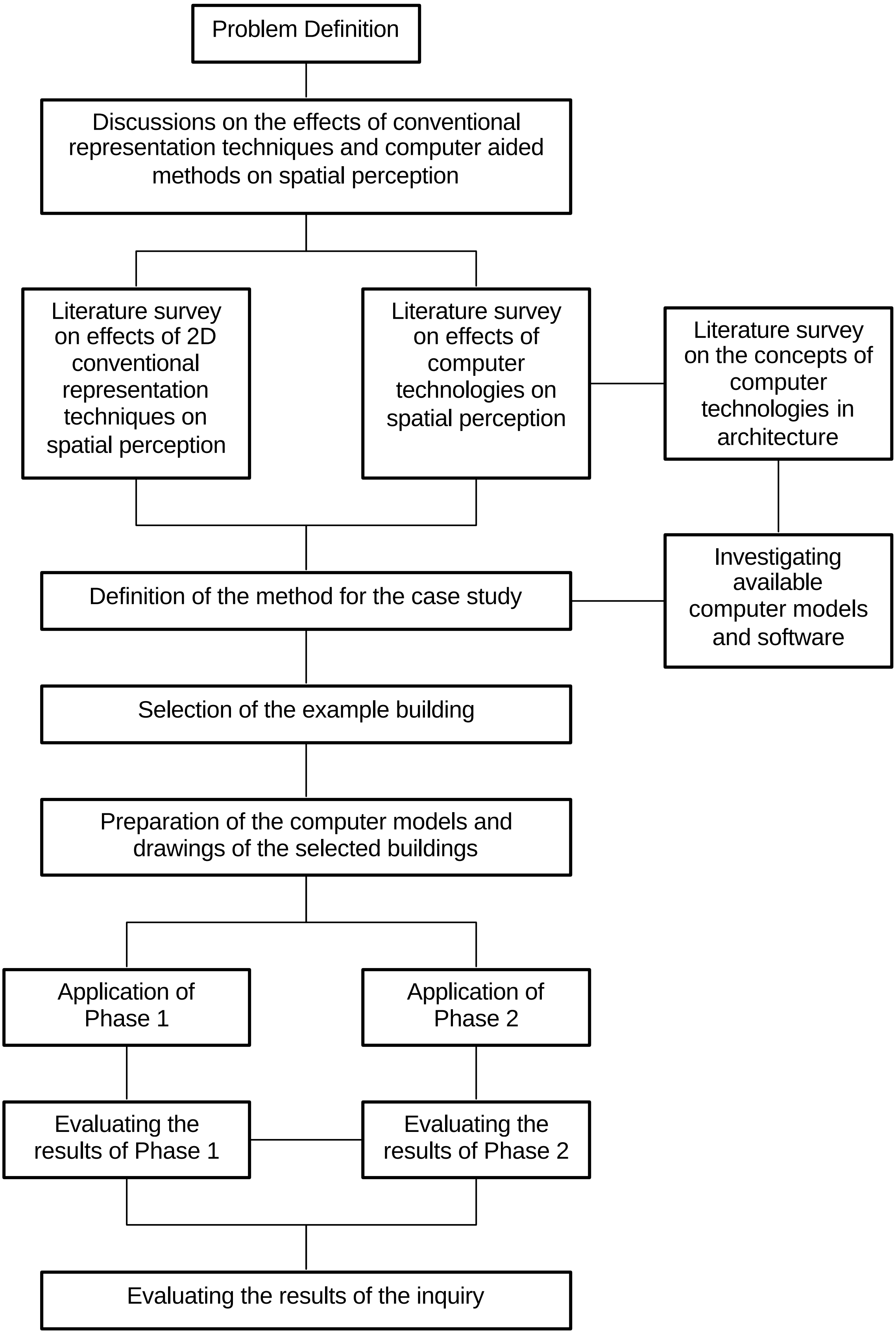


Figure 1.2 Flow Diagram of the Research Process

In the contexts of above mentioned objectives, following studies have been conducted. First of all, reasons for defining the problem are realized in the context of architectural representation techniques and perception of architectural space. In this point, the subject requires evaluation of conventional representation techniques and computerized representation techniques (virtual environments) in terms of perception of architectural space. It is important to reveal how the conventional techniques have represented the architectural space, how users have perceived space from these representations, and how virtual environments can effects perception of space.

To constitute a background for the thesis, in Chapter 2, development of conventional representation and presentation techniques during the history are examined and shortly summarized. All representation techniques such as plans, sections, elevations, perspectives, axonometric drawings and 3D physical models are inspected independently in the context of their capacity of representing space. Moreover, the efforts for reaching more realistic and perceivable representations during the history are examined. As a result of these investigations, advantages and shortcomings of these techniques on representing architectural space are evaluated.

In the Chapter 3, computer technologies and concepts used in architecture are studied. Mainly, concepts and terms which are entered to profession of architecture after the development of architecture are defined deeply. Moreover, effects of computer aided techniques on “representation in architecture” and “perception of space in architecture” are introduced during these definitions. Parallel to this introduction, advantages of computer aided design (CAD) tools and techniques in all phases of architecture profession are basically investigated.

Chapter 4 is investigation of preceding studies related to the use of computers in architecture. These case studies are generally based on comparisons of basic computer aided representation techniques with physical reality, conventional representation techniques and complex virtual environment systems.

After the evaluation of previous comparative studies, a new comparison based on perception of space, which is thought to be lacking, has been applied to the students of IYTE Department of Architecture. In Chapter 5, application steps of this case study have been told. Aim of this case study is discussing the advantages and limitations of conventional 2D representation techniques and 3D computer aided representation techniques in the context of perception of architectural space. As the main comparison material, Frank Lloyd Wright's Larkin Building's two-dimensional architectural drawings and 3D computer models of the same building are used and tested by students of architecture.

As a result, obtained data from the case study has been evaluated and the results of the study are determined.

Chapter 2

CONVENTIONAL REPRESENTATION TECHNIQUES IN ARCHITECTURE

Architectural representations play a significant role in design process as a mode of conversation, communication or documentation. Representations implant ideas, decisions and knowledge through 3D physical models, plans, elevations, sections and perspective views. These primary representation media have been known and used to conceive and represent architectural space for centuries.

Methods, role and importance of the presentation techniques have been changed during the history. In ancient era, physical models were the main tools in design process, and primitive illustrative drawings were used for representing some extra details and the imagined life style in the building. However, after Renaissance, orthographic drawings have gained importance as design media, and perspectives were used for representing imagined life style. Moreover, while ancient world's drawing techniques were not rational, easily perceivable and could not express the sense of real; after Renaissance, drawing techniques began to represent space in a more rational and realistic way. Today, orthographic drawing techniques and perspectives are common and conventional methods for architectural representation, but they are still not sufficient for representing sense and reality of architectural space.

This chapter is an overview of conventional representation methods in architecture; which are 3D physical models, plans, elevations, sections and perspectives; their origins, evolutions and roles in perception of architectural space.

2.1. 3D Physical Models

Use of 3D physical models in architecture has always been as ubiquitous as the use of drawings. In fact, models were the oldest representation technique known in architecture. In ancient Egypt and Greece, wooden and wax models were used generally for representational purposes. 3D Physical models were important tools to present architecture to authorities and prospective clients (Piccolotto, 2002, p.59). *In Roman Empire, some architectural model exist, and though they may often have been made not to show to a client but to be placed in an architect's tomb, or in the tomb of a person who had commissioned a temple or some other building* (Kostof, 1977, p.31).

Figure. 2.1. Model of the choir of the "Duomo of Como" (1519 – Made by Cristoforo Solari) (Piccolotto, 2002, p.64)

In Renaissance, use of 3D physical models changed into a more consistent way and the role of these models during design process has further elaborated with the opinions of Alberti. Alberti used models to show the relationship between site and the surrounding, the parts of the buildings, the construction methods, the financial costs, the thickness of walls, etc. Alberti thought that an idea in architecture could only be realized with the help of model. The model for him was not only a tool to present the complete design to client but also a means to study or evaluate a design idea. Moreover, the model was an instrument for him for the improvement of the design. It was a part of design process, related to study drawings instead of being a guide for construction. He studied with models for the refinement of his designs, especially for its proportional dimensions or structural possibilities (Duruk, 2000, pp.63-64). Moreover, in "Ten Books on Architecture", Alberti emphasizes the use of models in design process, and he writes*: "I would not have the model too exactly finished, not too delicate and neat, but plain and simple – more to be admired for the contrivance of the inventor than the hand of the workman"* (Porter 1979, p. 5). An example model from that era can be seen in Figure 2.1.

Today, 3D physical models are used in architectural design for several purposes such as exploration of new ideas, experimentation of decisions and presentation of final product. In an early design process, sketch or study models are created to examine particular aspects of a design idea. These rough models assist architects in their design process for concretizing their ideas. In addition, 3D physical models facilitate architect's perception of 3D imagery, exploration of different forms. Figure 2.2 is a good example for this kind of contemporary modells.

Models offer benefits of accessibility, tangibility, manipulability and collaborative engagement. For these purposes, models are used at all scales, ranging from town planning to explanation of particular building sub-components. In particular, complex mass-void relationships or spatial sequences are said to be more easily communicated in models (Kvan, 2003, p.6).

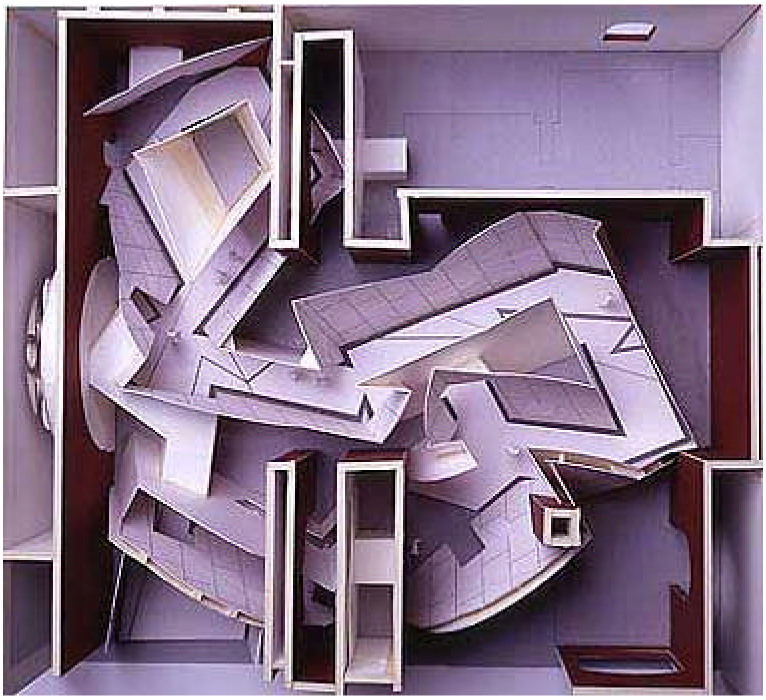


Figure. 2.2. One of the Study Models of Berlin Jewish Museum (Architect: Daniel Libeskind)

However, models are abstract representations, not replicas of realities. On this subject, Kvan claims that “*the reality of the model is a fiction, it’s not real, and it’s only a tool for the final building*” (Kvan, 2003, p.4). Therefore, contemporary architectural models do not generally represent properties of materials, true colors, textures and precise properties of the atmosphere. Instead of these aims, these models try to provide perception of mass-void relations, or adaptation of the building to the site. However, senses and psychological relations between building and user are very important factors for a complete perception of space; and because of their dimensions and materials, miniature physical models can not provide the sense of being inside the building. Briefly, these models can not fully represent buildings’ aura, and it is difficult to perceive architectural space only with help of these models.

2.2. Drawings

The most commonly used presentation techniques and principal representation media in architecture are technical drawings such as plans, sections, elevations, perspectives and supporter media such as sketches and paintings. *Architectural drawings can be seen as a representation or a language, or can be deconstructed as a form of signification, or can be understood as it embodies and symbolizes an idea* (Duruk, 2000, p. 7). In other words, all architectural drawings are abstracted media of architectural forms, concepts and buildings. They use symbols and abstractions referring to actual building materials and elements. For example, tiles are used for representing bricks, or specific signs are used for representing doors or elevators. By developments of these abstractions, in the course of time, architectural drawings have transformed to a common and peculiar language of architecture profession. For architects, drawings have always been the media for brainstorming, recording, studying and clarifying their ideas and built form, or imagination and translation into architectural form.

Generally, architectural drawings can be summarized in two groups: 2D drawings and 3D drawings. At this point, it is necessary to define these drawing types and representation techniques. 2D drawings are orthographic drawings that only represent the front view from the cut slice such as plans, sections and elevations. 2D orthographic drawings don't have sufficient information about the whole building. User can not perceive architectural space with the help of these drawings. For example, it is impossible to perceive the whole building from its plan, because a plan can not express the architectural space and relations in third dimension. Furthermore, 2D orthographic drawings are named as construction drawings. This is because, these drawings are purely formed by incorporated symbols of abstracted architectural elements, and their main aim is to define physical properties and dimensions of buildings. Thus, these drawings are generally unsuccessful to express proposed life and sensual effects of the building.

In architectural terminology, perspectives and axonometric drawings are named as 3D drawings. Aim of 3D drawings is to provide complete spatial properties of architectural form or building. These drawings are called as presentation drawings. However, presentation drawings can not express spatial properties of buildings as objective and successful as the physical models which are the most expressive 3D representation technique. Perspectives are a kind of imitation of men's view cone. By this way, they aim to represent how a man sees and perceives the object from that view point. However, perspectives are misleading and lack on providing full perception of object. They only provide perception of one or two sides of the object, and it is impossible to distinguish the other sides. Moreover, perception of observed sides of the architectural space can also be misleading because of the characteristics and deficiencies of perspective drawings. Modifications on view point and view angle changes the perception of the same space. This property of perspectives have permanently been using by architects. For example, same room can be illustrated bigger, higher or wider from the same view point.

Another deficiency of 2D perspective drawings is the lack of time and space relation, or the sense of movement. In a real 3D environment, viewpoint can be changed in real time. However, when a user looks at a perspective, it is impossible to change viewpoint in real time. Therefore, it is misleading to think perspective and axonometric drawings as real 3D representation techniques. It is more suitable to name them as "**3D in 2D**".

2.2.1. 2D Drawings

In orthographic projections, a building can be represented in 2D views as plans, sections and elevations. Plans present views of a horizontal slice of the design from above and can represent the patterns and dimensional relationships of a floor or ground plane. Sections are like plans except that they present a view of a vertical cross section through the building being represented and provide a sense of 3D spatial relationships. Elevations are like plans and cross sections except that they deal with the surfaces of a building (Robbins, 1994).

Each of these orthographic projections allows the architect to manipulate different aspects of the design, and provides different types of information about the architectural space. In conventional building process, these drawings are used to realize architects' design. Moreover, when we use them during the design process, they vary significantly in their degree of abstraction and the kinds of architectural issues that they address. Each of these drawing techniques can be done at different scales, can provide different shadows, textures, and tonalities by the use of color and line, and can range from the broadly general to the extremely detailed; the potential for variation in the architect's approach to design becomes apparent (Robbins, 1994).

Use of 2D drawings in architecture has always been ubiquitous since the Ancient Egypt. The depiction of architecture with drawings, paintings, and mosaics was common practice in ancient Egypt, and also in Greece and Rome. Plans and elevations were the principal illustration methods, and the combination of these orthogonal representations has been practiced since ancient Egypt era (Piccolotto, 2002, p.44).

Egyptian and Roman architects used squared grids overlaid onto plans and elevations, for the transformation of scaling factors and to control the carving of materials (Duruk, 2000, p.16). Figure 2.3 shows an example to the drawings with grids. On this drawing, the lines are drawn with clarity and simplicity of modern technical drawings and the orthographic projection is accurate.

Figure. 2.3. Parchment drawing (Frontal Elevation) from Ghorâb (Piccolotto, 2002, p.45).

Another technique used in ancient Egypt is “Bird’s-Eye View”. The images drawn with this technique were prepared to record the conceptual approaches rather than to show the physical or optical reality of the building (Kostof, 1977, p.8). In this drawing technique, three dimensional architectural elements and figures were projected to floor. By this way, plan and sequential elevations of the building can be presented in one drawing, and 3 dimensional perception was aimed to provide in one two dimensional drawing. In figure 2.4, an example of this technique can be seen.

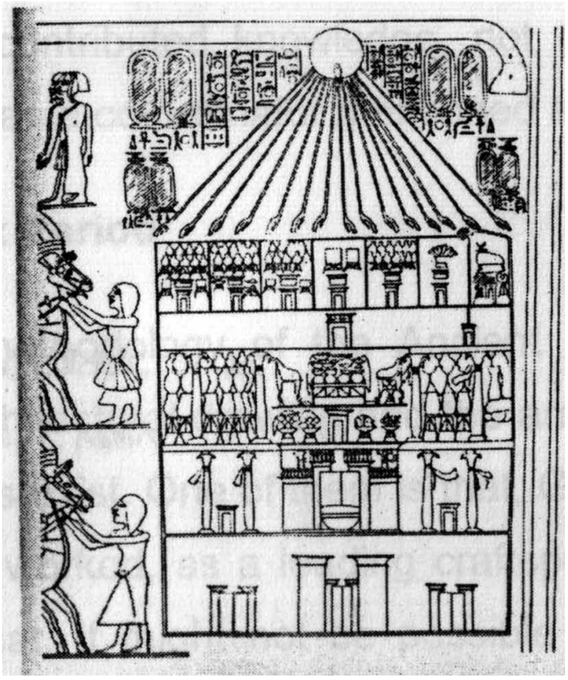


Figure. 2.4. Bird's Eye View of Amarna Palace from the Tomb of Mery-Re XVIII Dynasty (Kostof, 1977, p.8).

Until Renaissance, there were no important developments in architectural representations. In Ancient Greece, architects used architectural drawings rarely and they generally drew with "words" (Duruk, 2000, p.18). Furthermore in Roman architecture, there were no developments in 2D presentation techniques, and architectural plans were used rarely.

After Alberti's studies in Italy, plans, elevations, and sections became progressively orthographic. The drawing techniques were continuously refined. For example, line thickness and colors were unified, shading of architectural surfaces was restricted to the bare essential; measurements, scale factors, and annotations were integrated in the overall layout of the drawings. This normative process further reduced the architects' artistic autonomy in architectural drawings.

> *Standardized drawings and models eventually became part of the architects' contractual obligations with their clients. Architects, now empowered by these new techniques and standards, began to publicize their projects for their professional colleagues as well as for the general public, thereby disseminating their ideas and attracting potential patrons* (Piccolotto, 2002, p.68).

Another development in architectural drawing techniques in Renaissance was the use of sections as a representation medium. *Sections were seen as an interface between here and there referring the superimposition of inside and outside* (Duruk, 2000, p.65).

At this period, discovery of Sansedoni elevation by Franklin Toker suggested a shift in the use of architectural drawing (Robbins, 1994). This elevation had many features of modern architectural drawing. It was orthogonal, drawn to scale, provided dimensional measurements on it, and could guide the construction period by means of written notations (Duruk, 2000, p.50). As Robbins points out, we begin to see with Sansedoni elevation, the expression of an idea. This drawing provides an experimental tool for the architect to demonstrate his ideas on the paper (Robbins, 1994, pp. 16-17). Moreover, by this elevation, concepts of scale, dimension, and realist representation also gained importance. Sansedoni elevation can be seen in Figure 2.5.

Today, conventional 2D drawings serve as a primary medium for generating, testing and recording an individual architect's own creative and conceptual musings upon a design. It also serves as an instrument through which these musings are communicated to others directly involved with the project (Robbins, 1994).

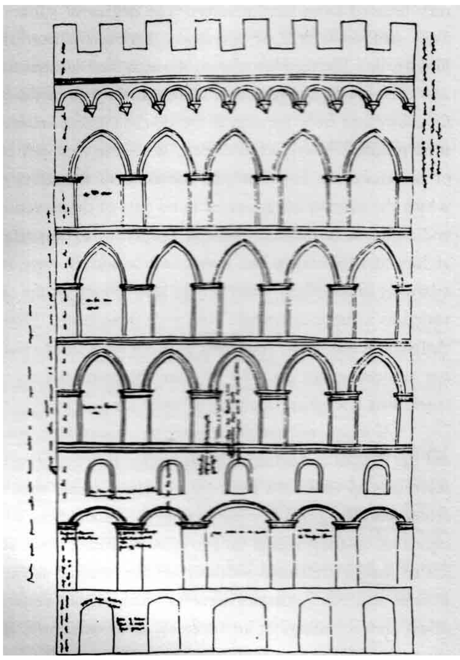


Figure. 2.5. The Sansedoni Elevation by Franklin Toker –14th century (Robbins 1994, p.14).

In a chapter called “Demonstrations” in his book *Monsters of Architecture*, the architectural theorist Marco Frascari describes the relation of drawing to building as follows:

> *The traditional interpretation of this translation is that an architectural drawing is a graphic representation of an existing, or future building. The present modern and post-modern condition of understanding... these translations is that buildings are representations of the drawings that preceded them.* (Hale, 2000, p.1)

When a contemporary architect works on a design project, he essentially follows traditions and adheres to the very same conventions established during the fifteenth and sixteenth centuries. He uses the same conventional early design and representation tools such as sketches and 2D drawings, because 2D drawings and sketches are the easiest way to depict ideas in design process. On the other hand, although architects still use conventional representation and design methods today, their tools and media have been changing according to the technologic developments.

2.2.2.Axonometric Drawings

Axonometric drawings and plan oblique combine the plan, section and elevation in a single drawing and are increasingly important to many architects today as a way to develop and to represent their designs. Axonometric drawings and plan obloquies are drawings are true to scale plans that projected vertically upward to find the ceiling or roof height or downward to find the floor plan (Robbins, 1994).

The plan oblique is a drawing in which the projection lines meet the picture plane and are shifted to an angle. Plan oblique offers two advantages: First, it gives a sense of the 3 Dimensional form of the object that is drawn to scale, and it can normally be generated from orthographic drawings and views, and second, the offer “a scaled representation of the size and proportion of an object. They can show the 3 Dimensional form of an object while still drawn to scale. Some architects argue that axonometric drawings present the most rational and true 3 dimensional view of a building, while others feel that technically true axonometric drawings are difficult for laypersons to read and therefore best used by architects for their own design purposes (Robbins, 1994).

Parallel projection appeared in the history of western representation as early as the 4th century BC. There is information on the usage of parallel projection in China but for military purposes. Although axonometric representation has been a method used for two thousand years, the beginnings of 20th century has witnessed its metamorphosis from only being a drawing typology into a representative of the abstract idea behind (Duruk, 2000, p.140). The contradiction between the three-dimensionality of the physical world and the 2 dimensionality of the media of representation, such as paper and canvas, provokes the need for finding a way to capture the missing third dimension. Several painters tried to express three dimensional scenes by using axonometric drawings (Bertol, 1997, p.11).

The 17th and 18th century has witnessed the connections of logical, mathematical and universal geometric rules to architectural representation. With the rationalistic viewpoint, the pictorial representation and the symbolic value of perspective has been reduced to geometric abstractions. The former transformation in this age was from the perspective representation and pictorial organization into less symbolic perspectives of 17th and 18th centuries and with the emergence of rational thought descriptive geometry in science. The secondary transformation was into axonometric projection of 19th and 20th centuries. 20th century's architects saw geometry as the most powerful tool in hand. Parallel to this thought, they attacked to traditional architectural representation, especially single point perspective. Shortly, parallel to rationalism, pictorial representation changed to geometric representation (Duruk, 2000, pp.142-143).

Axonometric representation has been preferred not only because of its ease of construction and measurability; but also because of its ambiguous character, which overlaps with the idea of abstraction of the avant-garde. Axonometric representation is "abstract" compares with perspective, since it does not offer the image as the reflection of the real world (Duruk, 2000, pp.147-149). The axonometric and isometric projections are drawings from which the third dimension is inferred. The physical of length, breadth and height are obtained by adding the third dimension usually to plan (Porter, 1979). But isometrics should not be considered as analogues to visual perception. Isometric viewpoints are monocular, static and fixed (Bertol, 1997, p.4).

Axonometric drawings penetrate volumes, while a plan offers the horizontal organization of the architectural object as if we were above and parallel to object. In addition, axonometric drawings have no direction. Perspective imposes a direction towards the infinity through the point of convergence. Axonometric projection on the other hand does not suggest directionality. Lambert claims that perspective is concerned with drawing an object as it is represented to the eye, placed at a certain height and a certain distance. Axonometric representations teach us how to trace its truthful figure in geometric plan (Duruk quoted from Lambert, p.145).

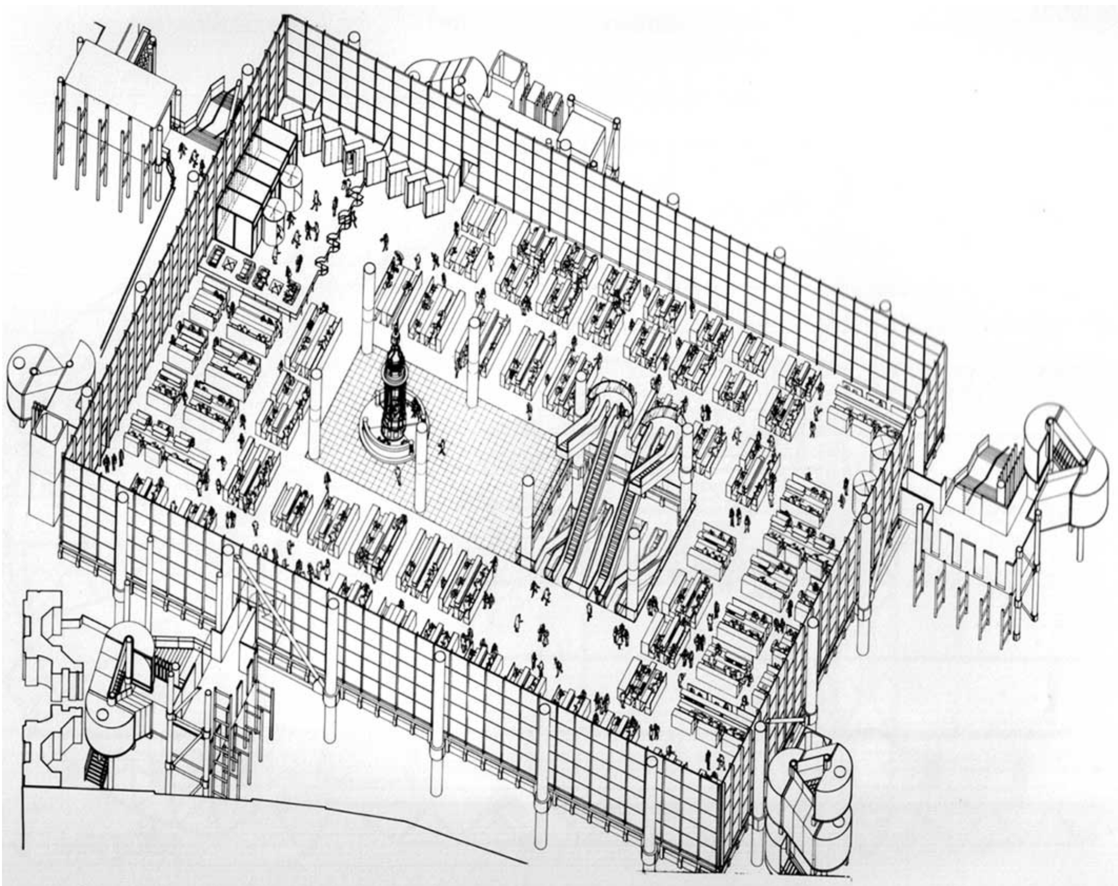


Figure. 2.6. An Axonometric View of Lloyd's Building – Architect: Richard Rogers (Robbins, 1994)

2.2.3.Perspectives

Perspectives, in simple terms, are drawings of solid objects on a 2 dimensional surface done in such a way as to suggest their relative positions and size when viewed from a particular point. Shortly, purpose of perspective is to represent in a 2D medium a 3D scene as it would appear to our eyes (Bertol, 1997, p.4). In geometric terms, perspective is a conic projection whereby the lines from an object converge to a single point. The image is created by the intersection of the converging projection lines with a transparent picture plane (Robbins, 1994).

As a science, perspective is directly related to optics, and created 3D world is perceived as a projection on the 2D surface of our retina. The stereoscopic effect, which causes the perception of depth, is given by our binocular vision (Bertol, 1997, p.4).

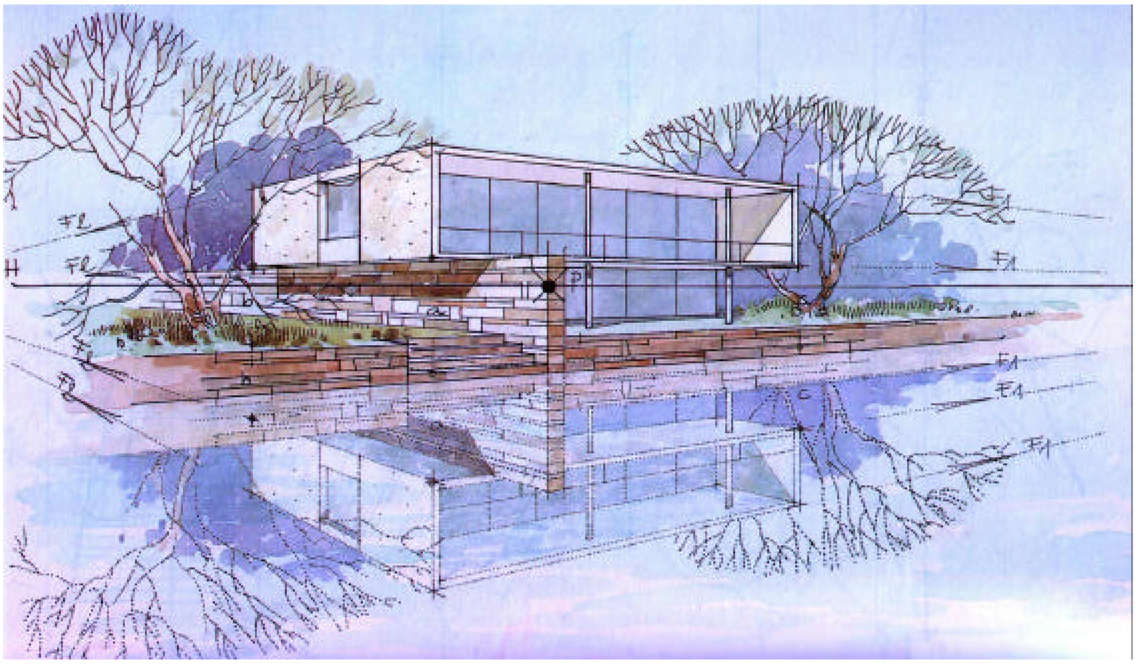


Figure. 2.7. A perspective from Architect Harbi Hotan (Hotan 1993, p.32).

