VIRTUAL REALITY AS AN EDUCATIONAL TOOL IN INTERIOR ARCHITECTURE

A THESIS
SUBMITTED TO THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
AND THE INSTITUTE OF FINE ARTS
OF BILKENT UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF FINE ARTS

By
Orkun Aktaş
February, 1997

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I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts.

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I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts.

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ABSTRACT

VIRTUAL REALITY AS AN EDUCATIONAL TOOL IN INTERIOR ARCHITECTURE

Orkun Aktaş
M.F.A. in Fine Arts
Supervisor: Assoc. Prof. Dr. Can Baykan
February, 1997

This thesis discusses the use of virtual reality technology as an educational tool in interior architectural design. As a result of this discussion, it is proposed that virtual reality can be of use in aiding three-dimensional design and visualization, and may speed up the design process. It may also be of help in getting the designers/students more involved in their design projects. Virtual reality can enhance the capacity of designers to design in three dimensions. The virtual reality environment used in designing should be capable of aiding both the design and the presentation processes. The tradeoffs of the technology, newly emerging trends and future directions in virtual reality are discussed.

Keywords: Virtual reality, interior architecture, education

ÖZET

İÇ MİMARLIKTA BİR EĞİTİM ARACI OLARAK SANAL GERÇEKLİK KULLANIMI

Orkun Aktaş

Güzel Sanatlar Yüksek Lisans

Tez Yöneticisi: Doç. Dr. Can Baykan

Şubat, 1997

Bu çalışma iç mimarlıkta sanal gerçeklik teknolojisinin bir eğitim aracı olarak nasıl bir verimle kullanılabileceğini sorgulamıştır. Sanal gerçeklik teknolojisinin üç-boyutlu modelleme konusunda iç mimarlığa nasıl yardımcı olabileceği tartışılmıştır. Bu değerlendirmelere göre sanal gerçeklik teknolojisinin sağlayacağı yararlar üç boyutlu tasarlama ve algılamayı kolaylaştırma ve tasarım sürecini hızlandırma olarak bulunmuştur. Sanal gerçeklik teknolojisinin mekan tasarımcılarının üç-boyut algılarını geliştirebilecek bir araç olarak çalışabilmesi tartışılmıştır. En uygun çalışma ortamı iç mimarlık uygulamalarını hem tasarım sürecinde hem de sunuş aşamasında destekleyecek durumda olmalıdır. Son olarak bu teknolojinin dezavantajları, en yeni eğilimler ve bu konuda geleceğe dönük yönelmeler araştırılmıştır.

Anahtar Sözcükler: Sanal gerçeklik, iç mimarlık, eğitim

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I dedicate this work to my family Ziya, Jale, and Can Aktaş.

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1. INTRODUCTION

Virtual reality is a type of application that enables users to navigate and interact with an environment which is three-dimensional and which is computer-generated -besides being computer-maintained- in real time. The aspect that totally distinguishes virtual reality (VR) from interactive computer graphics or multimedia is the sense of presence in a virtual world and user immersion in a synthetic environment produced by immersive VR technology.

The three basic elements of such a system can be defined as:

1. Interaction
2. Three-dimensional graphics
3. Immersion

Interaction can be defined as the process of inputting data to the system and receiving data from it. For example, an e-mail program is interactive in the sense that it allows the user to send and receive information from other users. Three-dimensional graphics, which is a form of computer output, allows the users to perceive a virtual environment, in the form of three-dimensional graphics representing a database. Immersion suggests that the user feels present in the virtual environment. Immersive applications convince users that they are in a replicated environment. An example to immersion is a movie. However, what makes an application VR is the combination of these three elements in real time (Pratt, Zyda and Kelleher, 1995).

In the early nineties, there was a strong belief that whatever the capability of the virtual reality system might be, interior architects would not see it fit to invest in the technology due to high prices. However in a few years time, computational power required to support virtual worlds became available, a large number of new firms were launched, and due to competition the quality of the products in the market rose and prices began to fall. In such a fertile situation, interior architecture firms did not waste time in discovering the real value of the newly available technology.

Virtual reality was primarily regarded as merely a presentation tool for interior architecture firms to convince their customers by producing strong illusions. It was not long before the true assets of the technology were discovered and virtual reality started to be used for educational purposes in aiding the mental construction of the three-dimensional images of three-dimensional spaces. The current situation of the technology is that there are now numerous firms and educational institutions doing research on various application fields of virtual reality. With this amount of research worthy of note, undirected towards a specific aim, it is hard to make precise predictions on the future of the subject.

This being the overview of the situation, this thesis aims to point out to the potential benefits of using virtual reality as a tool that enhances the three-dimensional perception of interior architecture students. This thesis will further underline more advanced results that would generate from the systematic implementation of the technology to interior architecture practice and education, such as enhanced critiquing process for students.

For accurately presenting the above mentioned information, the thesis has been structured as follows:

In the introduction, a brief description of the virtual reality technology, along with the development of the technology from its initial state up to its current state is overviewed.

Chapter 2 begins with an overview of the development stages in virtual reality technology over time, and then moves on to discuss various available software and hardware utilities and their specifications with the aim of identifying the ideal setup for interior architecture practice. The chapter then moves on to human factors and health issues; topics of great importance, which unfortunately have been researched very little up to this time.

Chapter 3 starts with the topic of how users learn to use computer systems. The chapter then proceeds to its main topic of interest; where two major issues are discussed: one is further suggestions on how to obtain a more appropriate design environment, and the second, the ideal conditions on which virtual reality support to the practice will be most immersive. The chapter concludes by giving further requirements related to system organization.

Chapter 4 discusses virtual reality applications in other fields including comments on the reasons for their implementation and the results of their application.

The last chapter briefly summarizes the key issues that were underlined throughout the thesis and further discusses the methodology of applying virtual reality technology to interior architecture education.

2. THE EVOLUTION OF VIRTUAL REALITY

Under this topic, the definitions of virtual reality are given, and the historical development of the technology is presented. Following these issues, the development of virtual reality software and next, virtual reality hardware is examined in depth. At the end of the chapter, issues such as human factors and health are handled.

2.1. Definitions Of Virtual Reality

The terminology used to describe spaces created within the computer environment is developing. There are terms such as artificial reality, cyberspace, environment technology and virtual environment, but it seems that "virtual reality" is more inclusive and straightforward. Virtual reality is defined as "interactive, virtual image displays enhanced by special processing and by nonvisual display modalities, such as auditory and haptic, to convince users that they are immersed in a synthetic space." (Boman, 1995). The amount that various technologies immerse users is diverse, depending on the intention of the experience and the professional background of the participant. However the most important aspect is the common desire to secure the link between humans and computers by allowing the users to enter the digital worlds that could only have been passively observed through the window of the computer screen (Porter, 1992).

Virtual reality can be defined as a computer generated spatial simulation of reality that is an inhabitable environment created completely within computers. The computer generated virtual reality can either be a 'simulation of reality', especially created to mimic the real world such that the body's senses can not distinguish between the real and the virtual; or it could be an 'alternate reality' constructed as an entirely new environment having its own rules, laws and logic. These rules, laws and logic need not necessarily correlate with reality's laws, for instance physics, social-dynamics or politics (Brath, 1991).

Virtual worlds can be defined as media that is multidimensional, interactive, and computer-generated, which allows people to make varying degrees of real-time interaction similar to the ones they make in the real world.

Every virtual world produces some effects on participants (Dagit, 1993):

- Immersion : The information environment surrounds the participant.
- Presence : The person has the feeling of actually being in the environment.
- Interactivity : One has a sense of being involved with the environment.
- Autonomy : The participant is free to act and explore the environment.
- Collaboration : Multiple users can interact in the same world, at the same time

2.2. The Historical Development of Virtual Reality

Jaron Lanier was the first to coin the term 'virtual reality' in the late 1980s, however the origin of the VR technologies can be traced back to mid-60s where Ivan

Sutherland was leading a research on interactive computing and head-mounted displays at MIT and Harvard University. Sutherland's research was partially funded by the Advanced Research Projects Agency of the US Department of Defence (Schroeder, 1995). In the paper entitled 'The Ultimate Display' contributed to the International Federation of Information Processing Congress in 1965, he outlined a computer display that could create a simulation of the physical world where the operator could interact directly by means of the senses. In a following paper entitled 'A Head-Mounted Three-Dimensional Display' presented at the Fall Joint Computer Conference in 1968, Sutherland explained how such a device could be built using a position sensor and computer graphics to build a three-dimensional world (Schroeder, 1995).

By January 1, 1970, Sutherland was at the University of Utah where he and a group of researchers developed the first operational interactive head-mounted display system. After this achievement, several strands that may have lead to the take-off of VR technology in the late 1980s can be identified. These different strands are in three major areas: art, flight simulation and robotics, and military and space-related research (Schroeder, 1995).

In art, Myron Krueger was the front-runner in exploring the potential of VR-like interactive computing devices. In the early 1970s, Krueger created a gallery installation that allowed users to interact with a two-dimensional computer-generated environment. The main difference between Krueger's approach and immersive VR systems is that he did not attempt to create a simulation which gives the person the impression of bodily presence in the virtual environment. Instead, Krueger's system allows participants to interact with silhouette images projected on a wall-sized screen by simply moving in front of these worlds. The system achieves interactivity by recording the user's movements with a video camera so that the user's silhouette image can interact with the projected world. This system could also allow multiple users to interact with each other in the projected world.

Jaron Lanier, an influential name in the 1980s, came from a completely different background of computer games. At the time, the firm Atari supplied many of the people who were involved in the Silicon Valley computer developments. Another important factor besides the ongoing research and the personnel was the increase in affordable computing power. Computing power is especially required for generating the necessary computer images to create a realistic three dimensional representation. The conceptual groundwork had been laid much earlier by Sutherland, however it was only during the 1980s that the technical means became available to produce working systems that were more than prototypes.

It was Lanier in the late 1980s who attached the label 'virtual reality' to interactive computer-generated three-dimensional immersive displays. Together with a group of colleagues, Lanier formed the first fully immersive system that has been identified with virtual reality -a head mounted display, bodysuit, and display.

In the 1990s, research and development efforts have expanded so that there are dozens of firms devoted to VR research, and the commercial projects have grown into a multi-million dollar industry. An emerging fact from all of this enormous research and investment is that the developmental path of VR is varied and thus does not give any information regarding the direction to where this technology might be headed (Schroder, 1995).

2.3. The Development of Virtual Reality Software

Our ability to manipulate intelligent objects and scenes in three-dimensions, and to integrate direct specification has started with the development of Sculptor, an experimental computer tool, that allows one to specify and manipulate intelligent objects and scenes in three-dimensions . The next important step towards creating a new design environment has been taken by embedding Sculptor into a virtual environment which resulted in augmenting the immediacy of the design project and the design process to the designer (Engeli et al., 1994).

2.3.1. Three-Dimensional Media

In this section we shall be investigating two forms of representing three-dimensional shapes: surface modelers and solid modelers. This issue is vital in virtual reality applications, as only with the representation of three-dimensional shapes can the user feel that he or she is really inside a virtual world, interacting with virtual objects.

2.3.1.1. Surface Modeling

Surface modeling produces realistic images where the effects of light and shade, color, texture, transparency, and reflection can be explored in greater depth. Surface modelers have often been presented as if their utilisation was merely as presentation tools. However when cheap and fast enough for everyday use, they are able to support graphic problem solving activities besides encouraging trial-and-error exploration of potential design alternatives in a cycle consisting of modeling, rendering, and modifying until the desired solution is achieved.

A crucial issue for generating realistic graphics displays is the detection of visible surfaces in a scene when viewed from a certain location. Various algorithms are referred to as visible-surface detection methods. Visible-surface detection methods are broadly categorised into two groups: the object-space methods and the image-space methods. The object-space method compares objects and object parts with each other within the scene to determine the ones that are visible. Image-space methods however, determine visibility point by point at each pixel position on the projection plane (Hearn and Baker, 1994).

In order to improve performance, various visible-surface detection algorithms use sorting and coherence methods. Sorting is used to facilitate depth comparisons by ordering each surface in a scene according to its distance from the view plane. Coherence methods, on the other hand, use regularities in a scene. An individual scan line can be expected to contain constant intensity intervals. Animation frames contain changes only near moving objects, so generally constant relationships between objects and surfaces in a scene can be obtained (Hearn and Baker, 1994).

2.3.1.1.1. Smooth Surfaces

Solid objects appear to have a skin composed of an outline defining a plane. There are various modellers such as Bezier, B-spline, and NURBS each having their own characteristics for producing smooth curvatures such as the case in Fig. 1.

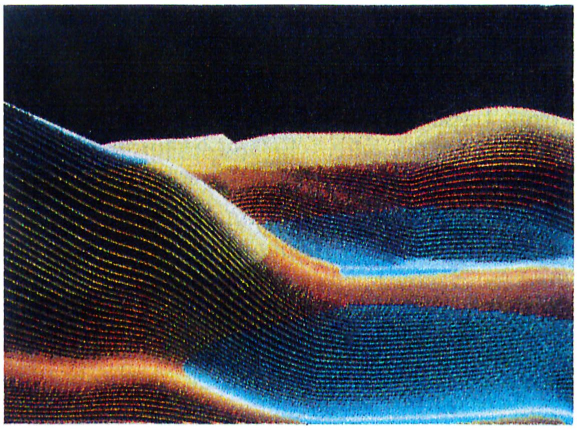


Figure 1. An example of a smooth surface (Hearn and Baker, 1994; p.489)

Discontinuities in smoothness often present themselves as ugly bulges, wrinkles, kinks, and dimples resulting in engineering problems (Mitchell and McCullough, 1991).

2.3.1.1.2. Fractal Surfaces

Fractal surfaces are the opposite of smooth surfaces. The term fractal comes from the Latin adjective *fractus* containing two meanings: to break and irregular. The family of shapes called fractals decribe many of the irregular and fragmented patterns in our environment. It has been stated that the most useful fractals are the ones involving chance and added that both their regularities and their irregularities are statistical (Mandelbrot, 1983).

Fractal geometry methods are used for describing natural objects such as mountains, clouds and trees, which have irregular or fragmented features. Fractal objects have two basic characteristics: infinite detail at every point and a self-similarity between the object parts and the overall features of the object. If we zoom in on a fractal object, we would continue to see as much detail in the magnified part as we did in the original view (Hearn and Baker, 1994). Such a surface can successfully be used to represent various types of terrain as well as different kinds of textured materials having variable types and levels of roughness (Mitchell and McCullough, 1991). For instance in Fig. 2, we can see the construction of a fern where the first figure of the branch is a scaled version of the same object and in the second figure we can see a fully rendered fern with a twist added to each branch.

