

CHAPTER I.

INTRODUCTION

Computer modeling is an integral part of today's interior design field as evidenced by designers' increased use (Waxman & Zhang, 1995). They have utilized computer simulations such as computer rendering and walk-through animation in interior design for visual communication. As studies have found, computer simulations are better communication tools to help people understand interior designs more so than traditional presentation tools such as two-dimensional drawings (McLain-Kark, Brandon, & Dhuru, 1994; McLain-Kark, Dhuru, Parrott, & Lovingood, 1998).

Interior images rendered on a computer monitor look like photographs as if they were taken by a camera in the actual interior rather than paintings or drawings because they have realistic texture, color, and lighting effects. The walk-through animation on the monitor adds movement effects to the images and provides a dynamic view as if it was taken by a movie camera in actual interior spaces.

However, there may be a difference between people's understanding of the three-dimensional spaces in photographs or movies from their understanding of the spaces when they are actually there. For instance, one who has been in an ancient building in Rome can explain about the spaces in the building better than one who has seen the spaces in photographs or movies. Walking into the spaces, looking about them in all directions, and moving around them help them to better understand the three-dimensional spaces (Gibson, 1979; Pile, 1988). In the same way, people's experience of seeing a designed interior environment in photo-realistic rendering or animation on two-dimensional computer monitor may not be enough for their understanding of the three-dimensional space and communicating with designers.

Designers are interested in virtual reality (VR) as a new representation tool of designed spaces because of its expected capability to enable people to feel as if they are in an artificially created environment (Henry, 1992). Although VR technology still has many technical limitations, the simulation with virtual reality has further focused attention of researchers as an advanced communication tool in interior design.

Many kinds of visual communication tools are used between design professionals and between the professionals and the users (or clients) in environmental design (Rey-Barreau & Whiteside, 1983). These communication tools can be distinguished between conceptual (abstract) or perceptual (concrete) tools (Helmick, 1993).

Conceptual visual communication tools illustrate an abstract idea such as a bubble diagram that presents a functional system of spaces. Floor plans, elevations, and sections are also considered conceptual (Lawrence, 1993). Usually, conceptual visual communication tools are useful for communicating designs among professionals for the practical execution of the work (Zevi, 1974).

However, it is difficult for lay people to imagine how the proposed interior design looks with only conceptual presentations. Different from conceptual presentations, perceptual visual presentations show how the proposed designs look. Sketches, linear perspective drawings, axonometrics, photographs, scale models, and computer simulation are considered perceptual visual communication tools (Helmick, 1993; Lawrence, 1993). They are necessary to communicate designs between designers and their users.

Generally, users are not professionals in design. They tend to understand designs perceptually rather than conceptually because they lack the professional training. Therefore, perceptual presentations help them understand the proposed design by representing how the design will actually appear.

Perceptual visual communication tools for environmental designs are either static or dynamic (Lawrence, 1993; Bosselmann & Craik, 1987). For instance, two-dimensional perspective drawings are static while filmed modelscope tours of scale models are dynamic. Moving the viewpoint as if people walk into the environment gives dynamic interaction between people and environments. The video taping of scale models and computer walk-through animation are examples of tools providing dynamic views of environments.

One of the main objectives for improving perceptual visual communication tools in environmental design is to simulate previews of the proposed design in order to get better responses to them during the design process (Bosselmann & Craik, 1987). Designers appreciate users' responses because they can be utilized to improve the proposed design and make it more compatible with user needs. For this reason, the simulation stage is essential in the design process (Zeisel, 1981; Studer, 1971; McLain-Kark, 1995).

The reliability of users' responses to the proposed interior design in simulation depends on how they perceive and understand the simulated interior design. Their perception processes start from grasping the basic visual information such as visual form, spatial relationships, colors, and textures (Hesselgren, 1975). If they cannot perceive this basic visual information accurately in the simulation, their responses may not be trustworthy enough to be considered in the design process.

Effectiveness of simulation refers to how accurately the basic information is conveyed through the simulation to leads to correct communication between designers and users during the design process. Therefore, the effectiveness of simulation techniques must be questioned and considered in any evaluation of design projects for confidence in the communication (Bosselmann and Craik, 1987; Lawrence,1993).

In this vein, this study was concerned with the effectiveness of two types of computer simulation as communication tools in interior design: computer monitor and virtual reality. The communication effectiveness of the two simulations was tested in terms of how accurately people perceive the basic visual information of the proposed interior design.

Statement of the Problem

Computer walk-through animation of an interior, which is generated on a personal computer (PC) monitor, is a dynamic perceptual visual communication tool. Hosken's study in 1992 found that the walk-through animation provided higher levels of understanding of the proposed interior design than the understanding that still-frame computer rendering provided. However, studies on the walk-through animation mention its limitation: the narrow vision and the jerky motion of a pre-determined path on two-dimensional computer screen (Henry, 1992; McLain-Kark, J., Dhuru, S., Parrott, K., & Lovingood, R. (1998)

Recently VR simulation techniques have generated a great deal of interest as a future simulation technique among designers and researchers. VR simulation techniques have immersive, three-dimensional, and more interactive effects, which we can not experience in walk-through animation on the PC monitor.

The Cave Automatic Virtual Environment (CAVETM), which is a newly developed retro-projection type VR technique, has many advantages of simulating interior designs. However, it

was not clear whether the simulation with VR was more effective than computer simulation on the PC monitor in terms of communicating the basic visual information about an interior.

Purpose of the Study

The purpose of this study was to investigate the communication effectiveness of two types of computer simulation: passive walk-through animation of an interior design on the PC monitor, and the immersive walk-through of the design in the CAVETM. To investigate the effectiveness, accuracy of participants' perceptions of the basic visual information, such as visual form, spatial relationships, colors and textures in a proposed interior design, was tested in the two types of computer simulation.

For the computer simulation, the interior of the Visualization and Animation Laboratory (VALAB) in the Advanced Communications and Information Center (ACITC), which is under construction on the Virginia Polytechnic Institute and State University, was designed and modeled by the computer for the test.

Research Objectives

The objectives of this research were:

- (1) to investigate whether computer simulation in the CAVETM is a more effective communication tool to use in the interior design process than computer simulation on the PC monitor.
- (2) to compare computer simulation in the CAVETM and computer simulation on the PC monitor in terms of how accurately people perceive the basic visual information about the proposed interior design.

Significance of the Study

This study determined how effective, and thus valid, the two computer- simulation techniques are for representing interior designs by testing participants' responses to each simulation. Establishing this validity is important to designers who are considering investing in virtual reality equipment or simulators. Likewise, design educators can find information on the effectiveness of computer-simulation techniques to be very useful as they consider using this technology.

This study also suggested ways to improve the computer simulation techniques on the basis of weaknesses and strengths of these techniques, which were found in this study. Furthermore, this study can promote future research about VR application in the interior design field.

Delimitation and Limitation

The delimitation of this study were:

- 1) This study investigated communication effectiveness of the computer simulation techniques during the simulation-test stage in the design process.
- 2) The communication effectiveness was investigated in terms of basic visual information, such as visual forms, spatial relationships, colors and textures.