Due to the three dimensionality of the world of our experiences, artists and architects have used perspective representations for centuries to create the illusion of three-dimensionality. Perspective's roots extend to Ancient Greece. Euclid first elaborated the science of optics and the investigations on the ways of seeing in the third century BC. However, representation of space in antiquity was not a systematic representation. The space was represented as the gaps between the objects without any systematic differentiation. The theories on this theme were not succeeded to define the space in a system based on the relations of height, width and depth. The interior space representations at that time were approximate presentations with some faults to today's perspective views.

In Byzantine, it can be observed that they were aware of the Euclid's theory of visual cone. However, their artistic expression never became a window opening into the space beyond. The space in Byzantine art was always in front of the represented image. The space in front of the image was more important than the depiction of depth behind the figures (Duruk, 2000, p.84).

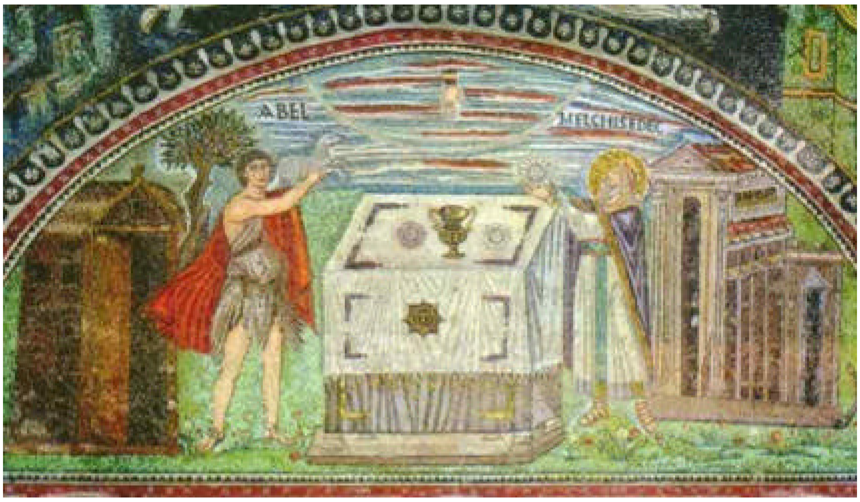


Figure. 2.8. The Offerings of Abel and Melchizedek (Mosaiken in Ravenna http://home.t-online.de/home/ravenn/rav-12.htm#Gesamtbild, 2004)

During the history of architecture, perception of depth in space, and its representation in drawings have always been an important problem for architects and artists. In the European art from the Antiquity to Modern period the description of space overlapped with geometric and mathematical methods; and for this reason, perspectives have been used to surpass this difficulty. For Gideon, two main functions of perspective are the rational representation of space and precise definitions of objects in spatial locations.

Perspective as a pictorial system was fully developed in the early 15th century in pioneering experiments of Brunelleschi and Alberti. But it was Alberti, who first discovered the underlying geometry of perspective and first used two-point perspective. It was related to mathematics and used as a means to express the physical structure of reality with the help of light. Development of perspective brought about an identity relation between vision, nature, and geometry (Bertol, 1997, p.3). In the European art from the Antiquity to Modern period the description of space overlapped with geometric and mathematical methods. The developing methods in perspectiva artificialis changed the act of creating, the perception and the understanding of the space. Perspesctiva artificialis refers to the geometric construction of scientific perspective (Piccolotto, 2002, p.69).

Although Renaissance has introduced the most important presentation of three-dimensionality, architects were not ready to accept artificial perspective as a means to generate the design of a building. Instead they preferred to use perspective as a system or as a form for visualization.

Nevertheless, invention of perspective marked a crucial turning point in architectural representations. Designers suddenly realized that they could translate their visual perceptions into an apparently comprehensible and manipulative series of delineated spatial events, capable of accurately rendering a design invention (Porter, 1979, p.6). The reasons why Renaissance artists preferred the *perspectiva artificialis* to express spatial clarity and depth can be summarized as follows; first, it can be suggested that **perspective allowed them to create reality in a way that is convincing to the eye as well as to mind.** Second, it enables the artists to give a new kind of unity to their design and to achieve a complete harmony. Finally, perspective gave to artists the freedom of playing with depth and creating illusionist scenes (Duruk, 2000, p.88). However, this property of perspective gave architects a chance to play with the reality of the space. Sometimes architects have been using perspectives for gaining impressive but unreal and liar views.

> One of the main objectives in perspective construction, the imitation of reality, still holds true today. At the time of the discovery of perspective, artists, architects, and scientists were interested in investigating and representing scenes and objects from the naked eye, in the form of landscapes, urban scenes, geometric shapes, or anatomic views. The interpretation and representation of reality is still the main focus of

investigating in the contemporary world, even if “real” goes beyond our ordinary perceptions, extending to the microscopic world of atomic particles or to the macroscopic scale of stars and galaxies (Bertol, 1997, p.16).

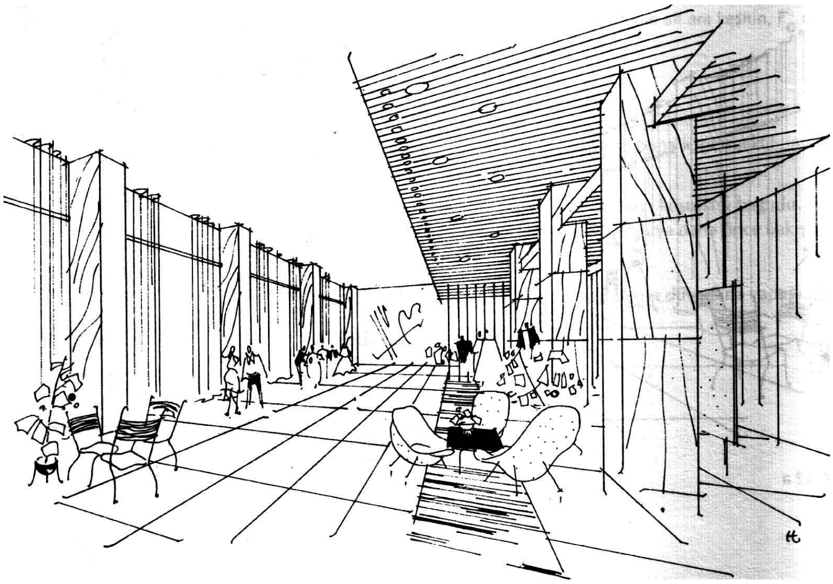


Figure. 2.9. A perspective from Architect Harbi Hotan (Hotan 1993, p.27)

Today; perspectives create rational, infinite, unchanging and homogenous space to be represented on two dimensional medium, so it can be thought as a suitable vehicle for representing space and depth in 2 dimensional media. However, perception of space and depth in perspective drawings can be so misleading for users of those drawings. Perspective drawings are not real 3 dimensional media, so they can not provide a complete spatial perception. In a real three dimensional media, users have a chance to look from different view points. Perspective drawings are a kind of imitation of human’s view from only one stable point. This means that users can not change his/her point of view, and parallel to this situation, they can not have real spatial perception.

2.3. Attempts to Reach Reality in Architectural Representations

2.3.1. A Brief History of Architectural Representations

During the history, getting more realistic imitations of reality in presentations has always been an important purpose for architects and artists.

To reach this aim, they have used color, texture, chiaroscuro effects in their models, drawings and paintings. Before standardization of technical drawings, they generally used models for reaching this goal. Moreover in 2D media; architects generally used paintings for this aim, because orthographic drawings can not fully represent color, texture, etc. of the object. However, after Renaissance, standardization of architectural drawings increased the use of this medium for reaching realistic representations. Especially development of perspective in the 15th century was indeed one of the most important milestones in the path which leads to the simulation of 3D forms through 2D media.

Before Renaissance and standardization of drawings, especially in Gothic era, architects had made attempts on realistic representations on orthographic drawings. Surfaces and material qualities were exalted by coloring the surfaces as well as the background, particularly in elevations, to the point of achieving a quasi-plastic relief effect. The elevation in figure 2.10 attempts to convey the material quality of the structure, but this drawing was just for clients and patrons not a guide for construction.

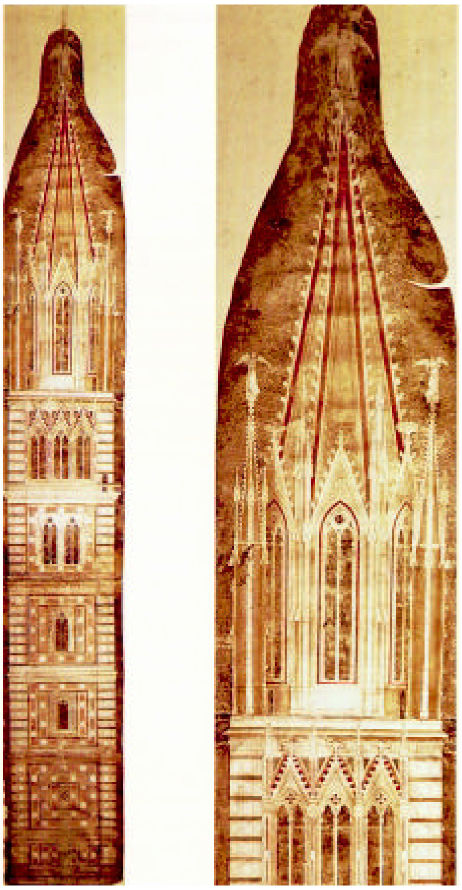


Figure. 2.10. Elevation of the campanile for the Duomo of Florence (Piccolotto, 2002, p.56).

Furthermore, the complexity of Gothic sacred architecture might have been an important inhibitory factor for building detailed representational models of these structures. The use of detailed architectural models in the design and construction process became common practice in Italy during construction of the cathedrals in the fourteenth century. As representational models, they played a crucial role in seeking approval from communal authorities and patrons (see figure 2.11). (Piccolotto, 2002, p.61). Some of these models were more detailed and embroidered than the real building.

Figure. 2.11. Model of St. Peter's by Antonio da Sangallo the Younger (Piccolotto, 2002, p.90).

In Renaissance; after standardization of orthographic representation and development of new technologies such as printing, engraving, and etching, architects began to produce more realistic technical drawings by the helps of variety of textures and shades. Illustrations in figure 2.12 and 2.13 are good examples for this style. Drawings in these figures are strictly orthogonal, indicating that architect did not intend to show the building from a specific viewpoint. These are analytical views of the building that emphasize spatial sequence, relative sizes and proportions by the help of plan, elevation and section. Also, these drawings allow for highly detailed depictions of architectural examples and they are most probably for architects (Piccolotto, 2002, p.94).

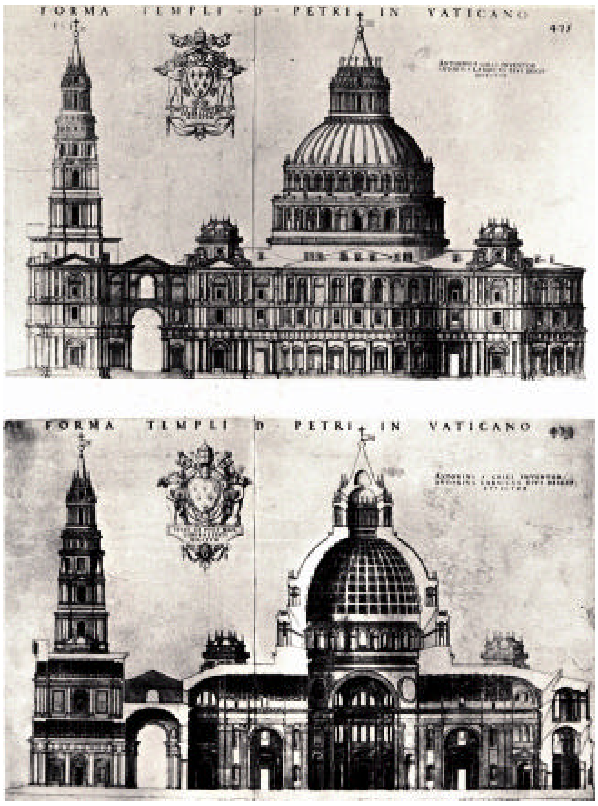


Figure 2.12. Print of St. Peter by Antonio Labacco (Piccolotto, 2002).

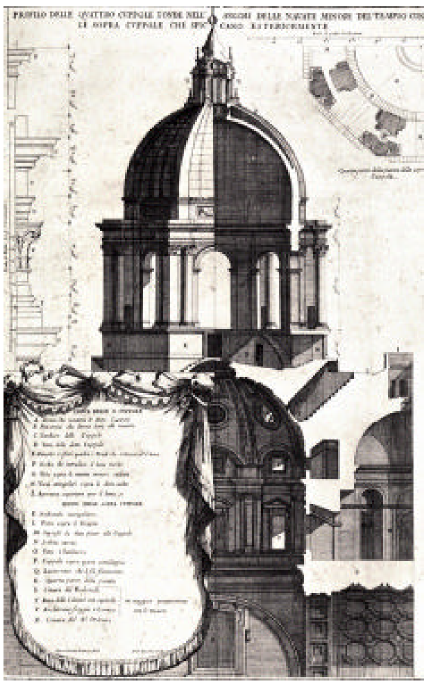


Figure 2.13 Print of the minor dome of St. Peter by Carlo Fontana (Piccolotto, 2002).

Moreover, in this era, geometric construction of perspective in painting was combined with the use of color to create realistic representations of three-dimensionality. The masterly use of color and chiaroscuro together with aerial perspective succeeded in defining volumes, masses and voids as well as the curvature of surfaces (Bertol, 1997, p.12).

By these attempts, a new style had been developed: "Trompe l'oeil". The expression of trompe l'oeil comes from the French language, and literally means "fool the eye". It denotes the painted representation of a three-dimensional scene, rendered in such a way that, from a particular viewpoint the monocular perception of it would be the same as that of the three dimensional objects represented in trompe l'oeil. The actual three-dimensional space becomes extended in the plane of the pictorial space of the representation. Trompe l'oeil has often been used to create the illusion of impossible three-dimensional constructions (Bertol, 1997, pp.20-21).

Figure 2.14 Baldassare Peruzzi: Salla delle Prospettive, Villa Farnesina, Rome (Kubovy, 1986, p.35).

Figure 2.15: Ceiling of the Church of Sant'Ignazio, Rome (Kubovy, 1986, p.33).

By this method, artists and architects tried to represent an unreal space, and this is a kind of architectural illusion or basic virtual reality. Viewers seem that the objects are there, but everything is an illusion. These paintings are thought as the ancestors of holograms and virtual reality systems which will be explained in Chapter 3. However, effectiveness of trompe l'oeil and similar techniques were limited. It can only be possible by the condition that the observer views the work from a particular viewpoint.

2.3.2. Contemporary Computerized Representations

The history of architectural representation is a gradual step by step development in thinking and technology starting with basic models and drawings to today's computer technology. Paper, which up to only a few decades ago was the only 2D medium, offered to architects and designers for the representation of the 3D world, has been replaced by the computer screen where the computer generated visualization is displayed. Although the technology and the media are changed, the fundamental purpose, "more realistic and successful representation", has not changed during these centuries. In today's architecture world, just tools are changed. While in the past, architects and artists were trying to illustrate space by hand made perspectives and water color presentations, today they use computer aided design (CAD) software and presentation techniques as supporter tools and intermediary medium for the same purpose.

Today, computer aided representation tools have begun to take places of conventional techniques used in architectural design and representation. For example, computer based 3D models began to substitute for 3D physical models. Basic computer perspectives and photorealistic renders can symbolize some specific characters of spaces better than models, but can not represent object exactly.

Computer based design process also began to take place of pencil based design processes. Today, computer techniques and architectural software have an important role in this area of architectural presentation. Today, most of architects use mouse and keyboard only in place of pencils. However, at this point it can be claimed that design strategies and use of computer based tools are still the same with conventional methods. Maybe in the future, this situation will be changed and architects will need to use developed computer aided design techniques and new representation methods in design process.

Computer technologies have not changed the aim and use of perspective drawings, but changed the drawing technique. While at the beginning these perspectives were prepared hand-made, today's architects use computers' graphic interface for the same aim. Moreover, basic rules of geometric construction are still used for visualization of 3D scenes in computerized presentation techniques and, therefore, in VR representations (Bertol, 1997, p.36).

Moreover, computer programs and software also use axonometric drawings as a representation medium. Today, most of the CAD programs use and benefit from axonometric drawings in their design interfaces and 3D Window logic (see Figure 2.16). This is because; program producers know that axonometric drawings have an important role in architects' early design process. Architects already use axonometric drawings to test their early design and perceive some characteristics of the buildings. Axonometric drawings easily show volumes and provide an objective look to the model building.

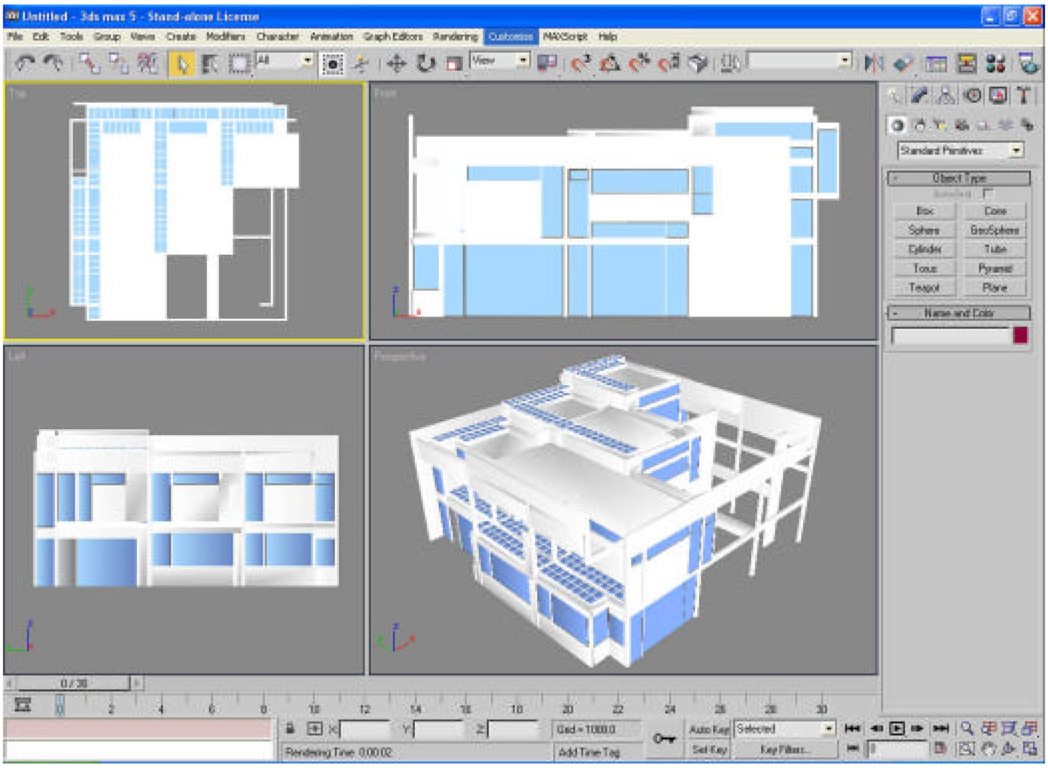


Figure. 2.16. A CAD Program's (3D Studio Release 5.1) Interface

Some of the researchers think that, in the future, by the help of the developments in computer technology, representation of space in 2D media (paper or computer screen) with static and fixed drawings will leave its place to dynamic virtual reality (VR) systems. VR is the ultimate representation, with the aim of simulating reality in such a way that our perceptions of the virtual environment replace the perception of real environment. Today, basic versions of this technology like "Desktop Virtual Environments" (DVE) began to take place in computer games or architectural representations.

Chapter 3

EFFECTS OF DEVELOPMENTS IN COMPUTER TECHNOLOGIES ON ARCHITECTURAL REPRESENTATION TECHNIQUES

This chapter aims to define computer terminology related to architecture, and introduce the development of computer programs and equipments used in computer aided design (CAD) process. These techniques have definitely affected and changed the design strategies and also the presentation methods in architecture.

3.1. Computer Technologies in Architecture

Computer systems have two components: Hardware and software. Furthermore, there are two common hardware systems. These are PC (Personal Computer) and NC (Network Computer). A PC is used in an office or home without the need to be connected to a larger computer, and NC is the client of a larger server system. Recently, most of the users in the world work with PC based computers. This is because of the flexibility of PC technologies that can be easily adapted to all disciplines and professions.

Today, software and hardware companies have collaborative researches to produce special computer technologies peculiar to specific disciplines. In architecture, software technology can be thought in two groups: First group consists of non-graphical, mathematical calculation based basic engineering softwares. Basic static, illumination, HVAC calculation programs can be thought in this group. Second group consists of visualization based complex and specialized softwares (Yarkan 2001, p.5). This kind of softwares calculates the necessary information and visualizes them on the screen. Drawing programs such as AutoCAD, ArchiCAD, and modeling and visualization programs such as 3D Studio, Cinema 4D can be suitable examples for this group. All systems and techniques in these two groups are generally called Computer Aided Design (CAD) programs. CAD technology and related softwares help designers to prepare drawings, specifications, parts lists, and other design-related elements using special graphics and calculations. CAD Programs are used for a wide variety of products in such fields as architecture, electronics, and aerospace, naval, and automotive engineering. Although CAD systems originally were merely used for automated drafting at the beginning, at present they usually include three-dimensional modeling and computer-simulated operation of the model. Rather than having to build prototypes and change components to determine the effects of tolerance ranges, engineers can use computers to simulate operation to determine loads and stresses. For example, an automobile manufacturer might use CAD to calculate the wind drag on several new car-body designs without having to build physical models of each one (Digital Encyclopedia, http://www.encyclopedia.com, 2004).

3.1.1. CAD Systems in Architecture

The first Computer-Aided Design system had been produced by Prof. Charles Eastman at Carnegie Mellon University. The research was called "The Building Description System". This system used simple algorithms to display patterns of lines in 2D, and it is a library of several hundred thousands architectural elements, which can be assembled and drawn on screen into a complete design concept (History of CAD, http://mbinfo.mbdesign.net/CAD-History.htm, 2004). However, this attempt had never been successful because of the difficulty in usage of the program.

Today's CAD system in architecture must have the hardware such as high resolution graphic screen (for vision), mouse, electronic digitizer (for input), plotter (for output), 2D or 3D scanner (for digitizing physical media), and electronic cards (for mathematical processes, coordinating the other components, saving files and etc.) Moreover it needs complex softwares that can make sufficient graphic visualizations.

From the beginning of 1980s, lots of Computer Aided Architectural Design (CAAD) softwares have been put on the market. At the beginning, these programs were usually used multi-purpose. Thus, they had the same interface for all designers such as architects, engineers. AutoDesk's AutoCAD program can be an example for this situation. Design of the AutoCAD program is not specialized for a specific profession such as architecture or mechanical engineering, and has a suitable interface for all professions' general use.

However, at the moment software companies have been choosing to produce specialized programs and interfaces for every discipline. Autodesk's Architectural Desktop, Graphisoft's ArchiCAD, Nemetschek's All-Plan FT are among the example architectural softwares. We can summarize practical benefits of CAD systems in 3 groups:

1. In Design Process

- The speed and productivity are improved by the use of automated design and representation systems. For instance, when you're working on paper and a customer wants to change a drawing, you have to draw it all over again. However, In a CAD based system, you make the change immediately and print out a new drawing in minutes, or you can transmit it via e-mail or Internet all over the world instantly. Thus, by CAD based design systems, architects have more time for real design process.
- One of the biggest contributions of computers to the design process is soft prototyping -the process of creating a 3D-computer model of a design that can be subjected to computer-based testing. Soft prototypes (Virtual prototypes) are almost faster and cheaper to built than real physical prototypes and are often better at their main activity than a real ones; that is because 3D physical prototypes usually use processes and materials very different from those ultimately used for the production version of the product, so it can be impossible to evaluate the performance of materials, or details.
- A computerized tender can be sent with the appropriate specification and technical details. On receipt of an order, all of the documentation relating to manufacture, testing, dispatching and invoicing will be available.
- Digital media of CAD systems gives architects opportunities of collaboration with the other professions. Both of architects and engineers, or different design groups can study on the same drawing or same project at the same time.

2. **In Perception of What is Designed:**

    - Generally, property of three dimensional design is another advantage of CAD systems. In a conventional paper based media, users only see the abstractions of architectural materials and elements, but in a CAD based system, architects can see what they have designed 3 dimensionally on the computer screen in real time. At this point, computer screen can be thought as a window from real to the virtual, and architects can watch and examine their thoughts' and imaginations' simulations from this window. By this way, most of the researchers think that perception of the 3D textured and colored computer simulations should be more successful than the perception of 2D architectural abstractions. However, in some cases, computerized representations can also be failed. Moreover, in some cases, textured 3D computer renders and imaginations can be misleading for users. Sometimes, especially in architectural competitions, architects benefit from this missing point of computer based design and presentation techniques. For example, by some graphical tricks on the final renders can cause misleading perceptions for users.

3. **In Presentation and Multiplication of What is Drawn:**

    - CAD information is stored in digital form and hence, irrespective of the size of the final printed drawings.
    - The soft prototypes can resemble the final product much more closely than any real material prototypes. Realistic images of the soft prototypes can be used by marketing people to produce sales collateral, manuals and the whole gamut of marketing materials. They can even be used for testing marketing to determine whether the product is worth producing at all. Sale departments use 3D illustrations in brochures and literature for promotional applications. Presentation programs with rendering models and animation in 3D form a large part of selling and advertising in today competitive market (Introducing CAD, http://mbinfo.mbdesign.net/CAD-Intro.htm, 2004).

3.1.2. Digital Simulations in Architecture

Simulation is the imitation of a reality or a process. As a word, simulation comes from the Middle English term “simulacion” at around the 14th century, and this word was derived from the Latin word “simulatus” (Webster, 2000). Although this word has been known for centuries, its definition was made clear in the 20.century after the development of computer and information technologies (IT). Computer simulation is the discipline of desiging a model of an actual or theoretical physical system, executing the model on a digital computer, and analyzing the execution output. Simulation embodies the principle of "learning by doing" - to lean about the system we must first build a model and make it run. Computer simulation is the electronic equivalent of this type of role playing (GMU, http://www.science.gmu.edu/~akhatri/intro.html, 2004).

First real time digital graphic system and simulation was the US Air Force's SAGE (Semi Automatic Ground Environment) air defense system. The system was developed at Massachusetts Institute of Technology's (MIT) Lincoln Laboratory in mid 1950s. The system mainly aimed to show computer-processed radar information (History of CAD, http://mbinfo.mbdesign.net/CAD-History.htm, 2004). After SAGE, simulation systems have been developed and became widespread for three decades. Today, simulations are used in a lot of professions and sector as a common technique.

Architects express themselves by drawings and models. Architectural drawings are the representation of objects and real buildings, so we can think all types of architectural representations and drawings (plans, sections, elevations, perspectives, 3D physical models) as a kind of simulation. Thus, it can be claimed that simulation has been used in architecture for decades. Furthermore, best simulation of an object is the most similar one to the original, so traditional architectural media’s best simulation is 1/1 physical models. Therefore, we can classify architectural representations and visualizations (simulations) in four groups according to their media:

1. Physical Paper Based Media: 2D and 3D drawings on papers such as plans, sections, elevations and perspectives.

2. 3D Physical Substances: Physical 3D Models (If its scale is 1/1, it completely meets the definition of the simulation.)
3. Digital Media: Computer based media and complex electronic systems.
    a. Screen Based Digital Media: Digital based plans, sections, elevations and perspectives on a monitor or digital visualization equipment. Graphical presentations, photo-realistic, hyper-realistic presentations and animations can be thought in this group.
    b. Virtual Reality (VR): It completely meets the definition of the simulation.
4. Holograms (Ates, 1998, p.53).

3.1.2.1. Visualizations with Digital Simulations

Simulation is a general term and almost affects five senses. Visualization is a sub-group of simulation, because it only addresses to eye. Conceptually all visualization techniques in architecture can be thought as simulation, but practically it is more suitable to use "visualization" for all presentation techniques in architecture except physical 1/1 model and digital virtual reality (VR) (Yarkan 2001, p.10). This is because; presentation techniques except physical 1/1 model and digital VR only address to eye. (Digital VR models aims to address not only to eye, but also to ears and tangible senses; and physical 1/1 model addresses to all five senses.)

It is possible to classify computer aided visualization techniques according to their presentation style in three groups:

1. Graphic Presentations:

This method is the union of physical based presentation techniques (Coloring, charcoal pencil, collage, texturing, etc), and digital presentation techniques (Wire-frame, animated collage, hyper real collage).

Figure. 3.1. Computer Based Graphic Image (Designer: Ozan Onder Ozener)

2. Hyper-Real Presentations:

When we look at the origin of the word, by hyper-real, Baudrillard means the representation of a thing or event which has no counterpart or analog in sensible reality. The hyper-real is, in a sense, a new thing which seems to refer to something real (Baudrillard, 1988). Moreover, as a CAD term, hyper-real is visualizing and animating the constructed view of design with elevations, perspectives, plans, etc. In this visualization, color, texture, light, shadows, etc. of the object and building imitate the physical building. This method is also called “photo-realistic presentation”.

Figure. 3.2. Hyper-Real Render Image [I.R.4]

3. Animations:

Animation is the simulation of movement through a series of pictures that have objects in slightly different positions. For animation to work, the pictures making up the animation must replace one another quickly enough to trick the human eye into believing there is movement. A replacement rate of at least 14 frames per second or faster accomplishes this sense of movement (Yarkan 2001, p.11).

Architectural visualization techniques are explained above from the most basic one to complex systems. Today's the most complex simulation (and also visualization) system is virtual reality (VR) system; and at this point, it is necessary to describe this system, and it's sub-groups and different methods.

3.1.2.2. Virtual Reality (VR) in Architecture

Traditional representation techniques and media don't allow users to perceive space's characteristics exactly. For this reason, virtual reality (VR) technology aims to insert five senses into the design process, and perception (Unaldi, 1999, p.56). Virtual Reality is a computer generated environment with and within which people can interact. Michael Heim defines virtual reality as an event or entity that is real in effect but not in fact. He points out that there is a sense in which any simulation makes something real that in fact is not (Heim, 1993).

VR environments offer users immersion, navigation, and manipulation. The advantage of VR is that it can immerse people in an environment that would normally be unavailable due to safety or perception restrictions (Digital Encyclopedia, http://www.encyclopedia.com, 2004). For these reasons Virtual Environments (VE) can be an experiment media for architecture.

Virtual Environments can be studied in two groups:

1. Desktop Virtual Environments
2. Complex Virtual Environments

3.1.2.2.1. Desktop Virtual Environments (DVE):

Desktop Virtual Environments (DVE) systems are less-complicated systems suitable for personal computers. They manipulate an image of three-dimensional space on a computer screen (Digital Encyclopedia, http://www.encyclopedia.com, 2004). Movement occurs by the help of conventional input equipments such as mouse or keyboard. In this technique, monitor is an interface between physical environment and virtual environment. Thus monitor screen becomes a window to VR.