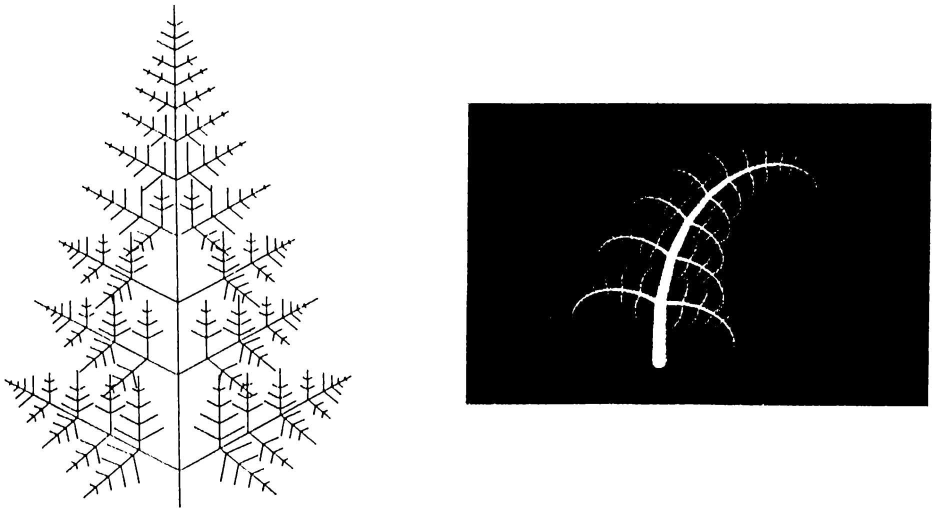


Figure 2. Consruction of a fractal object (Hearn and Baker, 1994; p.370)

In virtual reality applications, fractal geometry methods can be implemented with the aim of producing rapid and impressive representations of natural forms, as seen in Fig. 3.

Figure 3. A realistic scene created with fractal objects (Hearn and Baker, 1994; p.371)

In interior architecture applications, fractal geometry-produced natural figures, such as plants and trees, can be used to give the impression that the space being designed is actually an occupied one, giving a warmer atmosphere to the environment..

2.3.1.2. Illumination Models and Surface-Rendering Methods

Realistic displays of objects or scenes can be obtained by producing perspective projections of these objects or scenes and applying natural lighting effects to the visible surfaces. Illumination models can also be referred to as lighting models or shading models. The illumination model is used to calculate the intensity of light that we would be able to see at a specific point on the surface of the object. The surface rendering algorithm on the other hand, uses the intensity calculations produced by an illumination model in order to determine the overall light intensity for all present pixel positions for various surfaces on a scene (Hearn and Baker, 1994).

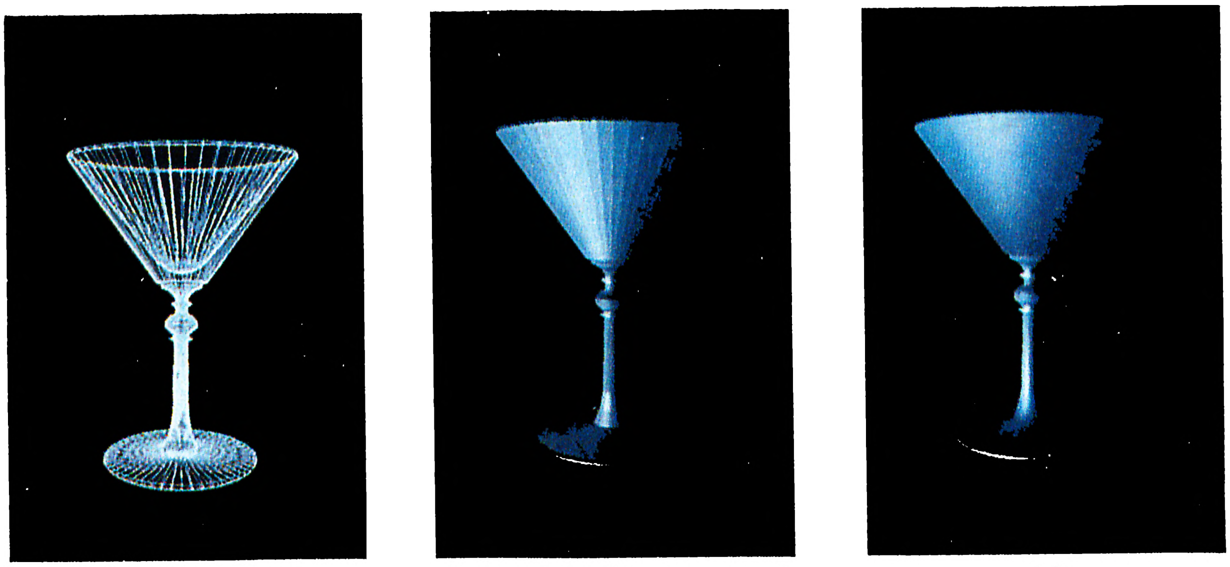
Surface rendering can be made by two different techniques. Firstly, it can be achieved by applying the illumination model to every visible surface point. Secondly, it can be performed by interpolating intensities across the surfaces from a small set of illumination model calculations. Scan line, image space algorithms generally use interpolation schemes, whereas ray-tracing algorithms utilise the illumination model at each pixel position.

2.3.1.2.1. Polygon-Rendering Methods

The importance of the effects of shading become especially important in virtual reality due to the fact that the main aim of virtual reality applications is trying to imitate reality. Without the necessary shading effects objects seem flat, angle variations in surfaces, besides variation in light, shade, color, texture, transparency and reflection can not be detected, thus objects appear unreal.

2.3.1.1.2.1. Constant-Intensity Shading

This method is a fast and simple technique for rendering on object with polygon surfaces. This method can also be called flat shading. In this shading method, a single intensity is calculated for each surface of an object. Then, all points over the surface of



(a) (b) (c)

Figure 4. (a) A wire-frame model, (b) the model rendered with constant shading and (c) with Gouraud shading (Hearn and Baker, 1994; p.525)

the object are represented as having the same intensity values as seen in Fig. 4.

In order to be able to render the object accurately the following requirements should be met:

- The object must be a polyhedron and not an approximation of an object with a curved surface.
- All light sources that illuminate the object should be far away from the surface, so that the intensity values of a surface remain constant (Hearn and Baker, 1994).

The most important aspect of this method that attracts our attention is that this is the rendering method that virtual reality applications widely use. This situation particularly stems from the fact that constant shading is a very rapid and effective rendering technique that requires a minimum level of computation. These qualities of the technique have attracted the attention of virtual reality software developers seeking to find the methods of producing convincing real-time renderings having a certain rendering quality.

2.3.1.1.2.2. Gouraud Shading

This method renders a polygon surface by linearly interpolating various intensity values across the surface. Intensity values for each polygon are compared with the values of adjacent polygons among the common edges and in this way eliminate discontinuities in intensity that occur in constant intensity shading.

The calculations for rendering each polygon surface performed by the Gouraud shading method are as follows:

1. Determine the average unit normal vector at each polygon vertex.
2. Apply an illumination model to each vertex to calculate the vertex intensity.
3. Linearly interpolate the vertex intensities over the surface of the polygon

(Hearn and Baker, 1994).

An example of Gouraud shading is shown in Fig. 4. Gouraud shading indeed removes the intensity discontinuities associated with constant shading, however, this method has some deficiencies as well. Highlights on the surfaces can sometimes be represented with anomalous shapes, and linear intensity interpolation can result in bright or dark intensity streaks -which are also called Mach bands- to appear on the surface of the object. The way to cope with these deficiencies is either to divide the surfaces into greater number of polygon faces or to implement other methods, such as Phong shading which requires more calculations (Hearn and Baker, 1994). The biggest disadvantage of Gouraud shading is that due to linear interpolation, objects never sparkle. Objects seem to be made of a dull and matt material (Mitchell and McCullough, 1991).

2.3.1.1.2.3. Phong Shading

Phong shading is a more accurate shading method that functions by interpolating the normal vectors and then applying the illumination model to each surface point. This method is also called normal-vector interpolation method. With this method, it is easier to obtain more realistic highlights on surfaces and this method greatly reduces the Mach-band effect.

Phong Shading is performed by carrying out the following steps:

1. Determine the average unit normal vector at each polygon vertex.
2. Linearly interpolate the vertex normals on the surface of the polygon.
3. Apply an illumination model along each normal axis to calculate projected pixel intensities for surface points.

Using an approximated normal vector rather than directly interpolating intensities, as in Gouraud shading, produces more accurate results. However, the disadvantage of this technique is that the number of calculations increases considerably. It has been noted that Phong shading takes about six to seven times longer than Gouraud shading (Hearn and Baker, 1994).

2.3.1.2.2. Intensity Interpolation Methods

2.3.1.2.2.1. Ray Tracing Method

Ray tracing works on the principle of a ray cast into the scene as shown in Fig. 5.

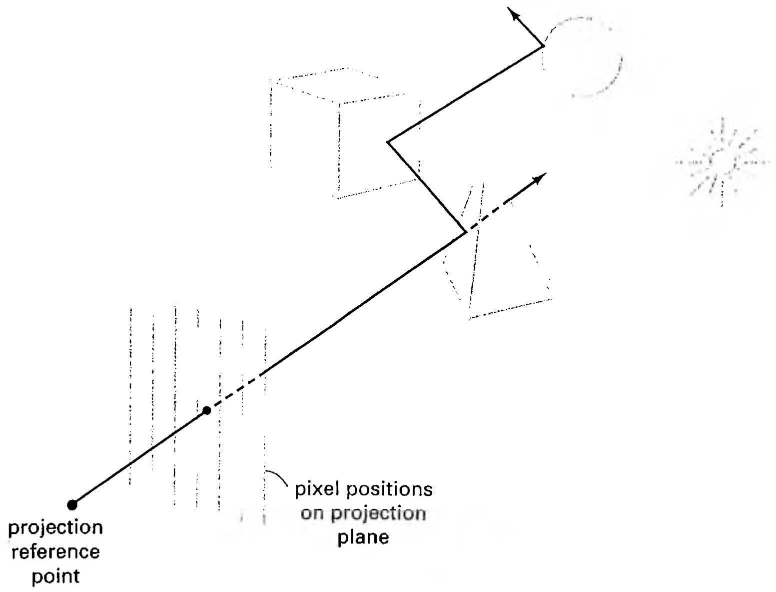


Figure 5. The schematic working principle of ray-tracing (Hearn and Baker, 1994; p.528)

Here the ray bounces around the scene, collecting intensity values. This is a powerful tool useful for obtaining global reflection and transmission effects, as seen in Fig.6.

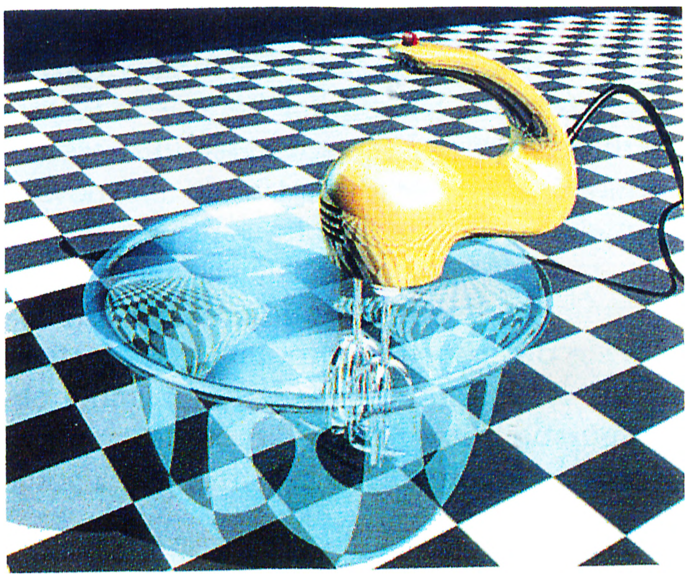


Figure 6. A ray-traced scene showing global reflection and transmission effects (Hearn and Baker, 1994; p.528)

The basic ray-tracing algorithm also supports visible-surface detection, shadow effects, transparency and multiple light source illumination (Hearn and Baker, 1994). Although requiring a considerable computation time for generation, ray-tracing method produces highly realistic images especially for shiny objects.

2.3.1.2.2.2. Radiosity Lighting Method

Diffuse reflections from a surface can accurately be modeled using the radiant energy transfers between surfaces which are subject to conservation of energy laws. In other terms, the radiosity model is the method that is the most accurate one used for describing diffuse reflections, as shown in Fig. 7.

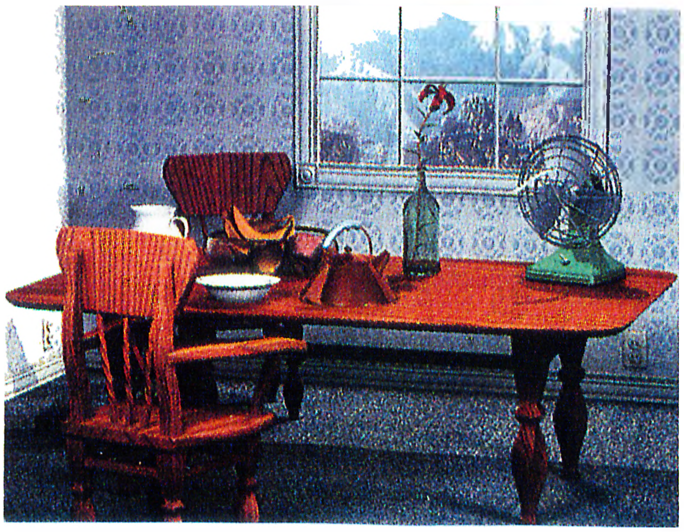


Figure 7. Realistic scene showing illumination effects produced with combining ray-tracing and radiosity methods (Hearn and Baker, 1994; p.544)

Light reflections from various surfaces are formed by constructing an enclosure of surfaces. Each surface in the enclosure is either a reflector, an emitter or a combination of both.