The limitations of this study were:

- 1) The effectiveness of simulation was limited by the present level of technology of the CAVETM and the PC, which was used in this study.

Definition of Terms

Communication effectiveness of simulation: how accurately information is conveyed through simulation to lead to the correct communication in the design process.

Validity of simulation: how accurately the simulation represents the design.

Computer simulation on the PC monitor: Computer generated simulation by using computer-rendering software on the personal microcomputer monitor.

Computer simulation with virtual reality: Computer generated simulation with virtual reality techniques, which enables people to feel present in the simulated environment by using technical devices such as head tracker, stereoscopic goggles, and data gloves.

The passive walk-through animation: An animation in which people see walking through a space along a path that is created on a computer model. For the animation, a sequence of still frame images are rendered along the path at eye level of camera view over time (usually 30 frames per second) (Duff & Ross, 1996).

The immersive walk-through: Walk-through simulation that is created by VR techniques to make a person feel immersed in the model or environment.

The CAVETM (Cave Automatic Virtual Environment): A 10' x 10' x 9' room sized, high resolution, virtual environment, which has been developed by the Electronic Visualization Laboratory of the University of Illinois. In the CAVETM, as many as 10 people at a time can experience the immersive virtual environment three-dimensionally ("The CAVETM User's Guide", 1997).

CHAPTER II.

REVIEW OF RELATED LITERATURE

This chapter reviews the theories and related research that form the theoretical basis of the study. First, an overview of the development of simulation techniques including computer and VR techniques is presented. Second, the usage of computer simulation in interior design and its evaluation are explained. Third, visual perception theories of environment are applied to the interior environment. Fourth, general visual communication theories are presented, and the importance of simulation in the design process is explained. The last section presents the theoretical framework of communication effectiveness of simulation in the design process, empirical model of the study, and research hypotheses of the study.

Development of Simulation Techniques

Simulation techniques have developed as visual communication tools for environmental designs including interior design from hand drafted drawings and scale models to computer simulations. Simulation of designs is an essential part in the design process.

Traditionally, hand drawings such as sketches and renderings were important tools to present designs. Artists and designers developed more sophisticated hand drawing techniques such as perspective and axonometric drawings. With the development of modern science and technology, small-scale models, photographing and video taping enhanced simulation techniques. However, each of the methods has strengths as well as weaknesses.

Drawings, which are two-dimensional simulations, are static and generally at a smaller scale in comparison with a real environment. It is generally understood that lay people feel that it is difficult to understand two-dimensional graphic simulations. It is difficult for them to extract or visualize full scale from small scale, and three-dimensional forms from two-dimensional representation. These difficulties make a gap between professional designers and users in terms of interpreting drawings.

Scale models have been used as experimental studies in architectural science and technology that tested illumination levels or the layouts of furniture by ergonomic criteria. The

surface treatment of walls, floors, and ceilings have also been studied using both small-scale and full-scale models (Lawrence, 1993).

Scale models are more interactive than two-dimensional drawings because they are three-dimensional. However, many people have difficulty in interpreting them because their viewpoints are much higher when they look down in small-scale models than in the real environment (Pinet, 1997). Conversely, full-scale models overcome many of the limitations related to the interpretation of traditional presentation because they enable people to step inside the simulation, observe it, use it, and modify it (Lawrence, 1993). Nonetheless, it is not always feasible to build full-scale models in terms of size, cost, and time.

Computer Simulation

Computer technology and VR technology have enhanced simulation to overcome some of the limitations of traditional ones. Indeed, computer simulations have developed rapidly and have influenced the design field. Simulation on the PC is widely used in interior design field according to Waxman and Zhang's 1995 survey of members of the Institute of Business Designers (IBD) in 1993. Seventy-one percent of the respondents used the PC for their design work. They also reported working on CAD for wire frames (47%) and renderings (21%).

During the past ten years, computers have developed dynamic images and photo-realistic renderings (Goldman & Zdepski, 1991). Images in computer simulations have become increasingly more realistic and sophisticated (Bosselman & Craik, 1987). Computer animation techniques show dynamic simulation by generating a series of image frames along a path representing a walk-through of the interior.

However, conventional computer simulation techniques which operate on the PC have limitations although they have significant advantages over traditional drafting methods and tools in terms of modifying size, shape, color, and viewpoints (Lawrence, 1993). First, there is no interactive component that one can achieve with full-scale models. Furthermore, although computer animation can be simulated dynamically as if people were walking through a building, views are restricted and the paths are pre-determined (Henry, 1992). Finally, the computer renderings are generated by full-scale, three-dimensional data, but a small-sized, two-dimensional perspective appears on the PC monitor.

Lawrence (1993) said, “The chasm between the viewer of the micro world of a computer screen and the experience of a full-scale, as well as reality, has not been bridged” (p. 312). The ambiguity inherent in two-dimensional representation on the computer monitor of a three-dimensional space can cause errors in people’s perceptions (Proffitt & Kaiser, 1991). This representation still has the disadvantage of being pictorial two-dimensional images of what is generally a three-dimensional design space (Smets, Stappers, Overbeeke, & Mast, 1995). Thus, the pictorial images on the computer monitor appear flat rather than in-depth (Kennedy, Cabias, & Pierantoni, 1990).

Virtual Reality

Conventional computer simulation techniques have enhanced the photo-realistic images of interior designs. However, they may not be good enough to satisfy the desire to make people experience and perceive the proposed interior environment as if they are in the environment, which might be an eventual objective of simulation. On the other hand, computer simulation with virtual reality has the possibility to fulfill this desire.

Psychologically, virtual reality gives the feeling of presence, not just seeing images. Technologically, VR technology adds the benefits of three-dimensional visual perception such as binocular disparity to previously developed computer technology by displaying a different sub-image to each eye to provide the stereoscopic effect and depth illusion (Cruz-Neira, Sandin, & Defanti, 1993; Miller, 1994). The psychological and perceptual advantages are the main strength in VR techniques. Helmick (1993) stated that virtual reality will be the most complete and accurate technique yet devised for design communication because it is strongly perceptual.

The term, ‘virtual reality’ has been defined in many ways. Greenbaum (1992) defined virtual reality as "an alternate world filled with computer-generated images that respond to human movements" (p. 58). These simulated environments are usually aided by technical devices such as stereoscopic video goggles and fiber-optic data gloves. Describing an experience in the simulated virtual environment, Rheingold (1991) said that a person is surrounded by a three-dimensional computer-generated representation, and he/she is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it.

Steuer (1995) considered virtual reality as human experience rather than technological hardware. He said, “virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence” (p. 37).

‘Presence’ is defined by Gibson (1979) as the sense of being in an environment: “it refers not to one’s surroundings as they exist in the physical world, but to the perception of those surroundings as mediated by both automatic and controlled mental processes” (Steuer, 1995, p. 35). ‘Telepresence’ is defined as the experience of presence in an environment by means of a communication medium. This term can be used to describe the presence: “Telepresence is the extent to which one feels present in the mediated environment. In other words, presence refers to the natural perception of an environment, and telepresence refers to the mediate perception of an environment” (Steuer, 1995, p. 36).