Today, desktop virtual reality is used widespread in some electronic games (such as Quake, Sims, MDK, Unreal, Soldier of Fortune, etc), in amusement-park attractions and in military exercises. Figure 3.3 is a good example for DVE systems.

Figure. 3.3. A DVE Example – “Soldier of Fortune” Game Interface

In architecture, this technique has been directly used in a few ways:

First, “3D Modeling Window” interfaces of CAD Programs (such as AutoCAD, ArchiCAD, All-Plan Ft) and solid modeling programs (such as 3D Studio) are a kind of DVE. These windows and interfaces aim to visualize design’s current situation. By these visualizations, the designer can easily walk around the design. Moreover, he can make real time rotate and zooms around the objects, and examine the design from all views. Briefly, the designer has a chance to perceive the design better.

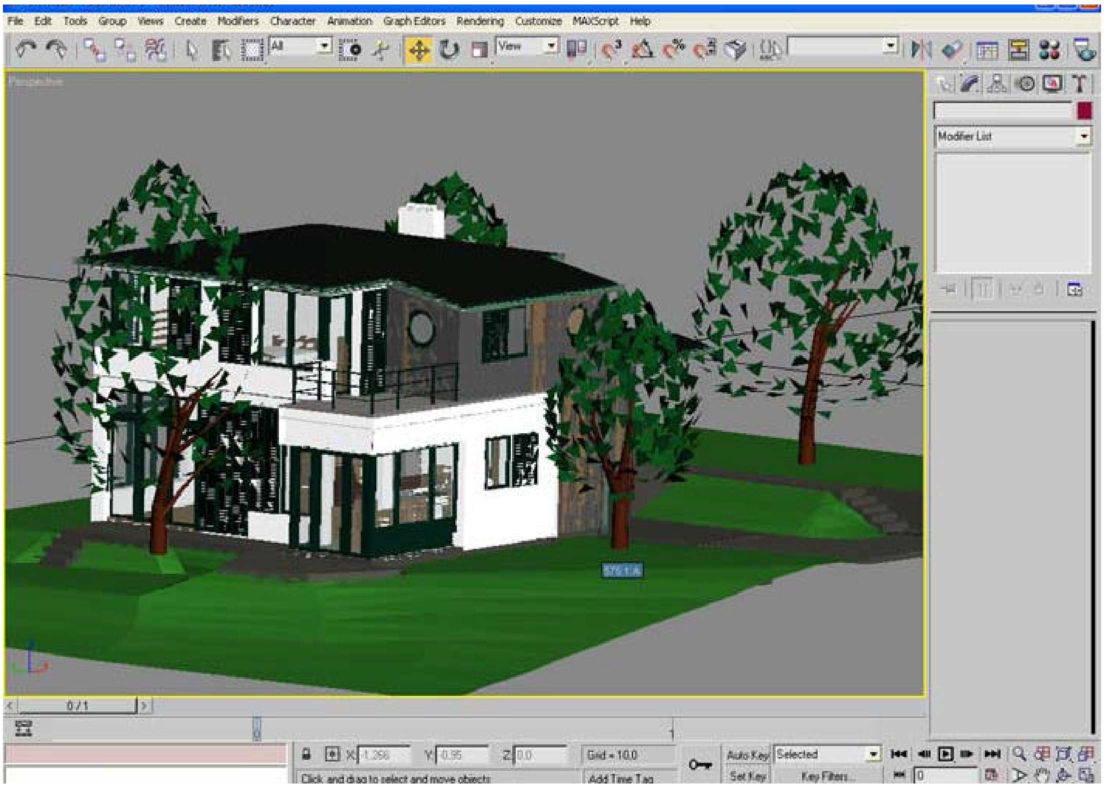


Figure. 3.4. A DVE Example – “3D Studio MAX 5.1” Program Interface

Second method is a kind of specialized version of first use. By the help of some computer languages like JAVA, VRML and XML more complex 3D models can be produced. These interfaces don’t need specific complex architectural programs to view model, and only Internet Explorer with a basic plug-in is sufficient to view. For this reason, architectural databases like “Great Buildings” (http://www.greatbuildings.com) generally use this method for publishing 3D models. Most widespread interface of these kinds of models is VRML Models.

VRML stands for “Virtual Reality Markup Language”. It parallels HTML (Hyper Text Markup Language) in many ways, but the difference between HTML and VRML is that instead of the media being presented in "hypertext" it is presented in “Virtual Reality”. This essentially means that instead of a world that you can only simply explore in two dimensions (with scroll bars), you have the world that can be explored in three dimensions. VRML is simply a 3D space to explore with links to other 2D or 3D spaces (Sagun, 1999).

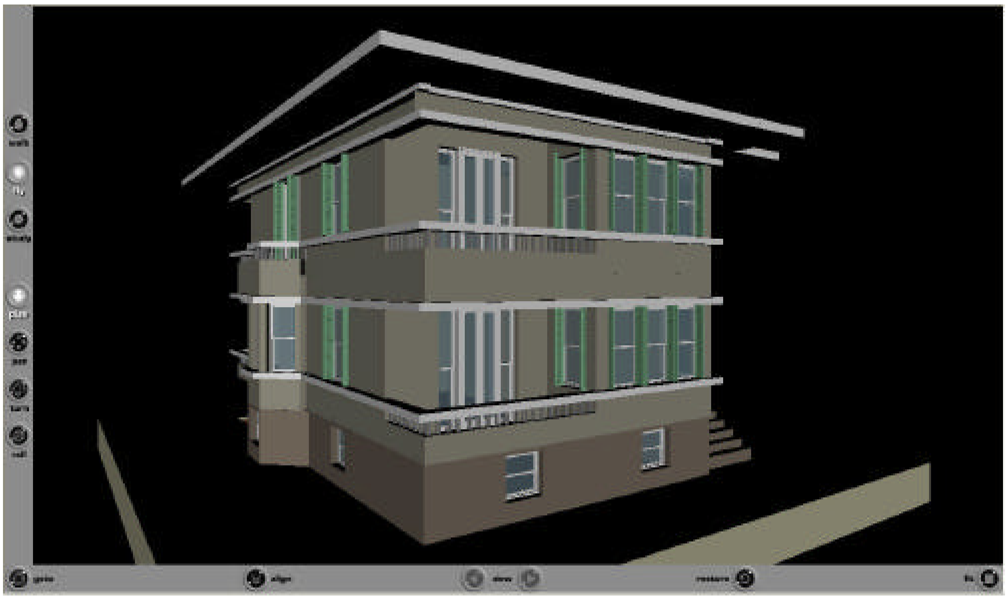


Figure. 3.5. A VRML Model – "Architect Necmettin Emre's Villa in Karantina" (Modeled by Yenal Akgun)

3.1.2.2.2. Complex Virtual Environments:

More complex virtual reality systems can achieve more realistic effects, sensible simulations and interactive environments, but they need very special and expensive equipments, so this system is only used by high-tech industries like defence, space, cars etc. These systems' most important advantage is "immersion". These systems generally provide this immersion and realistic by using a helmetlike apparatus, or specific glasses (one in front of each eye and each giving a slightly different view). Sensors attached to the participant (e.g., gloves, bodysuit, footwear) pass on his or her movements to the computer, which changes the graphics accordingly to give the participant the feeling of movement through the scene. Computer-generated physical feedback adds a "feel" to the visual illusion, and computer-controlled sounds and odors reinforce the virtual environment (Digital Encyclopedia, http://www.encyclopedia.com, 2004). Some of the Immersive Virtual Environments can be enumerated as follows:

1. **3D Shutter Glasses:**

An alternative way of creating more 3D images uses special eyeglasses, which vary the image being received by each eye, so that the two images can be fused to create a 3D perception. One variant uses simple Red-Blue filters to create two separate images, but these are relatively crude in their ability, being primarily limited to wireframe cartoons. More sophisticated are "shutter-glasses", which use a moderately high-frequency (above 20 Hz) shutter to alternately receive images in one eye and then the other, synchronized with a special projector or CRT which also alternates images at the same frequency. This technique can create quite convincing 3D very much like a hologram. The big disadvantage is the need for special glasses which must be tethered by a wire to the display device (Ervin, 2001).

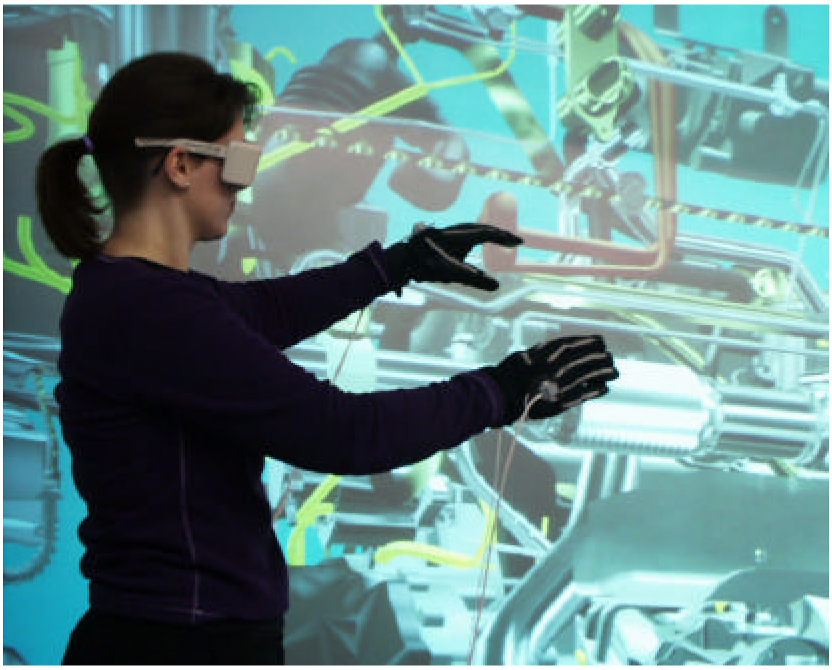


Figure. 3.6. Equipments of a 3D Shutter Glasses

2. Quick Time Virtual Reality (QTVR):

A computer based format for presenting landscapes is the animated panoramic view presented by Apple Computer's QuickTime Virtual Reality or QTVR format. This provides 360° cylindrical view, around a fixed viewpoint, which can be interactively "panned" by the viewer on an ordinary computer screen. Although the portal is still a rectangular frame, the sense that a "complete landscape" lies behind it helps to minimize the constraining effect of the frame. These QTVR format images can be constructed by stitching together a series of photographs, taken in a 360° circle, using special-purpose software, and some modeling systems can directly export QTVR format (Ervin, 2001).

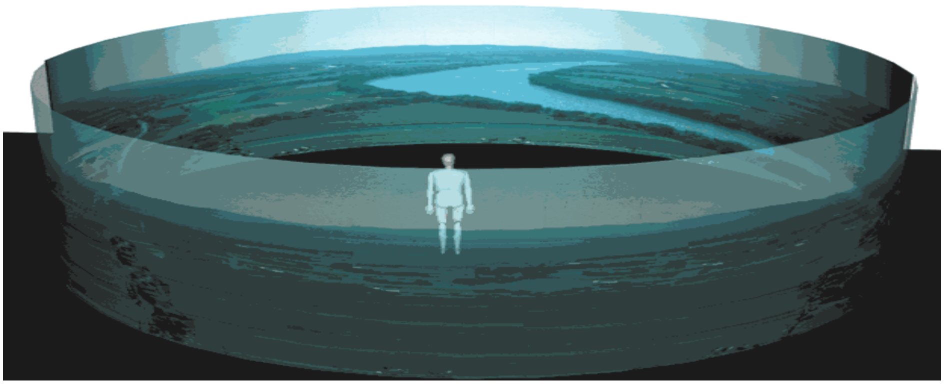


Figure. 3.7. QTVR Systems

3. Head Mounted Display Systems (HMD):

Other VR display systems use special head-mounted displays (HMDs) to create a stereo view by projecting two synchronized images directly in front of each eye of the viewer, and use motion tracking hardware and software to change the viewpoint of the scene as the viewer's head moves, from side to side or up and down. This can give the illusion of being inside a virtual landscape. These systems must create real-time imagery, at up to about 30 frames per second, and so usually have very simple, and highly stylized contents. The constraints on these systems include available resolution (thousands of pixels per eye), and the weight/comfort factors of the head mounted apparatus. In these systems, no awareness of other participants or ambient cues is possible, since each eye is completely covered. HMDs have been extensively explored for very expensive, high-tech, industrial/military systems, such as flight training simulators, and are also available for more modest 'VR' uses. Their ability to display landscapes is still constrained by the ordinary rectangular display presented to each eye (Ervin, 2001).

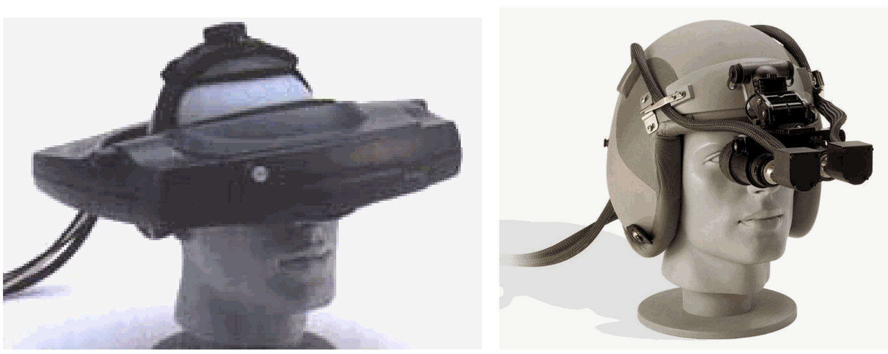


Figure. 3.8. Equipments of HMD Systems

4. CAVE Systems:

The most extreme variation of the surround-screen environment is the so-called "CAVE" visualization environment, in which a cubic volume of space has images projected, usually from the rear, on at least four surfaces, and up to all six surfaces including floor and ceiling. CAVE systems require the most demanding hardware, software, and presentation spaces, as well as special model formats. For real-time animation, as used in scientific visualization, massively parallel computers may be required to generate the 4 to 6 simultaneous images [I.R.6]. CAVE systems are sometimes augmented with shutter-glasses or other techniques, including haptic force-feedback systems, for extending the "virtual reality" of the immersive experience. CAVE systems, which are currently in active use for scientific as well as architectural visualization and simulations, requires more computers, cameras and projectors than any of the other systems, but also may increase the immersive sensation and the robustness of the virtual environment so created (Ervin, 2001).

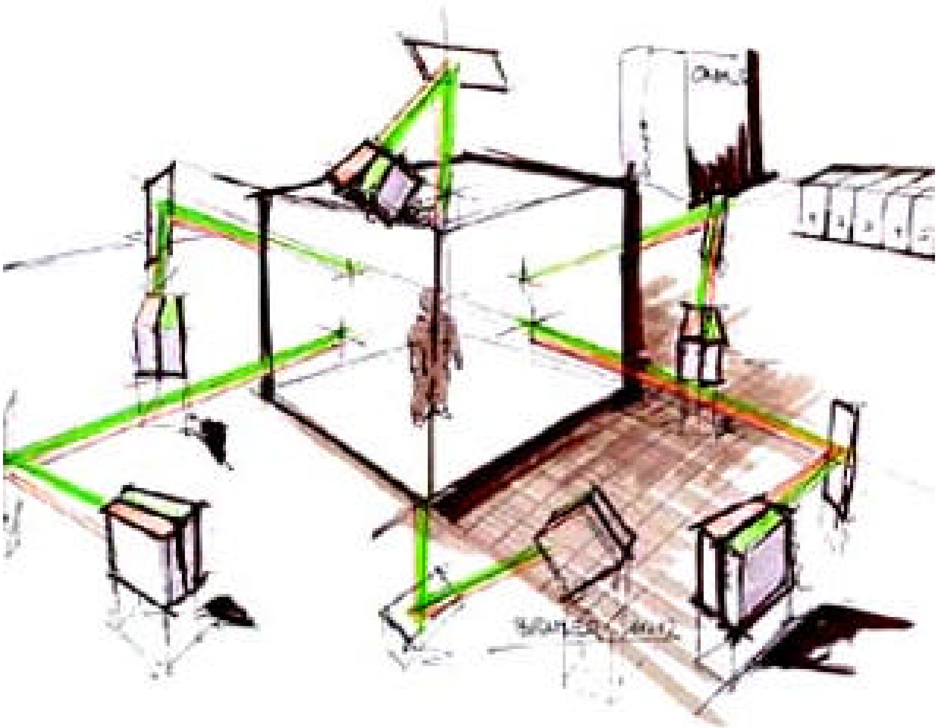


Figure. 3.9. Schematic Structure of a CAVE Environment (Fraunhofer Institute of Industrial Engineering Virtual Reality Lab., http://vr.iao.fhg.de/6-Side-Cave/index.en.html, 2004)

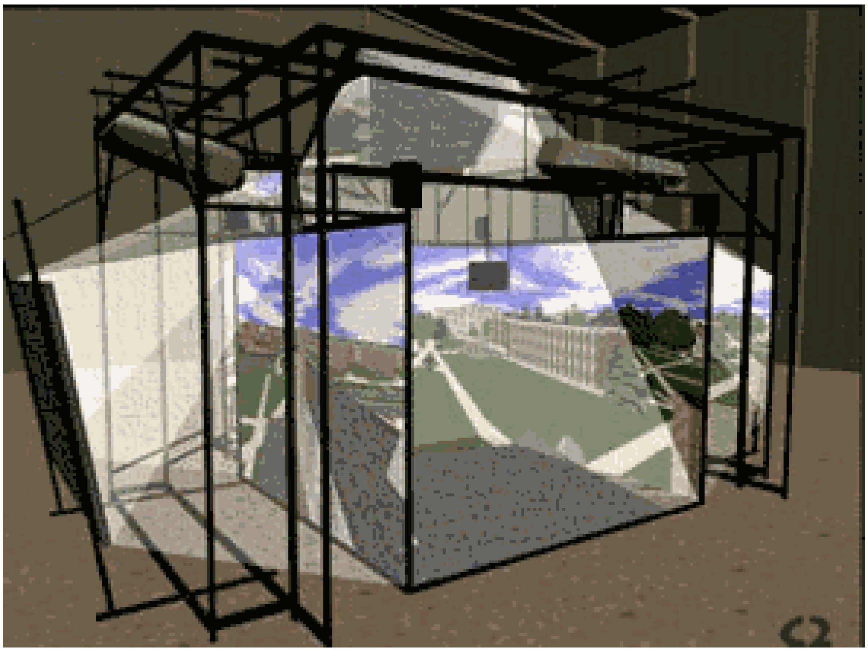


Figure. 3.10. Schematic Structure of a CAVE Environment (Fraunhofer Institute of Industrial Engineering Virtual Reality Lab., http://vr.iao.fhg.de/6-Side-Cave/index.en.html, 2004)

3.2. Effects of CAD Technologies to the Architectural Representations

At the beginning, CAD systems were being used only for digital drawings and representations. This situation began to change after 1990's; owing to the developments of the CAD programs for PC based technologies. After 1990's, CAD systems were began to use in all phase of design in architecture.

Architectural education has also followed a similar process. Although expensive and experimental CAD programs were tried only in a few universities like M.I.T. and Cornell before 1990's, it became widespread after these developments (Yarkan 2001, p.13).

During this time, focus of CAD Programs has been changed from "2D drawing" to "3D design". Thus, main aim of CAD programs changed from "facilitating and accelerating the drawing process" to "facilitating the design process, provide perception during designing and increasing the design quality". In other words, CAD programs try to visualize the architect's ideas during the design process. By the helps of these visual materials, architects can be more conscious about their design.

At this point, it is necessary to determine importance of visual materials and visualization in architecture. Petterson's experiments; that are used by Tokman; on this subject support this idea. These experiments has proved that the most perceivable information is "Visual Information", second is "auditory", and third is "written information". Thus, a person perceives A "bird's picture" faster than the "bird's voice" and a written word "bird" (Tokman, 1999). By the helps of the results of these psychological experiments, it can be claimed that visual and auditory representation techniques such as VR can be perceived better and faster than the symbolic language of conventional architectural representation techniques such as plans, sections, and elevations. This is because; in all versions of visual representations users see the object's itself, but in conventional representations, users see only the symbols and signs of the object.

Consequently, based on Petterson's ideas, we can claim that visual media in architecture (Virtual reality, 3D CAD models, multimedia tools, etc.) are more efficient in rapid perception of the space than 2D conventional representation techniques. However, rapid perception does not mean to perceive definitely. Moreover, another important question can be asked at this point: Is there any differences in perception of space with the change of media? This question will be tried to answer by the questionnaires in the case study.

Chapter 4

PREVIOUS CASE STUDIES ON THE USE OF VIRTUAL ENVIRONMENTS IN ARCHITECTURE

Today, developments in computer technologies have been affecting all sectors in the world and also architecture. In the profession of architecture, these technologies have been causing important changes in techniques of architectural representations and presentations. Computer technologies such as VR (and its sub-systems like CAVE, DVE…) and computerized 3D models began to take conventional techniques' places in numerous areas in architecture. Besides; in some researches, virtual reality systems have been tested and compared with physical realities.

As a result of above mentioned changes in architectural representation techniques, today there are several researches on testing advantages and disadvantages of computerized representation systems and digital media according to conventional methods. This chapter aims to summarize and evaluate these researches and comparisons between digital tools and conventional representation and presentation techniques. For reaching this aim; first, case studies on the subject will be summarized. Then, these case studies will be grouped and evaluated according to three main criteria: 1. according to presentation of architectural space, 2. according to perception of architectural space and form, and 3. according to design process. Finally, general advantages and shortcomings of virtual environments in perception of architectural space and design process will be enumerated.

4.1. Previous Studies on Comparison of Virtual Environments with Conventional Methods in Architecture

1. Case I: Use of VRML as Representation Medium:

This project took place as an experiment to test the validity of Virtual Environments as the primary communication media of building design or construction. In other words, the research aimed to analyze the effectiveness of Virtual Environments as a communication and representation tool for the design and construction industries. The research used VRML as the representation technique of virtual environments.

For testing the effectiveness of VRML as a representation medium, researchers made an experiment. For this experiment, researchers had prepared a 3D computer model of a metal stair. Then, they had converted this model to VRML for sharing world wide by an internet browser such as Internet Explorer. Finally, they implemented a web site which consisted of this VRML model of the metal stair. Because of the characteristics of VRML model, on this web site, users could view the model from where they want. Furthermore, when users clicked on an object of this metal stair, some important explanations about the material, and the dimensions of this object could be seen on screen (Campbell, 2000, p.4). An example view of the model on the web site can be seen in Figure 4.1.

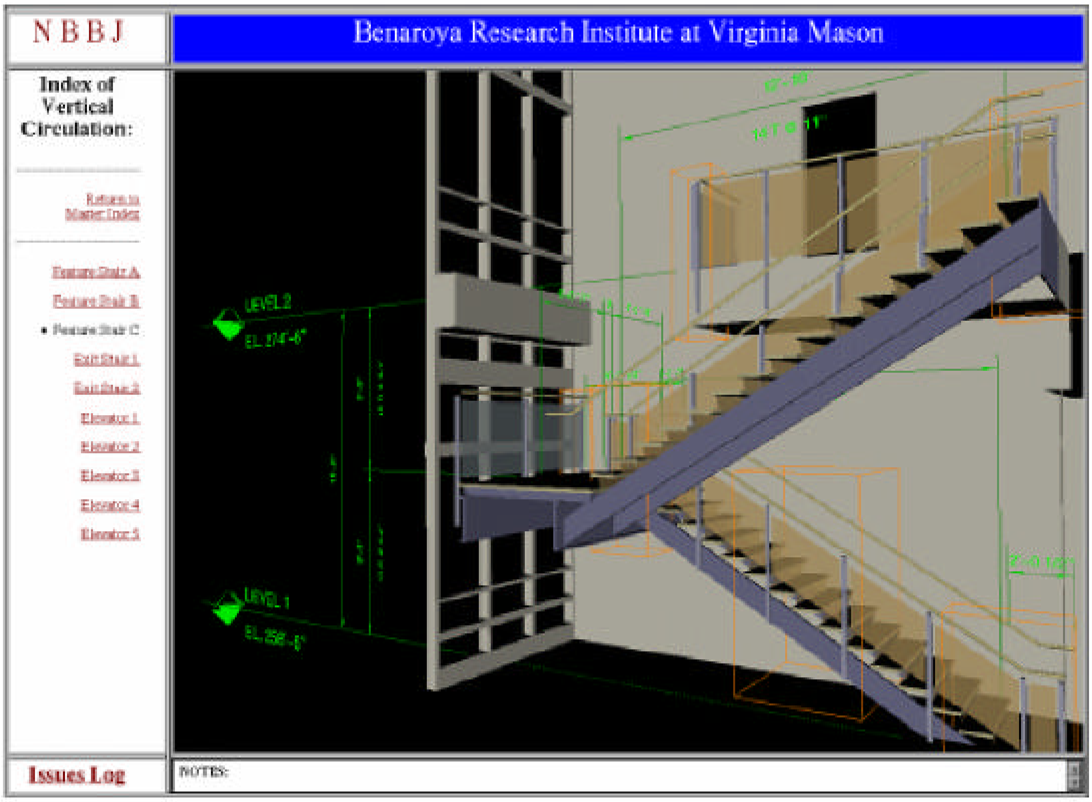


Figure. 4.1. Graphic Display of the VRML model of the Stair (Campbell, 2000, p. 131)

After the development of the web site, effectiveness of the VRML model of metal stair was tested in a series of interviews with the clients. By this way, researchers evaluated VRML as a representation medium in architecture, and they found several advantages and limitations to using VRML as primary representation and communication medium in architecture. Described benefits of virtual environments (especially VRML) as a representation medium in architecture can be summarized as follows:

- When the VRML models were presented to the clients, their reactions were in favor of its use for this application. Thus, it can be said that these systems are user-friendly systems.
- In the case study, details could be seen in different levels because of the use of diagrammatic model as an interface. It is an important reform to investigate objects in different scales by only one drawing.
- With the three-dimensional model available on-line, there is less need to show multiple views of a given space, which means less need for printing out documentation to distribute to subcontractors (Campbell, 2000, p.7).

However, there are also disadvantages and shortcomings of virtual environments as a representation medium. These shortcomings are summarized as follows:

- This kind of web-based models can not be used on the construction site or at the production site.
- The success of web-based construction documents requires that all members of the design or construction team have immediate access to the technology which holds the design data. Today, this is nearly impossible. Moreover, effective use of web based construction documents can be possible after if a truly ‘‘paperless’’ process is to become an industry standard (Campbell, 2000, p.8).

2. Case Study II: Comparison of Perception in Physical View and Televised View: (The Gulliver Gap Project)

This research was realized before the development of personal computers. The study was mainly aimed to compare perception of physical architectural space with its televised image. Even before the computer age, researchers were aware of the advantages of a motion picture than a still picture. Parallel to this thought, the idea of attaching a movie camera to a modelscope as a means of transporting the eye on an animated exploration of the spaces inside and outside of the scale models became an interesting prospect (Porter, 1979, p.92).

An example study on application of this idea was realized by collaboration of Mackintosh School of Architecture and Glasgow School of Art. For their study, they used scale models of real buildings, and they located several cameras to different point of the model (cameras were generally located to view indoor spaces). For moving and gaining realistic inside and outside walking through views from these cameras, they constructed various paths.

After location of the cameras to the 3D physical models, a series of tests were conducted to determine the integrity of the televised image in conveying a sense of space. In order to check responses, different groups of subjects were asked to estimate a series of dimensions such as heights, widths and depths from a televised image of real room, and a televised image of a scale model of the same room. It was significant that the subjects generally displayed a high rate of success in determining spatial dimensions from televised pictures of model spaces and, more particularly that those who had no knowledge of the real space or the nature of the experiment universally accepted the model simulation as a real space. In this way, experimenters demonstrated that it was potentially possible to show observers a convincing and dynamic picture of an architectural space before construction (Porter, 1979, p.93).

However, they saw some disadvantages and insufficiencies of this system according to physical reality. (Some of these disadvantages were because of the insufficiency of technology) The most important of these problems was about the low definition of television pictures (especially black and white) that tended to mask the lack of detail in rough models. As results of this study, researchers exposed that although television pictures can convey dynamic illusions of space; they would not totally replace traditional representational methods, but act as a powerful supplement to the inadequacies of drawings (Porter, 1979, p.93).

3. **Case Study III: Comparison of Perception in Physical Reality, Desktop Virtual Environments (DVE) and Complex Virtual Environments: (The Cube Experiment)**

Main aim of this study was to identify how designers perceive space in Virtual Environments (VE). Moreover; parallel to this aim, the research goals to compare perception in physical environments and virtual environments. To reach these aims, the research made an experiment with a colored cube as main tool and immersive virtual environments (Helmet aided VE), non-immersive virtual environments (DVE) and 2D orthographic drawings as comparison media.

24 architectural students were asked to explore and study the given 3D cube, which was built on a 4x4x4 grid framework and constructed of eight colored and distinguish different volumes (Figure 4.1). The spatial volumes were designed such that they were not intelligible from reading the surface descriptions only (Schnabel, 2002, p.592).

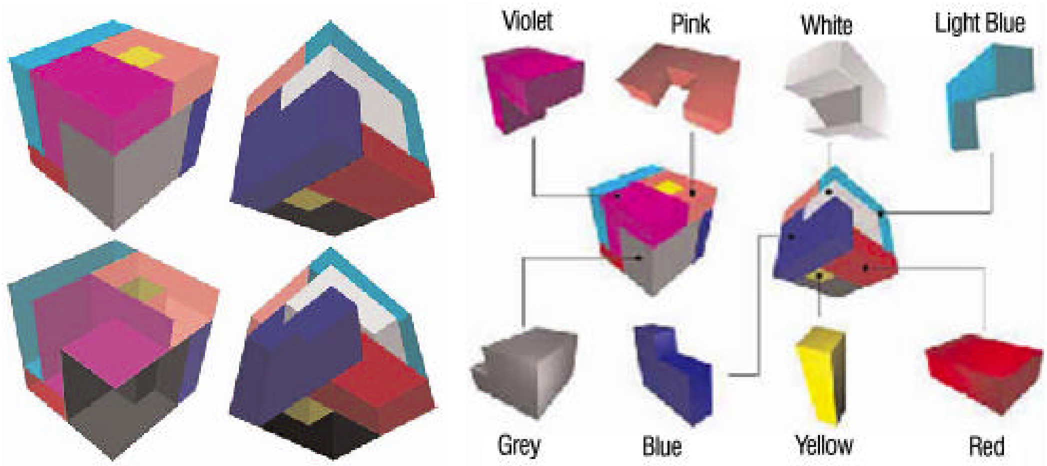


Figure. 4.2. Outside and Inside View of the Cube, and 8 Volumes of Cubic Structure (Schnabel, 2002, p.593)

Students were assigned to inspect one of the three representations (paper, DVE, IVE), and asked to reconstruct the cube using wooden blocks. A time limit of 25 minutes was given to study the cube as well as 20 minutes to rebuild the shapes using 168 wooden cubes, with 21 cubes available for each color. In the 2D design environment participants were given five 2D floor plans (Figure 4.2), represented the five levels of the cube structure. Participant of the

DVE-condition used a web-browser with a VRML plug-in (Cosmoplayer) to view interactively the 3D cube-model, while IVE-participants used the MAZE application, which allowed them to navigate and explore the given cube freely and in real time within the IVE (Schnabel, 2002, p.594).