Radiosity method also suffers from the problem of slow construction rate and tremendous storage requirements, associated with methods producing realistic output (Hearn and Baker, 1994). However, a method called progressive refinement radiosity method is being used to restructure the radiosity algorithm to speed up calculations and reduce storage requirements. The functioning of the method is as follows. First, the surface patch having the highest radiosity value, thus which is the brightest light emitter is selected. The selection process continues by selecting every other patch based on the amount of light received from the light sources (Hearn and Baker, 1994). Fig. 8 can be considered as an example representing the application of this method in interior architecture.

Figure 8. Image rendered with progressive-refinement radiosity method (Hearn and Baker, 1994 ; p.551)

2.3.1.2.2.3. Environment Mapping

Environment mapping defines an array of intensity values describing the environment around a single object or a set of objects. Rather than performing inter-object ray-tracing or radiosity calculations, one can simply map the environment array onto an object being observed.

In order to render the surface of an object, pixel areas are projected onto the surface and then the projected pixel areas are reflected onto the environment map in order to pick up the surface-shading characteristics of each pixel (Hearn and Baker, 1994).

2.3.1.2.3. Adding Surface Detail

Usually the surfaces to be rendered are not smooth and even, but contain textures such as brick walls, gravel roads and sand mounds. Additionally some of the surfaces may contain surface patterns such as a tennis court containing alley markings, or as highways having lane dividing lines and other details such as tire skids and oil spills. An example to environment mapping can be seen in Fig. 9.

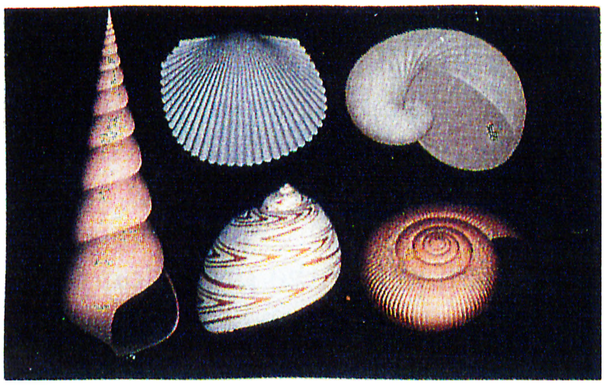


Figure 9. Examples of surface detail generation (Hearn and Baker, 1994; p.553)

2.3.1.2.3.1. Adding Surface Detail Using Polygon Facets

The simple method of adding surface detail to renderings is by modeling structure and patterns with polygon facets. For large-scale detail such as the squares in a checkerboard or lines on a highway, polygon modeling can provide good results (Hearn and Baker, 1994).

2.3.1.2.3.2. Texture Mapping

This method is based on mapping texture patterns onto the surfaces of objects. There are two methods of placing texture onto a surface: the object to image space mapping is achieved with the concatenation of the viewing and projection transformations. The major disadvantage of mapping from texture space to pixel space is the fact that the texture patch that has been selected usually never matches with the pixel borders, thus demanding calculations of the fractional area of pixel coverage. It is based on this factor that mapping from pixel space to texture space is the most widely used method for texture mapping. This method avoids pixel fractional calculations and allows for antialising procedures to be implemented (Hearn and Baker, 1994).

2.3.1.2.3.3. Procedural Texturing Method

This method uses procedural definitions of the color variations that will be applied to the objects present in the scene. In the case where values are assigned all through the three-dimension space, variations in object color are referred to as solid textures.

Procedural methods are used to transfer values from texture space to object surfaces. Solid texturing allows for the rendering of cross-sectional views of three-dimensional objects such as bricks, with the same texturing as their outside surfaces (Hearn and Baker, 1994). Fig. 10 contains examples of procedural texturing, such as wood grains or marble patterns, produced using harmonic functions (sine curves) implemented in three-dimensional space.

Figure 10. Scene generated using procedural texturing methods (Hearn and Baker, 1994; p.557)

Random variations in the textures of wood and marble can be obtained by adding a noise function on the harmonic variations (Hearn and Baker, 1994).

2.3.1.2.3.4. Bump Mapping

Texture mapping as a method may be useful in adding fine surface detail, however it is not an efficient modeling tool for modeling objects such as oranges, strawberries and so on. Usually the case is that the illumination detail of the texture pattern is not the same as in the illumination direction in the scene. A much better technique is the bump mapping technique used for creating bumpy surfaces by applying a perturbation function to the surface normal and then using the perturbed normal in the illumination model calculations (Hearn and Baker, 1994).

Fig. 11 shows us that random patterns are useful elements for modeling irregular surfaces, such as a raisin, whereas a repeating pattern would be useful in modeling the surface of an orange (Hearn and Baker, 1994).

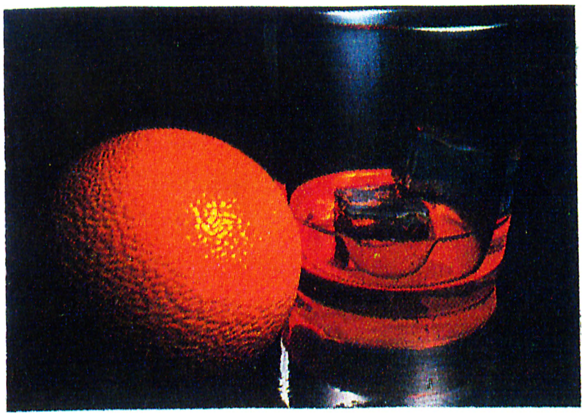


Figure 11. Surface texture characteristics rendered with bump mapping (Hearn and Baker, 1994; p.559)

2.3.1.2.3.5. Frame Mapping

Frame mapping is an extension of bump making. In this model, both the surface normal N and the local coordinate system attached to N are perturbed. The local coordinate system is defined with a surface-tangent vector T, and a third vector B which is the binormal vector of both N and T. The T is oriented along the grain of the surface and directional perturbations are applied in addition to the bump perturbations in the direction of N (Hearn and Baker, 1994). This technique is used to model wood-grain patterns, cross-thread patterns in cloth and so on.

2.3.1.3. Assemblies Of Solids

An alternative modeling method is via arrangement of volumes rather than collections of surfaces of light. A designer can work directly with volumes using wood or polystyrene blocks, however this method is rather cumbersome and time consuming. The practical method lies through employing solid-modeling software which readily provides prisms, cubes, cylinders, spheres and the like as geometric primitives, as well

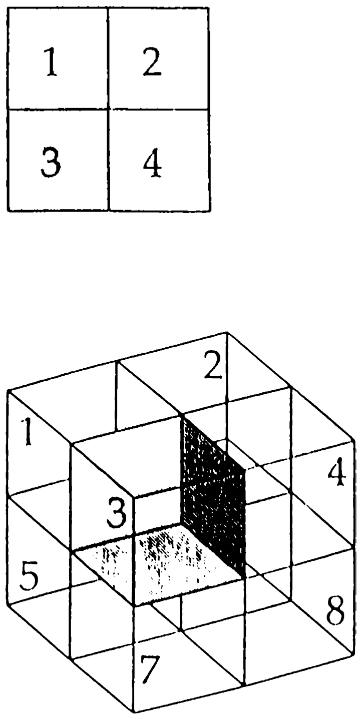


Figure 12. The representation of a voxel (Mitchell and McCullough, 1991; p.236)

as tools like insert, delete, transform to combine these (Mitchell and McCullough, 1991).

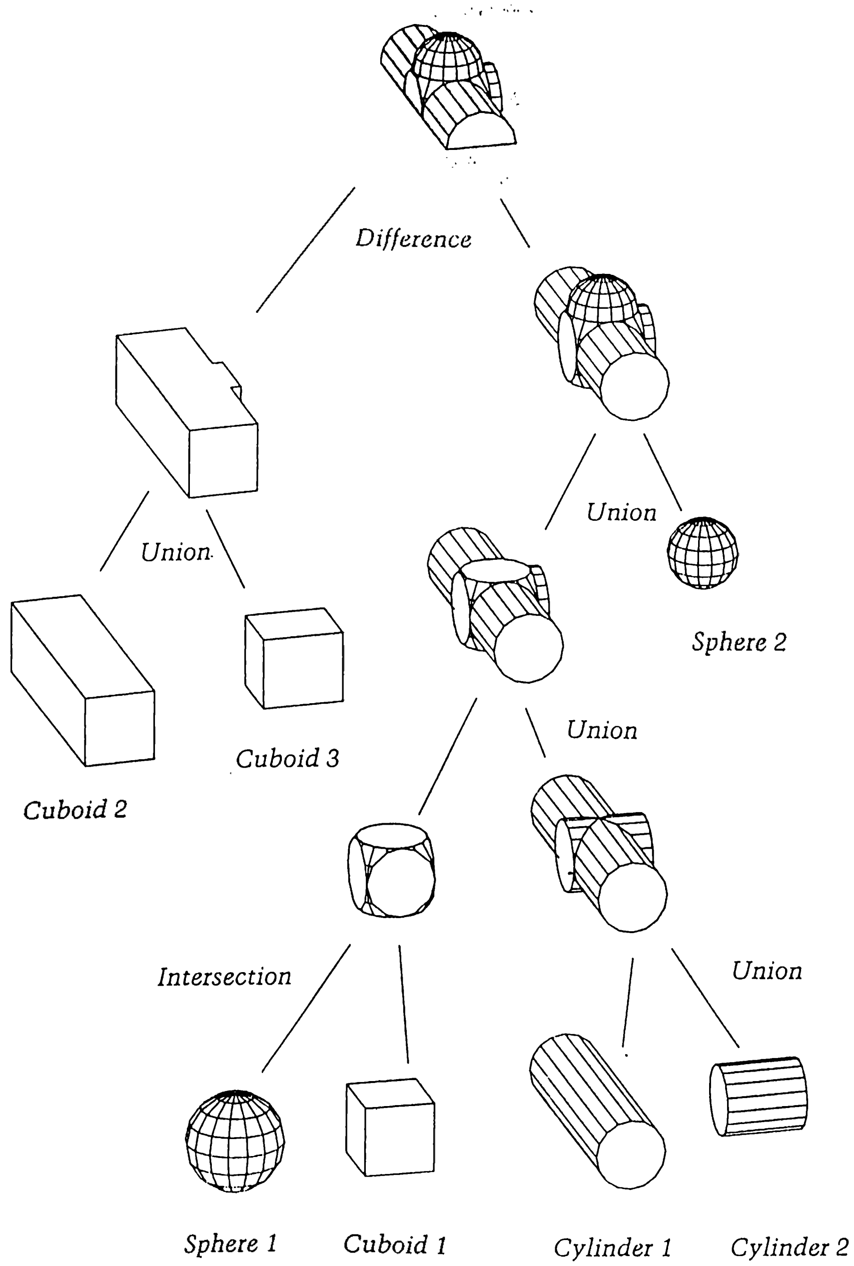


Figure 13. Formation of constructive solid-geometry trees (Mitchell and McCullough, 1991; p.255)

Solids can be represented as three-dimensional arrays of data points. To obtain this, a cuboid is subdivided into cubic voxels (volumetric elements) as seen in Fig. 12.

Spatial set operations can be applied to geometric primitives in order to obtain derived shapes. This procedure is known as forming constructive solid-geometry (CSG) trees. Fig. 13 represents the application process of spatial set operations where every higher node is either a union, intersection, or difference of two lower nodes.

The most apparent advantage of using solid models is a higher level of geometric completeness than corresponding bitmapped images, drafted drawings, wireframe models and surface models. In cases where the completeness and consistency of geometric representation is more important or where designers want to work sculpturally instead of working with abstract tools such as plans and sections, working with solid assembly models is more agreeable. However, the biggest problem with this method is that it makes great demands on memory, computational capacity and software engineering technique (Mitchell and McCullough, 1991).

2.3.2. Multidimensional Media

This section includes the forms of multidimensional media which are respectively: motion models, animation, and hypermedia.

2.3.2.1. Motion Models

In digital sound recording, each data point has one time coordinate. In a bitmapped image, every data point (pixel) has two space coordinates, and similarly in a voxel representation of a solid, every data point has three space coordinates. So in a digital model of a three-dimensional solid in motion over a certain time interval, each data point (hypervoxel) will have three space coordinates besides one time coordinate as represented in Fig. 14.

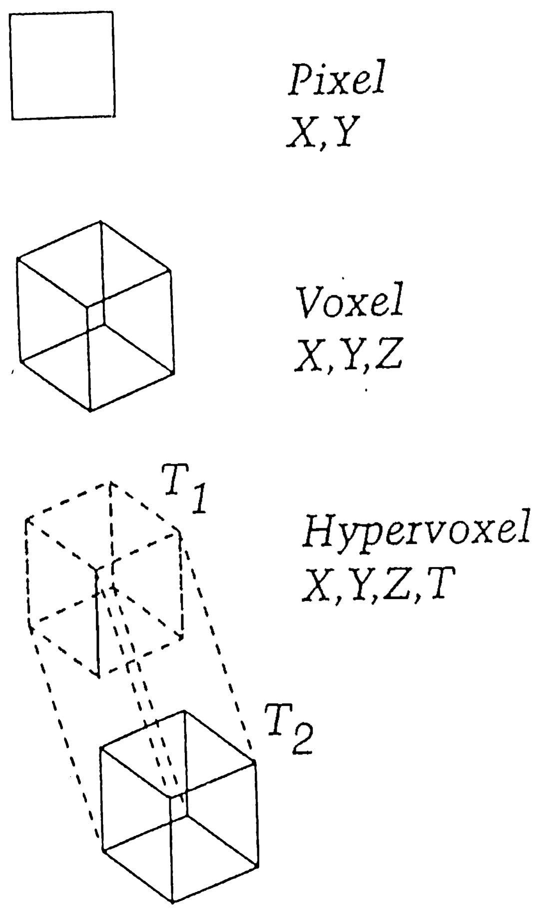


Figure 14. The representation of a hypervoxel (Mitchell and McCullough, 1991; p.271)