Many kinds of VR technology have developed. Biocca and Delaney (1995) classified VR technologies. ‘Window system’ is a technology that uses a computer screen and 3D glasses for stereoscopic effects providing an interactive, 3D virtual world. In ‘Mirror systems’, people see an image of themselves moving in a virtual world looking at a projection screen. ‘Vehicle-based systems’ use vehicles such as spaceships, cars, and planes. People enter the vehicle and operate controls that simulate movement in the virtual world projected on screens. The next section discusses the CAVETM systems, a recently emerged VR technology.

The CAVETM (Cave Automatic Virtual Environment):

High Resolution Virtual Environment

The CAVETM is a high-resolution VR environment developed by the Electronic Visualization Laboratory of the University of Illinois. In the 10’ x 10’ x 9’ room-sized, 3D video and audio environment, as many as 10 people at a time can experience immersive stereoscopic images which are generated by computers and projected onto three walls and the floor. To experience the stereo effect, the user wears active stereo glasses that alternately block the left and right eyes. The wand that is a 3D mouse is used to navigate and gives interactive effects.

The CAVETM software synchronizes all the devices and calculates the correct perspective for each wall. In the current configuration, one Silicon Graphics, Inc. (SGI) Infinite Reality Engine is used to create imagery. In the CAVETM, all perspectives are calculated from the point

of view of the user. A head tracker provides information about the user's position, and offset images are calculated for each eye ('CAVETM User's Guide', 1997).

The CAVETM enhances the applicability and the quality of the virtual experience. The large angle of view, creating high-resolution full color images, and a multi-person presentation format are the unique enhancement of the CAVETM. Compared to monitor-based head-mounted display (HMD), the CAVETM allows presentations of 3D stereo images with very low distortion, reduces user's encumbrance by using lightweight stereo glasses and thin wires to the head and hand trackers, and minimizes error sensitivity due to rotational tracking noise and latency associated with head rotation (Cruz-Neira, Sandin, & Defanti, 1993).

The CAVETM has a high potential in environmental design work. Bradshaw, Canfield, Kokinis, & Disz (1995) stated that CAD files created on the PC can be converted directly in the CAVETM and used for virtual prototyping early in the design process. If properly utilized, graphic objects of designs can be tested in dynamic real-time. During these tests, potential failure can be detected. Also, 3D Studio files on the PC can be converted to the CAVETM and used in the same way as well as for user evaluation of the design.

The CAVETM gives users the high levels of understanding necessary to accurately assess the design of the system being modeled by placing them inside the simulation. With the CAVETM it is possible to design and test critical components of complex design systems (Bradshaw, Canfield, Kokinis, & Disz, 1995)

For the communication between designers and users, some VR applications such as CALVIN (Collaborative Architectural Layout Via Immersive Navigation) (DeFanti, Johnson, Leigh, & Vasilakis, 1997) and CASA (Computer Augmentation for Smart Architectonics) projects (Barnes, Leigh, & Vasilakis, 1997) have been developed at the University of Illinois. Users can go into the simulated environment and manipulate the environment directly according to their own sense. They can move furniture where they want or adjust a desk height to fit their body sizes.

In contrast to the conventional computer simulation such as rendering images and the animation on the PC, the CAVETM has the advantage that people can experience three-dimensionality realistic in the simulated virtual world at full scale. Thus, they feel like they are there. In addition, users have a 270-degree visual field.

Considering visual perception of environment as an experience, Gibson (1979) stated that people need to see all the way around at a given point of observation and to take different points of observation to understand three-dimensional environments. The single and frozen field of view provides only limited information about the world. A person's visual system does not evolve from this static view. Rather, visual awareness is panoramic and persists during long acts of locomotion. He explains that natural vision, which is ambient and ambulatory, is not just a snapshot vision.

The CAVETM makes people perceive the simulated world as a real world by giving 'presence', which Gibson (1979) defined as the sense of being in an environment. These advantages of the CAVETM may overcome the limitation of the PC in visual communication between designers and users. When users evaluate the simulated interior designs in the CAVETM, they can experience it as if they are in the interior spaces. They do not have to transfer scale and imagine three-dimensional space from the flat pictorial images simulated on the PC monitor.

Bradshaw et al. (1995) compared conventional computer visualization with the CAVETM. They said that the CAVETM creates true three-dimensional visualization and has more advanced interactive capabilities. They stated, "While a workstation visualization package is a window to the model it represents, a CAVETM virtual environment is a gateway for stepping inside the model" (p. 10). The user can get an intuitive understanding by observing what is happening with the data inside the model.

To summarize, the CAVETM simulation provides full-scale, immersive, and three-dimensional images. These advantages may enable the CAVETM to be a more effective communication tool for people's accurate perceptions of proposed designs.

Evaluation Studies of Simulation

The computer simulation has been found to be a better communication tool than traditional drawing presentations (McLain-Kark, Brandon, & Dhuru, 1994). Compared to still computer image presentations, computer animation enhances people's ability to understand interior designs (Hosken, 1992).

McLain-Kark, Brandon, and Dhuru (1994) explored the use of a computer model (done with 3D Studio) of the interior design of a health-care unit as a presentation technique. The

computer-generated model was shown to a group of gerontologists, business people, and health professionals. They immediately could provide more specific suggestions that they were not able to give when they saw two-dimensional drawings. This research, although based on only one case study, indicated that a computer model was more effective in terms of communicating than the traditional two-dimensional drawings.

Another study (McLain-Kark, Dhuru, Parrott, & Lovingood, 1998) compared three types of kitchen design presentations: line drawings, a showroom display, and a computer model. The three types of presentations were introduced to a sample of residents from Blacksburg, Virginia and the subjects were asked about each presentation. The showroom display was the best to understand the space and design, but its disadvantage was difficulty in presenting alternative finishes. A computer model was the easiest for presenting color and finish alternatives, but it had the technological limitation of a jerky motion during walk-through animation.

The participants responded that the computer model appeared similar to the showroom display, and over 90% of them preferred the computer model. However, some of them mentioned that they got less information about dimensions, finishes, and color than the showroom display. The authors concluded that computer models cannot replace showroom displays, but it can be acceptable for economical benefit.

Compared to still-frame rendering by a computer, computer walk-through animation provides dynamic effects. Hosken (1992) found that computer walk-through animation offers a greater level of understanding about the proposed design than a still computer presentation. These two forms of computer presentation of a mall interior generated by the PC were shown to participants and their interpretation of the designed space was compared to the designer's interpretation of the same space. The results showed that participants' interpretation of the space in the animated presentation was closer to the designer's interpretation than in the still presentation.