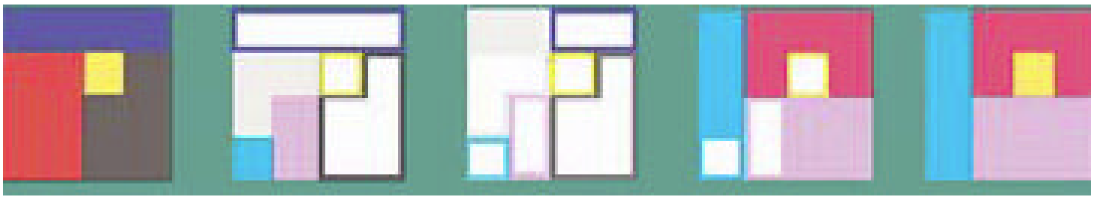


Figure. 4.3. 2D Plans for the 2D Condition

Results of this case study showed that only participants of the 2D media were able to rebuild the cube nearly without any error (Figure 4.3). In some cases participant of the VE conditions placed shapes at a wrong location of the cube (such as upside down or back to front), however the volume was recognized correctly and placed in con-text (Figure 4.4 and 4.5). Desktop interactions with mouse and keyboard are very common and students are well trained in the use of DVE. Nevertheless, the overall outcome was much lower than expected. Students named technical problems of interface and navigation as a major obstacle in their analysis of the cube. They were able to rebuilt distinct shapes, which were easy read and accessible. While participants were able to use the IVE system, the results showed that their performance was substantially worse than the other systems (Schnabel, 2002, p. 594).

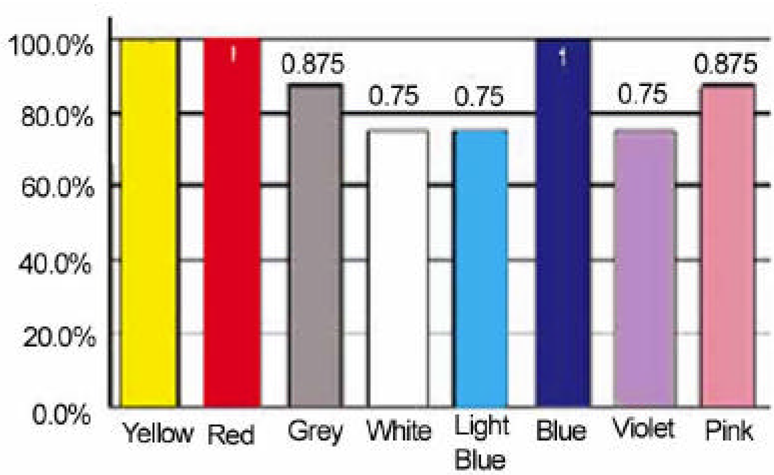


Figure. 4.4. Percentage of Correct Volumes in 2D

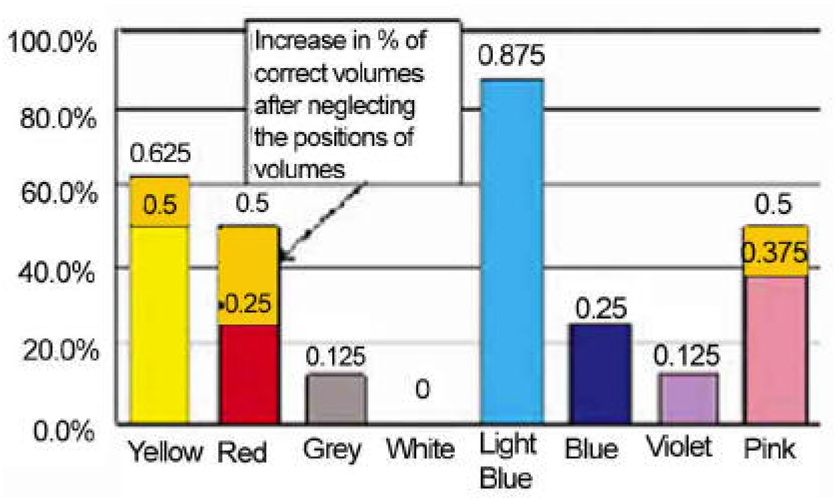


Figure. 4.5. Percentage of Correct Volumes in DVE

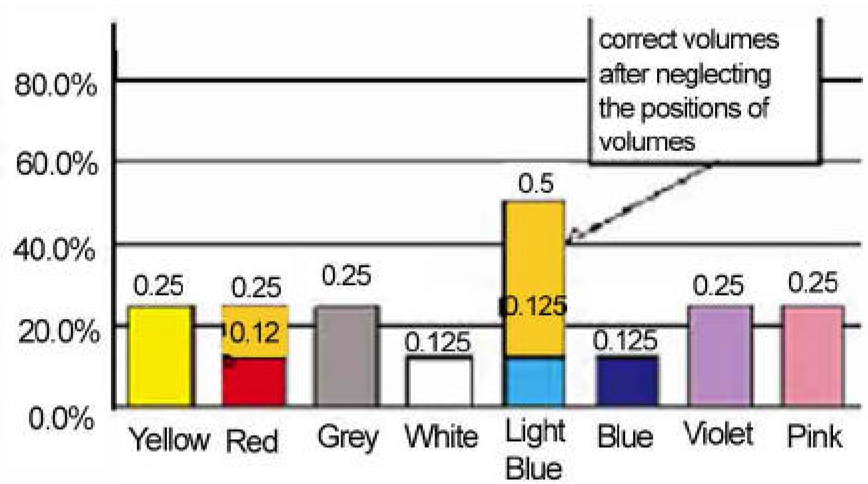


Figure. 4.6. Percentage of Correct Volumes in IVE

However, contrary to statistical results; the research showed that students working within the two VE settings explored and investigated the spatial form and relationships of the volumes more fluid and had therefore a better understanding of the 3D. The participants studied and rebuilt each shape and their relationship to each other within the cube. In total contrast of that, students using the 2D medium analyzed the cube as a stack of 2D 'floors' not relating to the spatial expression of the eight volumes. They simply memorized the floor plans and rebuilt them in the same manner. The evaluation of questionnaires, completed by the participants after the experiment, supported these findings. VE therefore offer designers a greater overall 3D understanding of space and volumes (Schnabel, 2002, p.595).

4. Case Study IV: Perception of Historical Buildings in Virtual Environments: (The Miller Project)

Main aim of this research was to prove that the virtual environments could represent architectural spaces as successful as the physical environments. Moreover, parallel to this thought, the study claimed that it was sufficient to visit virtual versions of the buildings for understanding and perceiving its architectural space and aura.

As it is known; today, in architectural history courses, course materials include images, drawings, sketches and texts as instructional media. However, these media cannot fully communicate the characteristics of three-dimensional spaces. For these reasons, many architecture schools offer study-abroad courses in Europe to offer students first-hand information about the masterpieces of architecture.

For passing over these problems, this research project aimed to develop a VR library of important historical buildings, and use this computer models in architectural education as main course materials instead of sightseeing, or the other conventional information media. The benefits of these VR models were their easy accessibility at any time from various geographic locations and the immersive experience that enhances viewers' understanding of the effects of spatial proportions on form, architectural space and colors of the materials. Thus, these VR models would be a kind of simulations of those physical buildings, and by these models, it would not be necessary to visit real buildings (Chan, 1999, p.1).

For the virtual library, researchers chose seven significant buildings from seven selected periods of Western architectural history: Egyptian (Mortuary temple of Queen Hatshepsut), Greek (Parthenon), Roman (Pantheon), Romanesque (Speyer Cathedral), Gothic (Notre Dame Cathedral), Renaissance (Tempietto), and Modern (Des Moines Art Center). For reaching the aim, the study used two methods and interfaces. First method was to constitute materials to be displayed on the World Wide Web, including rendered still images for perception, movies for a visual guide, and VRML models for user navigation. Second method was to construct complex VR models to be displayed in the CAVE facility (Chan, 1999, p.2). (For detailed information about CAVE Facility, see Chapter 3, page 49)

Figure. 4.7. VRML Models: The Exterior and Interior of Pantheon

Using VR to see numerous buildings in different locations around the world, this research has proposed a new tool for teaching architectural history. Viewers can experience the changes in architectural forms over time and across geographic boundaries without having to visit the actual sites or piece together old drawings and texts. Besides, by this virtual environment, buildings that existed in the past but have since been destroyed or altered can be visualized in full scale in their original form, overcoming the limitations of time and space (Chan, 1999, p.4). In other words, Chan emphasizes the advantages of this library as follows;

> *This library provides immediate visualization of famous buildings in various countries. This provides viewers with an instant perception of the differences in colors and materials used on different sites, and the changes in spatial proportion of forms associated with the cultural beliefs at different periods in time. It is a valuable new tool for teaching architectural history, as it allows viewers to experience various historic buildings and periods in a much fuller way than through text, photos and drawings alone.* (Chan, 1999, p.5).

5. Case Study V: Perception and Application of Virtual Environments in Design Process: (Lund University Project)

This research aimed to evaluate the perceptual effects of complex virtual environments in architectural education. To reach this aim, study used the

CAVE-Interface as test medium, and tried this medium on students of 3rd and 4th years with a three step experiment.

First step's concept was "compact living", and the students studied on various subjects related to this concept. "An airplane cabin for tourist passenger on long charter tours" is one of these subjects. Students used ArchiCAD program as design and drafting tool.

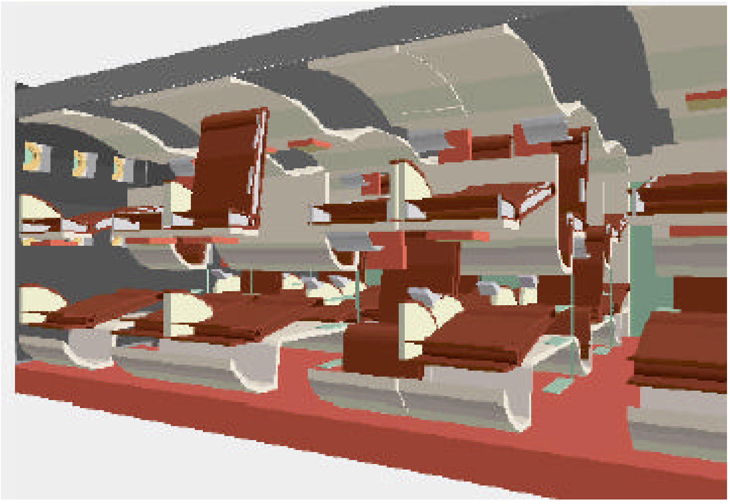


Figure. 4.8. The cut interiors of an airplane cabin for tourist class passengers on long charter tours. It is obvious that the 3D impression is impossible to show in 2D image.

When the model was analyzed and the design criticized by instructors in CAVE-Interface, it was seen that; in the CAVE, it was possible for up to five persons to stand "in the model" and discuss the different details of the proposed solutions. The possibilities of moving about within the limited physical space of the CAVE were very useful and some design solutions were inspected kneeling to look underneath for example a table. Only a big physical model could be an alternative to this system. Both students and teachers were quite impressed by the models and the results (Klercker, 1999, p.3).

In second step of the experiment, same students undertook a new task. This time each of them modeled and visualized a project which had been designed by one of their teachers. Eight unbuilt projects were modeled by ArchiCAD, so the impact of their three dimensions had not been experienced before.

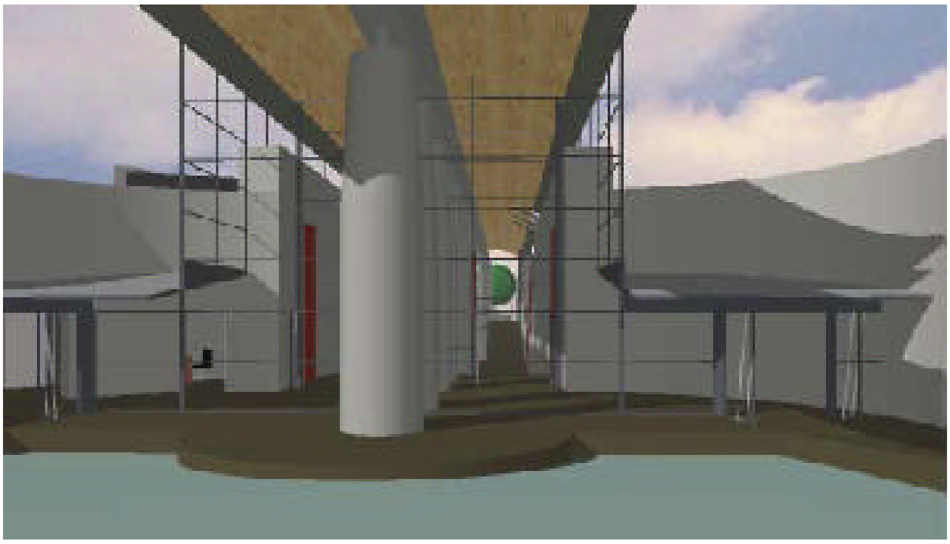


Figure. 4.9. A Design from the Experiment

One conclusion from this test was that you could have a tendency of getting lost as you would in any new building. Because of this situation, researchers used schematic plans in tests. Except this limitation, the test was sufficient and successful for clients (Klercker, 1999, p.4). By the help of CAVE environment, students could perceive these unbuilt projects by strolling around and inside them.

Third and the last step was “to model a design of their own”. The variation of the projects was therefore large from a villa with detailing close to reality to a “fill in” on a market square with detailing for experience from a distance. After the modeling, students made a guided tour around, into and inside the model of there project describing the ideas and the advantages of their solutions. Critical comments could then be discussed on the spot - both students and teachers pointing and explaining.

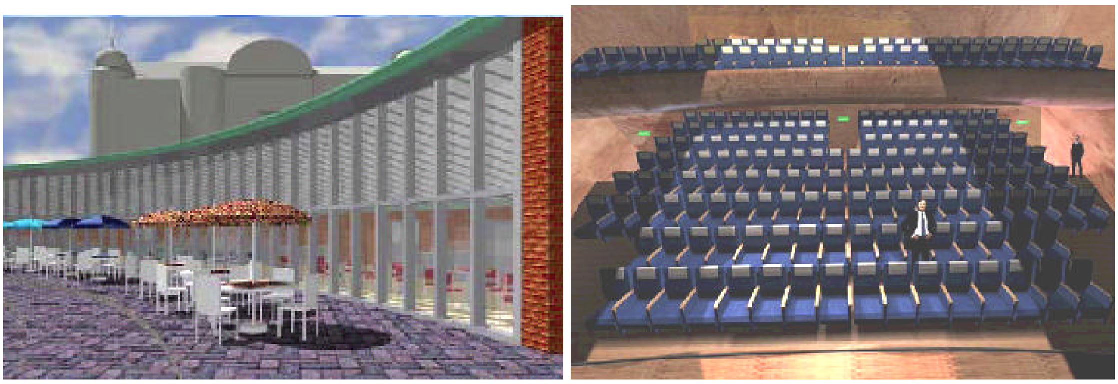


Figure. 4.10. Students’ Designs used in the Experiment

From these three CAVE experiments, researchers determined three main advantages of this system:

- The first; use of the CAVE-interface made the students aware of the visual impact of computer modeling.
- By this system, interaction of the design with clients and users were provided.
- The third use is more special. Researchers seem to be thrilled by the unusual spaces and forms as for instance the Guggenheim museum in Bilbao by Frank Gehry. But in reality most of us have not the possibility to get efficient training using unusual forms and spaces like that. The CAVE offers a possibility to do some designs with unusual, primarily curved forms and evaluate their visual end cognitional effects (Klercker, 1999, p.5).

6. Case Study VI: Comparison of Perception in Physical Environments (PE) and Virtual Environments (VE):

This research was based on a comparison between the perception of virtual and physical environments. Moreover, the study stated some differences between the characteristics of virtual environments and architectural spaces. Thus, the study claimed that virtual environments had their own characteristics.

To examine affectivity of virtual systems on architectural representation, researchers studied on an experiment. Students of architecture strolled in a 3D computer model of the Faculty of Business; 15 students used HMD-helmet, 15 navigated on screen, and another group visited the building physically. After that, all of them answered a questionnaire about the experience. The evaluation was based on general descriptions of architectural living; asking about configuration of rooms and building, proportions, associated feelings, semantic interpretation, constructive elements, urban and geographical context and duration of experience (Alvarado, 2000, p.2).

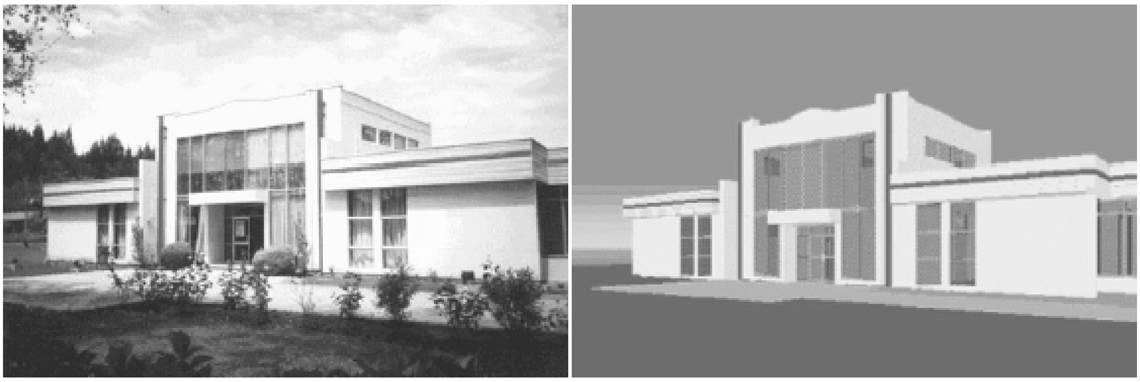


Figure. 4.11. Images of the “real building” and “computer simulation version”

The result of the experiments showed an overall match between perception through real visit and virtual media. In virtual tours, students correctly identified the material properties as successful as the physical tour. They also properly inferred the location of building. However, the main divergence between the two experiences was about the perception of spatial organization of the building. In virtual environments, especially in helmet based system, most of the users couldn’t perceive the spatial organization exactly (20% against 80% of the real visit). Moreover, in virtual tours, users could not perceive the concepts of intensiveness of feelings and time (Alvarado, 2000, p.4).

7. Case Study VII: Evaluation of Virtual Environments in Design Process: (A Virtual Design Studio in Yildiz Technical University)

Main aims of this study were to identify the role of virtual environments and computer systems in design process in architectural education; and to recognize the advantages and disadvantages of virtual environments according to conventional methods in architectural design education. To reach this aim, researchers made a “Virtual Design Studio Experiment” in “Architectural Design Studio II” courses; and compared the effectiveness of this method according to conventional design processes.

All students in the course prepared projects on the same site and same subject. Subject of the course was “design of a residential building”. Moreover, 6 students from the class used CAD systems (3D Studio MAX R 2.5) during the design process, and during the course term, design processes of these 6 students were examined.

As results of this study, researchers determined several advantages of virtual environments on perception of architectural space and on architectural design process. Advantages of CAD systems on perception of architectural designs and representations that are obtained in this research can be explained as follows:

By the help of CAD systems, students designed everything in 3D, so they could perceive the concept of space and depth of space easier than the conventional 2D representation techniques such as plan, section and elevation. On this subject, a student said “In 3D window of the program, it is easier to see and perceive every object in my design 3 dimensionally“, and another student said “I can see my designs and thoughts on computer screen in real time”. By this way, students could design what they really want, and they could reappraise their thoughts easier than conventional systems.

By the real time elevation, real time section, and real time animation properties, computer programs provided a chance to make endless numbers of models. Thus, it could be easier to distinguish misconceptions in designs. Moreover, it can be easier to perceive effects of light, sun and etc to the design process. For example, one of the students designed an open court in his house for more benefiting from sunshine, but after he modeled and tested in the computer, he saw that his court was all in the shadows, and there was no sunshine (Yarkan, 2001, p.51).

8. Case Study VIII: Evaluation of Virtual Environments in Architectural Education: (Virtual Construction Project in Texas A&M University)

For a student of architecture, learning about the constructing process of a design is an important point. For meeting this point, today, many architecture schools try to provide practical lessons for students to study the relationship between design and construction. As an alternative to this way, this research proposed to integrate construction into design education through computer methods that help to isolate construction issues and provide experience through computer simulations (Clayton, 2002, p.1). During the study, researchers applied 5 different tests to the students. These tests were:

- Virtual design-build projects; in which students construct 3D CAD models include all elements that are used in construction.
- Virtual office; in which several students must collaborate under the supervision of a student acting as project architect to create a 3D CAD model and design development documents.
- Virtual sub-contracting; in which each student prepares a specific part of the building. After preparation of these models, students combine them into a single model.
- Construction simulations; 4D CAD in which students build in 3D CAD models showing all components and then animate them to illustrate the assembly process.
- Cost estimating using spreadsheets (Clayton, 2002, p.1).

In first study, students made 3D models of a wall with its all elements such as windows and floor (One of the prepared models can be seen in Figure 4.15). For this study, they used AutoCAD R14 as design medium. The process of building digital models of details and wall sections was thought as a close analogue to building an actual wall in this test. For realizing this idea, every brick, anchor bolt, wall tie, stud and joist is included in the model, with particular consideration of weatherproofing, structure, and finish materials. By this way, students virtually learned and simulated the construction process of a brick wall.

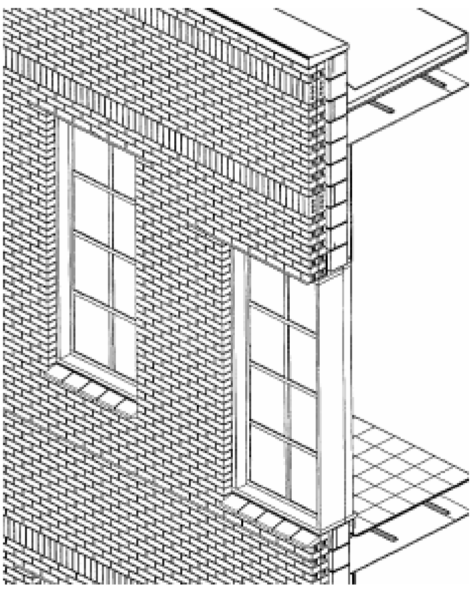


Figure. 4.12. 3D Model Produced in “Virtual Design-Build” Study

In second study, students formed subgroups and each group designed a part of a determined building such as exterior walls, toilets, vertical circulation.

In third study, it is aimed to make students aware of the construction process and effects of time in this process (4^{th} dimension of construction). For reaching this aim, students prepared animations to show the process of a steel construction (Figure 4.16).

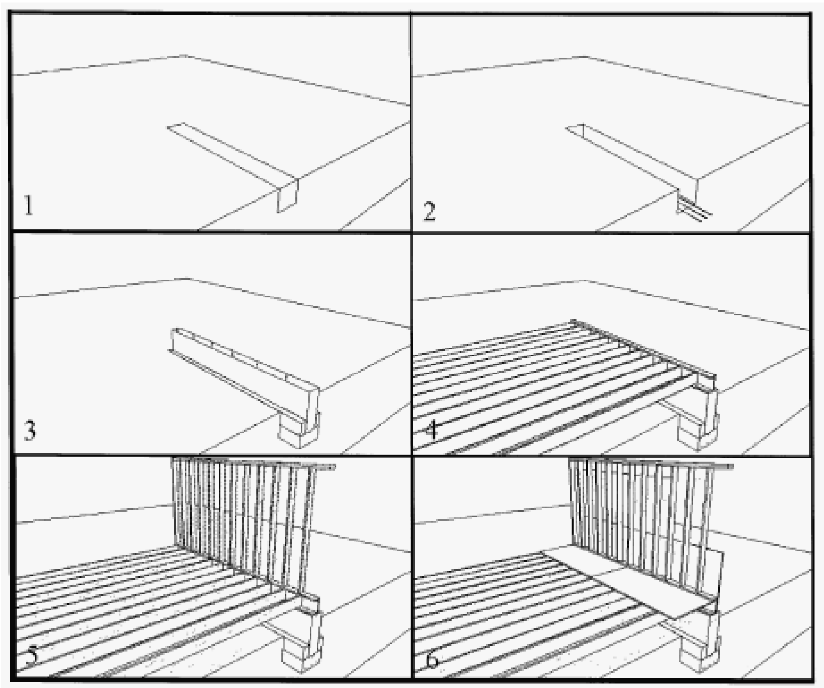


Figure. 4.13. Example of 4D CAD Animation Prepared by students

General conclusions of the study can be summarized as follows:

- The discipline of creating all 3D objects helps students to obtain an awareness of construction materials. The creation of 3D models of details clarifies the issues of assembly and construction in a more powerful way than conventional 2D drafting.
- The problem of building a collective 3D CAD model introduces students to the practical necessity of collaboration. Students become aware that a designer must coordinate his or her work with that of other participants in the design process.
- Construction animation illustrates construction process graphically, sequence, and issues of form work and temporary structures. It brings misconceptions to the forefront and clarifies the lesson that architectural

design must be constructible to be successful. It can grab students' interest and make them aware of the construction aspects of architecture.

- Virtual construction can be integrated into multiple courses to reinforce learning in a way that is unlikely from a singular design–build experience.
- In comparison to design–build studios, virtual construction can more easily reach more students in a wider variety of learning situations and wider variety of projects. Physical design–build studios nevertheless provide a valuable tactile experience that is not reproducible in virtual construction (Clayton, 2002, p.7).

4.2. Evaluation of the Effects of Virtual Environments in Architecture in the Context of the Previous Studies:

All of the above mentioned case studies are generally comparisons of virtual environments with conventional representation techniques and physical environments. Some of these case studies are comparisons with conventional representation techniques, some of them are comparisons with physical environment, and some of them are comparisons between different virtual representation techniques. However, it can be possible to group these case studies (comparisons) in three groups:

- **Evaluations of Previous Studies according to Presentation of Architectural Space:** Case study 1 can be thought in this group. In case study 1, advantages and shortcomings of virtual environments as a representation medium were evaluated. Furthermore, effects of computer related tools and internet on architectural representations were compared with conventional paper based media.
- **Evaluations of Previous Studies according to Perception of Architectural Space and Form:** Case studies between 2 to 6 are examples for this group. In these case studies, assistance of virtual environments on perception of architectural space was mentioned. By the help of several experiments, sufficiency of this assistance was tested

and compared with conventional representation techniques and physical environments.

- **Evaluations of Previous Studies according to Design Process:** Case study 7 and 8 can be thought in this group. In these case studies, specific contributions of virtual environments and digital media in design process were evaluated. Moreover, especially in case study 8, positive effects of these digital media on simulating the real construction process were strongly mentioned.

At this point, investigation of previous case studies on comparison of virtual environments with conventional representation techniques and physical realities has been completed. These case studies generally regard computerized systems as proper and better techniques than the conventional ones for design and presentation processes. Moreover, many of these case studies claim that the virtual environments are always the most efficient way for perception of architectural space. Generally, it is logical to use virtual environments to perceive architectural space better. However, there are important points. First, in some cases, conventional representation techniques can be more effective to depict architectural space. Second, users can perceive the space different according to the representation media.

Parallel to the above mentioned thoughts and guidance of the questions, the case study in the Chapter 5 is constituted.

Chapter 5

CASE STUDY: COMPARISON OF DESKTOP VIRTUAL ENVIRONMENTS (DVE) WITH CONVENTIONAL 2D REPRESENTATION TECHNIQUES

5.1. Definition of the Proposed Case Study

In the thesis, first, conventional 2D representation techniques and computer supported 3D representation techniques were investigated in the context of perception of space. Then, previous studies on the subject were studied in the same context. By the help of these case studies, advantages and shortcomings of conventional and computer supported representation techniques were generally determined. However, advantages and shortcomings of virtual environments on perception and sensation of architectural space were not adequately mentioned in these previous case studies. By proposed survey study, this thesis mainly aims to compare desktop virtual environments (DVE) and conventional 2D representation techniques in the context of perception and sensation of architectural space, and to expose how the perceived space is recorded mentally.

In this study, because they are the most basic, easy to use and widespread computer based representation techniques in architecture, DVE systems are used as virtual environment systems.

5.2. Method of the Case Study

As it is mentioned in Chapter 1, comparison is the main method for this thesis; and case study is the most important step for this comparison. By this survey, the thesis aims to prove its claims. The study use comparison as the main method for this case study, too. Case study includes the comparison between 2D conventional representation techniques (plan, section, elevation) and computer based 3D virtual environments (DVE systems) in the context of perception of architectural space. This comparison and also the case study are applied through a questionnaire and a survey. This survey has been applied in two steps to 38 first year students of Izmir Institute of Technology, Department of Architecture. In first step, 2D conventional drawings and first 10 questions in

Appendix 1 have been given to the test subjects. After they have answered these questions, 11th and 12th questions have been given to them. In second step of the survey, same questions have been asked in the same order; but DVE environment has been used instead of 2D conventional drawings.

As it is mentioned in the previous chapters, although perception of space can change according to the age, culture, knowledge, etc., in this study, first year students are used because of their similar profiles as beginners into architectural education. It could be possible to apply this survey to the professional architects, but all of them would have different architectural backgrounds; and this situation could affect the success of the case study. However, first year architecture students are all inexperienced and unconditioned in for evaluating architectural representations, and they all have almost the same knowledge and background in discipline of architecture. This situation increases the success and reliability of the case study and its results.

To achieve the objectives defined above, the following steps can be enumerated as follows and a flow chart has been developed. Following steps below are shown in the flow chart Figure 5.1.

1. Related to the general aims of the study, definition of the problem and aim of the case study (Comparing and evaluating 2D conventional representation techniques with 3D virtual environments).
2. Definition of the comparison method.
3. Literature survey on the applied case studies about the spatial perception of 2D conventional representation methods and 3D virtual environments.
4. Determination of the building that will be used in the case study.
5. Literature review for the suitable software.
6. Determination of the used software that will be used in the case study.
7. Preparation of the questionnaires.
8. Control of the questionnaires.
9. 1. Stage: Questionnaire on conventional representation techniques.
10. 2. Stage: Questionnaire on computer based representation techniques.
11. Evaluation of the results.