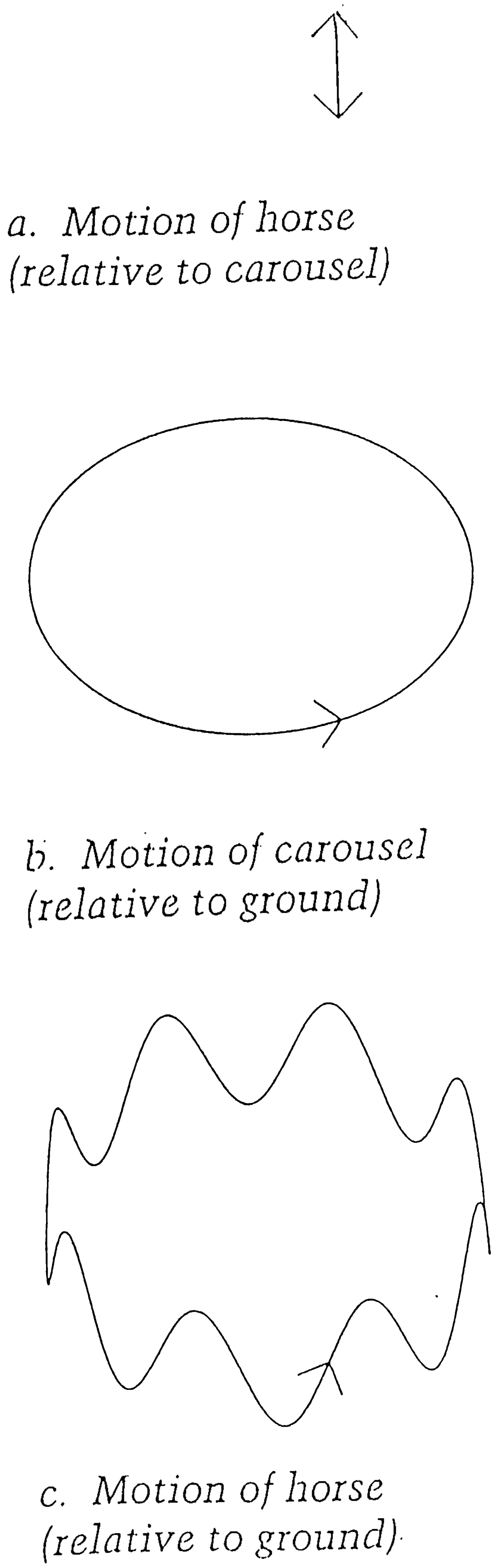


Figure 15. Result of concatenation (Mitchell and McCullough, 1991; p.281)

In representing very complex motions, a technique called concatenation is used. For example, if we study the motion of a horse on a carousel, it can be said that relative to the carousel the horse translates up and down along a straight path. Relative to the ground, the carousel rotates about one single axis. Concatenating these two simple motions forms the more complex path of the horse relative to the ground as shown in Fig. 15 (Mitchell and McCullough, 1991).

The motion models of three-dimensional assemblies are relatively costly to build, to modify, and to maintain, so these models are most useful at a late stage of design process after the details of geometry, materials, and connections have been solved.

2.3.2.2. Animation

An animated picture, by definition, is a sequence of two-dimensional images displayed in fixed order. When there is sufficient similarity between one frame and the next, and the frames are shown faster than the eye can detect individual frames, the illusion of smooth motion in the scene is produced (Mitchell and McCullough, 1991). The rate of sample for a sufficient result is 30 to 60 frames per second (fps). 24 fps is the normal rate at which movies are shown.

The animation sequence is produced with the following procedures: firstly, the storyboard is formed. The storyboard is an outline of the action. Depending on the type of animation the storyboard could consist of rough sketches or a list of basic ideas for the motion. Secondly, an object definition is given for every object in the scene.

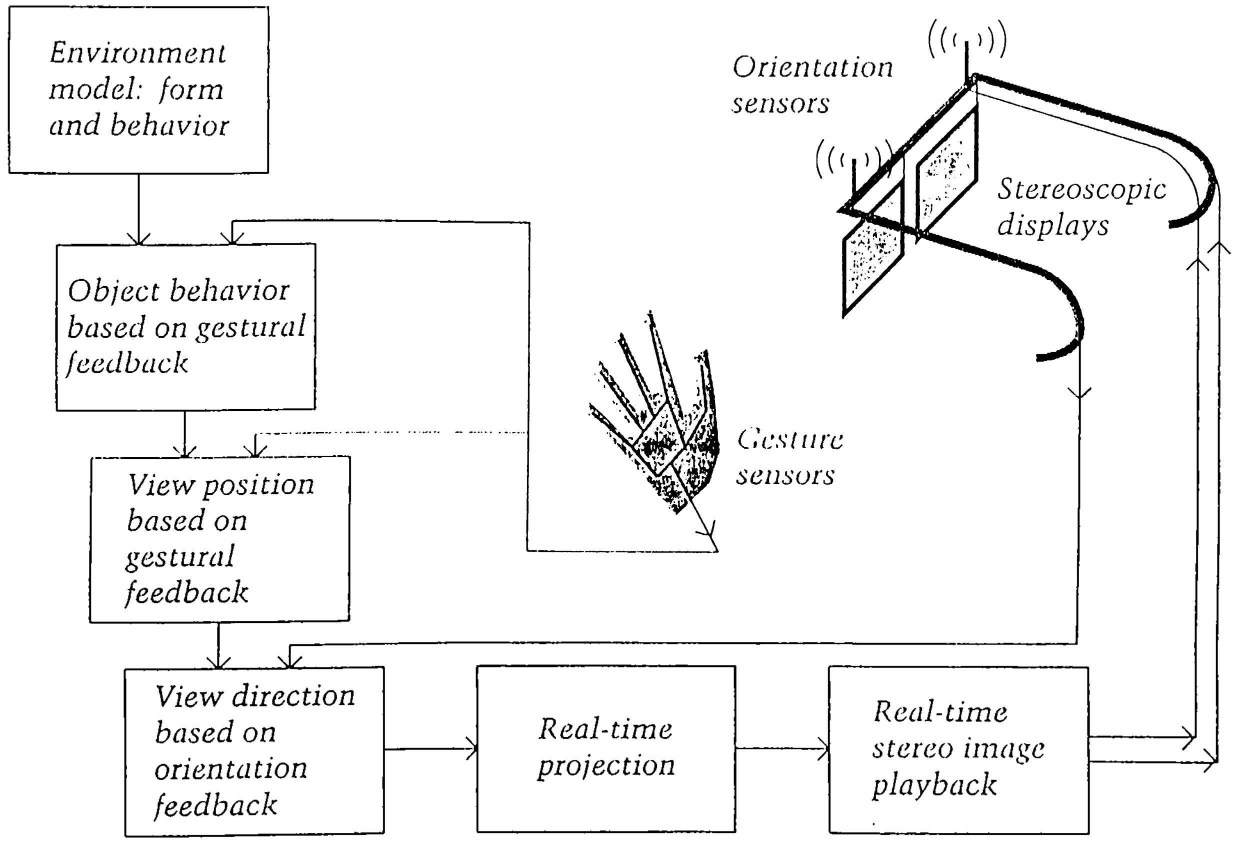


Figure 16. The schematic representation of a virtual reality setup (Mitchell and McCullough, 1991; p.310)

2.3.2.3. Hypermedia

In our everyday lives, finding information is rather cumbersome and slow. In order to find a piece of information, one would have to go to a library, scroll through the card catalogue to find a book, and then find the floor where the book is located, find the

Objects can be defined in terms of basic shapes, such as polygons and splines. Thirdly, a key frame is a detailed drawing of the scene at a specific location within the animation sequence. More key frames are required for intricate motions. Lastly, in-betweens are used to fill in the gaps between key frames. In-betweens are effective tools for critically minimising the effort and the time required to prepare an animation (Hearn and Baker, 1994).

The most common way of drawing the division between action variables and the frame of reference is keeping the geometry and lighting of a scene constant while changing camera position and viewing direction. The result of this process will be an animated walkthrough simulating the experience of a person inside the place (Mitchell and McCullough, 1991).

VR can be defined as one of the most innovative playback devices for computer animation. Slightly different images are shown to each eye to form a stereo effect. The mentioned setup is shown in Fig.16, where the eyephones are linked to three-dimensional position-sensing devices for the system to be able to keep track of the position and direction of the user's head. This way the user can be placed inside a building in which he can walk around and explore. Associating gloves or bodysuits allows the user to grasp, carry, and throw virtual objects (Mitchell and McCullough, 1991). As a result, the static structure of design that was embedded in paper can now be animated, thus unfrozen and made movable just like the real world.

correct stack, find the book, look through the index page of the book, flip the pages, and finally scan the page to obtain the required information. A computer system on the other hand can greatly speed up this cycle and instantly bring the required information up to the screen.

The most striking feature of any hypermedia system is an access structure. The software used for creating hypermedia representations have tools used for defining nodes, and for specifying the connections between the nodes. Hypermedia software can follow the links from node to node. There are some basic methods for following links, as shown in Fig. 17.

The simplest is a linear list in which every node has a single successor and a single predecessor. This form is used for connecting episodes in a narrative or instructions in a step-by-step format. In the two way linked list one can move both forward and backward, and the last node points to the starting node. In the tree form, each node has a single predecessor and multiple successors which is used for guiding one to information about increasingly specialised subtopics. When paths through a tree connect so that there are multiple routes to reach a node, such a structure is called a re-entrant tree. The final form is called a free-form network in which there are no restrictions to how nodes may connect.

Texts and text collections stored in digital form and provided with an access structure for quick navigation are called hypertexts. Hypertexts usually provide access to huge amounts of text data such as architecture codes, lighting manuals, and fire manuals.

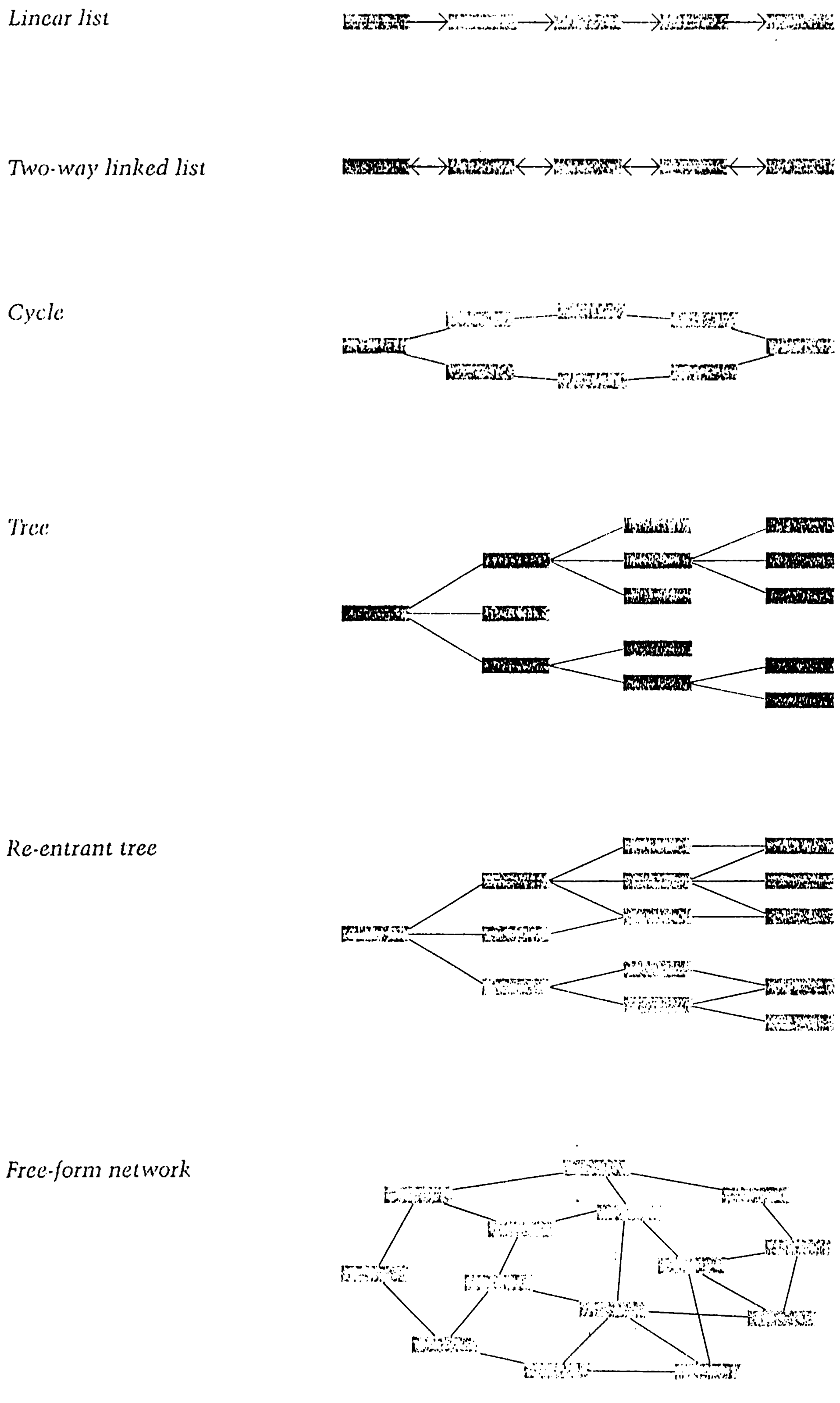


Figure 17. The methods of moving through files in a hypermedia structure (Mitchell and McCullough, 1991; p.316)

If a user is placed inside a three-dimensional structure via a VR interface, data navigation is experienced as movement through cyberspace. Files might be arranged as three-dimensional books on shelves so that one would be free to select and open one. Cyberspace provides a greater liberty of movement than physical space. For instance you might point at a location on a plan to transport yourself instantly to another simulated room.

Hypermedia authoring tools are formulated to reduce the cost and effort of developing and maintaining access structures. Hypermedia user software is also designed to exploit access structures by providing quick, efficient transversal of them via collections of text, graphic, audio and video material. Hypermedia technology can effectively provide efficient access to enormous amounts of material. Hypermedia can also provide richer associations and cross-linkages among items and support entirely new modes of research such as browsing through a hypertext or exploring a town through a movie map (Mitchell and McCullough, 91).

2.3.3. Relationship With CAD

All two dimensional compositions hide the possibility of a third dimension. The dimensionality of an object is dependent on the view from which the composition is being presented. This view may be only a single composition present in the objects. For example a square may really be a cube seen from the front and the third dimension reveals itself only when the square is rotated. Conversely, all three dimensional objects are perceived as projections on a two-dimensional plane in the absence of motion (Gianni, 91).

This ambiguity between the two-dimensional presentations of three-dimensional objects has nowhere been more definite then in the composition modeling environment. Unlike three-dimensional models made of cardboard which can be touched as well as seen, the composed model is much more than a conventional perspective or axonometric drawing, as it is able to provide an infinite number of views and projections. It is a plain fact that the difficulty of constructing axonometric presentations manually tend to make these drawings ends in themselves. These types of projections are readily available in three-dimensional computer modeling media, so as a result they can be treated as steps in a process besides other presentation tools.