Research about VR application for interior simulation has focused on peoples' perceptions in the VR simulation. Lindsey's study in 1997 is about whether there are differences in the perception between a real world environment and a virtual world simulation of the same environment. A group of National Aeronautics and Space Administration (NASA) engineers and university faculty members in NASA's faculty fellowship program observed the Payload Operations Control Center at NASA's Marshall Space Flight Center in Huntsville, Alabama. A

Head Mounted Display (HMD) with data gloves was used in her study. The software used to simulate the VR environment was Swivel 3-D by VPL Research Inc. and Body Electric Visual Programming Language.

Her findings revealed that there are few differences between the real world and the VR world in participants' perception of physical characteristics, objects, and distances. VR simulation was found to be a useful method for planning, creating, and testing environments before construction or for creating simulation of existing environments. However, she pointed out that the VR technology used in her study in 1993 was at an early level of development. People felt uncomfortable or disoriented while exploring the VR environment because the equipment was heavy and awkward. The Head Mounted Display (HMD) and gloves have improved to be lighter and more comfortable.

Similar to Lindsey's study, Henry's research in 1992 was a comparison of perceptions in a virtual environment and a real environment. He questioned whether virtual interfaces can be accurate representations of real spaces and used as architectural representation tools. Participants were professional space designers, graduate students, or professors in architecture.

He used an HMD with a head tracker and a space ball. Computer modeling software Alias Wavefront was used. Interaction software was designed by Marc Cygnus in Human Interface Technology Laboratory at University of Washington. Computer rendering was made by a Silicon Graphics 320 VGX workstation.

He concluded that the virtual interface used in his study is not quite enough to replace architectural representations, but it can be useful to represent the feeling of the spaces. Different from the result of Lindsey's study, he reported underestimation of distance and difficulties of spatial orientation in peoples' perception. He said that those results were due to the technical limitation of the VR device such as the narrowness of the field of view and the effect of head-position tracking. However, the VR interface's representation of the general feel of the spaces was successful. He said that the reason was probably that people felt as if they were really inside the model. Those studies investigated general communication effectiveness of computer simulation techniques. They found limitations and strengths of the computer simulation techniques. However, validity of those simulation techniques, which enhance the communication effectiveness have been rarely mentioned in them. Valid simulation techniques

represent the proposed design more accurately so that people can perceive the proposed design accurately.

The validity of simulation is a fundamental requisite of any simulation technique and needs to be tested. In order to understand how validity of simulations can be tested, it is necessary to understand how people perceive the interior environment.

Perception of Interior Environments in Simulation

To test perceptions of a proposed interior design in simulation, people's perceptions of an interior environment needed to be studied. A study independently conducted on the perceptions of interior environments does not currently exist. Thus, theories on environmental perception and visual perception were applied to this study of perceptions of interior environments.

An interior environment is a man-made, built environment. Interior spaces are created by being surrounded and limited by architectural structures such as walls, floors, and ceilings (Zevi, 1974). Interior environment refers to what people experience and perceive when they are inside of a built structure.

People perceive environments by their senses such as seeing, hearing, smelling, tasting, and touching (Hesselgren, 1975; Thiel, 1981). In terms of perceiving restricted spaces such as architectural or interior spaces, the visual sense plays a bigger role than any other sense (Thiel, 1981).

Hesselgren (1975), who analyzed the perceptual process of the man-made environments from the point of view of architectural theory, stated that the visual perception of a restricted space is based on the integration of simple perceptions perceived by eyes. According to his analysis, the simple perceptions can be categorized into perceptions of visual form, color, light, texture, and movement.

Applied to Hesselgren's (1975) perceptual process, it can be said that the visual perception of an interior space (Figure 1) is composed of the simple visual perceptions. Hesselgren (1975), who was concerned with architectural perception, includes perception of spatial relationships in the perception of visual form category. However, this study considers the perception of spatial relationships as an independent category because spatial relationships such as depth, distance, and proximity have more to do with three-dimensionality than visual forms.

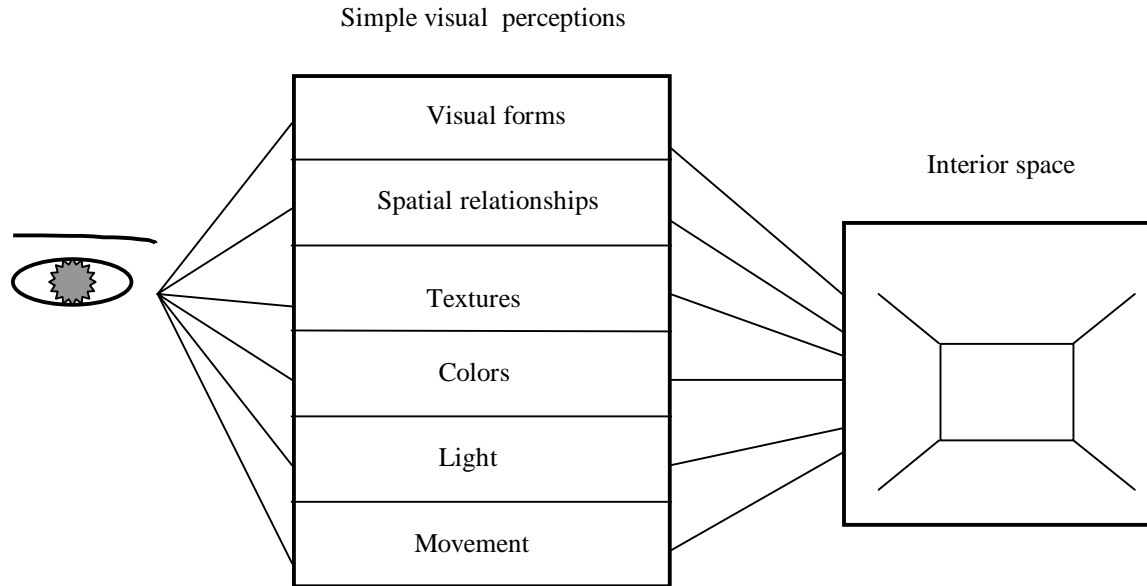


Figure 1. Perception of an Interior Environment (Adapted from Hesselgren's the perceptual process from the point of view of architectural theory, 1971, p. 9).

The objective of simulation in the interior design is to make people experience and perceive an interior environment created by designers before it is implemented. People perceive an interior space by perceiving visual forms and spatial relationships of its components. A three-dimensional interior space is composed of many components such as ceilings, walls, floors, and furniture, etc. (Zevi, 1974). Each of the components has its own visual form and all components are organized with spatial relationships in a three-dimensional interior space. The surfaces of the components are finished with materials that have textures and colors. As a result, people understand an interior space as an organization of the components by perceiving their visual forms, spatial relationships, textures, and colors.

The simple visual perceptions of an interior space are important. These are starting points from which people construct their perceptions of the proposed interior design in simulation. This study measured how accurate people's simple visual perceptions of the proposed interior design are in the simulation.

Light enables people to see their environment and movement provides various viewpoints. These are essential for people to perceive three-dimensional spaces. However, the

perception of light was not tested in this study because of the limitation of the current computer technology (light in the computer model on the PC is not imported into the CAVETM yet). Movement was not tested but controlled by giving the same pattern (the walk-through had the path along the same sequence of spaces on the PC and in the CAVETM).