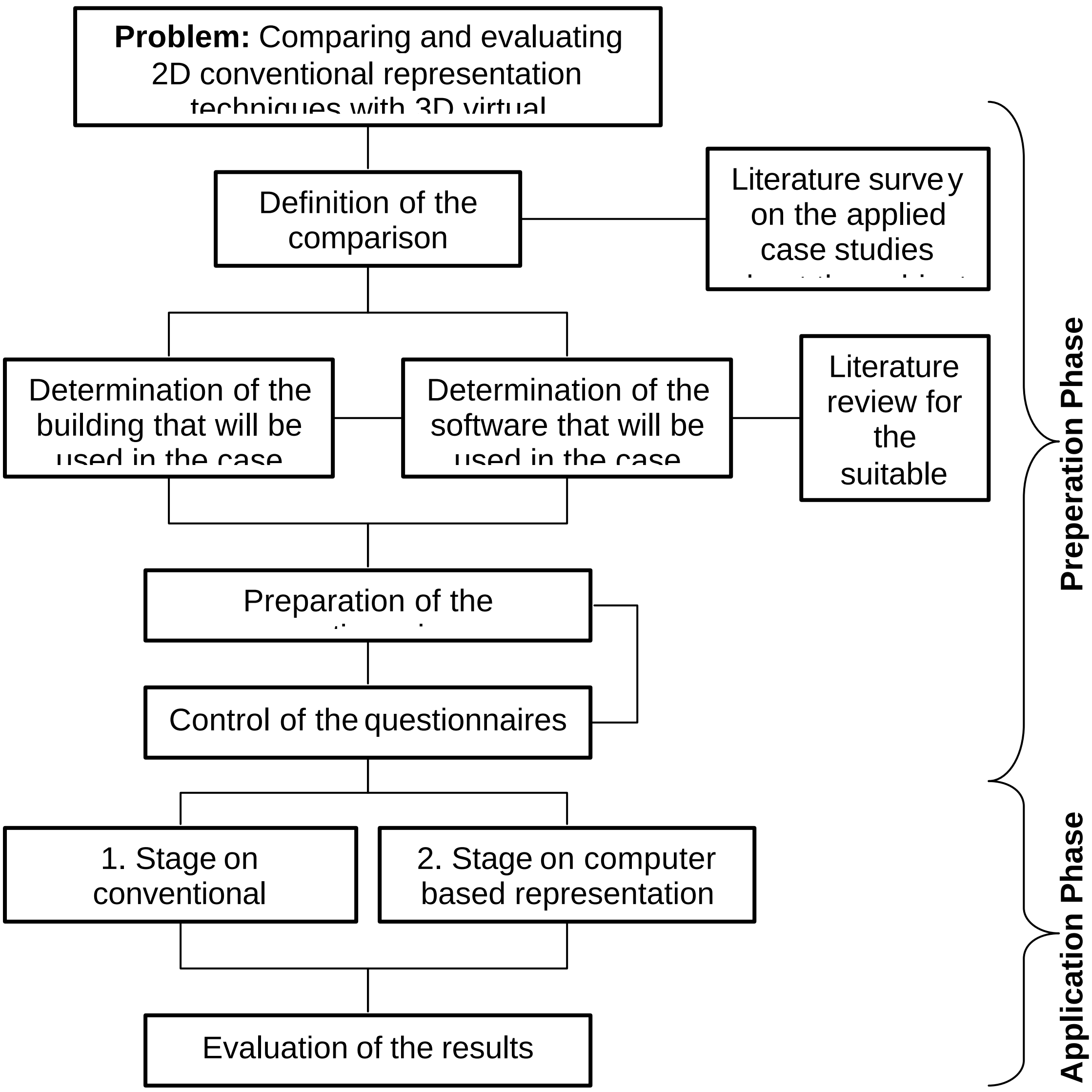


Figure. 5.1. Flow Diagram of the Case Study

5.3. Preparation Phase of the Case Study

After the analysis of former studies comparing 2D and 3D representation techniques, it is clearly seen that there are curtain differences between these two representation techniques. Although all of them try to approach to reality by simulating it, what is perceived and how it is perceived is not explained clearly. Therefore, a new method of comparison for the perception of space has to be developed. In this method, as the first step, a comparison method was needed to decide. For determination of this method, first of all, applied case studies and their comparison methods in chapter 4 were investigated deeply. During this investigation, a technologically and methodologically suitable comparison method for this thesis's case study was searched. Finally, the case study process mentioned in Figure 5.1 was constituted. Main concept and structure of this method can be summarized as follows: First, a questionnaire on spatial perception in 2D conventional representation techniques were applied to the test subjects. Second, same questions were asked to same users for determining the spatial perception in 3D virtual environments. Finally answers of the users for both questionnaires were compared and evaluated.

For this comparative survey, the thesis primarily needed an architectural space as a tool, so next step of the preparation phase was determination of this architectural space (building). At this point, it was needed to ask some questions and discuss about the characteristics of this architectural space. For example; was it suitable to use a simple single space or a complex building for the case study? Which kinds of technologies were needed for preparation of the virtual version of this space? By the help of these questions, 3 main characteristics of the architectural space used in the case study have been determined:

- First, the space used in the case study had to have important architectural characteristics to evaluate. However, it didn't have to be a commonly known building for test subjects (first year architecture students), because test subjects could know every important property of that space without investigating its representations.
- Second, it had to be easy to reach orthogonal conventional drawings of this space, because these drawings would be used in the first questionnaire.
- Third, 3D models of that architectural space were necessary for the second questionnaire, so it had to be easy to reach 3D computer models of that space, or it had to be easy to prepare its computer based 3D models.

After the discussions on above mentioned thoughts, Frank Lloyd Wright's Larkin Building was chosen to be used as the tool in the questionnaires, because this building had important advantages for the case study: First, its architectural space had important architectural characteristics. Second, it is easy to find its orthographic drawings (plan, sections, and elevations) from the books about Frank Lloyd Wright. Third, detailed 3D models of this building were obtained from Microsoft Press's "The Ultimate Frank Lloyd Wright: America's

Architect" CD-ROM. 3D model in this CD-ROM gave the chance of browsing the interior spaces of the building by a virtual tour. Example views from the virtual tour of Larkin Building can be seen in Figure 5.2.

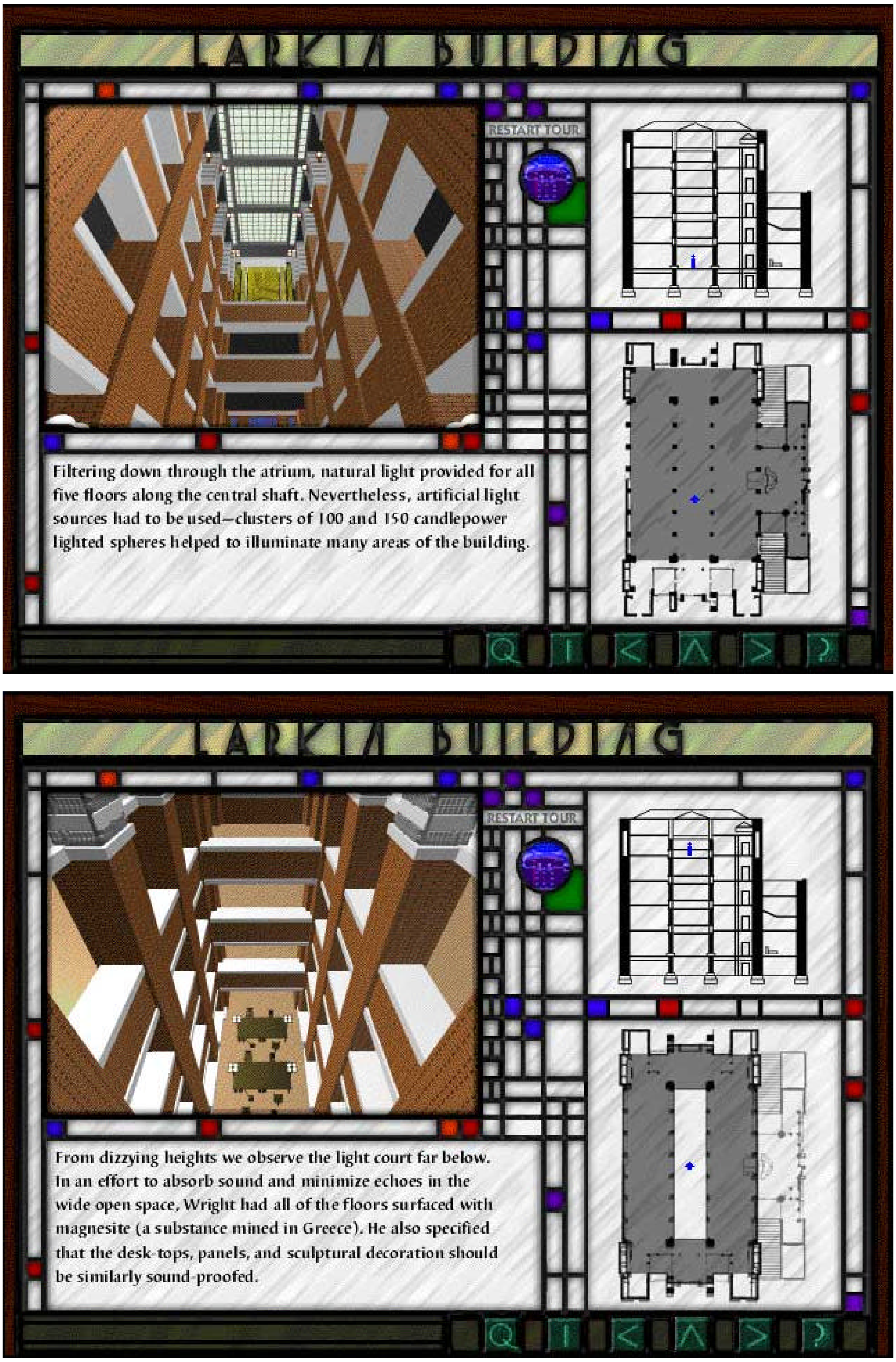


Figure. 5.2. Example Views from the Virtual Tour of Larkin Building

The other important phase for the case study was the preparation of the questionnaires. As it is mentioned above, application of the case study survey was applied in 2 steps; and for first step (Questionnaire on perception of 2D representation techniques), preparation of the 2D orthographic drawings of Larkin Building had a principal role. Therefore, these orthographic drawings were prepared by the helps of the 3D model in the above mentioned CD-ROM, 3D model of the building obtained from the web site of "The Great Buildings On-line (http://www.greatbuildings.com)" and 2D drawings obtained from the books about Frank Lloyd Wright. It is possible to see these 2D drawings in Appendix 1.

Next step was the preparation of the questionnaires. Aims of these questionnaires can be summarized as follows: (Questionnaire is given in Appendix 1.)

- First 7 questions constituted a preparation phase for following questions, and these questions aimed to attract attention to the building's fundamental physical characteristics. In addition, by these 7 questions, it was aimed to test and evaluate the perception of physical properties of a space according to the different representation media. After the first and second step of the survey, same users' answers would be compared and evaluated. By this way, the effects of representation techniques on perception of basic physical properties could be understood.
- 8th question was one of the most important questions in the questionnaire. By this question, it was aimed to test perception of physical, spatial and sensorial characteristics of the space. For this question, adjectives that could depict an architectural space were used. For choosing these adjectives, "*Longman Dictionary of Contemporary English: 3rd Edition*" was searched and related adjectives were chosen. 8th question included 3 subgroups: First subgroup aimed to test perception of spatial properties by the help of adjectives. Second group aimed to test perception of physical properties; and finally third group aimed to test perception of sensorial properties.
- By 9th question, representation techniques' ability on depicting materials' properties were interrogated. To reach this aim, a question on understandability of the wall covering materials of Larkin Building was asked.

- 10th question was an interrogation of the perception of fundamental spatial characteristics. At this question, dominant spaces of Larkin Building were asked; and by this way, representation techniques' effects on perception of primary spatial characteristics were tried to evaluate.
- 11th and 12th questions were aimed to test representation of perceived space. For 11th question, a perspective view from a "Point X" was expected from the users; and this question aimed to evaluate the differences on visual perception according to representation media. Finally, 12th question was asked to evaluate how users could remember the space and its characteristics after the drawings were taken.
- There is a 13th question only in second stage quesitonnaire. By this question, it was aimed to take comments of the students about the representation techniques, their shortcomings and advantages according to the applied case study.

After the preparation of the questionnaires, as a control phase, the dual questionnaires were applied on a group of students. By the help of the data obtained from this experiment, some questions and adjectives were edited and they were prepared for the final study. (You can see the final questionnaires in Appendix 1)

5.4. Application of the Case Study

38 first year students from Izmir Institute of Technology's Department of Architecture participated in the final comparative survey. First step questionnaire (Test of 2D representation techniques) was applied in the project studio and second step questionnaire (Test of computer based 3D representation techniques) was applied in Faculty's CAD laboratory. 50 minutes were given to answer questions for both questionnaires. Every user answered the same question sets in both steps, so these 12 questions provide a chance to compare and evaluate the spatial perception according to the representation techniques.

After the application of questionnaires to the test subjects, results are evaluated. In this phase first, percentages of given answers in both questionnaires were aimed to calculate. In other words, numerical results of the questionnaires were aimed to calculate. During this step, software of SPSS V11.0 was used as a numerical evaluation media. Data obtained from the questionnaires was entered to the SPSS, and percentages of given answers were got. These numerical results of the case study can be seen in Appendix 2.

After the calculation of numerical results, it was the time to evaluate these outcomes. In the context of spatial perception, the results of the case study surveys can be summarized in three main groups:

- Results on “How it is perceived”.
- Results on “How it is mentally recorded”.
- Results on “How it is represented”.

5.5. Results of the Case Study

5.5.1. Results on “How it is Perceived”:

a. Physical Characteristics:

According to the numerical results of the case study, it is understood that both of the 2D representation techniques and 3D virtual environments have different advantages and shortcomings on depiction of physical properties of the space. Advantages and disadvantages of these representation techniques obtained from the case study can be described as follows:

- The results of the case study survey showed that both of the conventional and computer based representation techniques have been successful in perception of general physical properties of the space such as the number of entrances, the number of staircases and etc. However, case study results showed that the students have perceived general properties of the space better by 2D representation techniques. For instance, for the question of “How many storey does the building have?” percentage of correct answers was % 97.3 in the first questionnaire, but percentage of correct answers decreased in the second (computer based) questionnaire to % 90.9. Similar to this example, for the question of “How many entrances does the building have?” percentage of correct answers was % 86.8 in the first questionnaire, but percentage of correct answers decreased to % 78.8 in the computer based questionnaire. Only exception of this group is the question of "Which storey has two different levels". Only in this question, 3D computer based representation techniques were more successful than 2D conventional ones. The percentages were % 73.7 in first questionnaire and %87.1 in the second questionnaire.

- Contrary to above mentioned results, case study survey showed that material properties of a building can be more definitely understandable in 3D representation techniques. Question 9 of the questionnaires can be a good example for this subject. In this question, understandability of the wall covering materials was interrogated. The results showed that in first try, only % 44.7 of the students could perceive the materials of the wall coverings; but in computer based questionnaire, % 93.5 of the students could perceive the material. These results also show the positive effects of computer based 3D representation techniques on perception of the materials, colors and textures used in the architectural space.

According to the case study's results, it can be possible to make following comments: On 2D conventional representation techniques, users can see all fundamental materials, spaces and subspaces as a whole on the paper, easier than computer based representations. For this reason, by conventional representation techniques, users can answer the questions about the fundamental physical properties more successful than the computer based methods. However, specific physical properties such as texture, color and material type can be more understandable and perceivable in 3D representation techniques.

b. Spatial Characteristics:

- In the case study survey, main spatial concepts of the Larkin Building were perceived successfully in both of 2D and 3D representation techniques. Main spatial characteristics such as modern, rational, regular could be perceived in both questionnaires. However, the percentages of the correct answers increased in second questionnaire. For example, the percentage of modern was % 38.0 in first questionnaire, % 56.7 in second; rational was % 96.9 in first, % 100.0 in second; regular was % 75.8 in first, % 85.2 in second questionnaire.

- Another important point about the spatial concepts was the perception of dominant spaces. In Larkin Building, office areas and the gallery in the middle of the office zone were the main dominant spaces. Question 10 was asked for testing the perception of dominant spaces of this building. In both questionnaires, most of the students successfully perceived the dominant spaces in Larkin Building.
- Case study results showed that the students could perceive the hierarchy of the space by two dimensional representations better than virtual environments. For example, in first questionnaire, % 51.4 of the students described Larkin Building's office zone as a total space; but after second questionnaire, this percentage decreased to % 39.3. When students walked through the virtual model of the building, they could focus on subspaces or less important spatial characteristics; so in virtual environments, it can be possible to overlook main spatial characteristics of the space.
- Contrary to above mentioned point, structural properties of the space such as symmetry, consistency were perceived better in second step of the case study. For example, in first questionnaire % 81.6 of the students described the space as symmetrical, but in second questionnaire % 100.0 of the students noticed this property. Parallel to this example, in first questionnaire, %87.5 of the students described the space as consistent, % 94.7 well shaped, % 80 proportional, % 86.5 balanced. However, in second questionnaire, these percentages increased to % 96.8 for consistent, % 96.4 for well shaped, % 96.7 for proportional and % 96.8 for balanced.
- Three dimensionality of the main space of Larkin Building could not be perceived absolutely by the 2D representation techniques. It was seen in the case study that computer based three dimensional representation methods were more effective on this subject. For example, dominancy of the main gallery space in the office zone was not perceived sufficiently by the 2D techniques. In first questionnaire, only % 68.8 of the students could perceive this dominancy, but in second questionnaire, this

percentage increased to % 89.3. Moreover, vertical characteristics of the gallery space could not be perceived in first questionnaire. Only % 50 of the students described this space as vertical. However, this percentage increased to % 76.7.

- Finally, according to the comments from 13th question, most of the students have claimed that computer based 3D representation techniques are more effective to depict the characteristics of the space. One of the students has declared that "We can perceive the space and its main characteristics better when we see and browse it in 3D". Another student has said that "Sometimes it can be difficult to imagine third dimension of a space from two dimensional materials. Computer based methods facilitates this process". Another student has told that "By virtual tours in the space, it can be easier to perceive space.", Finally another student has claimed that "I can remember the space and its characteristics better, when I study it three dimensionally." According to the above mentioned results, and comments of the students, it can be claimed that computer based three dimensional representation techniques (virtual environments) are more effective to depict an architectural space than the conventional 2D methods. Moreover, by user- friendly interfaces and multimedia opportunities of these systems, investigating an architectural space can be a more joyful process. By these properties, perception will be better by these techniques.

5.5.2.Results on "How it is Mentally Recorded":

All people can perceive the same space differently. Moreover, this case study showed that representation techniques have also important effects on this perception. For example, when a user investigates a space by 2D plans, sections and elevations, his/her feelings about the space will be different from when same user investigates the same space with 3D representation techniques. According to the numerical results of the case study, these psychological effects of representation techniques can be summarized as follows:

- At the end of the first questionnaire (test by 2D representation techniques), the results showed that students generally thought Larkin Building's main office space as a compressed, stifling and cramped space. However, this idea changed after the second step of the case study. For example, after the first questionnaire, % 57.1 of the students described this space as cramped, but after the second questionnaire this ration decreased to % 36.7. Like this example, in first questionnaire, %54.3 of the students described the space as stifling, but after second questionnaire, only % 40.1 of the students thought it as stifling (Figure 5.3). It can be possible to see all ratios in Appendix 2.

Table. 5.1. Some Ratios of the Answers from Question 8.

Adjectives	1. Step (2D)	2. Step (3D)
Cramped Spacious	% 57,1 % 42,9	% 36,7 % 63,3
Relieved Stifling	% 45,7 % 54,3	% 57,1 % 42,9

- Similar to above mentioned examples, most of the students described the space as boring, antipathetic, depressive or inhospitable after the first questionnaire. For example; percentage of depressive was % 67.6, boring % 91.2, antipathetic % 63.6 after 2D representation techniques based questionnaire. However, all of these high percentages decreased for the computer based presentations used in questionnaire. For example; depressive's ratio decreased to % 40.7, boring to %74.1, antipathetic to % 46.4 (Figure 5.4). According to the results of these examples, it can be claimed that 2D representation techniques can be misleading to understand the space's aura. When the plans, sections or elevations are drawn too dense, the space can be perceived as dense, restricted or depressive. In 3D representations, it can be more possible to investigate the space as its natural condition.

Table. 5.2 Some Ratios of the Answers from Question 8.

Adjectives	1. Step (2D)	2. Step (3D)
Reassured	% 32,4	% 59,3
Depressive	% 67,6	% 40,7
Boring	% 91,2	% 74,1
Interesting	% 08,8	% 25,9
Antipathetic	% 63,6	% 46,4
Sympathetic	% 36,4	% 53,6

5.5.3.Results on “How it is Represented”:

The case study survey has two questions about this topic: Question 11 and Question 12. Both of these questions have different aims and roles in the case study. According to these aims and roles, evaluation of question 11 and 12 can be summarized as follows:

a. Evaluation of Question 11:

In question 11, sketch of the view from the “Point X” was expected from the students. By these sketches, the question 11 aimed to evaluate and compare the representation of perceived space according to the representation media. For a more objective evaluation, every student and his/her sketches in two questionnaires were evaluated independently. In other words, any students were not compared with the others. His/her sketch on the first questionnaire was compared with his second questionnaire results.

Here are some example sketches from the answers of the question 11. These examples are all chosen from the same students’ first and second questionnaire results.