In the light of evidence we can conclude that the computer model is more than a simple form of illusion or simulation. The interaction the user has with it is completely different from the experience of illusion in films or animation. The diversity generates from the fact that one can interact directly with it, tweak it, move it and transform it using the mouse in a perspectival space (Gianni, 91).

It can be said that the computer raises unique questions about the nature of representation and the relationship of projections to models and models to reality. Benjamin Gianni from the Ohio State University states that with computer modeling, one's sense of three-dimensionality would be developed significantly by this above mentioned dynamic interaction with the model. Gianni further states that the boundaries which once separated reality from VR -taken for reconstituted or simulated form of ideality- and the two-dimensional projection from the model were not as definite and strict as they used to be (Gianni, 91).

2.3.4. Virtual Reality Software

VR software developments directly benefit from developments in all computer software research areas. VR systems require high degrees of real-time input and output besides high-speed graphics rendering. The visual, audio, and physical properties of virtual objects must be modified and then created in real time. As many systems prefer distributing the computational load across several computers, these systems require networked VR applications having various hardware platforms. Besides being networked, VR applications also require efficient authoring and database management systems. The focus of research is to develop intuitive interfaces along with capabilities to create programs involving all of these functions quickly and easily.

A majority of the commercial VR software packages available today can be defined as tool kits that are able to import few graphical databases, manage I/O for various displays and sensors, facilitate programming simple interactions, and sometimes provide limited networking capabilities.

2.3.4.1. Simulations

An experiment lead by Randy Pausch of the University of Virginia has developed software which allows interdisciplinary teams to quickly create and modify VR simulations. The prototyping system software has been divided into two parts, of which one is for maintaining the simulation environment and the other is for maintaining and rendering the graphical database. By separating the two functions, Pausch records that graphic rendering proceeded at high frame rates even when the simulation environment was being updated at slower rates (Boman, 1995).

Mark Green and Chris Shaw of the University of Alberta on the other hand, have developed a VR software product called MR Toolkit. This software utilises a client/server model in driving interaction devices. The programmer writes code for a master process that manages the simulation and dispatches data to conduct processes that drive the displays. It has been recorded that MR Toolkit software can be distributed and used on multiple computers (Boman, 1995).

2.3.4.2. Knowledge Representation

Another tool based on a different approach has been developed by the researchers at National University of Singapore. The tool they have developed, called Bricks, makes extensive use of knowledge representation techniques. Bricks has mainly two layers: a support layer and a knowledge layer. The support layer handles input devices, communication and knowledge on geometric shapes. The knowledge layer on the other hand organises the virtual environment based on the principles of the real world, then creates an environment which consists of the system user and classes of solid objects with physical properties. With Bricks the user can select sets of objects, assign behaviours to them, choose a set of physical laws and then run the simulation.

2.3.4.3. Multiple Users

Researchers Michael Zyda and David Pratt have formed a research team at the Naval Postgraduate School in Monterey California with the aim of developing a software architecture for large-scale networked VR called NPSnet. The communication between low-cost, workstation-based simulators is achieved using NPSnet via the Distributed Interactive Simulation networking format. The aim of this process is to support the real-time simulations of thousands of participants.

Another research group at the Swedish Institute of computer Science is also working on software for multi-user VR systems. The research team is developing the Distributed Interactive Virtual Environment (DIVE) within the program called MultiG -a Swedish national effort to develop high-speed communications and distributed applications.

2.4. The Development of Virtual Reality Hardware

Interfaces for VR can be categorised in two main categories.

- Devices of navigation and physical interactions: dashbound, flying mice, gestural devices, and navigation devices which are built into viewing devices.
- Viewing devices: head mounted display, counter balanced display, shutter glasses and immersive 'desktop' viewers.

Immersive display systems require an 80-degree or greater field of views, and a resolution of at least one million pixels per eye. The most important aspect of immersive displays is that they must be able to cope with variations in interocular spacing and head size in humans. It has been stated that in training systems designed to simulate military operations, this problem is overcome with adjustable mounting systems. It has also stated that trainees who are willing to finish the training program can tolerate a head-set weighing four or more pounds (Bolas, McDowall, and Mead, 1995).

The situation in consumer entertainment applications shows that participants do not reject wearing head sets where there is a wide range of head set options available, and the duration of immersion is short. However in longer immersion durations such as scientific and commercial research, concurrent engineering, and design projects, research indicates that users reject wearing devices (Bolas et al., 1995).

The most dramatic elements of virtual reality can be stated as headsets, datagloves and datasuits, allowing the user to be cut off from the everyday world and to enter the virtual world. Using articles of clothing, such as masks, gloves and suits as a means of connection to the computer system demonstrates that the natural interface has started to appear as a working prototype. The naturalness of the equipment used originates from the fact that gloves, headsets and bodysuits are familiar objects linked with everyday life, so the user knows how to use them. These traditional objects have only been given a new meaning within virtual reality. Thus the equipment used for virtual reality interfaces have become not only the means of interacting with the machine via using many aspects of the human sensory system, but also immediately understandable icons of interaction (Porter, 1992).

2.4.1. The Development of Virtual Reality Interfaces

In the period between 1988 to 1992 the most popular interfaces were the glove and goggle interfaces. The goggles were special scuba-type gloves having fiber optic wiring in them that allowed the participant to reach into the virtual environment and manipulate computer-generated objects. The goggles were head mounted displays (HMDs) projecting 3D images on small CRT screens in front of each eye and adjusting the images according to the user's head position thus enabling the environment to completely surround the participant. The biggest disadvantage of the system was the resolution in the head-sets -denoting that the user is legally blind, besides the abnormal weight of the head-set making it impossible to wear for prolonged periods of time (Dagit, 1993).

In 1992, experts started to lean away from the cumbersome glove and goggle interface towards the flying mice or wands and wrap around stereoscopic video screens. A flying mouse is different from the traditional mouse in the sense that it is able to track six degrees of freedom; x, y, z, roll, yaw,and pitch, thus can be used in 3D space. Wands on the other hand are extendable pointers in 3D space .

In July 1992, Electronic Visualisation Lab at the University of Illinois, Chicago, introduced a projection screen system called the CAVE,which is a 3x3x3 meter cubic space having screens on each of the interior surfaces. The sense of presence was greatly achieved by the highly immersive display, high resolution and minimum level of intrusive gear the participant was obliged to utilise (Dagit, 1993).

2.4.2. Virtual Reality Display Systems

The main trend in the developing display system technologies is to involve most -if possible, all- of our senses in acquiring information. It is also true that initially the development trend was towards developing the visual information display. Newly developed technologies for delivering information to our other senses are still in their development stages, such as, acoustic displays presenting three-dimensional sound environments to a person's sense of hearing, and haptic displays presenting tactile and force feedback to a person's sense of touch (Boman, 1995). Research on haptic displays is still ongoing but a device for presenting tactile and force sensations is not widely usable yet.

2.4.2.1. Visual Displays

The immersion event in VR involves a head-referenced visual display, covering a considerable field of view. Usually a head-mounted display (HMD) that includes LCDs or miniature CRTs features a spatial tracking device which provides information on changes in head position, which is then used to update the images in the displays. A large number of pixels in LCDs or CRTs are desirable as image magnification encompassing large fields of view reduces the visual display resolution significantly.

With reduced weight and cost, HMDs have gradually become commercially available. The development in the technology has led to HMDs weighing only 340 grams, whereas previous systems usually weighed nearly 3 kilos (Boman, 1995). The present state of the HMD market is such that a game version HMD is only around $200. The HMDs used for activities such as designing or scientific visualisation on the other hand cost only about 4 or 5 times much as a game version HMD, however prices are getting cheaper and cheaper as research into the matter deepens.

It has been recorded that in August 1991, the Pixel-Planes 5 computer at the University of North Carolina had set a world speed record by displaying 2 million triangles per second. Another example was the systems that used Sense8 software that could display approximately 500 to1000 polygons per second at the time. Reality, however as declared by officials is 80 million polygons per second; a figure outstanding the achieved computing power of the time (MacLeod, 92).

2.4.2.1.1. Laser Scans

This new type of HMD system is being developed at the Human Interface Laboratory at the University of Washington. The device uses a laser to scan images directly into the retina of the eye. The device which is still in its development stage has a red laser diode displaying monochrome video that has a 1000 X 1000 pixel resolution. The main aim of the project is to develop a full-color-scanned laser HMD but in order to achieve this, first blue and green laser diodes have to be developed; and next further development on weight reductions of available optical components and scanning deflectors have to be made (Boman, 1995).

2.4.2.1.2. Stereoscopic Projectors

An alternative to the HMDs is a system called Cave Automatic Virtual Environment which has been developed by the Electronic Visualisation Laboratory of the University of Illinois, Chicago. The CAVE system functions by projecting images on three surrounding walls and on the floor from stereoscopic video projectors. The participants inside the system wear glasses with LCD shutters which enable them to view the three-dimensional images (Boman, 1995).

The most prominent characteristic of CAVE is that multiple participants can be involved, however only one is tracked and other participants view the three-dimensional images in relation to the head position of that person. Such use of multiple projection systems provide immersive displays that present 1280 X 512 pixels to each eye on each of the screens thus covering the participants' entire visual field (Boman, 1995). However, it is a fact that requirements for computing graphics increase dramatically when increasing the number of screens.

2.4.2.2. Acoustic Displays

The most beneficial aspect of acoustic displays is that they increase the amount of information that can be presented thus greatly enhancing VR applications. Much research is being carried out on constructing complete three-dimensional sound environments where sound objects are spatially localised and where these objects can be attached to virtual objects that maintain their locations as the participant moves through the environment. The basic outcome of similar researches will be a more realistic simulated environment (Boman, 1995).

The notion of sound localisation implies the relative amplitudes and frequencies of signals received by the participants' two ears, the high-frequency filtering characteristic of the participants' body, the outer ear or pinna, and the filtering or reflective attributes of objects in the environment (Boman, 1995).

2.4.2.2.1. Filtering Simulation

An experiment being carried out at the NASA Ames Research Center in California is researching the methods for rendering complex acoustical environments via headphones. The working principle of these acoustic displays is by using head-related transfer functions (HRTFs) in order to simulate the filtering abilities of the outer ear and body. According to research, HRTFs are different for each person, however a non-individualised HRTF can be used for many people. Recently, the research group added another feature called synthetic reverberation functioning on an extension of a ray-tracing model. It has been recorded that with the reverberation feature added, participants can correctly identify the sounds as distant but have difficulty in discriminating the direction of the sounds (Boman, 1995).

2.4.2.2.2. Simplified Localisation

Researchers in the DS Lab at the Swedish Institute for Computer Science have devised an aural renderer based on a geometrical model of the relation between the listeners' two ears and the sound source (Boman, 1995). The advantages of the simplified model for auditory localisation cues are reducing computational overload, overcoming the need for specialised equipment, as well as increasing the number of spatialised sounds that can be presented. A disadvantage of the recent sound technology is that it is a difficult task to record new sounds and prepare sound files for VR presentation. The difficulty of the process lies in the complexity of the methods required for creating acoustic presentations which in turn hampers the use of acoustic displays in VRs.

2.4.2.3. Haptic Displays

In developing haptic devices, researchers base their experiments on electro-mechanical devices delivering force feedback to the head or arm within limited range of movement. An example for this is the device developed by Makato Sato of the Tokyo Institute of Technology's Precision and Intelligence Laboratory which is called Spidar (Space Interface Device for Artificial Reality). Spidar is a force-reflecting system in which the user inserts his or her thumb tips and index finger into a pair of rings each having four strings attached to rotary encoders (Boman, 1995). The encoders are located at the corners of a tube. String movements can be altered using brakes, providing touch sensations. This device is being applied in collaborative design .

2.4.2.3.1. Force Feedback Alternative

The alternative method for delivering force feedback to the hand is via a device that is hand-held or incorporated into a glove. The device alters finger movements but it is mobile so that the user can carry it around in the VR besides a spatial tracker that monitors the position of the hand in three-dimensional space. For example Grigore Burdea from Rutgers University's Human-Machine Interface Laboratory has devised a portable force-feedback device consisting of three or four pneumatic micro-cylinders which are attached to the finger-tips and the palm (Boman, 1995). Another example is the device developed by the Advanced Robotics Research and Airmuscle in the UK, which has approximately 30 pneumatic air pockets which can quickly be inflated and deflated to give the feeling that a virtual object is grasped (Boman, 1995).

2.4.2.3.2. Touch Feedback

G.J. Monkman of the University of Hull's Robotics Research Unit has used electrorheological fluids which harden under the influence of an applied electric field in order to provide tactile arrays (Boman, 1995). This type of haptic display sends touch feedback to the user, causing the person to feel the texture of virtual objects.

2.4.3. Sensors And Command Devices

The nature of VR includes not only updated images related to the participants' movements, but the ability to interact with and control virtual objects in the environment. VR systems that provide these functions include a variety of sensors besides the equipment which monitor the participants' movements. These VRs include a spatial-tracking system and either a hand-gesture recognition device or a hand-held controller.

The most appropriate display tools for long immersion periods are hands-free and counter balanced displays which are head-mounted. These display devices have been devised according to three main principles. Firstly, comfort is of most importance. Secondly, users want to view the same scenes repeatedly whether it is in interactive entertainment or in the work place. Lastly, it is important to minimise the unnecessary time lag between viewing of the immersive experience as this situation might make donning a head set inefficient and useless. Although desktop viewers tend to reduce the need for manipulation devices and peripheral navigation, most applications still depend heavily on these devices. The requirements from input or control devices in virtual worlds can be stated clearly as providing full and simple control over movements in three linear axes and three possible rotations (Bolas, 1994).

In summary, in commercial and research applications, planned usage is the most important aspect during system configuration. For systems developed for single users who will use the system for extended periods of time such as in the case of designing, a head-mount or a hands free counterbalanced display is suitable. In the case of team-oriented and design development work, the crucial aspects are ease of entry and exit to the virtual world as well as stereo glasses.

2.4.3.1. Spatial Tracking

These devices view the VR participants' position over time. Most systems track the location and orientation of the participants' head so that the displays can be updated accordingly, and either one or both of the participants' hands to achieve a mode of interactivity. A major goal in research is to extend the three-dimensional space in which a person can be tracked, and providing non-intrusive wireless trackers while doing so (Boman, 1995).