Simulation for Communication in the Design Process

Theories on the design process explain the importance of simulation for communication. The theoretical background of this study is based on the design process theories such as the human system design process model by Studer (1971), the enhanced design process by McLain-Kark (1995), and the design development spiral process model by Zeisel (1981). Also, general visual communication theories by Pettersson (1989) and Thiel (1981) are adapted to the design process theories to explain the communication effectiveness of the simulation.

Communication in the Design Process

Pettersson (1989) stated, “A message/content with given design/form is conveyed by the sender to the receiver with the aid of a medium” (p. 6). He defined the term medium as “an aid used in the transfer of information from a sender to a receiver” (p. 5). The term information is “content, message, and knowledge etc.” (p. 5). The information is carried by a medium such as paper, plastic, film, electromagnetic waves, magnetic tapes, etc. He said, “A general principle of human communication is that the likelihood of successful communication increases when a concrete reference is present. In the absence of the actual thing, the next best reference is a visual representation of the thing. A medium plus its contents or message is a representation” (p. 6).

In a design communication by a simulation, design information (message) is transferred by a simulation (medium) of the design from the designers (senders) to the users (receivers). For visual representation of design, a simulation is used as a medium to aid the transfer of the design information from the designers to the users (Figure 2).

Although simulation technology has improved, at issue is the congruence between message intention and its perception. The receivers’ perception does not always coincide with the senders’ message (Pettersson, 1989). Pettersson (1989) said, “Communications are

successful when a receiver comprehends the message a sender has wished to convey to him or her” (p. 5).

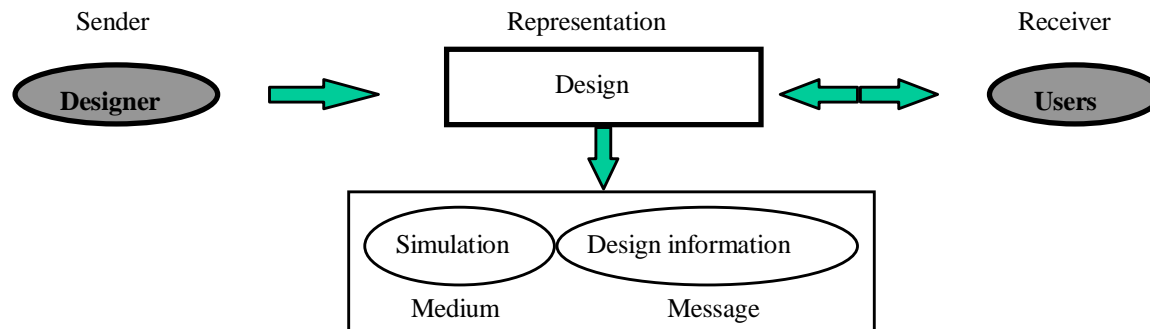


Figure 2. Visual Representation of Design by Simulation (adapted from Pettersson, 1989, p. 6).

Communication between designers and users has been considered to be important in design process theories. Providing the design development spiral process model (Figure 4), Zeisel (1981) explained the importance of the visual representation of designs and its test for communication in the design process.

In his design process model, designers repeat three elementary activities (Figure 3): imaging design, presenting design, and testing how appropriate the design is suited to users' needs. Through the procedure, designers can reduce the gap between themselves and the users. In doing so, presentations are the main tools for designers to communicate their designs that they created based on initial information from the users.

Presentations allow designers to test whether their designs are satisfactory to the users' needs. According to the results of the communication, designers can re-image their initial designs to make the designs closer to the users' needs. In this regard, Zeisel emphasized whether the modes of presentations are best suited as important in the design process.

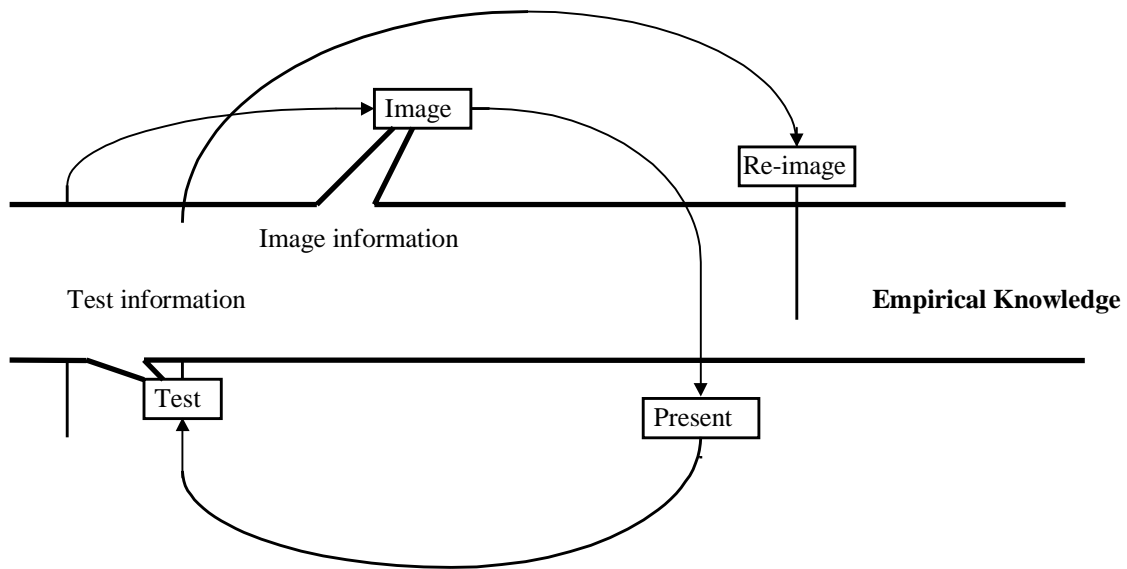


Figure 3. Three Elementary Activities of Designing: Imaging, Presenting, and Testing (adapted from Zeisel, 1981, p. 10).

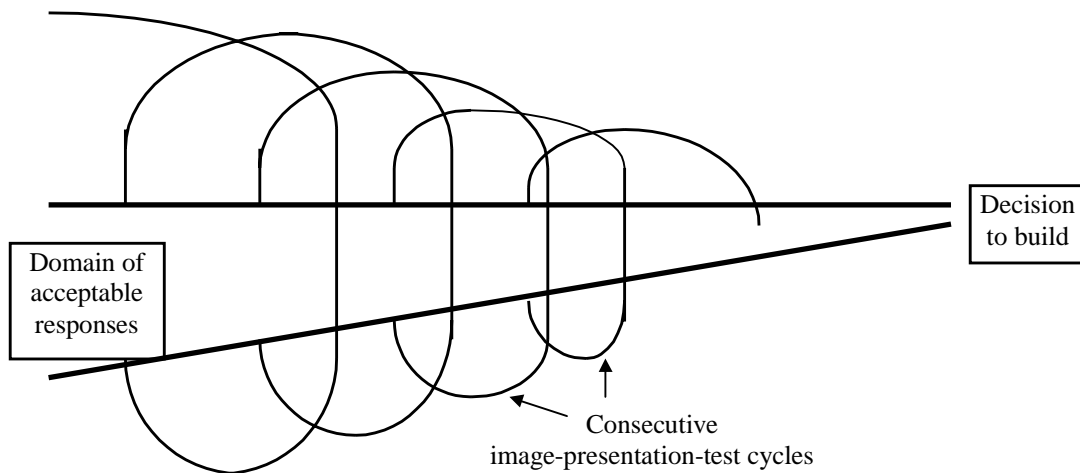


Figure 4. Design Development Spiral Process (adapted from Zeisel, 1981, p. 14).