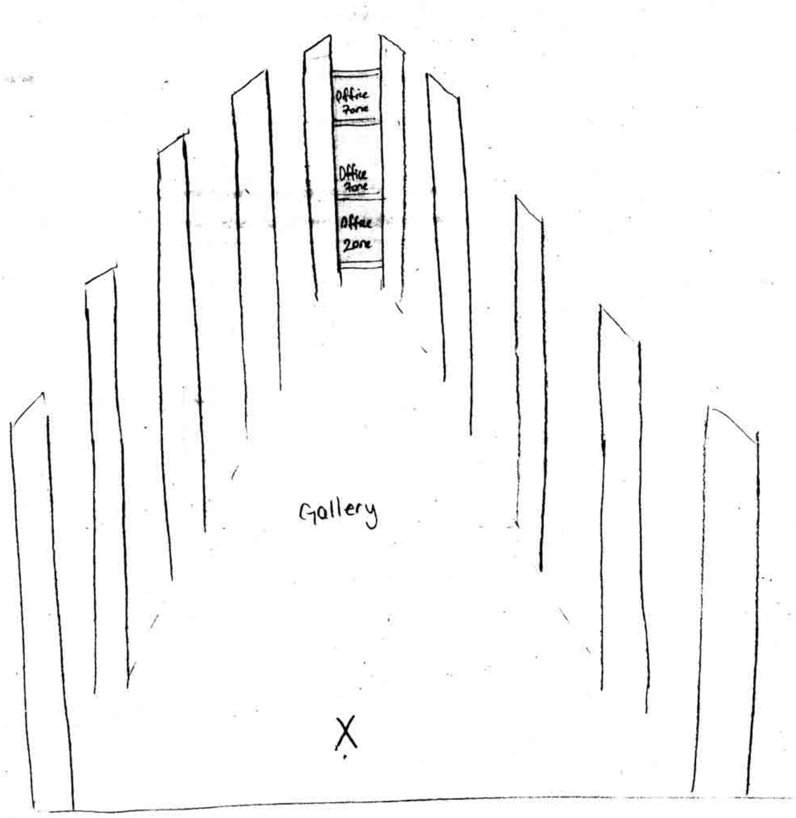


Figure. 5.3. The Sketch of the Student 3 in First Questionnaire

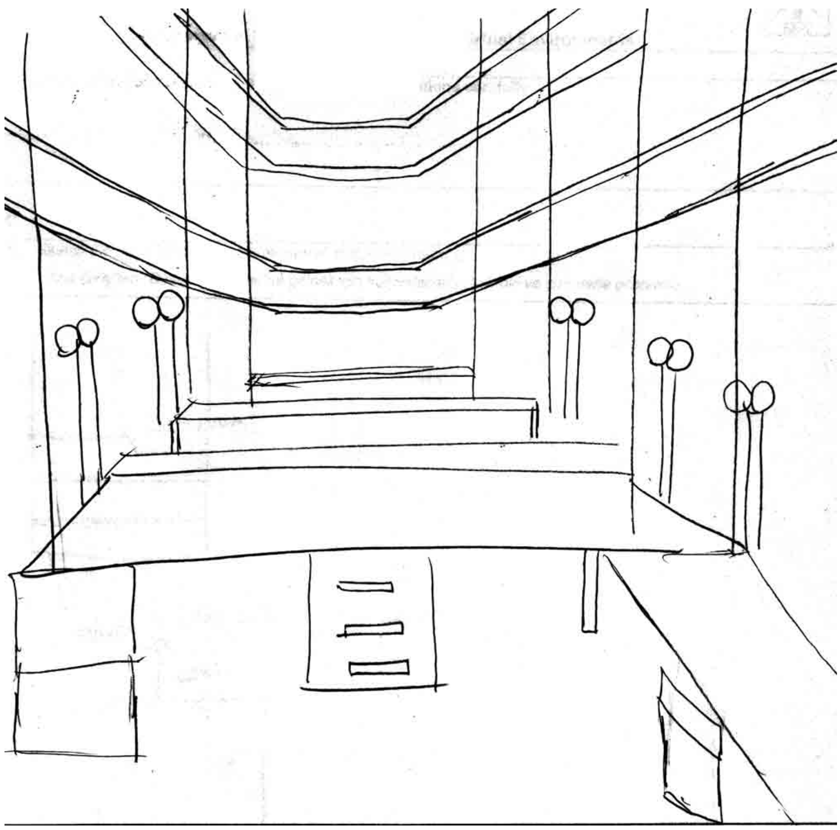


Figure. 5.4. The Sketch of the Student 3 in Second Questionnaire

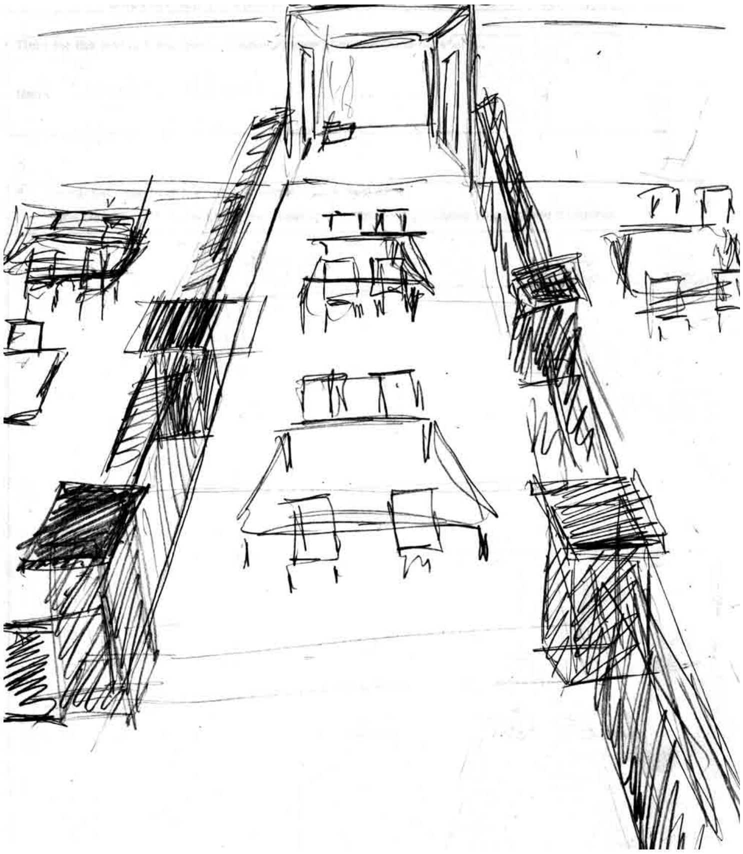


Figure. 5.5. The Sketch of Student 6 in First Questionnaire

Figure. 5.6. The Sketch of the Student 6 in Second Questionnaire

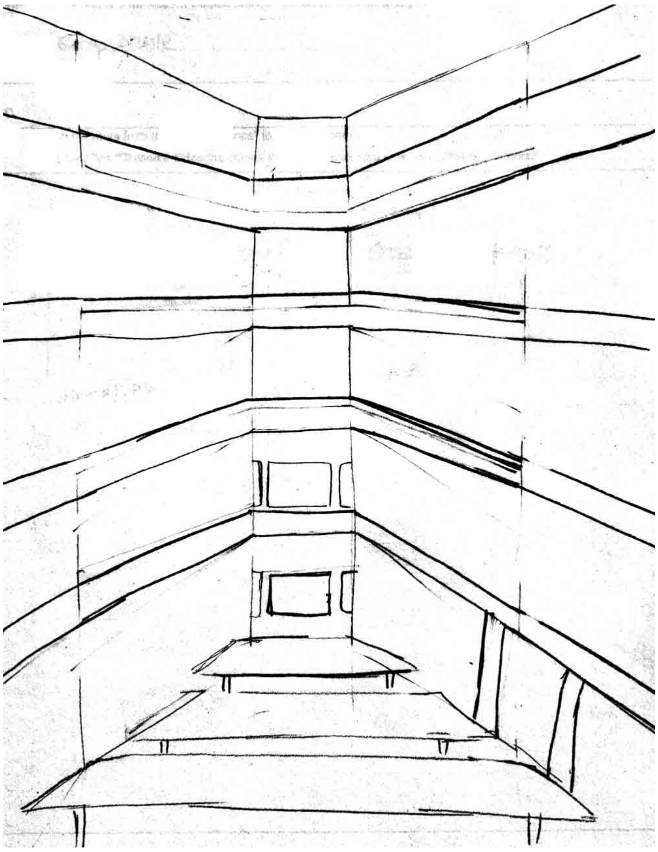


Figure. 5.7. The Sketch of the Student 28 in First Questionnaire

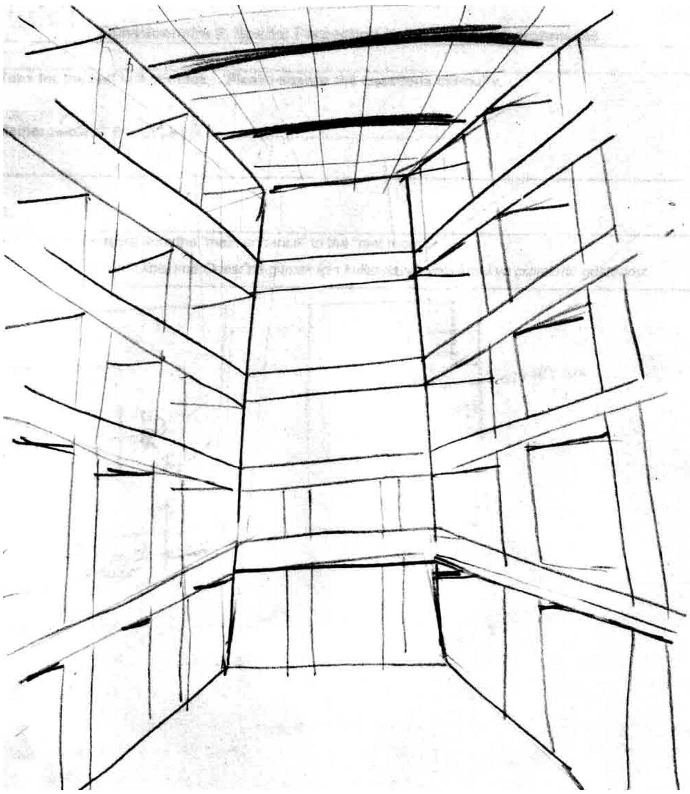


Figure. 5.8. The Sketch of the Student 28 in Second Questionnaire

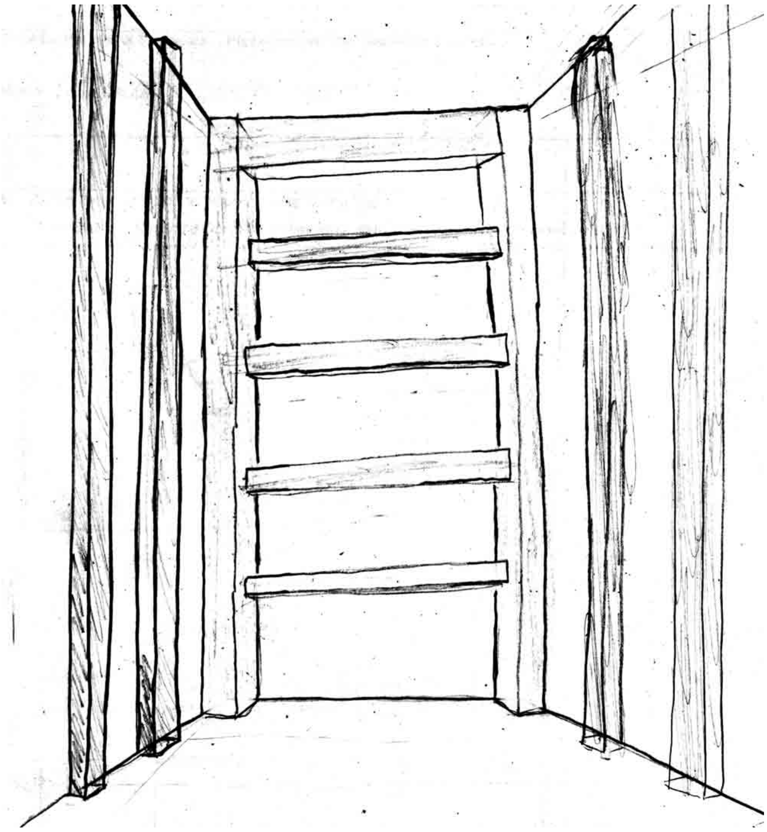


Figure. 5.9. The Sketch of the Student 10 in First Questionnaire

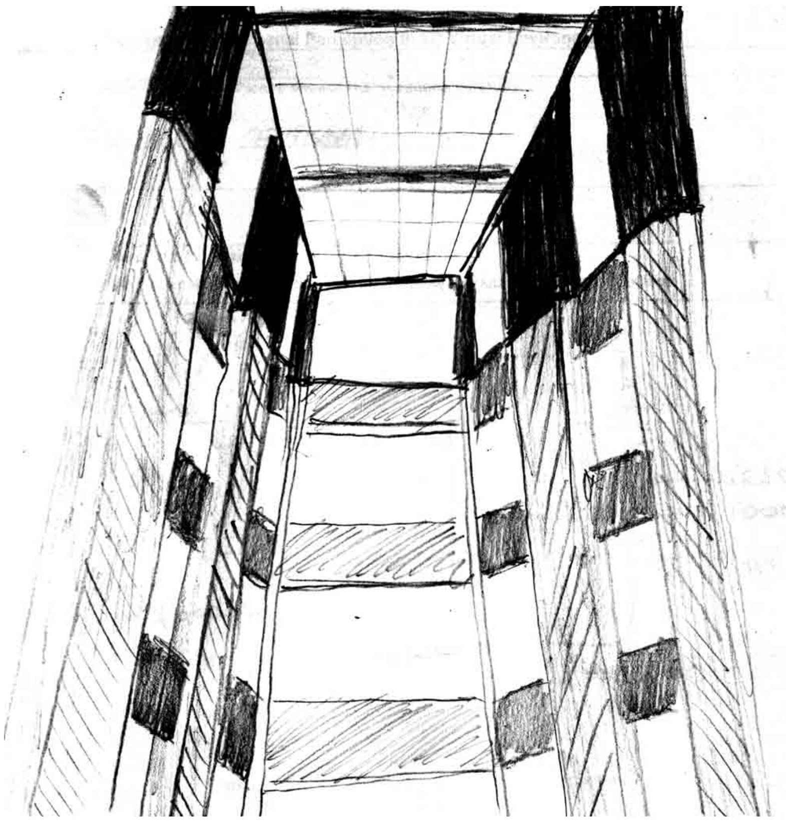


Figure. 5.10. The Sketch of the Student 10 in Second Questionnaire

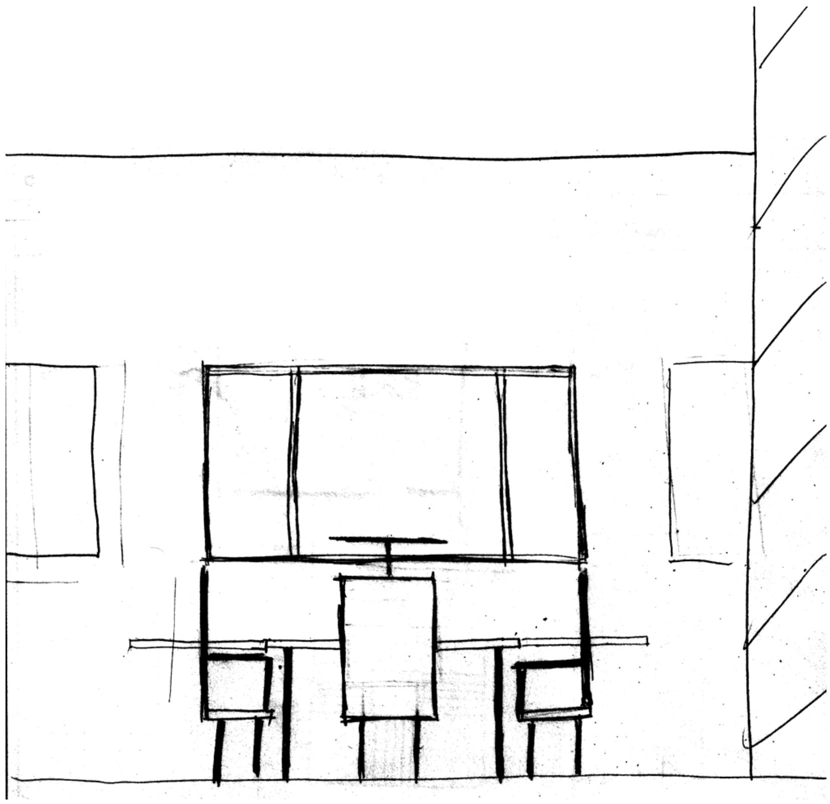


Figure. 5.11. The Sketch of the Student 12 in First Questionnaire

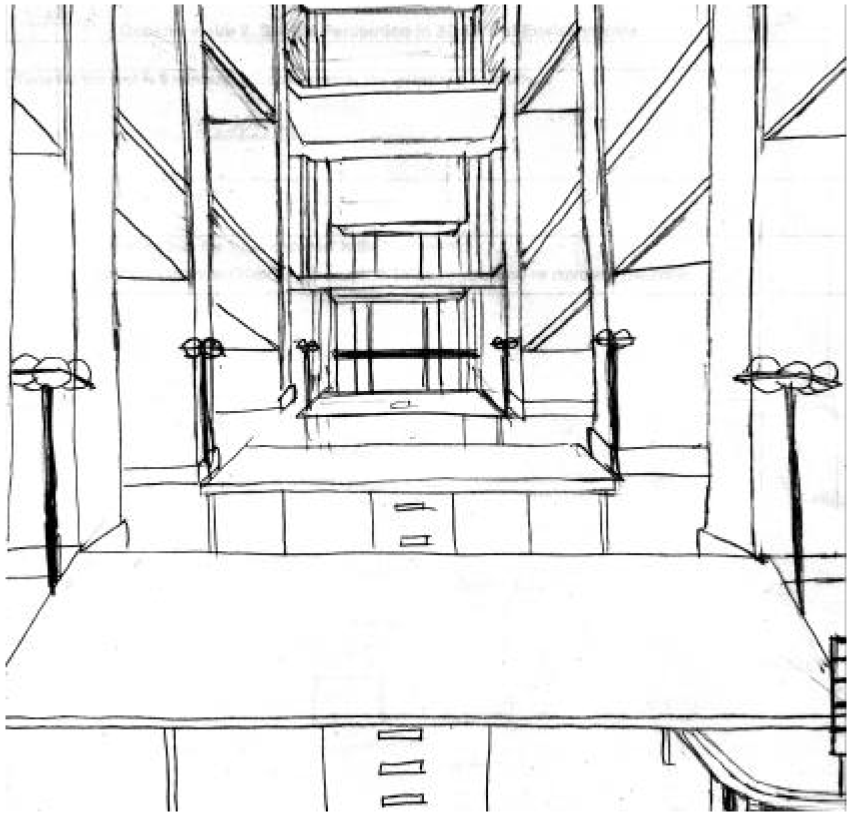


Figure. 5.12. The Sketch of the Student 12 in Second Questionnaire

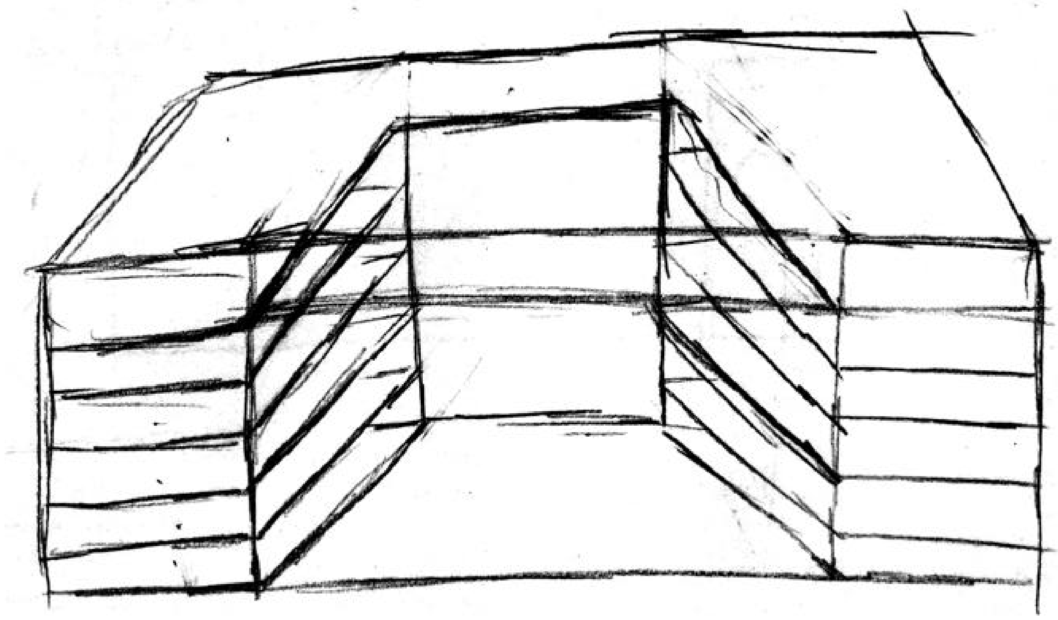


Figure. 5.13. The Sketch of the Student 14 in First Questionnaire

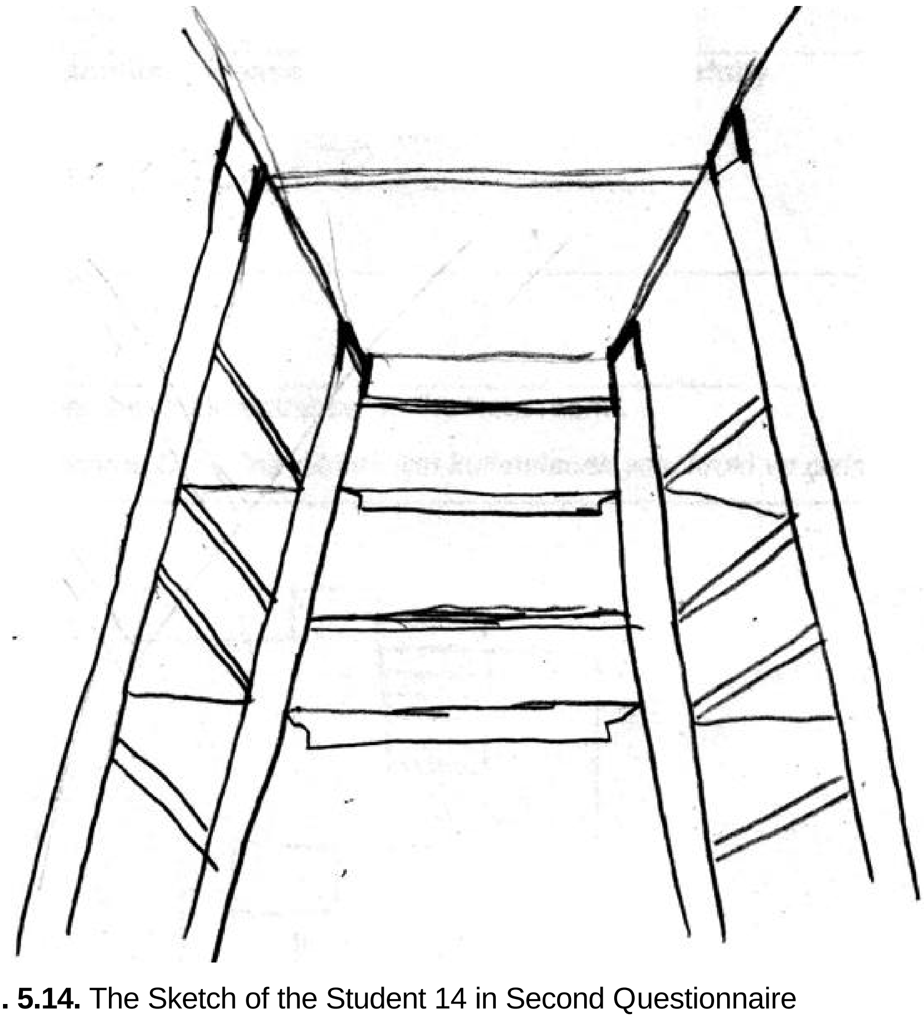


Figure. 5.14. The Sketch of the Student 14 in Second Questionnaire

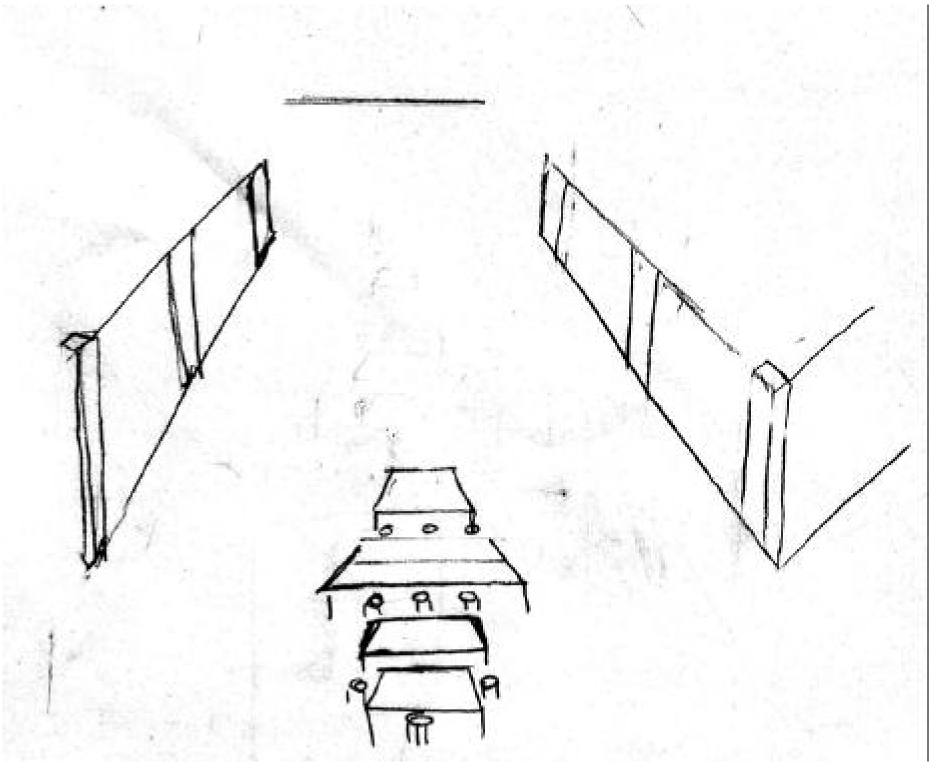


Figure. 5.15. The Sketch of the Student 31 in First Questionnaire

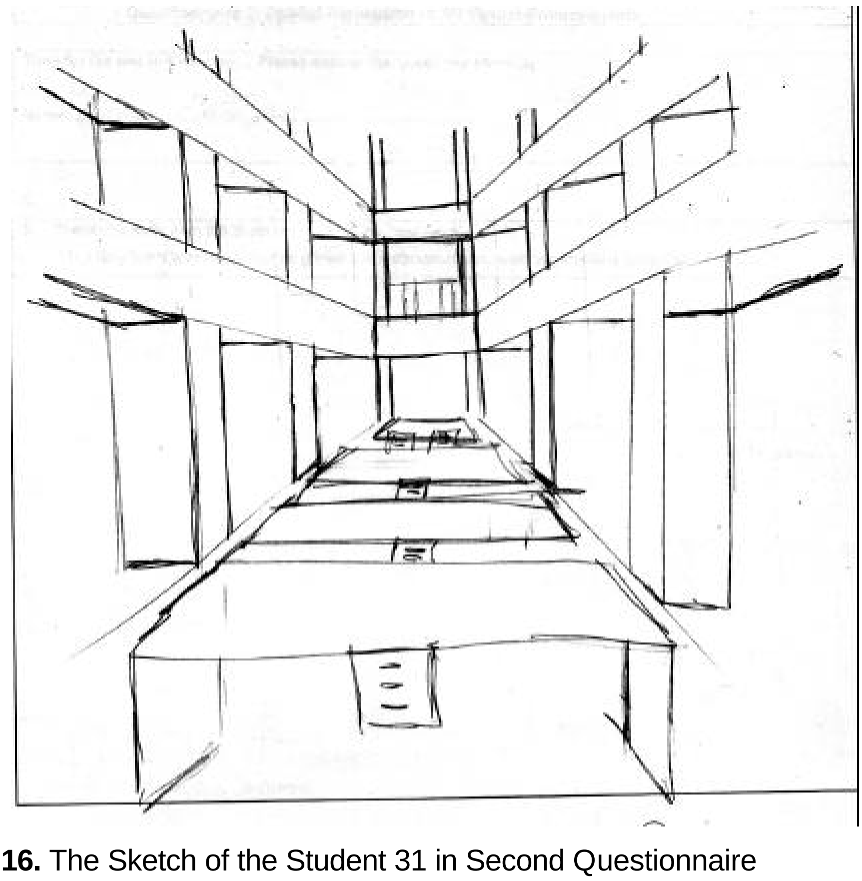


Figure. 5.16. The Sketch of the Student 31 in Second Questionnaire

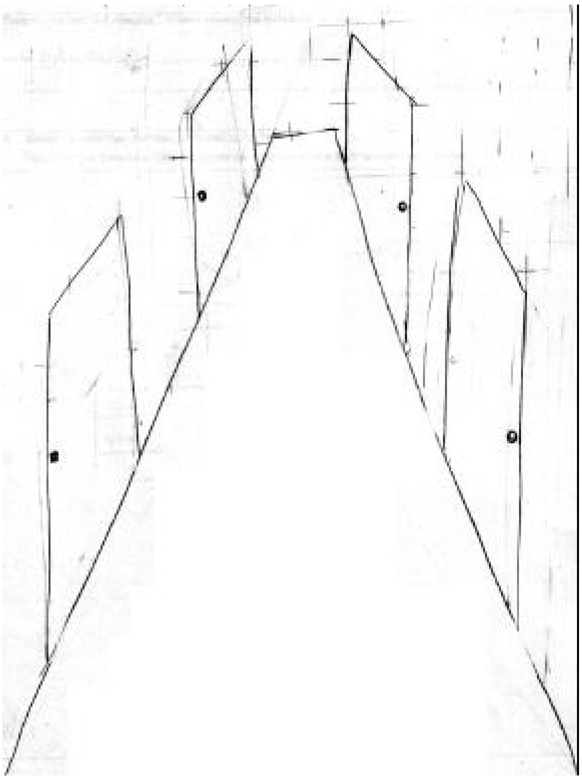


Figure. 5.17. The Sketch of the Student 36 in First Questionnaire

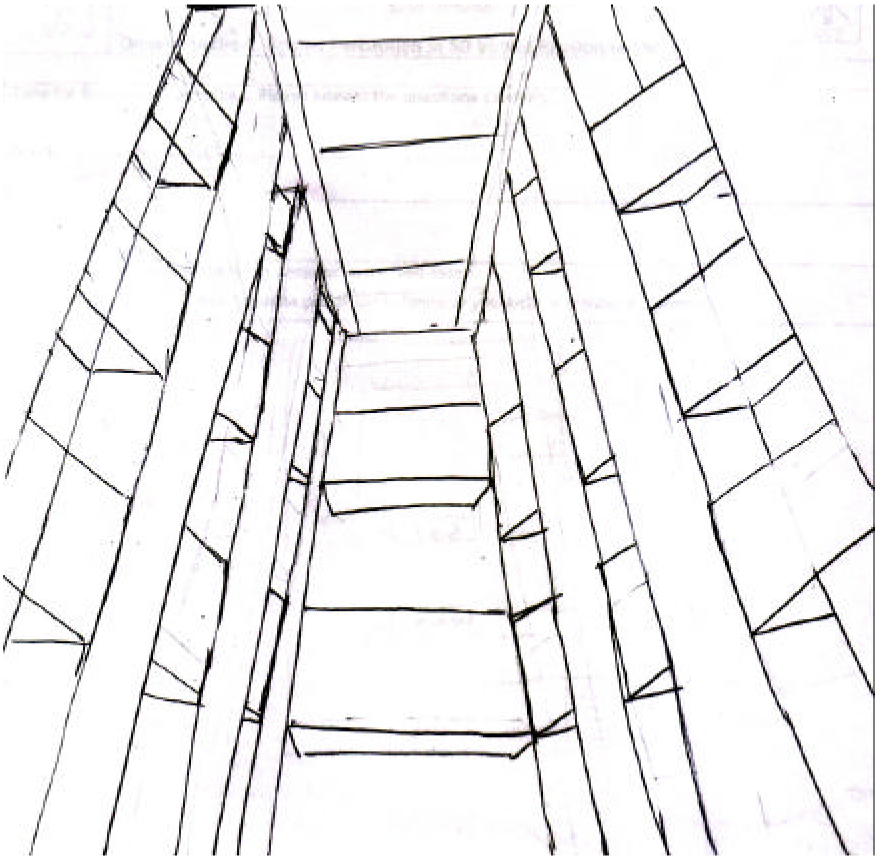


Figure. 5.18. The Sketch of the Student 36 in Second Questionnaire

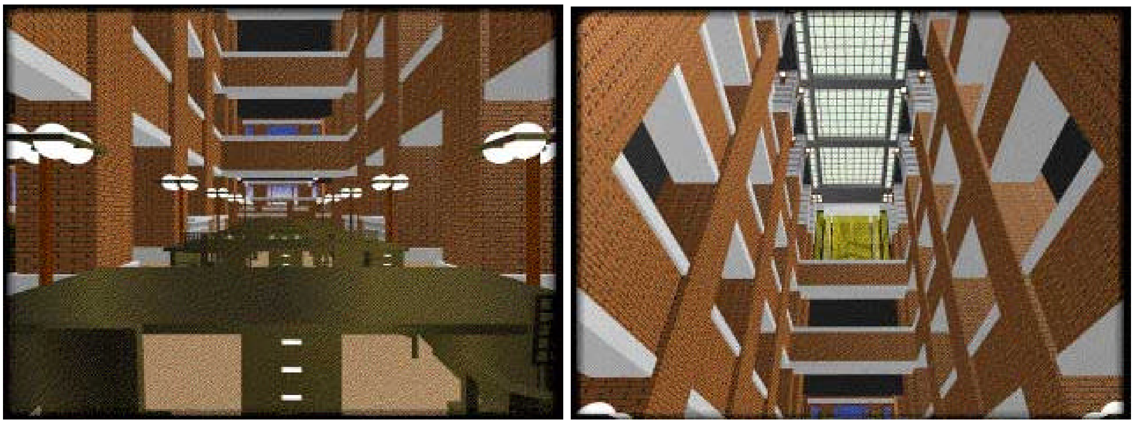


Figure. 5.19. The view from "Point X" in "The Ultimate Frank Lloyd Wright" CD-ROM

As it is seen in the examples above, the results of the question 11 have showed that the students were more successful to draw the expected view from "Point X", by the help of 3D representation techniques. According to the results of question 13 in the second questionnaire, most of the students declared that sometimes it could be difficult to imagine the aura of an architectural space by 2D representation techniques. At this point, 3D computer models have an important role. By these models, users can see and browse the space by its own materials and objects, so it becomes very easy to imagine that space.

b. Evaluation of Question 12:

In the profession of architecture, representation techniques have very important effects on how users perceive the space and how they remember it. Parallel to this thought, question 12 aims to evaluate users' remembrance according to the representation media. To reach this aim, route from the "main entrance" to the "rest room" was asked in the question. Results of the question 12 can be investigated in a few headlines:

Final sketches showed that the students used two different strategies for both of the questionnaires. In 2D representation techniques based questionnaire, generally they first tried to draw the plan of the building, and then tried to show the expected route from the entrance to the rest room on these plans. Besides, in computer based questionnaire, they only represented the route from the entrance to the rest room by arrows and basic schemes.

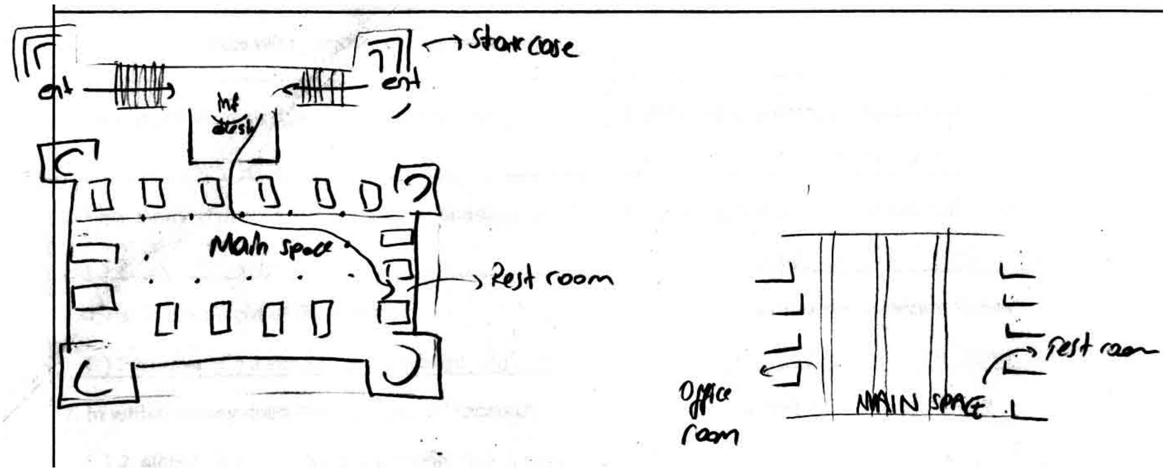


Figure. 5.20. Route from “Entrance to Rest Room”–First Questionnaire, Student 15

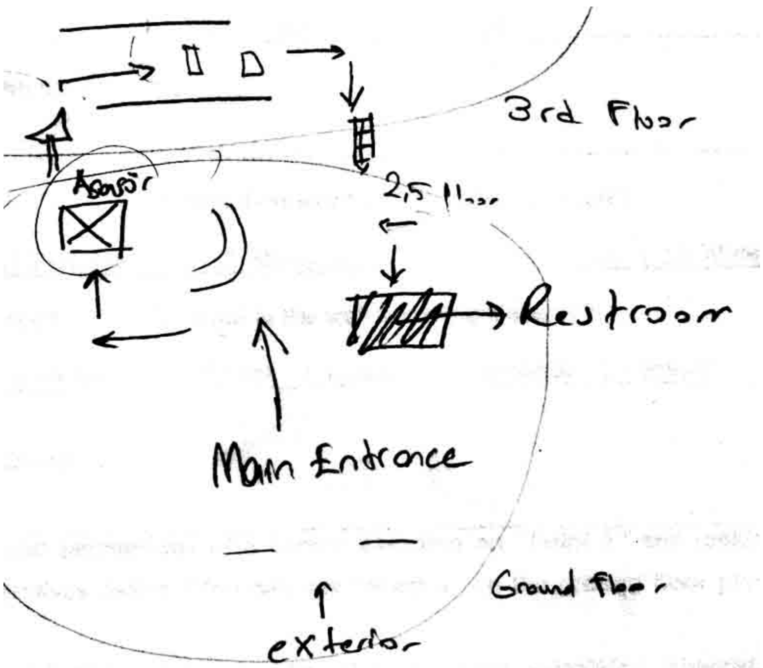


Figure. 5.21. Route from “Entrance to Rest Room”–Second Questionnaire, Student 15

At the beginning of the evaluation phase of this question, it can be thought that the students were more successful to perceive the whole space with its three dimensional properties by 2D representation techniques. This is because the results of the question showed that the students who used 2D representation techniques have remembered the whole plans and whole sections of the building better than computer based representations. However, when the results were investigated and evaluated deeper, it can be seen that the students haven’t remembered the space as a 3 dimensional phenomenon. They have just remembered the graphical representation of the space.

A supporting example can be seen in this deeper investigation. In first questionnaire's papers, the location of the rest room was signed on the plan and section papers. This questionnaie's results showed that the students, who could not definitely remember the location of the rest room, just drew the section of the whole building, and tried to show the location of the rest room on these sections. However, the location of the rest room on their plans was generally wrong. (See Figure 5. 11) As a result, it can be claimed that they could not remember the location of the rest room, and they could not perceive the space sufficiently. They just remembered the graphical representation of the sections, and draw those representations as good as they remembered.