2.4.3.1.1. Optical

Research on optical tracking systems is still continuing however UNC, Chapel Hill has developed a system which has four lateral-effect cameras positioned on a helmet for detecting the positions of light-emitting diodes evenly spaced across a ceiling. The system developed by UNC is presently used in a 3 X 3.5m area. One major drawback of the experiment is the weight of the helmet, weighing over 4.5 kilos due to the positioning of the cameras (Boman, 1995).

2.4.3.1.2. Ultrasonic

Boeing Computer Systems have developed large-volume tracking technology. Boeing officials aim to use this system to help workers in assembling complex aircraft wire bundles. The system tracks ultrasonically using three helmet mounted detectors and multiple sets of ultrasound sources. In every set there are three emitters covering a 100 degree field. The ultrasound sources are aligned to form overlapping cells and the system uses prediction so that the number of cells that are actively being tracked is kept at minimum (Boman, 1995).

2.4.3.1.3. Pattern Recognition

The product called ImageGlove originally developed by Siemens, AG, can track the position of the participants' hands in real time. The special gloves the user wears speeds up and simplifies image processing with the help of the two circular markers -a large white one surrounding a smaller black circle- located on the back of the glove. The system can detect hand position with 6 degrees of freedom at 25 frames per second at the moment but research is continuing further into improving the system so that it can work regardless of the glove and also to detect finger position (Boman, 1995). This and similar research on pattern recognition by computer vision systems will result in non-intrusive, wireless spatial tracking, however the present state is that the system is still far off from the required sample rates and the minimum level of system errors.

2.4.3.2. Gesture Tracking

Gesture tracking involves monitoring the relative positions and movements of multiple body parts. Gesture tracking is the most widely used method for command input to VR systems. The majority of the commercially available systems monitor only hand gestures, although there are few systems that monitor the whole body. These systems also require the users to wear cumbersome mechanical devices or instrumented clothing. Research goals are to develop less-intrusive tracking methods and algorithms which will be able to recognise a broader range of gestures without requiring calibration which is a long procedure.

Currently there are some systems which can recognise two-dimensional gestures within a specialised image background. The system devised by Myron Krueger of the University of Connecticut, that is called Videoplace, for example, uses silhouette analysis for computer interactions (Boman, 1995). Another researcher, Jacub Segen at

AT&T Bell Laboratories has developed a system called GEST, which is a gloveless hand gesture-recognition system that can easily be adjusted to recognise two-dimensional gestures (Boman, 1995). Future developments on the issue are headed towards devising systems that can recognise gestures against any background.

2.4.3.3. Manipulation And Navigation Devices

The main research goal in the field is to develop a tool which will be able to help the user to accomplish a task as easy and error-free as possible. However at the moment there is not one single tool which can both cope with all of the system requirements, and offer ease of use at the same time (Boman, 1995).

The most common characteristic of manipulation devices is that they are either instrumented gloves or handheld pointing devices which include a few buttons besides a spatial tracker for increased control. The biggest disadvantage of these systems is operator fatigue, as the user has to keep his arm raised for long periods of time. Manipulation devices in the form of joysticks greatly reduce the problem of arm fatigue, however these devices do not allow direct manipulation of virtual objects. Moreover object position is controlled by devices such as three-dimensional cursors.

Usually by pointing to a desired direction of movement and either pressing a button or making a specific gesture most of the above mentioned devices can be used for navigation. Devices that can be controlled by other parts of the body have also been developed. Stationary bicycles, treadmills, stepping machines and even foot pedals have been used in VR navigation. Experimenters at UNC Chapel Hill have used a treadmill for navigation in architectural applications. It is recorded that multiple treadmills would have been very useful for VR navigation (Boman, 1995).

2.4.3.4. Speech Recognition

Spoken language can provide a natural and intuitive command input to computers. In ideal conditions an automatic speech-recognition system should have a large vocabulary, be speaker independent, recognise continuous speech and also understand natural language constructs. Recently available commercial systems have limited vocabularies and tend to require extensive training for new users besides being able to understand only single-word commands.

SRI International's Virtual Perception Program has been researching the application of spoken language for VR commands with SRIs Decipher. SRIs Decipher is a speaker-independent, continuous-speech recognition system. Researchers report that spoken language provided to be very useful for discrete commands such as navigating through a VR site. Spoken commands for movement towards specific locations such as "chair" also proved to be useful (Boman, 1995).

2.5. Relevant Topics In Virtual Reality Applications

In the following section, human factors, and issues that are currently being developed will be examined.

2.5.1. Human Factors

Similar to other newly developed technologies, VR affects people in unexpected ways. Research is still ongoing to reveal the physiological, perceptual, cognitive, and social effects of VR technologies. Instead of the trial and error method, researchers are keen to forestall problems before they effect the general public by examining the effects of VR technologies in their early stage of development (Brill, 1992).

2.5.1.1. Sensory Distortion

The research in Tom Piantanida of SRI International Virtual Perception Program related to the effects of VR technologies on visual perception and physiology has shown that HMD optical systems create conditions not encountered in normal viewing conditions. An HMD can make virtual objects appear to lie at certain distances from the viewer. The problem here lies in the focus of these objects at a constant distance which quickly leads to eye strain and headaches as the situation induces discrepancies between physiological systems for setting convergence angles between the eyes and for focusing the eyes (Brill, 1992).

Similar situations induced by VR technologies and their limitations are called sensory distortions. Many of these distortions which produce physiological adaptations can leave a person temporarily maladapted for normal viewing conditions. Other research on simulator sickness is still ongoing but has not been concluded so as to reveal the causes, time courses, and the potential long-term effects of VR use.

2.5.1.2. Health And Safety

In the light of research, Simon Rushton and John Wann of the University of Edinburgh state that as little as ten minutes of HMD use produces temporary changes in binocular function (Brill, 1992).

Stephen Ellis of NASA Ames has based his research on investigating the effects of visual distortions on task performance and with this knowledge, on developing methods for effectively presenting information within VRs. The outcome of this work has led to both subjective methods for measuring optical distortions in HMDs and for examining axial misalignments between displays and users (Brill, 1992).

3. VIRTUAL REALITY APPLICATIONS IN ARCHITECTURE AND DESIGN

3.1. Virtual Reality in Design

Johannes Itten, the Bauhaus teacher and designer wrote the following in an article in 1965:

> The creation of a work of art often requires that the creative potential has at its disposition a multitude of possibilities to arrive at the simplest and clearest formulation (Itten, 1965).

The creative potential -as Itten names it- now has virtual reality as a creation tool at its disposition. The immense possibilities that this technology offers are explored in greater depth in this section.

Robert F.Woodbury at the University of Adelaide and Carnegie Mellon University has begun his discussion on virtual reality by drawing attention to the distinct differences between virtual reality and designerly virtual reality.

A visual virtual reality is one that only provides the eye with only what it might see when moving in a physical environment. A visual virtual reality is said to be as partial and metaphorical as any other virtual reality in the sense that one would only experience partially the factors needed to interpret a building fully. The eyes would not be able to experience the role of the environment in the economy in which it takes part in, nor would he or she be able to experience the way people would habitually use it. Rather than these, a visual virtual reality would provide the user with what the eye might see and this in only a partial sense. Visual virtual reality is based on the notion of using the eye as a perspective device. This situation also holds biases, as the eye-as-perspective metaphor although being able to address the events in our foveal view; is not able to express events in our peripheral or night vision. Finally the eye-as-perspective metaphor is not in a direct relation to our decisions in design. Considering the fact that the design process is never complete, this type of simulation of unfinished designs would hide more than they would show (Woodbury, 1991).

As a result, a visual virtual reality would suit a client perfectly; however designers have greater concerns. This is apparent in the example of the realistic simulations of a furnished house. When one turns a corner into another room although no such room exists, the room is there. The user experiences a realistic space while he moves.

The main problem occurs when the user wants to make changes to his environment. What would the virtual reality explain about the options for changing the environment? The answer lies in another example which is a designerly virtual reality where the user is placed in a space of designs. At any point the user might want to change the design. The user would point to the design with a pointing device and immediately be shown several alternatives of it. The user is free to move through any design alternative and explore it further. At any time the user would be present in a space surrounded by virtually present designs (Woodbury, 1991).

Interaction with a virtual reality setup involves two major issues. The first is a direct interaction with three-dimensional objects as if one was modeling with physical building blocks or clay resulting in the user being able to formulate design ideas in three-dimensions. The second issue is allowing the whole body to take part in the process of designing and adding the memory of motor actions to the activities of the brain thus leading to intensified involvement with the task and enhancing the designer's productivity and satisfaction. Non-realistic features can also be incorporated in a virtual reality system to display additional information. For instance walls could become transparent to reveal the plumbing, or some parts may start blinking to focus attention on unresolved design conflicts (Woodbury, 1991).

If computation is to be used to develop design alternatives then symbol structures must be used. Designs are treated as symbol structures representing aspects of a design. Making changes in design occurs through operations made to symbol structures. Mathematical means of characterising designs and design processes is possible via grammars. Rules, which are the main devices of grammars specify conditions under which they affect. Grammars also contain an alphabet of symbols which are necessary to provide a library of possible symbols on which to compute.

Drawing with a pencil is fluid in the sense that the medium does not get in the way. While drawing we are simply concerned with drawing, we neither think about the parts of the pencil, nor the composition of the paper. A similar fluid interaction needs to be achieved in grammar-interpreter interface. There are two proposals for the principles of design:

- The working process of rules and designs should be as similar as possible.
- Rule editing must be in an appropriate mode.

During the early stages of design, usually unencumbered and rapid exploration alternatives are preferred by designers, as the design alternative has not been developed thoroughly and inconsistencies at this point generate newer thoughts. Later in the design process, the attention shifts towards resolving problems, handling details, making cost and performance analyses, abstract methods become less appropriate and solid modeling becomes more attractive.

Recent commercial VR systems and the subsystems they require signal a VR industry for expansion. The main deficiencies of current VR applications in providing effects of support for the professions is cost of application development, ease of use of VR systems, and user acceptance.

Stereo displays have always confronted ergonomical problems. The reason for this is the simple fact that the eyes of people differ from each other. The current state of the issue is that an adjustment is required for each user. An instrument devised to handle the problem of designing with virtual reality is the BOOM (Binocular Omni-Orientation Monitor) developed by Fakespace Inc. (Bolas, 1994). The BOOM which can be seen in Fig. 18 approaches the issue with three critical considerations. Firstly the users' comfort is important. Secondly designers work together on projects. Thirdly, every designer works on a different aspect of a task simultaneously.

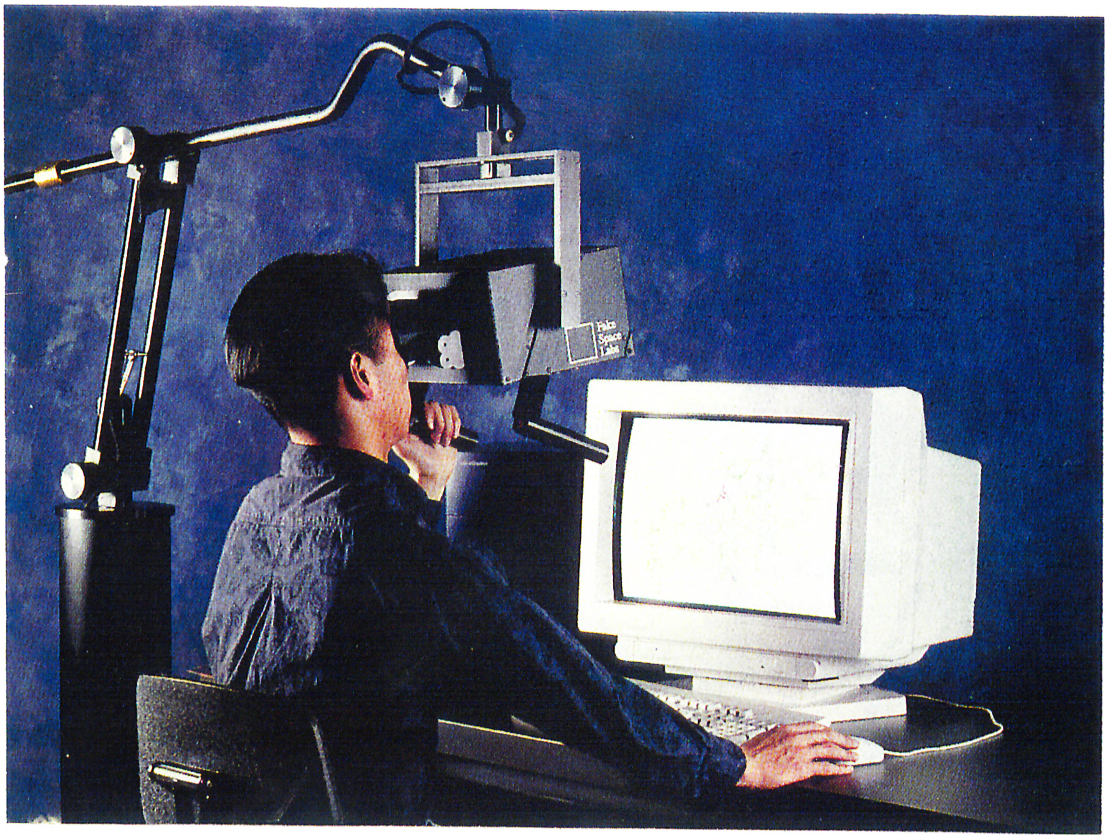


Figure 18. The Boom Device (Bolas, 1994; p.57)

The BOOM meets these requirements with its stereoscopic display mounted on a counter-balanced arm having six degrees of freedom in motion. The device allows a head-coupled interface rather than a head-mounted interface which can be moved easily with the touch of a finger as it is a counter-balanced system having nearly no weight.

The main trend in most VR systems today, is to immerse a single user in the artificially created environment instead of supporting multiple users simultaneously. This situation leads to the user being restricted to a passive role as well as a limited chance for him or her to interact with the environment (Mastaglio and Callahan, 1995). An example to this situation is a person wearing a head mounted display immersed in an architectural walk-through.

VR will most probably prove to be more beneficial when two or more participants can interact both with each other and with the virtual environment. The procedure to be followed in order to achieve this sort of interaction is to network the users (Mastaglio and Callahan, 1995).

The idea of an ultimate medium -using all of the human senses- is the key factor which is leading human-computer interface design toward virtual reality systems. As equipment such as obtrusive and head-mounted displays (HMDs), body tracking suits, and force-feedback exoskeleton devices tend to separate users from each other, several alternatives have been presented to overcome this drawback. The tendency is towards a universal interface (intended for all users) based on the most advanced computer and display technology available (Krüger et al., 1995).