Simulation in the Design Process

As Zeisel (1981) underlined the presentation and test in the design process, Studer (1971) emphasized the simulation and test in his design process. Studer stated that failures in planning human settings are caused when the plans have not been appropriately linked to the realities. He said that a design of human system is concerned with things as they are and things they ought to be. The objective of planning and design is to predict and control human affairs and to develop human settings to overcome environmental deficiencies.

The human system design process was described by General Problem-Solving Paradigm (Studer, 1971)(Figure 5), which is a framework for the process: “(1) model (what ought to be), (2) simulate (what would happen if ...), (3) implement, and (4) test (what happens when ...)” (p.135).

Studer (1971) developed this paradigm for the environment-behavior system of a human. The model is a representation of a human system, and simulation transforms the model into reality. He underlined the necessity of simulation and the improvement of simulation techniques: “Pretesting a solution via simulation does not, of course, insure success, but these tools are essential and must be greatly improved to reduce the risk of implementing untested models” (p. 137). The failure of already implemented human systems is to be found by testing it in the real world. However, effective simulation can reduce the risk of failure by realizing and predicting the risk before the implementation.

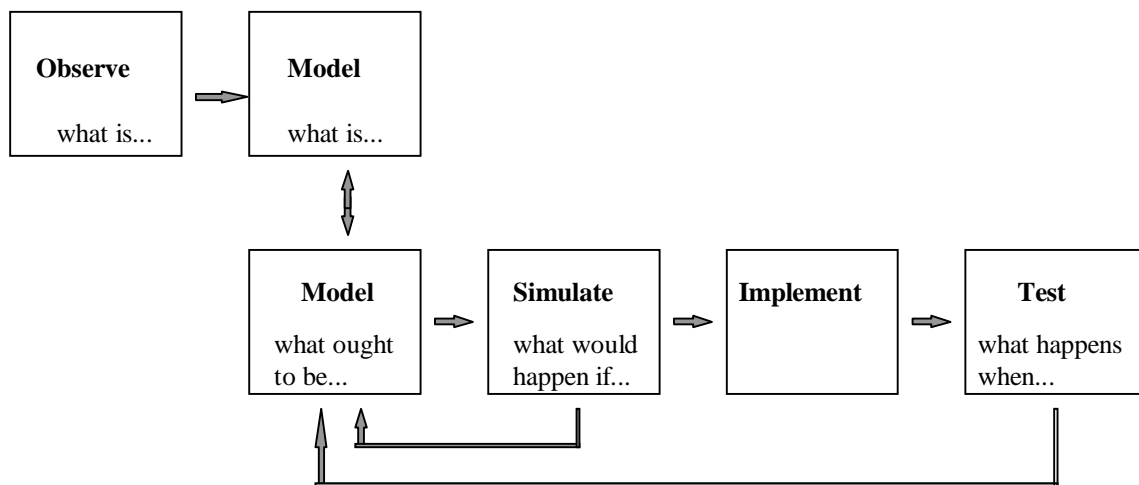


Figure 5. General Problem Solving Paradigm (Studer, 1971, p.135).

Explaining the enhanced design process model (Figure 6) by computers, McLain-Kark (1995) also emphasizes the simulation and test in the design process. She stated that computer simulation can add a well-defined pre-occupancy evaluation step to the general design process. This modified design process is modeled after Studer (1971) who proposed adding a simulation to the process of human settings as a pre-design evaluation loop.

The pre-occupancy evaluation is a method for user participation where future users evaluate designs before implementation. For the pre-occupancy evaluation, future users evaluate an interior design in the simulation. Depending on the results of the evaluation, designers can go back to the preliminary design stage to modify the design or go forward to the implementation stage. This pre-occupancy evaluation can be repeated to make the design closer to the users' needs as Zeisel's design development spiral process does. This process enables designers to analyze the users' desires more closely.

The useful feedback systems in the design process need valid simulation techniques to reduce the risk of failure in implementation, which is caused by miscommunication between users and designers. In this regard, the design development spiral process and the pre-occupancy evaluation are very useful to reducing error in the final design decision, as long as designers and users can get correct and objective information through appropriate communication by valid simulation.

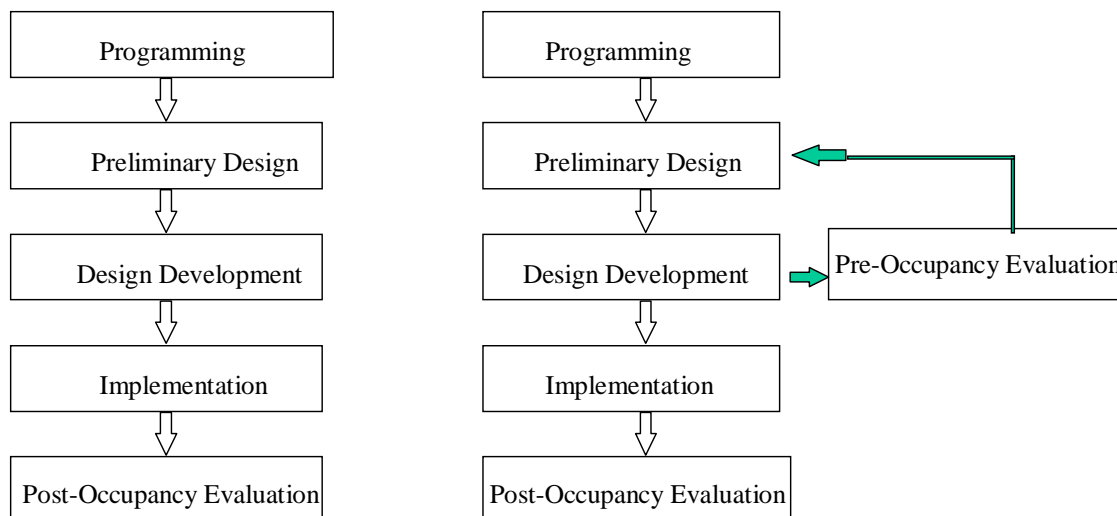


Figure 6. General Design Process and the Enhanced Design Process (McLain-Kark, 1995).