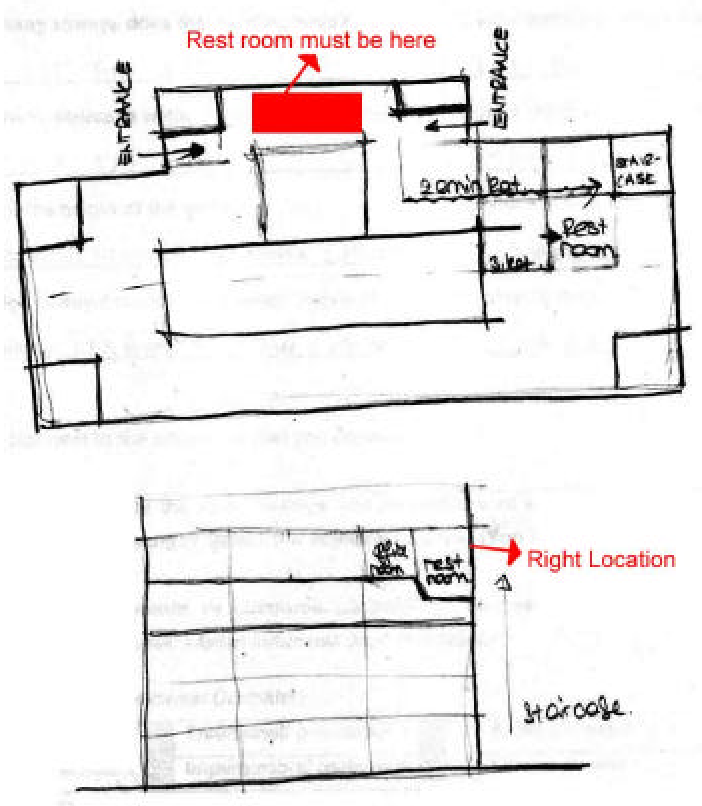


Figure. 5.22. Route from "Entrance to Rest Room" – First Questionnaire, Student 17

On the other hand, second (computer based) questionnaire's results showed that the students could not definitely perceive the whole spaces of the Larkin Building. We can understand this point from the sketches. After the second questionnaire, most of the students could not draw the whole building to their sketches. However, it can be understood from their sketches that they really perceived the spaces that they virtually walked through. Moreover, sketches and schemes showed that the students described the route from the entrance to the rest room like a description of a real place. The arrows on the sketches mean that "turn left from the first turn, turn left from the information desk, etc…"

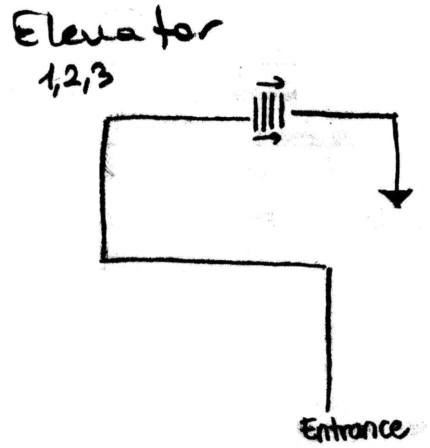


Figure. 5.23. Route from "Entrance to Rest Room" – Second Questionnaire, Student 5

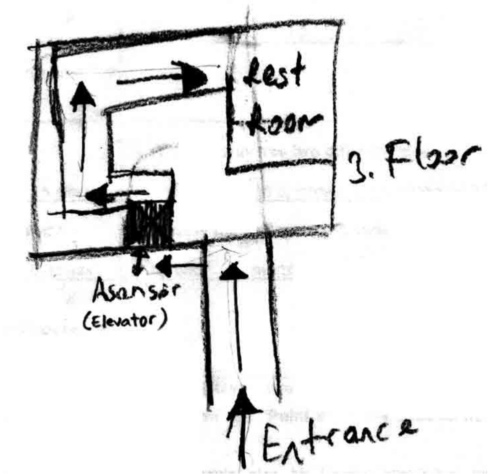


Figure. 5.24. Route from "Entrance to Rest Room" – Second Questionnaire, Student 6

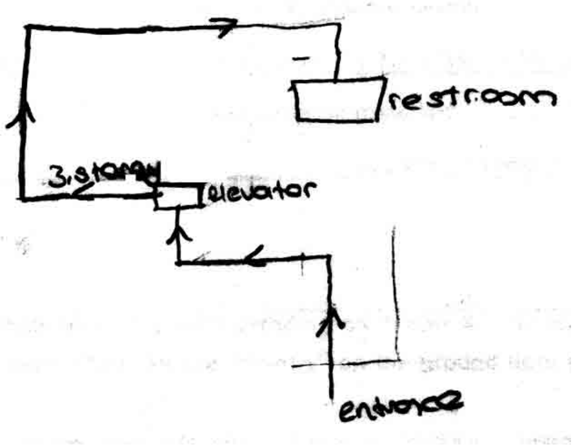
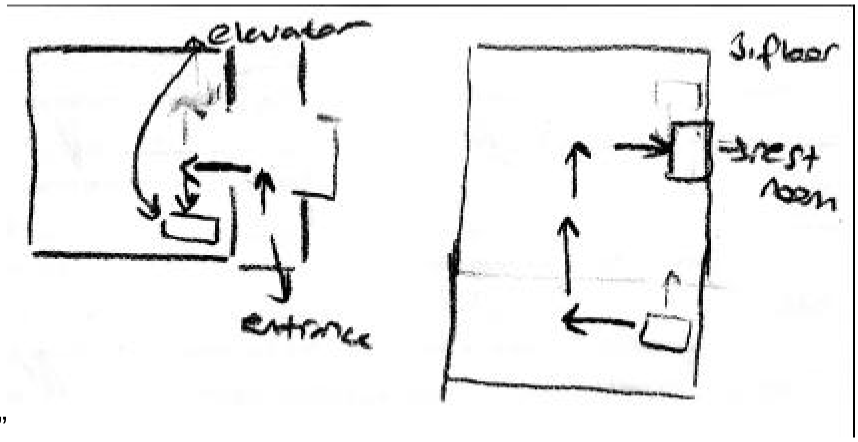


Figure. 5.25. Route from "Entrance to Rest Room"–Second Questionnaire, Student 13



“”

Figure. 5.26. Route from “Entrance to Rest Room”–Second Questionnaire, Student 7

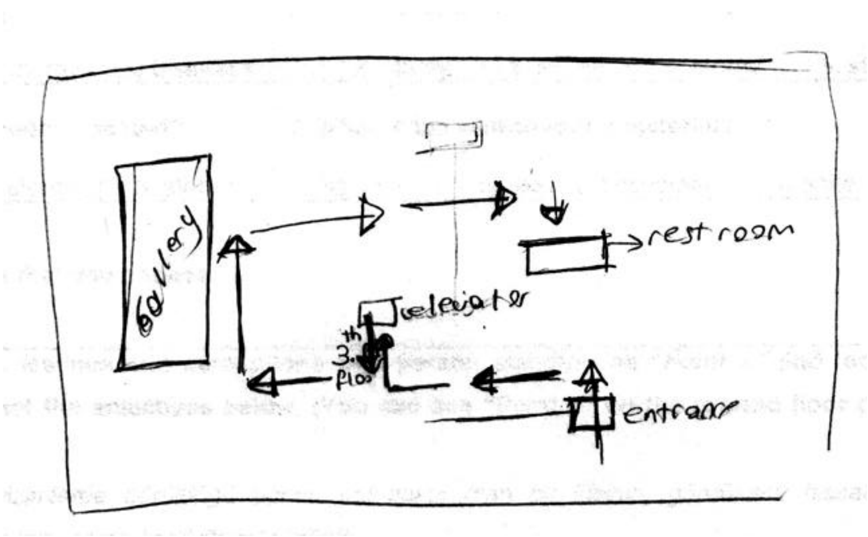


Figure. 5.27. Route from “Entrance to Rest Room”–Second Questionnaire, Student 29

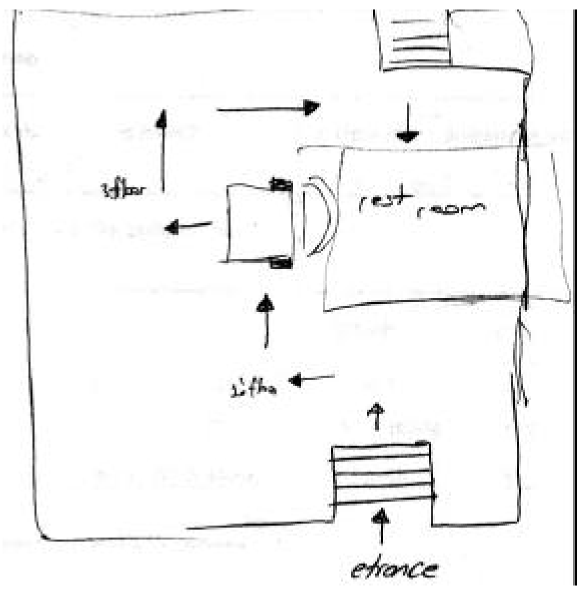


Figure. 5.28. Route from “Entrance to Rest Room”–Second Questionnaire, Student 34

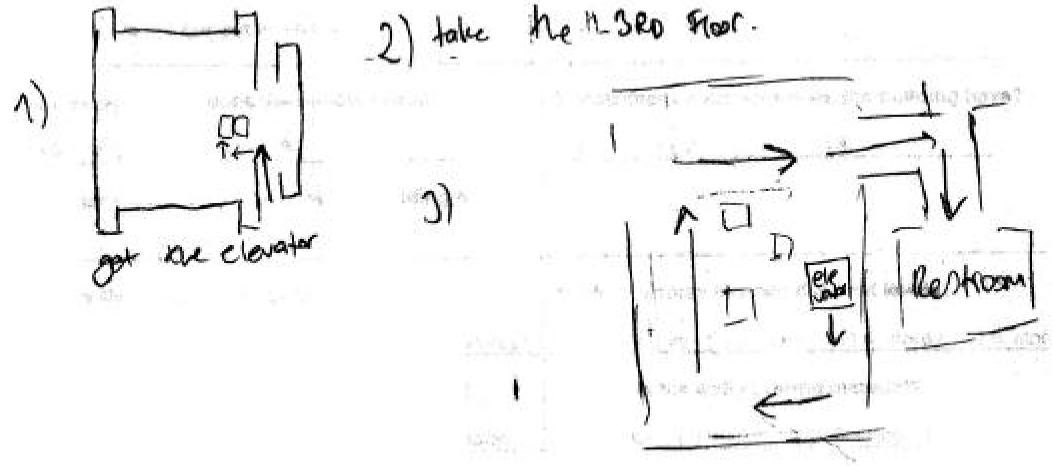


Figure. 5.29. Route from “Entrance to Rest Room”–Second Questionnaire, Student 8

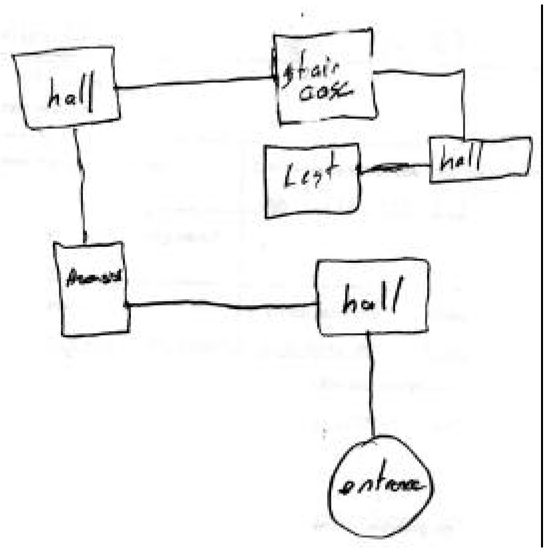


Figure. 5.30. Route from “Entrance to Rest Room”–Second Questionnaire, Student 23

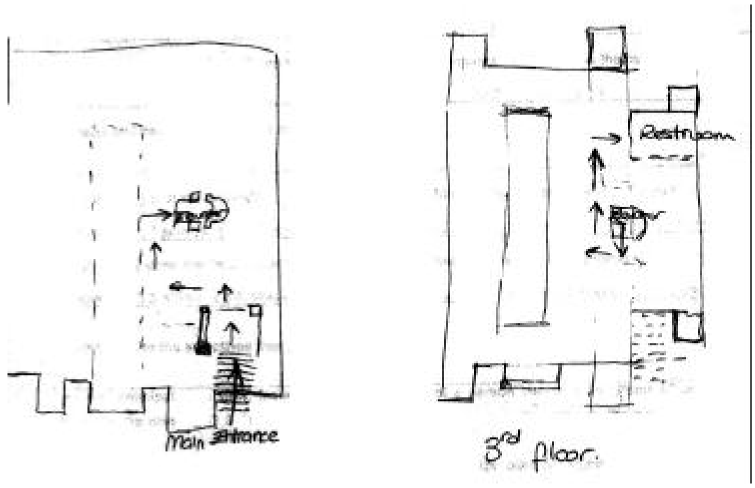


Figure. 5.31. Route from “Entrance to Rest Room”–Second Questionnaire, Student 31

Chapter 6
CONCLUSION

Today, 2D representation techniques such as plans, sections, elevations and perspectives are still the main communication media for the profession of architecture. Architects still design and represent their ideas by these representation techniques. Moreover, they try to perceive other architects' thoughts by the symbolized language of these 2D representation techniques.

By the rapid development of computer aided design (CAD) techniques, alternative representation media such as computer aided 3D representation techniques and virtual environments (VE) have entered to the world of architecture. By the time, these new tools and media began to take on the role of 2D representation techniques. Virtual environments and also digital media provide positive effects on all phases of architectural design process. Designers, users and also contractors get some conveniences from the use of these environments. Main characteristics of these digital media such as three dimensionality, interaction, and immersion (the feeling of "being inside" the computer generated world), have facilitated the preparation of architectural representations and execution of design process. Although these new technologies have lots of advantages according to the conventional 2D representation techniques, computer based 3D representation techniques and virtual environments have not been using widespread as the communication medium of architecture.

Today, computer aided systems have been commonly using in design process, visualization and presentation of the designs. Besides, today there are lots of researches on completely digitizing the architectural design and representation process. These researches mainly claim that perception of architectural space can be easier and more successful by computer based 3D simulations according to the paper based 2D symbols of the real objects and buildings, so whole design practice can be processed in digital media.

At this point, this thesis has compared 2D conventional representation techniques and 3D virtual environments in the context of spatial perception. For this comparative research, an experimental case study has been constituted in the study; and perception manners of the students according to the representation media have been tested, compared and evaluated. With the guidance of the data obtained from the previous studies and our comparative case study, it can be possible to generalize the advantages and shortcomings of virtual environments in architectural design process and perception of architectural space.

6.1. Advantages of Virtual Environments in Architecture:

Advantages of virtual environments on architectural design process and perception of architectural space can be summarized in a few main headlines:

1. Virtual environments offer a developed design and evaluation medium.

As mentioned in Chapter 2, before the development of computer related media and representation techniques, hand-rendered representation methods were used in architecture. In these methods, architects were preparing plans, sections, elevations, perspectives, sketches or axonometric drawings separately. Further detailing was a new drawing process. Moreover, it was so difficult to represent textures, materials or effects of light by these traditional methods. By these reasons, perception of the whole project with only using one of these drawings was nearly impossible.

Computer technologies facilitate the use of all design tools such as plans, sections, perspectives and 3D physical models at the same time in design process. Thus, designers can evaluate their designs by more various design tools and media by using computer techniques in design process. Generally it can be said that architectural representations are simulations of the original building; and today, effective simulations can be achieved by using digital technologies for architectural design and presentations. It is possible to claim that fundamental advantage of computer models over physical models or drawings is that the computer-generated model is a three-dimensional, full-scale mapping of the ideated design and can be viewed from any viewpoint, from its outside as well as its inside. Multitude of renderings, axonometric drawings, and perspectives can be automatically generated by the machine with minimal human effort. Animations and walk-throughs can also be generated by using the same computer-generated model which is employed for two-dimensional graphic renderings, such as perspective, axonometric, plan, and elevation view (Bertol, 1997, p.146).

By these developments in computer technologies, today, digital modeling has been replacing the capacity of physical models as an analytical and thinking tool, and as a communication and presentation device (Proctor, 2001, p.193). Architects who once used CAD as a drafting tool are now investigating ways to develop their buildings with digital models as their primary design medium. With model-describing languages like VRML, architects are now looking for ways to distribute digital models of their designs electronically, potentially eliminating the need for distribution via printed construction drawings and specifications (Campbell, 2000, p.130).

2. Virtual environments increase perceptual quality according to conventional methods.

2D representation techniques can not be sufficient to depict the architectural spaces; because these drawings are just the combinations of the architectural and geometric symbols, and these symbols can not permanently represent 3D objects and their whole characteristics. Because of this situation, 2D representation techniques can sometimes be misleading for perception of space. Some lines, symbols and hatches in 2D drawings can astonish the user, and cause misleading perceptions. However, in 3D representations, users can see the object with its own color, texture and material, so users can perceive the architectural space better.

The other important point is about the view points. Perception of architectural space is a dynamic process, and it changes according to viewpoint. Generally, visual materials are the fundamentals of this profession. Thus, the best enjoyment and judgment of an architectural environment is provided by the change of perspectives that give a succession of views. In other words, only the totality of these views can provide a fair perception of an architectural space. The act of dynamic looking while walking (versus the static viewing of 2D drawings) gives relatively enough knowledge and analytical tools to judge a work of architecture (Bertol, 1997, p.39).

Best way of providing this totality of views is possible in real physical environment. In a physical environment, user can view the 3D object from different points; he can study the objects with their original material and texture views. Moreover, observer can take imaginary walks through the designed building in a much more intuitive fashion than looking at plan and elevation drawings. Thus, only with 2D drawings, it is impossible to provide real space perception, because viewpoint can be misleading for users. For example, there can be objects that are different but their plan, section or elevation can be similar, or the same. Figure 6.1 is a suitable example for this situation. All objects on the figure are actually different but they look like the same object from the top view.

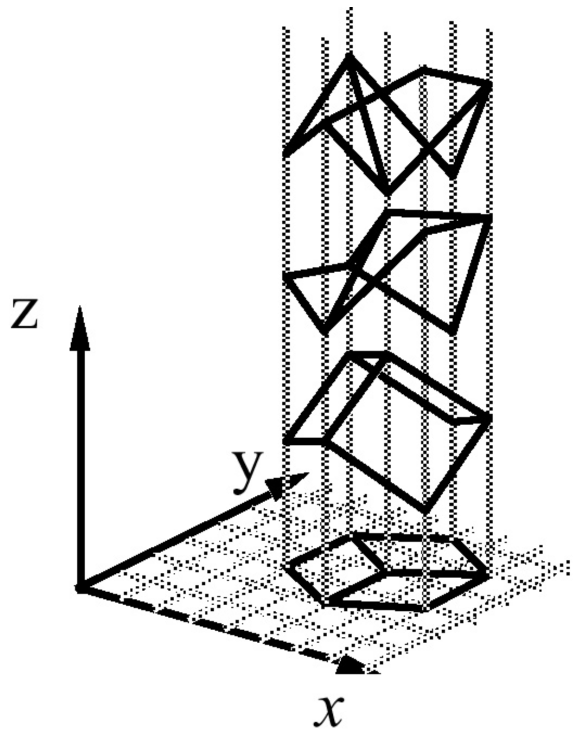


Figure. 6.1. Different objects can have the same plan, section or elevation (Kersten, 1999, p.11)

Similar to this example, a series of different perceptions arise when we drive and walk around a building or if we are inside of it. Moreover, perception of a mountain completely different depends on if we fly over it, drive around it or climb on it. In all of these examples, material of the object, illumination, and viewpoint are also important for perception of an object or an image. All of these factors for perception of an object or image can be seen in Figure 6 .2.

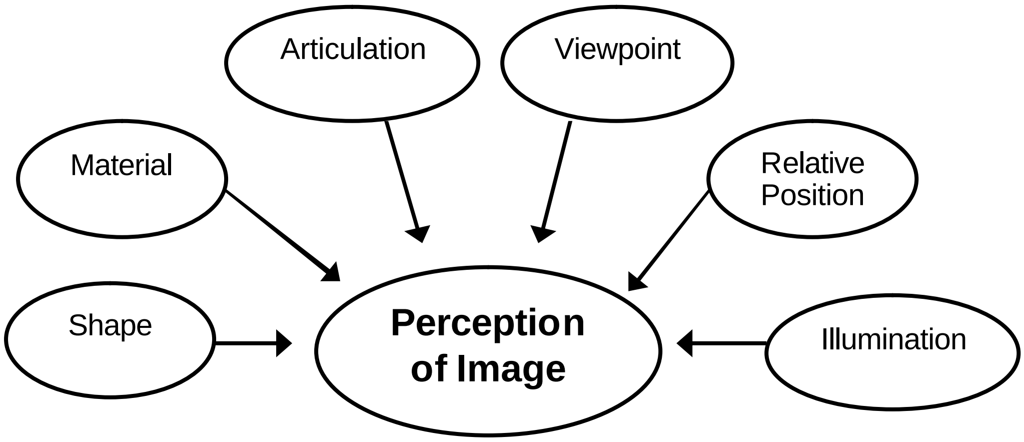


Figure. 6.2. Effective Factors for Perception of an Image (Kersten, 1999, p.20)

Only physical reality can meet all of these effective factors for perception by its interactivity; and clients use these factors and interactivity simultaneously in real world. Conventional representation techniques, on the contrary are very primitive in this context, and they don't include these effective factors for providing a definite perception. Today, computer technologies try to simulate physical reality and provide necessary perception as a representation technique. This 3D representation technique is the ultimate representation that users are not only passive viewers, but also players in real time interaction. This interaction is the generator of the representations of the virtual world. While the content of the virtual world could also be provided in different computer simulations and visualizations (graphics, charts, and rendered images) only in virtual reality applications can provide interaction between the perceiving subject and the object of perception. It is because of this "natural" interaction between the computer-generated world and the user that VR is defined as the ultimate interface between man and machine (Bertol, 1997, p.117). Developed virtual environment representations can also involve not only our sense of sight, but also the other senses; images, sounds and tactile sensations. By these specific and splendid properties of these systems, it is possible to have a more successful perception according to conventional methods. Users can virtually walk through and fly around the design. By the way, for users it can be easy to perceive complex designs that can not easily perceive by 2D conventional tools.

In other words, users who investigate an architectural space by 3D representation techniques can remember the space and its characteristics better than a user who use 2D conventional methods. This situation was proved by the case study results in Chapter 5.

3. Virtual environments increase realism of the presentations:

Realism is one of the major achievements of computer-generated models. By 3D models and virtual environments, architectural representations became more realistic, and graphically sophisticated. Because of the full scale representation of architectural elements, proportions and relations between different elements of a composition can be visually tested for aesthetic and functional considerations. Materials can also be applied to the surface of the model as texture maps, adding another level of realism to the images (Bertol, 1997, p.225). For example; by hyper-realistic simulations materials, shadows, etc. can be perceived more than the physical models, because, generally these models can not fully represent materials. The effect of light is also rendered in representations of computer worlds: Algorithms such as raytracing or radiosity are used to simulate the effects of light on surfaces and volumes. Moreover, by the virtual environment systems designed for internet such as VRML, architectural representations can be shared world-wide.

4. Virtual environments provide opportunities for immersive design.

Design of architecture uses mainly 2D media as communication tool such as papers (Even with CAD techniques, the output which is displayed on the screen or printed on paper is also a 2D view). The other architectural design media are physical models. However, the scale of a physical model limits the user's ability to experience the quality of the space, because the model cannot be inhabited and perceived from the inside.

These problems can be overcome by the helps of virtual environments. For a complete understanding of a 3D space, virtual environments offer new opportunities of languages to designers. It is the virtual environments which open up the possibilities for the production of better built environment by:

- Addressing sustainability through environmental simulations and appraisal;
- Engaging design creativity through immersive design;
- Enabling users' participation in immersive design environment through collaboration between designers (Petric, 2001, p.389).

Digital 3D models are generated with immediacy similar to physical models, constructed to improve the perception of designs developed by drawings. Thus VE provide through its involvement an immediate feedback to its users, which is not possible within CAD or conventional design media. Designers can therefore work more three-dimensionally since every object within VE is experienced through movement and interaction. This possibility offers a different 'conversation' with the design that otherwise is not obvious or possible. Spatial issues are addressed in a manner similar to the real world. The process of design becomes more immediate in some aspects, with the tools enhancing the translation of the designers' and users' mental intention, experiences that were encountered perhaps in spite of the technology used and the abstractness of VE (Schnabel, 2002, p.595).

Within an immersive design environment, the creation of form in space becomes possible for the first time, without any intermediation. Like a magician, the architect's gesture can raise walls, cut openings, and adjust the slope of roofs. Floors and stairs can be added and subtracted according to the reaction and judgment provoked by the perceptual impact. If the design is based on volumes, Boolean operations of addition or subtraction can be utilized, allowing the molding of virtual space similar to the creation of a sculpture by a molding and carving motion. Proportions between various architectural elements can be verified by inhabiting the space they define. The 1:1 scale of the immersive design environment gives the ability to perceive the designed space without the false assumptions which so often accompany to 2D representations (Bertol, 1997, p.122).

5. Virtual environments are user-friendly systems for designers and users.

6. Virtual environments increase interactivity with design media in design process:

In conventional hand-rendered representation techniques and also in basic and primitive CAD methods; final rendering or animation can only be seen passively, without any interaction. What truly differentiates virtual reality applications from their historical antecedents is the dynamism of the medium and the interaction between viewer and representation. Moreover, “physical immersion” of architecture can be rendered at its best in immersive virtual environments. While other architectural representation methods (hand-rendered and basic computer applications) depicts drawings or images on 2D media, VR environments completely cover us, providing a substitute to the real world environment that we occupy (Bertol, 1997, p.69). By these interactions, design process has also had differences. Creating the thoughts in 3 dimensionally and evaluating it in real time can be possible in virtual environments. By these techniques, perception and cognition of space can be easier especially for students.

7. Virtual environments facilitate sharing and collaboration opportunities.

Computer based drawings and renders have an important advantage according to conventional hand-rendered paper-based representations: These drawings and images are in digital medium, so it is so easy to share these files worldwide by the support of programming languages like VRML or XML. With the Internet and its graphic interface, architects have been promised a new medium for communicating with other players in the architecture-engineering-construction (AEC) industry. Texts, raster-based images, and recently vector-based graphics and models can all be exchanged and distributed widely and instantaneously with the internet. Developers of VRML and proponents of technology in the AEC industry alike proclaim the benefits of communicating design in three dimensions via the Web. VRML offers a standard way to represent and exchange both geometry and the associated text inherent in construction documents (Campbell, 2000, p.2). By these programming languages, object or projects can be transformed to a format that can be seen from anywhere in the world with only the help of an Internet browser (such as Internet Explorer or Netscape Navigator) and a small plug-in (such as Cosmo

VRML Player, Cortona VRML Player and etc.). By this way, collaboration of architects from the different locations can be easier.

8. Virtual environments provide opportunities for automated design.

Immersive characteristics of design in virtual environments are mentioned above. However, general contributions of computer aided technologies, especially virtual environments on the design process must also be explained. Generally for an architect, design process begins with sketching about the subject after the determination of needs and definition of the problem. During this design process, drawings, especially sketches take an important place for transforming ideas to the geometric forms and spaces. This is because; design process is a kind of union of analyzes and feedbacks; and sketches are the easiest ways for explaining ideas. By sketches, architects try to perceive and develop their designs. After the development of computer technologies, virtual environments have begun to join this process' every phase. Figure 6.3 shows the roles and effects of computer technologies in design process.

As it is mentioned in the figure 6.3, in the design process there are many stages, and computer technologies can be used in all of these stages. What differentiates an initial sketch from a construction drawing is the amount and accuracy of information contained in the representation. While a sketch is mostly expressive of an intuitive and unpredictable individual creation, the evolution of the sketch into presentation and working drawings represents a predictable sequence of steps which can be programmed in a series of instructions to be executed by the computer.

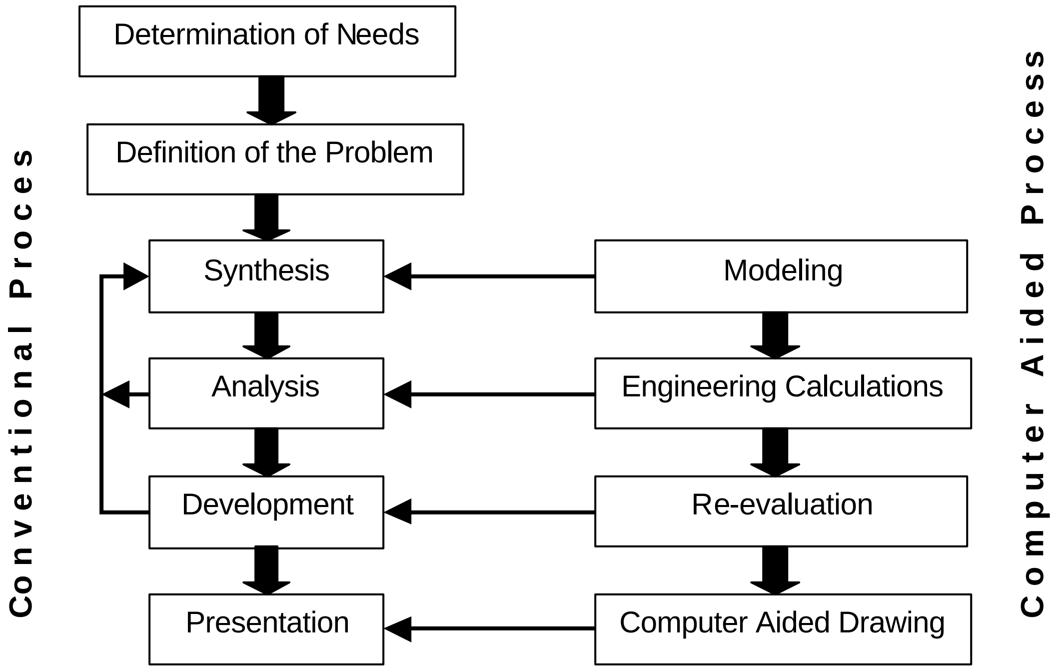


Figure. 6.3. Role of Computer Techniques in Design Process (Tokman, 1999, p.74)

Computer aided design provides valuable tools for an automated architectural design. For instance, envisioning a facade as a curved wall with triangular openings is part of the creative process, while the implementation of its model with exact dimensions of the wall and the openings, its curvature angle, and the solid proportion can be accomplished by an automated sequence of steps. Many of the operations which are performed in a repeating fashion can be automated and implemented in a CAD application (Bertol, 1997, p.115).

An automated design system is easily implemented as a CAD application. In addition, VE can be applied as a final presentation and evaluation tool, using a CAD or modeling package. If alternative design solutions are suggested by the VR evaluation, they can be developed outside the immersive environment and translated to the CAD application. This process loses the strength of the solutions envisioned from the interactive and immersive evaluation. The implementation of an automated design in an immersive environment could translate a sketch into a functional model, which could be tested and evaluated at the same moment it is created. The immediacy of the process could enhance the creative act and instantaneously test the validity of a design solution (Bertol, 1997, p.203).