A different trend in human-computer interface design has originated from the user's point of view. This trend pioneered by Myron Krueger's research work tends to treat the computer as an intelligent server in the background giving the user information across multi sensory interaction channels. Such an arrangement of the computer together with its connected sensors and reaction devices represent what is called a responsive environment. The design of user-centered, task-driven responsive environment must be based on a comprehensive user analysis which includes tasks that should be conducted by an interdisciplinary team. These tasks are as follows:

- Define a class of end users according to their major tasks
- Study the end users' daily work environments
- Characterise the users' working behaviours through their use of specific tools
- Determine the role of cooperative work and the communication requirements
- Explore the incorporation of computers such as workstations for use in simulation, visualization, and graphical database access.
- Identify additional requirements for future computing and I/O systems
- Estimate the importance of interactivity, capability of manipulation, and the use of multisensory interaction devices in parallel
- Describe the essential output modes of task results (Krüger et al., 1995).

Users usually prefer focusing on the daily tasks they must perform rather than on operating their computers. The systems, some of which are still in their development stages, should be adapted to the complex working environments of these specialists instead of forcing these specialists to adapt to the computer system. At present however, their drawing tables seem to be the main design medium for a majority of architects. The desired computer workbench application should include the following:

- Every action should be controlled by head movement, grasping and pointing with the hands, or with vocal commands. Additional WIMP (windows, icons, menus, pointing device) -like interfaces should not be incorporated

- The design process should be iterative, starting from sketches having little detail to fully detailed final drawings
- The virtual medium should allow the interactive manipulation of the position, shape, size, and material properties of 3D objects
- Object movements should reflect the natural laws of gravity, and collision
- The user should be able to observe the architectural environment from arbitrary points of view (birds' eye view and pedestrian view)
- Simulated lighting conditions (sun, overcast sky) should be possible
- Rapid comparison ability with earlier design alternatives should be possible (Krüger et al., 1995).

The research group at the German National Research Center for Information Technology (GMD) has formed a workbench using a projector, a large mirror, and a special glass plate as a tabletop. The group has also added additional items to the system such as off-axis stereoscopic rendering, adapted prediction filters for hand and head movement, voice and gesture recognition systems based on an artificial neural network and application-dependent control buttons (Krüger et al., 1995).

In Fig. 19, two architects can be seen in front of the table to discuss the model. They can add or translocate buildings or other objects such as trees in the virtual environment. Additionally they can alter light sources with the gloves they wear, to simulate different times of the day or night (Krüger et al., 1995).

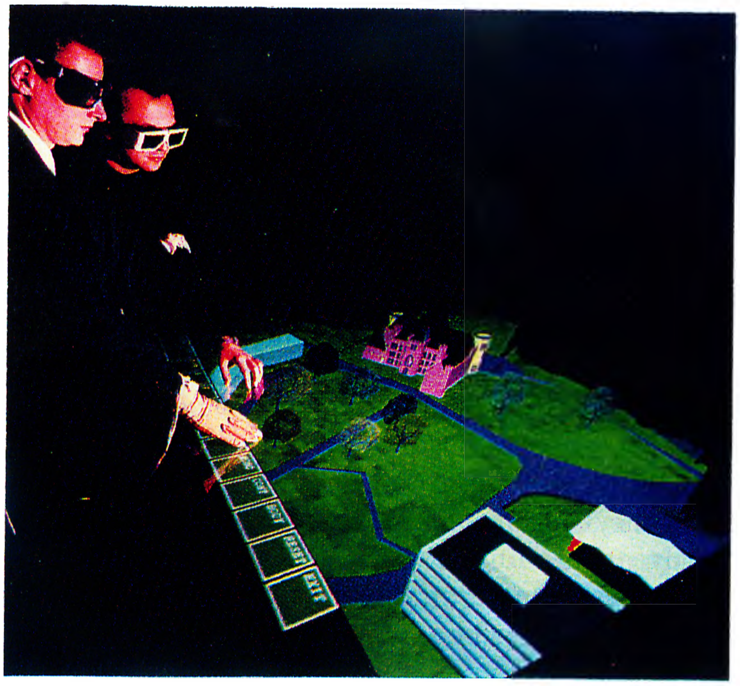


Figure 19. The responsive workbench system (Krüger et al., 1995; p.45)

The results of the research has showed that the concept of active objects seems to be essential (such as cars driving around, pedestrians walking along the street). The problem of generating an animation path for each object can be solved by an additional Polhemus sensor, that can be moved around in the virtual environment like an object to be animated. The Polhemus is a device capable of generating the position, orientation and velocity data for the animation path. For walkthrough experiences on the other hand, where the architect's task is to construct interior building structures, a high-resolution head-mounted display is essential. The responsive workbench system shares common problems with other virtual environments some of which are:

- Real-time, high-resolution rendering of stereoscopic images with realistic appearances
- low latency rates with respect to the multisensory I/O devices
- Parallel management of rendering, tracking ,and the speech recognition system
- Effective generation of large object samples within a hierarchical ordering
- appropriate system adjustments to allow cooperative work for multiple users (Krüger et al., 1995).

When applied, motion models clarify the organisation and behaviours of an assembly and besides motion models also help in pointing to design inadequacies. With time the demands for more exact evaluation of designs has grown and come to a point where some city municipalities require detailed analysis of the volumes of shadows that will be cast by proposed new buildings (Mitchell and McCullough, 1991).

3.2. Design Applications in Interior Architecture

In order to aid the design process an ideal virtual design environment should have the following features:

- It should be applicable to all phases of the traditional design process:

    1. Architectural Program Analysis
    2. Preliminary and Schematic Design
    3. Bidding and Project Proposal
    4. Design Development

5. Pre-Occupancy Evaluation

A system that meets all requirements will generate better designs, minimize errors and facilitate better communication between experts and lay people. The system will aid interior architécts in understanding the design constraints imposed by existing building conditions, code limitations, and program requirements. After that, the system will be utilised as a marketing tool during presentations, and finally as a tool for design development.

- It should provide varying points of view at varying scales.

Architects should be able to view models from a self-referential scale so that they can study issues concerning small children and the disabled. Architects should then be able to modify the scale to understand useability issues.

- It should provide the architect with the ability of applying a client-centered approach to the full design process.

VDE's will provide architects to involve their clients more in the design process. This will provide that the end users of the built environment will participate more in developing quality space.

- The system should enable collaborative design within the environments flexible enough so that a number of experts will be able to apply their own rules and constraints to the situation for design and engineering.

Architects should be able to use the computer as a collaboration tool.

- The system should provide powerful presentation tools for walking clients through proposed designs.

This will enable architects to communicate ideas to clients in the most effective way. The technology will prove to be useful during the bidding and project proposal stage.

- The system should be able to perform strong spatial precedent studies.

This topic calls for a three-dimensional digital architecture encyclopedia providing architects with quick comparative space analysis capabilities.

In other words, the most important feature of an ideal VDE is that it should support collective problem solving, concurrent engineering, and collaborative project management. The methodology to be followed is to accomplish networked interconnectivity and multi-user interfaces.

The whole design process might be reformulated so as to develop around the designer positioned in the middle, placing design elements with the gestures of his or her hands, or adjusting the distances of virtual building elements with respect to each other (Mitchell and McCullough, 1991).

In 1994 a student exchange took place between Montana State University and Eindhoven University of Technology in the Netherlands. The main goal of the project was investigating the pedagogical results of virtual reality applications in the architectural design studio as a design tool to 'create, understand, and describe three-dimensional space' (Hill and Smeltzer, 1994).

In a distinctive project, nineteen fourth-year students participated in the two week activity whose aim had been defined as determining the possibilities of incorporating

VR into the architectural design studio, and to explore whether VR could somehow improve the design process. The students formed groups of three or four to work on the Bauhaus Competition which was sponsored by ACBA. The main aim of the competition was creating a new architectural campus for the existing Bauhaus located in Weimar, Germany by using existing buildings and creating a new school facility.

The design environment at EUT consisted of two studios, having ten traditional drafting tables and five computer stations. Software available was AutoCAD 3D and 3D Studio. The VR software was provided some time later by the faculty.

Prior to the design activity the students were asked about their previous computer experiences. The results showed that nearly half of the students had used AutoCAD previously, two had used AutoCAD 3D, and one had used 3D Studio. The remaining two students had never taken a computer course. Before starting the design process a small demonstration of AutoCAD 3D and 3D Studio was made. The students also had the chance to experience VR where they donned an HMD and used a flying mouse to direct their way in an input building.

The students were given two options. Either they would input their projects into AutoCAD 3D or they would continue working in traditional format. Every team chose to work with computers however they preferred to develop their drawings at the drafting table. After developing their sketches in traditional format, the students input their designs in AutoCAD 3D. Next, they were given a tutorial on 3D Studio, so they spent the next two days applying texture maps to their designs. With the finalisation of this process all designs were input into EUT's VR system and representatives of every team prepared a walkthrough of each design.

When the time for the final presentation had come, a team member which donned an HMD presented the group's design to the audience as seen in Fig. 20. Although the audience could only experience the projects by viewing a computer screen, it is reported that being in the same environment and observing the presenter and the presentation process was nearly as exciting as experiencing each project firsthand with VR (Hill and Smeltzer, 1994). When walking through the building they had actually designed, the students were able to experience size, proportion, and texture. The students also found much more to describe inside their HMD than in the case of presenting in traditional two and three-dimensional media.

Figure 20. Student immersed in the process (Hill and Smeltzer, 1994; p.232)

As a result, students had the chance of understanding the spatial qualities of their own designs much more comprehensively than that provided by three-dimensional computer models of the same projects. The critiquing process was also effected in two ways. Firstly, the students had the chance of describing and demonstrating their projects to their audience much more effectively through VR. Secondly, the final presentation and critique was successful in terms of helping students to understand their own designs. An agreement was reached that only intermediate VR presentations and critiques could enhance this understanding as changes could then be made throughout the development of the design process electronically (Hill and Smeltzer, 1994). In the light of evidence it has been reported that loading a design, moving through it, understanding its spatial qualities, and then going back to the drawing keyboard and making the necessary changes could all be experienced in only a few minutes' time and as a result, immensely speeding up the design process.

Involvement is an issue that is relatively new but of utmost importance in design applications. The issue of involvement brings factors such as emotions into consideration. Emotions can be described as processes which help define our experience of reality. The way to evoke emotive responses on the other hand is via employing imagery and sound. Evidence states that the more a participant is involved in a virtual experience, the less he or she thinks that it is a construct and more that it is a personal experience (Goslin and Morie, 1996).

At certain levels of emotional arousal, the participant begins to receive less information from the real world and concentrates on obtaining more information from sensations directly affecting himself or herself. In the case when the only available data source is the artificial environment, the person may begin to perceive it as being more realistic than it might actually appear. The reason for this is that the brain fills in the gaps in the environment so that it can effectively produce a coherent mental representation of the environment thus producing a much more immersive and stimulating experience (Goslin and Morie, 1996).

Computer graphics researchers Goslin and Morie have devised a virtual environment and called it Virtopia which consists of a collection of different environments each represented with an oasis figure populating a desert.

In the experiment, HMDs were used as visual displays. Additionally, to comply with the requirements of spatial tracking, electomagnetic based trackers were mounted on top of the HMDs. When actions within the environment caused sounds, the computer automatically sends a request to the synthesizer to produce a pre-recorded output. The sound is then sent to a device called Convolvotron which computes the mathematical relationship between the participants' location and the location of the sound source. The convolvotron then passes the signal to the amplifiers which release the sound to the users' ears.

Each of the worlds were created in order to cause some kind of emotional mood. The main aim of the project was to provoke as many emotions as possible. The setup was tested at the Florida Film Festival in Orlando where one participant at a time could test the device while the crowd could see what the viewer was seeing through two large video monitors.

One of the participants -a young woman- decided to enter the Spider World which is an environment that has an enormous spider web and a huge spider seen in Fig. 21.

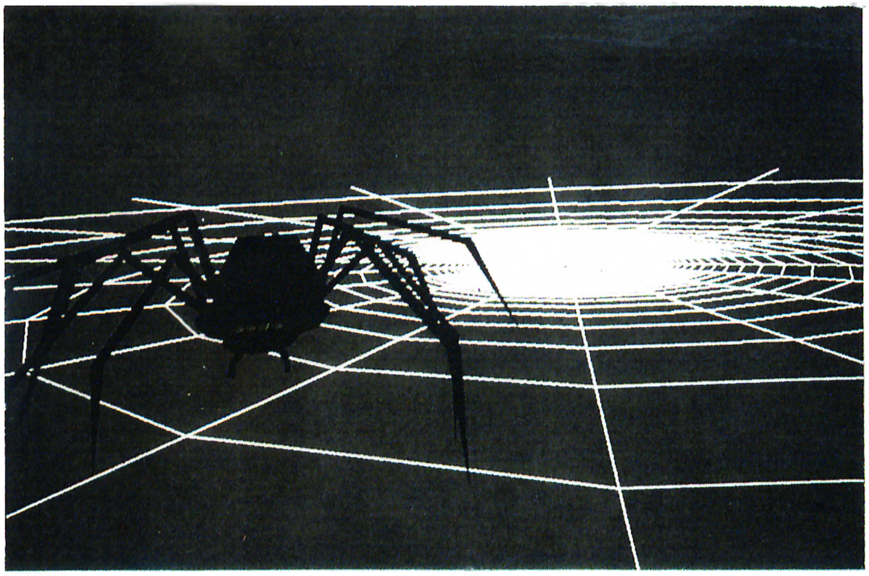


Figure 21. A scene from the Spider World (Goslin and Morie, 1996; p.96)

The spider was not realistic in the sense that it did not contain hair and other physical parts but the asynchronous movements of the spider's legs produced a realistic whole when compared to its parts. The spider was programmed to produce reactions to the movements of the participant. For example running towards it would cause it to run away. However, the young woman caused the spider to chase her and grab her with its feet and at the time this happened, the participant tore off her helmet and ran out from the room. After the woman, the waiting crowd refused to enter Spider World (Goslin and Morie, 1996). Researchers state that in spite of the technical limitations, if a meaningful whole can be constructed using imagery, sound, story and a meaningful interaction with the aim of engaging the participant at an emotional level, the virtual environments will be able to provide us with the environments we dream of constructing.