Communication Effectiveness of Simulation

The communication effectiveness of simulation refers to how effectively design information is conveyed by a simulation in the design process. The effectiveness can be measured by the accuracy of the perception of people who receive the design information, which, in turn, is dependent on the validity of the simulation.

The validity of simulation that influences communication effectiveness during the design process can be explained by Thiel's (1981) statement. Thiel (1981) mentioned 'mechanical noise' in the general communication model. He said, "Whatever channel is used, the signal may be perturbed by mechanical noise-a term which betrays the origins of information theory in telecommunications, where it refers to the clicks, bumps and hisses of a telephone channel. But it can be applied to any channel; smudged lettering, tea-stains on a drawing etc."(p. 76).

The channel is the medium used for transferring a message. Applied to simulation that is used as a medium, the term 'mechanical noise' can explain the invalidity of simulation. The mechanical noise increases when a simulation technique is not capable of conveying a design message correctly. As a simulation technique causes more mechanical noise, the invalidity of simulation increases. The invalidity of simulation hinders communication effectiveness due to the decreasing degree of congruence between the design message given by designers and the users' perception of it. It leads to miscommunication between designers and users by causing the users' inaccurate perception of the proposed design.

On the contrary, the valid simulation decreases the mechanical noise, thereby representing a design accurately. The accurate representation of simulation enhances communication effectiveness in the design process. In the results, the valid simulation leads to correct communication.

Theoretical Framework

Conceptual Model

The conceptual model (Figure 7) of this study is based on the design process models and the communication theories that were mentioned above. The human system design process model by Studer (1971) (Figure 5), the enhanced design process model by McLain-Kark (1995) (Figure 6), and the design development spiral process model by Zeisel (1981) (Figure 4) are

applied for the design process. A visual representation model of Pettersson (1989) (Figure 2) and the validity of simulation explained by the term ‘mechanical noise’ (Thiel, 1981) are adapted to explain design communication. This model describes the communication effectiveness of simulation in the design process.

Based on Studer’s (1971) human system design process and McLain-Kark’s (1995) enhanced design process, the simulation and pre-occupancy evaluation stage is added to the general design process between the design development stage and the implementation stage. The loop of design, simulation, and pre-occupancy evaluation stages are easily repeated and manipulated as the three activities of designing are in Zeisel’s (1981) development spiral process.

In the simulation and pre-occupancy evaluation stage followed by the design development stage, designers provide a simulation of the final design and test it. For communication with users, design information of the proposed design is sent from designers to users by simulation that is used as a medium.

If the simulation of design is less valid, users cannot perceive the design accurately because ‘mechanical noise’ interrupts their perception (Thiel, 1981). On the other hand, the more valid simulation of the design enables users to perceive the design more accurately. It means the communication by the simulation is more effective. As the validity of simulation increases, the accuracy of perception of users increases.

According to users’ perception of the design, users decide whether they are satisfied with the proposed design or not. When users are not satisfied with the design in the pre-occupancy evaluation, the designs will go back to the preliminary design stage to be improved to satisfy the users’ needs. However, when the users are satisfied with the designs, the designs will be implemented.

If the users were satisfied with the design based on their inaccurate perception, the communication between designers and users is eventually of no use. In the miscommunication caused by the invalid simulation, a big gap exists between the visual information the users perceive and the visual information the actual design has. On the other hand, valid simulation leads to correct communication and minimizes the gap.

Considering that exact accuracy of peoples’ perception by perfect valid simulation may be only idealistic, it can be said that a less valid simulation leads to a less accurate perception, or

a more valid simulation leads to a more accurate perception as this model describes. If users are satisfied with the design with less accurate perception, there is a higher risk of miscommunication. Conversely, communication is correct if the users are satisfied with the design by a more accurate perception.

When we test communication effectiveness of two kinds of simulation, we can show the two simulations to people. If people perceive the information of the design more accurately through a simulation when we measured the accuracy of their perceptions, the simulation is more valid than the other simulation. Thus, the communication by the simulation is more effective than the communication by the other simulation.

Post-occupancy evaluations take place after implementation. They can be used mainly as a reference for other designs because once the interior environment is implemented, extensive modifications are difficult because of construction costs and time.

In the real world, the design process is difficult to be repeated, and also designs are difficult to modify. On the other hand, in the simulated world, the design process is easily repeated, and designs are easily modified. Therefore, designers should repeat their design process by providing a simulation of designs and testing users' responses to the designs until the users are satisfied. While repeating it, designers should consider the validity of their simulation of the proposed design for communication effectiveness because the reliability of users' responses depends on the validity of simulation (Bosselman & Craik, 1987).