By the results of this thesis and related case study, it is seen that computer based 3D representation techniques have very important potentials for improving spatial perception. By the helps of three dimensional, textured and colored representations of all kinds of virtual environments, architects can design and perceive their designs' results synchronously. Another important advantage is on the perceiving and understanding of the applied projects. By the help of the virtual environments, complex architectural spaces can be perceived better than the 2D conventional techniques.

6.2. Limitations of Virtual Environments in Architecture:

Although virtual environments open new opportunities for architects on design process and perception of architectural space, there are some shortcomings and disadvantages of these tools according to conventional 2D drawings and especially physical models. These shortcomings and disadvantages can be summarized as follows:

1. Virtual environment systems can not approach the resolution and complexity of experiencing a physical environment.

2. Virtual environments have some limitations on addressing to five senses.

First of all, it can be said that all complex virtual environments can not exactly address to five senses of the users. Output devices of these computerized systems provide feedback (visual, auditory, tactile) for only three of the five senses (Bridges, 1997). It means that smell and tactile senses can not be met by virtual environments. These senses are also important for perception of the space, because body contact with the edges of space has a key role for our awareness of spatial location (Porter, 1979, p.22). Tactile senses are also important in design process. An architect must know the texture of the materials, and this sense can not be simulated by any virtual environments. Architectural theorist Marco Frascari emphasizes the importance of tactile senses and bodily experience in architectural design and perception as follows:

In architecture, feeling handrail, walking up steps or between walls, turning a corner and noting the sitting of a beam in a wall, are coordinated elements of visual and tactile sensations. The location of those details gives birth to the conventions that tie a meaning to a perception. (Hale, p.121)

3. Virtual environments can not represent certain fundamental physical properties of architectural spaces as successful as conventional 2D representation techniques.

As it is seen in previous studies and our comparative case study, general physical properties of an architectural space such as number of the entrances and staircases can be perceived better in 2D representation techniques. This is because of the characteristics of virtual environments. In virtual environments, users sometimes don't browse the space totally, and miss some important characteristics and elements of that space. However, in a 2D paper based plan, it can be possible to see all elements (such as columns, walls, some rooms, etc) easier than virtual environments.

4. Users do not receive enough visual, auditory or tactile kinesthetic information from the representation of their bodies in the virtual environments.

This point is also related to first limitation. When a client virtually walks through the design and tries to perceive and evaluate the materials in virtual environments, seen materials and given space can be misleading for the user. This is because geometric shape of some spaces cannot be easily understood with an inner view, and a guide such as a plan may be necessary.

5. Additionally, there are some practical shortcomings of virtual environments. For instance, architects must have the necessary knowledge on the computer systems for using this kind of complex drawing tools. However, 2D techniques don't need an extra knowledge; a simple pencil can be the only tool. For these reasons, the fully-enabled use of VR technologies will probably not take place in the AEC industry for many years to come. One huge technical issue centers on the fact that at a certain point in the process the building and its components must be built. It is unclear just how web-based models can be used on the construction site or in the factory, as construction methods are rarely sympathetic to the relative fragility of the technology used to render such models. Ways need to be investigated to display digital media in full-size on the job site, with robust technology that is accessible and manageable by the personnel who need to use it. Fields of study like wearable computing and augmented reality begin to address this issue, but they are still many years away from being pervasive in the construction industry (Campbell, 2000, p.8).

Because of these shortcomings, 2D conventional techniques are still so essential for the architectural representations.

For a few years, main communication language of the architecture has been transforming to a combination of 2D conventional techniques and computer based 3D methods. Besides, in the future, by the development of the digital technologies, virtual environments will be more effective in all areas of architecture as well as architectural representation techniques. Maybe, design and presentation procedures will be a whole digitized process and phenomenon. As a preparation to these transformations in the profession of architecture, designers must adapt themselves to these digital tools and media from today. At this point, today, use of computer aided design (CAD) tools, 3D modeling tools and virtual reality must be encouraged. These tools must be used especially in architectural education. Architectural educators must benefit from the positive effects of these tools on improving the spatial perception.

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APPENDIX 1

CASE STUDY QUESTIONNAIRES

Perception of Space through Representation Media:
A Comparison between 2D Representation Techniques and 3D Virtual Environments

Questionnaire 2. Spatial Perception in 3D Virtual Environments

This questionnaire is the second phase of a two step test, and it will be used in the case study of Yenal Akgün's master thesis. Please answer the questions carefully…

Time for the test is 30 minutes…

Name: ………………………………………………………………

Put a tick to the correct answers.

1. How many storeys does the building have? ( ) 3 ( ) 4 ( ) 5 ( ) 6	**2. How many entrances does the building have?** ( ) 1 ( ) 2 ( ) 3 ( ) 4
3. How many staircase wells does the building have? ( ) 2 ( ) 4 ( ) 6 ( ) 8	**4. What is the height of the gallery?** ( ) 2 storeys ( ) 3 storeys ( ) 4 storeys ( ) 5 storeys
5. Which storey has two different levels? ( ) 2. storey ( ) 3. storey ( ) 4. storey ( ) 5. storey	**6. In which storey does the "rest room" located?** ( ) 2. storey ( ) 3. storey ( ) 4. storey ( ) 5. storey
7. What is the wall covering material? ( ) brick ( ) marble ( ) concrete ( ) granite	

8. Can you anticipate the view, feelings and perceptions of a person standing on "*Point X*" and looking a shown in the drawings? Select the adjectives below. (You can see "Point x" on the ground floor plan an sections.) Put a tick next to the adjectives that you choose.

X noktasinda durmakta ve çizimlerde görüldügü yönde bakmakta olan bir kisinin, gördükleri, hissetikleri v algiladiklarini asagidaki sifatlari kullanarak öngörür müsünüz? Size yakin gelen sifatlarin yanina bir isaret koyunuz.

Spatial Properties: ***(Mekansal Özellikler)***

Modern/ *modern*		**Traditional/** *geleneksel*		**Axial/** *aks esasli*		**non-axial/** akssiz	
Permeable/ *(geçirgen)*		**Impermeable/** *geçirimsiz*		**Linear/** *çizgisel*		**Central/** dairesel	
Adaptable/ *uyumlu*		**in-adaptable/** *uyumsuz*		**Total/** *bütüncül*		**Divided/** bölümlü	
Natural/ *dogal*		**Artificial/** *yapay*		**Regular/** *muntazam*		**Irregular/** *çarpik*	
Symmetrical/ *simetrik*		**Asymmetrical/** *asimetrik*		**Variable/** *degisken*		**Constant/** sabit	

Complex/ *karmasik*		**Simple/** basit		**Rational/** *akilci*		**Irrational/** *mantik disi*
Static/ *durgun*		**Dynamic/** hareketli		**Vertical/** *düsey*		**Horizontal/** *yatay*
Balanced/ *dengeli*		**Unbalanced/** *dengesiz*		**Monumental/** *anitsal*		**Modest/** *gösterissiz*
Homogeneous/ *homojen*		**Heterogeneous/** *heterojen*		……………………..		………………………

Physical Properties: *(Fiziksel Özellikler)*

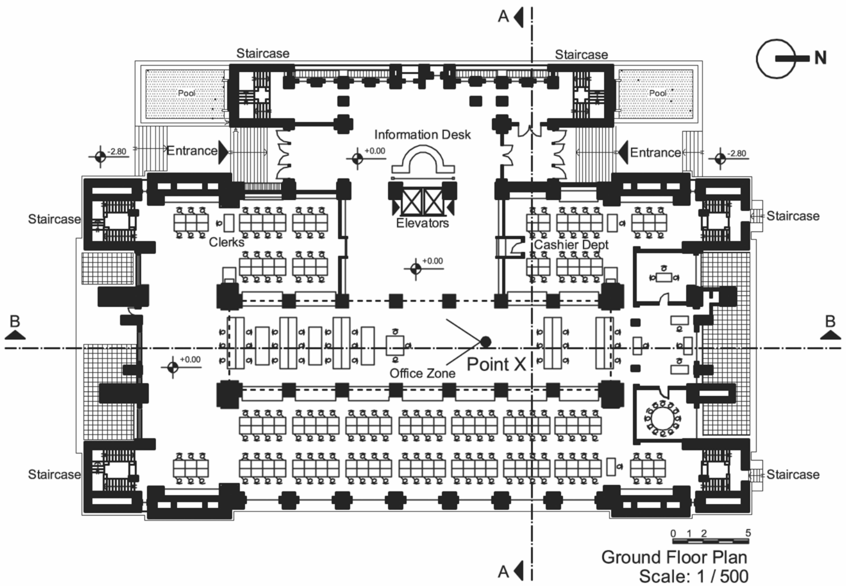
Proportional/ *oranli*		**Disproportional/** *oransiz*		**Balanced/** *dengeli*		**Unbalanced/** *dengesiz*
Wide/ *genis*		**Restricted/** *dar*		**Unpretentious/** *iddiasiz*		**Pretentious/** *iddiali*
Spacious/ *ferah*		**Compressed/** *sikisik*		**Dominant/** *baskin*		**Recessive/** *çekinik*
High/ *yüksek*		**Low/** *alçak*		**Slender/** *narin*		**Fat/** *iri*
Bright/ *parlak*		**Rough/** *mat*		**Frayed/** *yipranmis*		**New/** *yeni*
Transparent		**opaque**		**Clumsy/** *hantal*		**Elegant/** *zarif*
Exaggerated/ *abartili*		**Modest/** *mütevazi*		**Stiff/** *sert*		**Soft/** *yumusak*
Cold/ *soguk*		**Hot/** *sicak*		**Strong/** *güçlü*		**Weak/** *zayif*
Organic/ *organik*		**Inorganic/** *inorganik*		**Natural/** *dogal*		**Artificial/** *yapay*
……………………		……………………				

Perceptual and Sensorial Properties (*Algisal ve Duyusal Özellikler*)

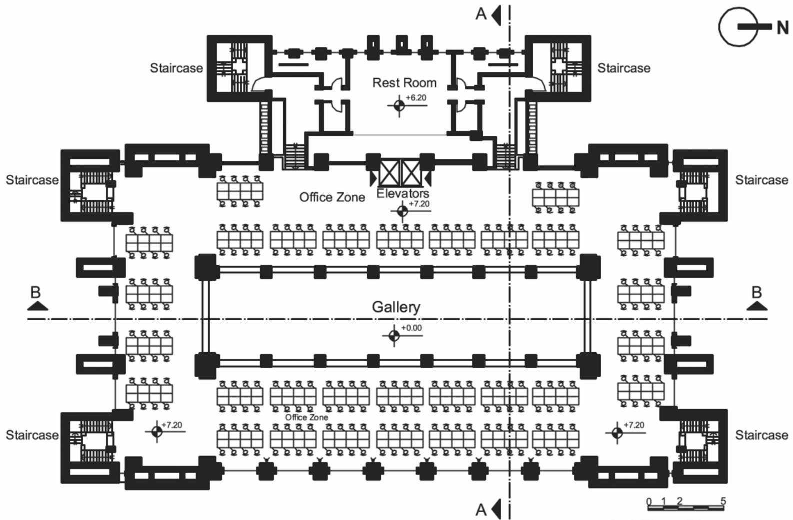
Symmetrical		**asymmetrical**		**positive**		**negative**
Dark/ karanlik		**Light/** *aydinlik*		**Dense/** *yogun*		**Seldom/** *seyrek*
Spacious/ *ferah*		**Cramped/** *sikisik*		**Static/** *duragan*		**Kinetic/** *hareketli*
Aesthetic/ *estetik*		**Unattractive/** *çirkin*		**Adaptable/** *uyumlu*		**Inadaptable/** *uyumsuz*
Permeable/ *geçirgen*		**Opaque/** *opak*		**Chaotic/** *(karisik)*		**Regular/** *muntazam*
Social/ *sosyal*		**Unsocial/** *asosyal*		**Private/** *özel*		**Public/** *kamusal*
Unexciting/ *sikici*		**Entertaining/** *eglendirici*		**Scattered/** *daginik*		**Ordered/** *düzenli*
Natural/ *dogal*		**Artificial/** *yapay*		**Surprising/** *sürprizli*		**Boring/** *sikici*
Pretentious/ *iddiali*		**Unpretentious/** *iddiasiz*		**well-cared/** *bakimli*		**Neglected/** *bakimsiz*
Calm/ *dingin*		**Agitated/** *yaygarali*		**Classical/** *klasik*		**Modern/** *modern*
Ordinary/ *olagan*		**extra-ordinary/** *siradisi*		**Total/** *bütüncül*		**Divided/** *bölünmüs*
Thorough/ *özenli*		**Slipshod/** *bastan savma*		**Monotonous/** *tekdüze*		**Varied/** *çesitli*
Restful/ *dinlendirici*		**Tiring/** *yorucu*		**well-shaped/** *biçimli*		**ill-shaped/** *biçimsiz*
Consistent/ *tutarli*		**Inconsistent/** *tutarsiz*		**Spacious/** *ferah*		**Compressed/** *sikisik*
Opaque/ *opak*		**Transparent/** *transparan*		**Stifling/** *bogucu*		**Relieved/** *ferahlatici*
Living/ *yasayan*		**Nonliving/** *yasamayan*		**Temporal/** *geçici*		**Permanent/** *kalici*
Noisy/ *gürültülü*		**Silent/** *sessiz*		**Contradictory/** *çelisik*		**Consistent/** *tutarli*
Inhospitable/ *itici*		**Hospitable/** *konuksever*		**Chaotic/** *karisik*		**Regular/** *muntazam*
Unexciting/ *sikici*		**Entertaining/** *eglendirici*		**Interesting/** *ilginç*		**Boring/** *sikici*
Optimistic/ *iyimser*		**Pessimistic/** *kötümser*		**Sympathetic/** *sempatik*		**Antipathetic/** *antipatik*
Functional/ *islevsel*		**Useless/** *ise yaramaz)*		**Restful/** *dinlendirici*		**Tiring/** *yorucu*
Depressive/ *bunaltici*		**Reassured/** *rahatlatici*		**Extrinsic/** *disa dönük*		**Intrinsic/** *içe dönük*
Imposing/ *gösterisli*		**Unimpressive/** *gösterissiz*		**Understandable/** *anlasilir*		**Incomprehensible/** *anlasilmaz*
Proportional/ *oranli*		**Disproportionate/** *oransiz*		…………………………		………………………

9. When you look at the drawings, can you definitely anticipate the texture, color and material of the walls? *Çizimlere baktiginizda duvar kaplamasinin rengini, okusunu ve malzemesini kesin olarak anlayabiliyormusunuz?* ( ) Understandable ( ) Not understandable	**10. Which spaces are dominant in the building? What are their functions?** *Sizce binadaki baskin mekanlar ve islevleri nelerdir?* …………………………………………………………………… ……………………………………………………………………

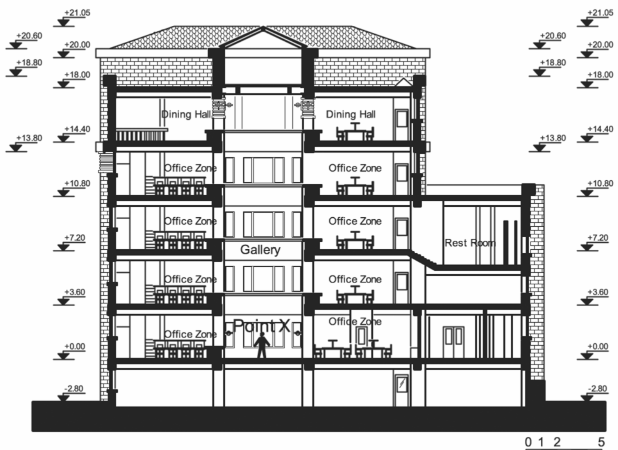
Case Study: Application 1



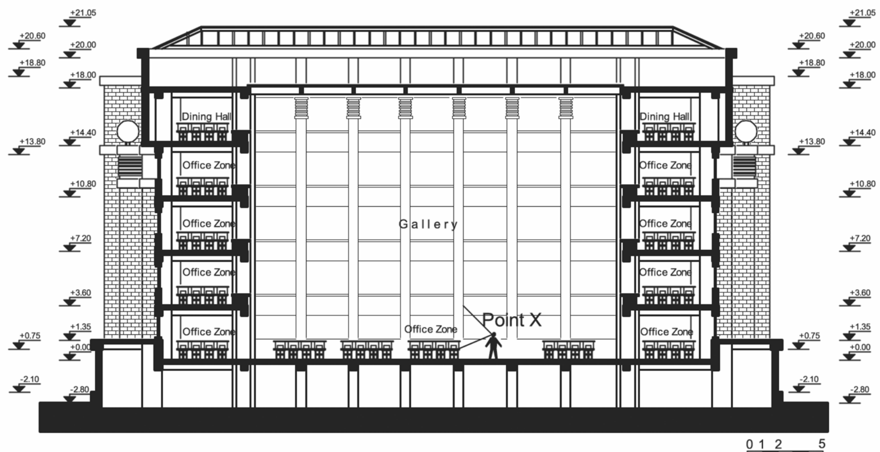
Ground Floor Plan
Scale: 1 / 500



3rd Floor Plan
Scale: 1 / 500

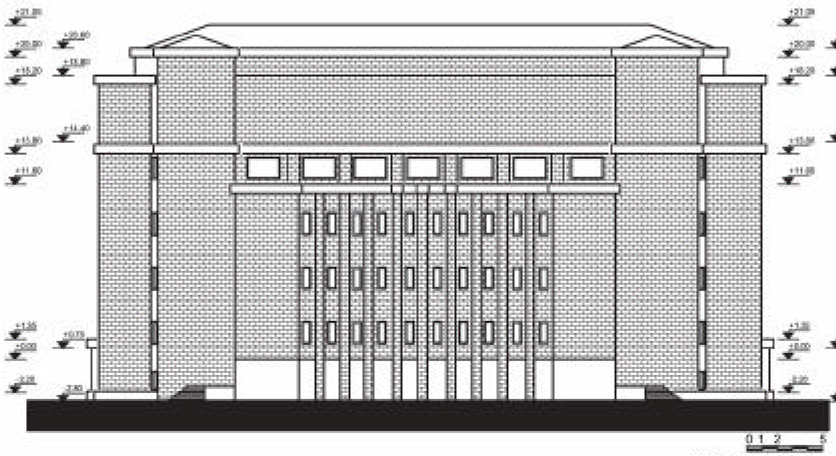


Section A-A
Scale: 1 / 500

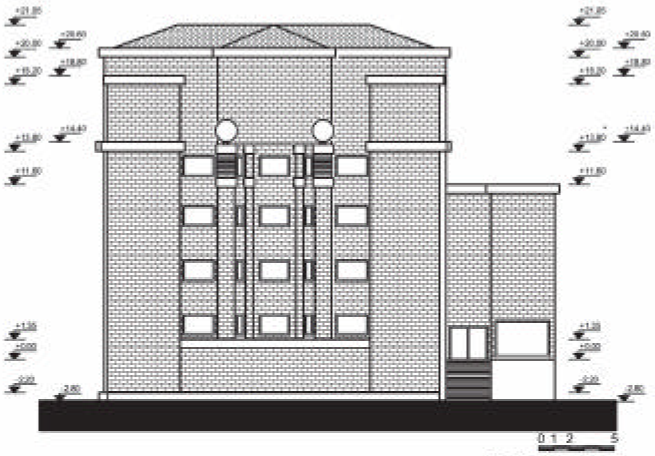


Section B-B
Scale: 1 / 500

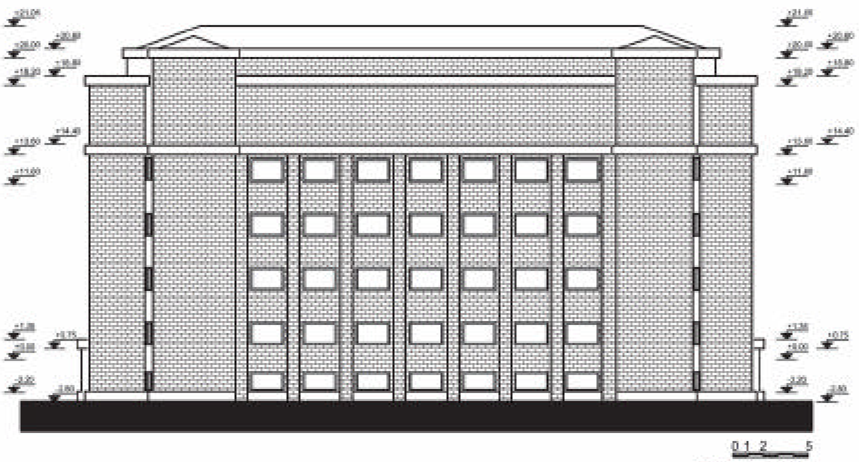
Case Study: Application 1



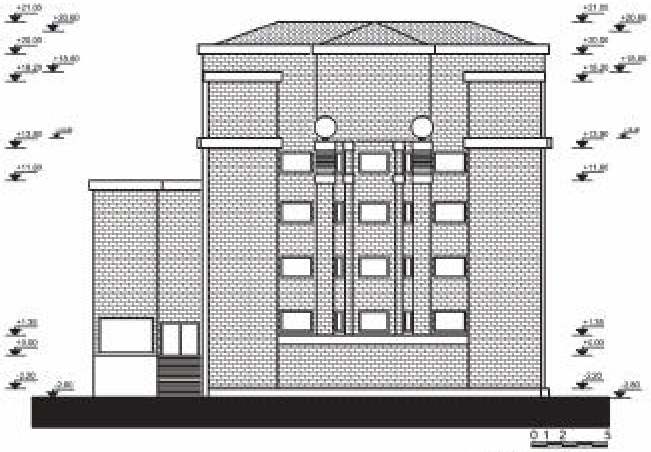
West Elevation
Scale: 1 / 500



North Elevation
Scale: 1 500



East Elevation
Scale: 1 / 500



South Elevation
Scale: 1 / 500

11. Describe and sketch the view of a person on “Point X” by a perspective.

X noktasinda durmakta ve çizimlerde görüldügü yönde bakmakta olan bir kisinin gördüklerini bir perspektifle ifade ediniz.

Perception of Space through Representation Media:
A Comparison between 2D Representation Techniques and 3D Virtual Environments

Questionnaire 2. Spatial Perception in 3D Virtual Environments

Time for the test is 5 minutes… Please answer the questions carefully…

Name: ……………………………………………………………………….

12. Sketch the route from the "main entrance" to the "rest room".

"Ana Giris"ten "Dinlenme Odasi"na gitmek için kullanilacak yolu kroki ve çizimlerle gösteriniz.

13. **(*) You have seen both of the conventional and computer based representation techniques in these two tests. In your opinion, which technique is more efficient to depict an architectural space?**

Her 2 testteki mekanin temsil edilis tekniklerini gördünüz. Sizce geleneksel yöntem mi, yoksa bilgisayar temelli yöntem mi mekani ifade etmekte daha basarilidir?

(*). 13th question is asked only in the second step.

(**). Plans, sections and elevations of the Larkin Building are given only in the first step of the case study.

APPENDIX 2

NUMERICAL RESULTS OF THE CASE STUDY

The percentages below represent the correct answers' proportions.

Questions:	1. Test	2. Test
1. How many storeys does the building have?	% 97.3	% 90,9
2. How many entrances does the building have?	% 86,8	% 78,8
3. How many staircase wells does the building have?	% 80,6	% 57,6
4. What is the height of the gallery?	% 65,8	% 59,4
5. Which storey has two different levels?	% 73,7	% 87,1
6. In which storey does the "rest room" located?	% 86,8	% 80,0
7. What is the wall covering material?	% 100,0	% 100,0

Question 8:

The percentages below represent the answers of the users to the 8th question. (For reading question 8, please see Appendix 1.)

Spatial Properties:

Adjectives:	1. Test	2. Test		Adjectives:	1. Test	2. Test
Traditional Modern	% 61,1 % 38,9	% 43,3 % 56,7		non-axial Axial	% 28,1 % 71,9	% 10,3 % 89,7
Impermeable Permeable	% 33,3 % 66,7	% 17,2 % 82,8		Central Linear	% 13,9 % 86,1	% 07,1 % 92,9
In-adaptable Adaptable	% 13,3 % 86,7	% 03,7 % 96,3		Divided Total	% 48,6 % 51,4	% 60,7 % 39,3
Artificial Natural	% 65,5 % 34,5	% 59,3 % 40,7		Irregular Regular	% 05,7 % 94,3	% 03,4 % 96,6
Asymmetrical Symmetrical	% 18,4 % 81,6	% 00,0 %100,0		Constant Variable	% 77,1 % 22,9	% 89,3 % 10,7
Simple Complex	% 76,7 % 23,3	% 82,1 % 17,9		Irrational Rational	% 03,1 % 96,9	% 00,0 %100,0
Dynamic Static	% 35,1 % 64,9	% 48,3 % 51,7		Horizontal Vertical	% 50,0 % 50,0	% 23,3 % 76,7
Unbalanced Balanced	% 13,9 % 86,1	% 00,0 %100,0		Modest Monumental	% 65,7 % 34,3	% 53,6 % 46,4
Heterogeneous Homogeneous	% 36,4 % 63,6	% 17,9 % 82,1				

Physical Properties:

Adjectives:	1. Test	2. Test		Adjectives:	1. Test	2. Test
Disproportional Proportional	% 20,0 % 80,0	% 03,3 % 96,7		Unbalanced Balanced	% 13,5 % 86,5	% 03,2 % 96,8

Restricted Wide	% 44.1 % 55,9	% 48,3 % 51,7	Pretentious Unpretentious	% 23,5 % 76,5	% 46,4 % 53,6
Compressed Spacious	% 48,6 % 51,4	% 31,0 % 69,0	Recessive Dominant	% 31,3 % 68,8	% 10,7 % 89,3
Low High	% 13,9 % 86,1	% 03,2 % 96,8	Fat Slender	% 64,7 % 35,3	% 82,8 % 17,2
Rough Bright	% 78,1 % 21,9	% 69,0 % 31,0	New Frayed	% 79,3 % 20,7	% 85,7 % 14,3
Opaque Transparent	% 54,8 % 45,2	% 53,5 % 46,7	Elegant Clumsy	% 32,3 % 67,7	% 34,6 % 65,4
Modest Exaggerated	% 60,0 % 40,0	% 81,5 % 18,5	Soft Stiff	% 12,9 % 87,1	% 06,9 % 93,1
Hot Cold	% 36,4 % 63,6	% 75,0 % 25,0	Weak Strong	% 11,8 % 88,2	% 03,3 % 96,7
Inorganic Organic	% 69,7 % 30,3	% 41,9 % 58,1	Artificial Natural	% 64,7 % 35,3	% 48,3 % 51,7

Perceptual and Sensorial Properties:

Adjectives:	1. Test	2. Test	Adjectives:	1. Test	2. Test
Asymmetrical Symmetrical	% 07,7 % 92,3	% 00,0 %100,0	Negative positive	% 39,1 % 60,9	% 23,8 % 76,2
Light Dark	% 55,6 % 44,4	% 65,5 % 34,5	Seldom Dense	% 17,6 % 82,4	% 10,0 % 90,0
Cramped Spacious	% 57,1 % 42,9	% 36,7 % 63,3	Kinetic Static	% 20,0 % 80,0	% 40,0 % 60,0
Unattractive Aesthetic	% 41,9 % 58,1	% 37,0 % 63,0	Inadaptable Adaptable	% 26,5 % 73,5	% 03,7 % 96,3
Opaque Permeable	% 48,5 % 51,5	% 34,5 % 65,5	Regular Chaotic	% 90,9 % 09,1	% 92,6 % 07,4
Unsocial Social	% 26,5 % 73,5	% 10,3 % 89,7	Public Private	% 94,3 % 05,7	% 89,7 % 10,3
Entertaining Unexciting	% 21,2 % 78,8	% 30,8 % 69,2	Ordered Scattered	% 91,4 % 08,6	%100,0 % 00,0
Artificial Natural	% 65,7 % 34,3	% 48,3 % 51,7	Boring Surprising	% 94,1 % 05,9	% 81,5 % 18,5
Unpretentious Pretentious	% 81,8 % 18,2	% 48,3 % 51,7	Neglected well-cared	% 08,6 % 91,4	% 03,6 % 96,4
Agitated Calm	% 34,4 % 65,6	% 17,9 % 82,1	Modern Classical	% 19,4 % 80,6	% 37,9 % 62,1
extra-ordinary Ordinary	% 17,6 % 82,4	% 10,3 % 89,7	Divided Total	% 38,2 % 61,8	% 36,7 % 63,3
Slipshod Thorough	% 12,1 % 87,9	% 06,9 % 93,1	Varied Monotonous	% 14,7 % 85,3	% 25,9 % 74,1
Tiring Restful	% 55,6 % 44,4	% 44,4 % 55,6	ill-shaped well-shaped	% 5,9 % 94,1	% 00,0 %100,0
Inconsistent Consistent	% 12,5 % 87,5	% 03,2 % 96,8	Compressed Spacious	% 48,6 % 51,4	% 28,6 % 71,4
Transparent Opaque	% 48,5 % 51,5	% 51,7 % 48,3	Relieved Stifling	% 45,7 % 54,3	% 57,1 % 42,9
Nonliving Living	% 37,5 % 62,5	% 30,0 % 70,0	Permanent Temporal	% 75,8 % 24,2	% 90,0 % 10,0
Silent Noisy	% 44,4 % 55,6	% 55,2 % 44,8	Consistent Contradictory	% 82,4 % 17,6	% 96,6 % 03,4

Hospitable Inhospitable	% 50,0 % 50,0	% 70,4 % 29,6	Regular Chaotic	% 75,8 % 24,2	% 85,2 % 14,8
Entertaining Unexciting	% 17,1 % 82,9	% 39,3 % 60,7	Boring Interesting	% 91,2 % 08,8	% 74,1 % 25,9
Pessimistic Optimistic	% 41,9 % 58,1	% 34,6 % 65,4	Antipathetic Sympathetic	% 63,6 % 36,4	% 46,4 % 53,6
Useless Functional	% 22,9 % 77,1	% 10,0 % 90,0	Tiring Restful	% 62,5 % 37,5	% 39,3 % 60,7
Reassured Depressive	% 32,4 % 67,6	% 59,3 % 40,7	Intrinsic Extrinsic	% 88,6 % 11,4	% 71,4 % 28,6
Unimpressive Imposing	% 75,8 % 24,2	% 69,0 % 31,0	Incomprehensible Understandable	% 16,7 % 83,3	% 06,5 % 93,5
Disproportionate Proportional	% 13,9 % 86,1	% 03,2 % 96,8			

Question:	**1. Test**	**2. Test**
9. When you look at the drawings, can you definitely anticipate the texture, color and material of the walls?	% 44,7	% 93,5