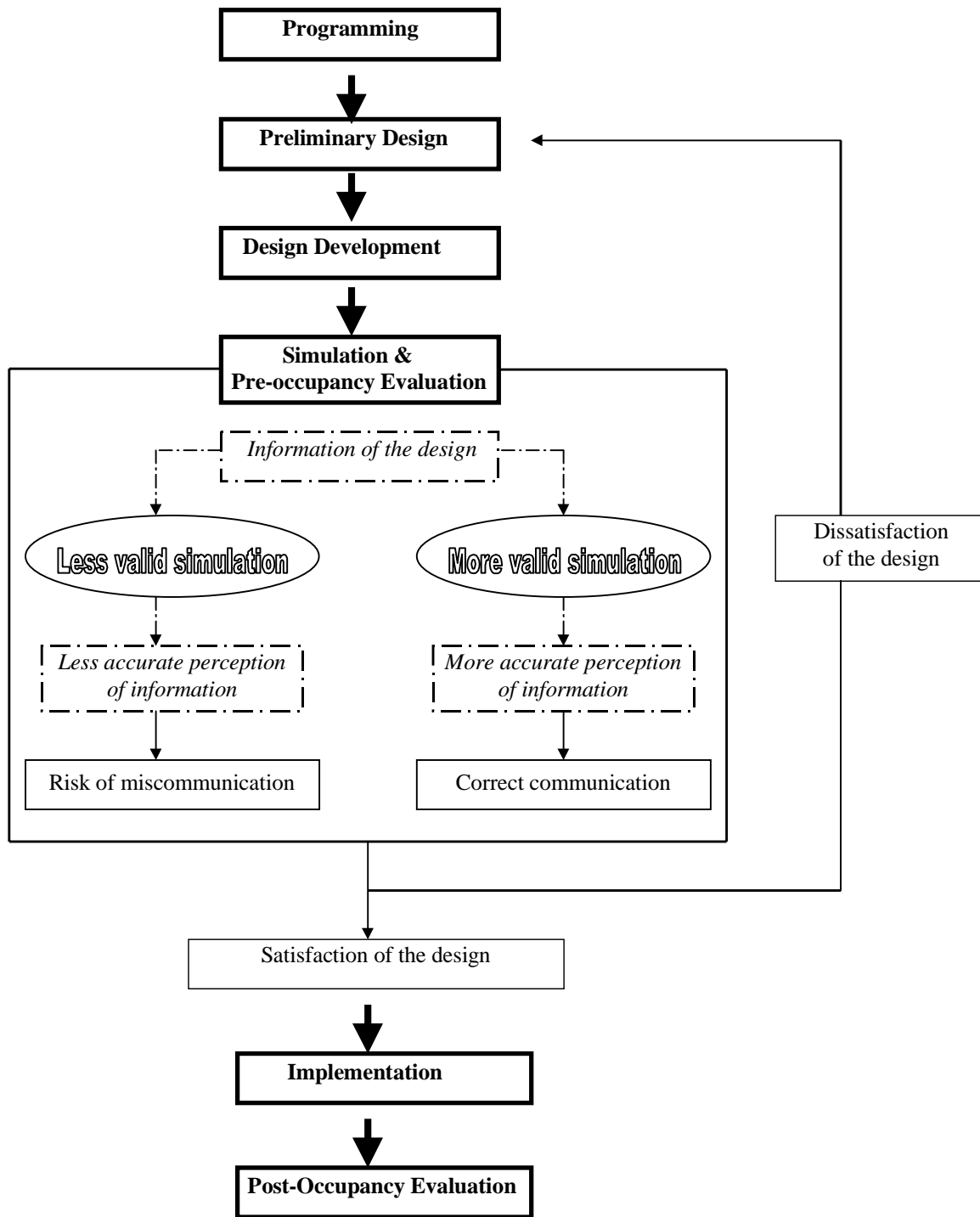


Figure 7. Conceptual Model of the Study: Communication Effectiveness of Simulation in the Design Process.

Empirical Model

This study investigated the communication effectiveness of the computer simulation technique from the design development stage to the simulation and pre-occupancy evaluation (Figure 8). The interior design of the VALAB in the ACITC building was simulated by two computer simulation techniques: the passive walk-through animation of the laboratory interior design on the PC monitor and the immersive walk-through of the design in the CAVETM.

In the simulation and pre-occupancy evaluation stage, the accuracy of participants' perception of the proposed interior design was measured to investigate the research hypotheses of this study. In detail, their perceptions of the information about visual forms, spatial relationships, colors, and textures of the design were tested during the simulation.

The research hypotheses of this study are based on the literature review. The passive walk-through animation on the PC provides small scale, pictorial, and non-immersive images. On the other hand, the walk-through in the CAVETM provides full-scale, three-dimensional, and immersive images.

Measuring the accuracy of perceptions is to test the communication effectiveness of simulation. Accurate perceptions of information means that the information is conveyed more accurately in communication. Thus, communication by the simulation is more effective. Whereby, it can be inferred that the simulation is more valid.

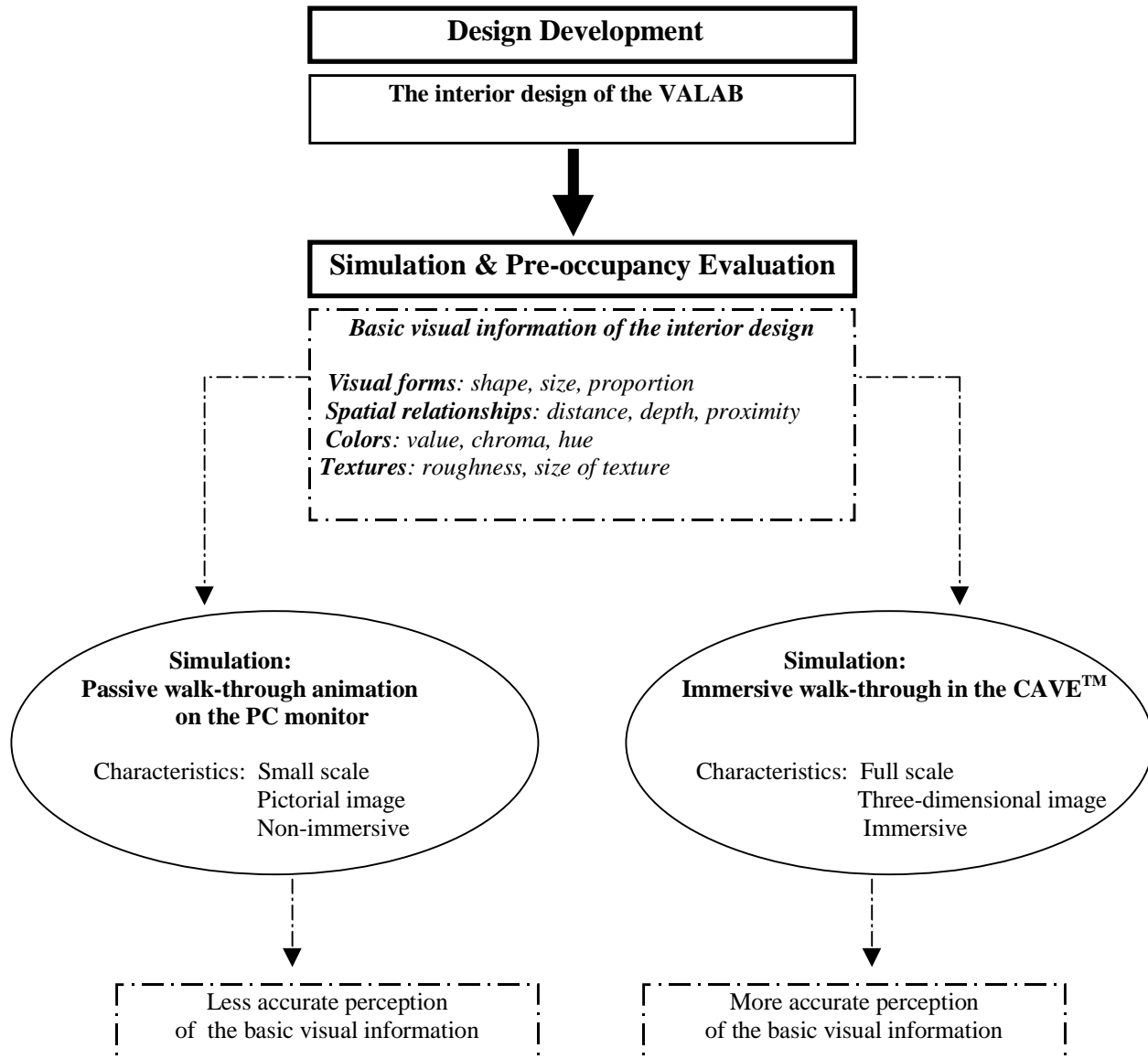


Figure 8. Empirical Model of the study.

Research Hypotheses

Research hypotheses of this study were:

- 1) Participants' perceptions of visual forms shown the simulation in the CAVETM will be more accurate than those of participants shown the simulation on the PC monitor.
- 2) Participants' perceptions of spatial relationships shown the simulation in the CAVETM will be more accurate than those of participants shown the simulation on the PC monitor.
- 3) Participants' perceptions of colors shown the simulation in the CAVETM will be more accurate than those of participants shown the simulation on the PC monitor.
- 4) Participants' perceptions of textures shown the simulation in the CAVETM will be more accurate than those of participants shown the simulation on the PC monitor.