It is needless to say that designing has to start from an empty paper any more. Instead of making the interior architect look at the empty site and expect him or her to develop a design, a virtual reality system could initiate the design process on its own. The interior architect, this way will be observe the development of the design, recognise good tendencies and make selections among them. This way the designer's energy can be channelled towards formulating and refining an idea rather than being spent with producing initial volumes and forms. The way to make this possible is via the application of shape grammars or case based reasoning together with other intelligent behaviour in the design environment.

The designer should be able to interfere with the ongoing design process to add his or her own abstract design ideas. This process could happen in two ways. It can happen either when patterns get recognised and characterised thus becoming re-applicable. On the other hand, it can happen with the characterisation of transformations such as waves in a certain direction, or cutting and merging transformations.

When examining their artwork it is evident that architects tend to form a corpora of designs. Shape grammars in this sense provide us with the exclusive opportunity of forming a corpora of designs and accounting for the differences among the corpora as a result of the transformations of grammatical rules (Woodbury, 1991).

We can say that during the design stage time will be relative. The relativity of time is only for creating simulations and comparing different points in time of the project, but in the sense of promoting the non-linear character of design thinking. Instead of linearity, the volumation process of a design can be thought of having a tree-like structure as things happen closer after each other and nodes can be remembered.

In interior architectural design applications, besides the functions of collision detection or gravity modeling, other functions which are more important to the profession, such as autonomous motion and transformations are a necessity. These features add an intensity and speed of motion to every object in a certain form. These objects not only have color and a position but also certain types of behaviour in time which makes them change constantly. This situation forms complex scenes that change over time as different parameters can be defined for every object or group separately. Such a behaviour adds realism to an existing static scene besides attracting attention with the help of vibrating objects (Schmitt, 1994).

Research has led to the development of a new workplace for the design activity. Now designers wear their HMDs and are able to select from a set of walls, doorways, and columns. The designer will point his or her wand at an object that appears like a wall with a doorway in it, select it, and then press a button to put it into place. Then the designer will alter the appearance of the wall by pressing the button of the joystick to observe the different patterns that come up with each press. The designer then asks the opinion of his or her colleague on the pattern he or she selects, and receives an audial response. The mentioned system is the virtual home-building demonstration of the Workroom. The Workroom is a system developed by Sense8 and the Institute for Simulation and Training at the University of Florida in mid-1992. The system was one of the first representatives of applications of collaborative design systems based on real-time three-dimensional voice and sound processing and immersive virtual reality technologies (Pimentel and Blau, 1994).

Interior designers can also use the virtual reality technology to let their customers participate in the designed spaces. For example, Matsushita Kitchens is showing virtual kitchen alternatives to their customers and letting them choose between various kitchen alternatives, thus defining a new marketing strategy and increasing their market share (Dagit, 1993).

3.3. Stages Of Learning To Use A Computer System

John Fraser who is the Director of CAD at the University of Ulster, states that there are five levels of teaching:

1. Awareness
2. Operational Competence
3. Operational Fluency
4. Creative Interaction
5. Creative Extension

It is stated that simple five finger exercises, like drawing shapes, manipulating them by scaling, rotating and repeating them are defined as the Operational Competence Stage which usually takes about a week or 3½ working days. Then one would need an additional week to complete a project that would be given, in which using the computer would be easier relative to other methods. Fraser points to Creative Interaction as the most important category in the list. Until one utilises the system creatively, the system is not much of a help to a designer. Fraser describes the last item on his list by stating that using the computer in a task improves the user's creativity to perform a task that may not possibly be achieved using another technique. Fraser also states that using the computer has other advantages as well, such as the speed and ease of using the computer encouraging its use in tasks so complicated that one would not have dared to undertake without the aid of the computer (Fraser, 1993).

3.4. Issues Under Development

The design environments are enhanced by intelligent agents which may influence the quality of human-computer collaboration. The agents mentioned have some specific qualities. The agents:

- Contain knowledge
- Are designed to work on a specific task
- Can work autonomously
- Act on behalf of the user

- Have the ability to learn (Schmitt, 1994)

To give an example, some of the most common agents are the navigator, which follows different interactions such as, moving to a specified place, moving in a previously determined direction or composing a tour. The navigator accepts commands via voice interface. Another agent is the sound agent which tries to enhance the visual impression of spaces by adding an auditory component to it. A neural network built in to this agent needs to be trained specially in order to be able to select the most appropriate sound from the database and also be able to apply various effects on it. The presenter agent on the other hand learns the preferences of each user while examining a project. This issue becomes very important when users having different professions, such as, architects, engineers or clients, are involved. For instance, an architect may choose to look at floor plans to get an overview, whereas a client may prefer getting three-dimensional views and tours through the building. When comparing an architect with an engineer, the architect may be more interested in the surface materials and colours, however an engineer needs to know the material of the different parts of the building (Schmitt,1994).

Other agents which will be useful in the future but are still in their development stages are: cost agents to calculate overall construction costs, illumination agents to simulate various lighting conditions, HVAC agents optimising energy exchange for buildings, and flood and earthquake agents to aid in designing buildings resistant to these disasters.

3.5. Application of Virtual Reality to the Design Studio

This section discusses the effects of using virtual reality in the design studio as a design and teaching tool. The method of teaching three-dimensional design to first year students at Bilkent University has always been through the construction of three-dimensional cardboard models. Instructors explain that making models is necessary to enable the students to see what they are actually designing in three-dimensions. Using a VR system may achieve the same purpose. One available software is the Virtus Walkthrough Pro (Virtus Corporation, 1994) that enables a non-complicated interface and quick manipulation abilities.

In the program there are two menus side by side: one of them is the plan view menu and the other is the walkthrough menu. The student will start drawing his or her design as a two-dimensional plan and then be able to view it as a three-dimensional object having height, width and length in the walkthrough menu. If it is a model of a building, the student will be able to walk around inside the place starting from the first representative rectangle drawn in the plan view. The student will be able to see the transformation of the plan into a three-dimensional solid model without wasting time with cutting and pasting cardboard pieces. The student will not even be concerned about the craftsmanship of the model.

The design procedure is as follows: first, the student draws plans of the designed space in the Plan Menu. After drawing the plan, the student can switch to the Elevation Menu and make changes in the heights of the modelled blocks. When the student thinks that the drawings have reached a certain level of maturity, the student has the chance of applying architectural effects such as color, texture and lighting to the drawing and achieve realistic representations of the modelled object.

The most impressive part of designing with Virtus Walkthrough Pro is that the student is able to specify a route on which to examine the environment that has been created, save it and view the playback. It has been reported that the best way for novice users to explore an environment is through examining the contents of the environment from a fixed path as novice users are generally cautious when wearing an HMD. This situation reveals another benefit to the students: rather than being obliged to deal with navigation data, the student can concentrate on exploring the environment. after observing and understanding the spatial characteristics of the environment from one route, the student can change routes, record them, replay them and observe the environment from different angles.

The greatest advantage of such an application is that from the first moment onwards, the student has the chance to see where the project may lead to, where potential problems might occur and decide whether or not to continue developing it. It is a fact that designing is a collaborative experience where a design evolves by sharing the opinions of experts on the subject, colleagues and instructors. The way of achieving such a communication becomes possible only by networking the users. This is important for rapid information exchange between the students themselves, and between the instructor and the student.

With this issue in mind, it is obvious that the role of the working model in interior architecture education will have to be reconsidered. The costs and benefits of actually designing in three-dimensions with computers, against designing with working models will become evident at the end of further research and a time sequence of actual application.

Related to the issue of using virtual reality as a design tool, it can be said that the present state of the technology is promising, in terms of evolving computing power, high quality graphic displays and reducing price of purchase. The inefficiencies of the technology can be stated as the hardware equipment that is used, suffering from adjustment problems for each user, and besides this, available equipment that a user would use for an immersion process limits the movements of the user so navigation techniques such as walking become extremely difficult. Though dropping, the overall price for a complete virtual reality setup continues to discourage interior architectural firms from investing in purchasing such a system. Another reason that interior architecture firms hesitate on investing in the system is that research on the technology still has not produced a system especially developed for the interior architecture profession. When interior architects want to use the system, they are forced to adapt to the system, rather than the system adapting to them. Due to lack of research, the complete potential that the technology offers has not been able to be fully exploited by interior architects.

However, the current state of the technology offers us some unique tools that can be successfully used in design. The results of my study have shown that, in the design process the most beneficial viewing tool for interior architects to work with is a head-coupled interface rather than a head-mounted one. The reasons for such a preference have developed from the fact that the process of designing continues for long time periods and is almost never uninterrupted. It is senseless to expect an interior architect to put on and off the headgear every time the phone rings or he or she has to use the calculator. Instead, the interior architect pushes away the head-coupled viewing device, deals with the matter, and pulls the device back to his or her eyes. Additionally, research on office behaviour states that people prefer to hold the office equipment and then place it back when finished dealing with it, rather than using apparatus to mount the piece of equipment on their bodies.

In current VR applications constant intensity shading method is widely used. The necessity for this is due to the fact that other rendering methods increase the computational load, slow the machine down, and thus make real-time interaction impossible. Constant shading enables real-time computer graphics generation, but the problem associated with this method is that round objects never seem smooth, rather they seem to be formed of flat surfaces. This shading method does not pose problems for flat surfaces but in the case of round objects, makes the environment look unreal.

Recent studies have shown us that, it is possible to give the user a realistic impression using only a combination of imagery and sound. This system works by emotionally engaging the user with the environment. It is stated that when participants are emotionally involved, their brains interpolate the visual and mental gaps in the virtual environment and perceives it as a more realistic environment (Goslin and Morie, 1996). This is a relatively cheap method of producing convincing illusions by only using a combination of imagery and sound. Such a setup can be used in interior architecture to produce fast and convincing representations of the designed spaces.

4. VIRTUAL REALITY IN OTHER FIELDS

This following chapter will cover other application fields where virtual reality has successfully been implemented. These fields are: education and training, augmented reality, telepresence, and art.

4.1. Education And Training

Researchers at NASA Johnson Space Center is using VR systems to train astronauts and flight controllers on extravehicular activities (EVAs) for actual space missions. According to researchers, VR technology demonstrates the weightlessness on EVA tasks perfectly and in fact was first used as a secondary training tool for the EVAs on the Hubble Telescope repair mission (Boman, 1995).

R. Bowen Loftin is developing a virtual science lab in collaboration with NASA Johnson in which students can perform physics experiments that normally can not be carried out in school laboratories. With this facility a student has direct control over variables including gravity and friction, and is able to stop, start or slow down the experiment at will (Boman, 1995).

VR has been used as an education tool in two separate cases; one at the summer school for pupils aged between 10 and 15 at the Human Interface Technology Laboratory in Seattle in 1991. The second took place in March 1992 at the West

Denton High School in Newcastle where VR was integrated into the standard curriculum for pupils aged between 13 and 19 years.

The results of introducing VR as an educational tool can be summarised into two points: firstly, in both cases VR encouraged the pupils to work independently from teachers. Pupils found it easy to learn creating virtual worlds due to the ease of use of the equipment and the imagination and skills involved in the task of world building. The second apparent result of these applications was that pupils generally preferred to construct their own virtual worlds instead of using ready-made ones. The worlds they had designed or told that they would like to design when asked, ranged from medieval space stations to utopian future neighbourhoods.

This situation clearly states that pupils were able to identify the potential uses of the technology in an imaginative way. However what both of these experiments did not reveal was how to fully exploit this potential. There remain the questions concerning which skills can best be taught using VR as opposed to other means, or how can VR best be used as an education tool, that demand answers (Schroeder, 1995).

4.2. Design Testing Applications

Design testing is one of the first areas of commercial VR applications. Caterpillar Inc. together with the University of Illinois, Urbana-Champaign has been working on a VR system to test the visibility in different tractor designs. The implementation of VR testing saves both time and money by minimising the need for design prototypes. In this system, a designer wearing a VR HMD sits in a cab mockup including only standard mechanisms such as the steering wheel, pedals and levers for controlling bucket scoops and buckhoes. Next, tractor models are imported into the VR system to check the visibility during simulated construction tasks (Boman, 1995).

Boeing Computer Services has developed VR capabilities for testing aircraft designs. Lockheed on the other hand is working on an ARPA-funded VR project to test designs for ships and submarines. The complexity of the designs make VR testing especially attractive but also bring limitations to VR applicability as increased complexity tends to slow the system down by reducing system update rates (Boman, 1995).

The US Army is using large-scale virtual worlds for mission planing, and researches, and autonomous-agent simulation. Advanced distributed simulation (ADS) produces its results with Simulator Networking (SIMNET) by supporting three important techniques: synthetic environments, synthetic forces, and computer networking (Polis, Gifford and McKeown, 1995). Synthetic environments mentioned here consist of a set of data elements describing a geographical region; simulation entities such as vehicles, airplanes and humans; events that are expected to take place during interactions with the environment.

The construction of the large-scale virtual worlds requires information from a range of sources such as digital map data, aerial imagery, detailed line drawings, and ground base photography. The information required for the construction of virtual worlds is obtained from a variety of sources including US Geographical Survey's (USGS) digital elevation models (DEMs) and the Defence Mapping Agency's digital terrain data (DTED) for obtaining terrain data, Landsat Thematic Mapper (TM), SPOT (Satellite pour l'Observation de la Terre, or Earth Observation Satellite) for obtaining aerial imagery data, High Resolution Visible (HRV) data for obtaining remotely sensed imagery data. The combination of digital terrain data, which can be used to generate three-dimensional bare-earth skin, with the transportation network results in an integrated surface mode that accommodates the road network in terms of road grade and tilt (Polis, Gifford and McKeown, 1995).

4.3. Augmented Reality

Augmented reality (AR) systems combine computer-generated imagery with views of the real world, instead of completely immersing the user in a simulated environment. A spatially tracked, partially transparent HMD is used in this type of system. In practice, AR systems can be used to overlay information on real-world objects; for instance displaying the location of a component inside a machine, or to provide additional information when turning pages in a manual. In order to be successful, the system requires spatial-tracking equipment which is accurate over large tracking volumes, besides graphics display hardware quickly updating the images in response to head movements. If such requirements are not met, the registration of real-world and computer-generated images does not successfully occur (Boman, 1995).

An AR system being developed by Boeing Computer Services will be used in manufacturing, assembly, and repair works in the future but at the present it is being used for the assembly of aircraft wire bundles. Large form boards used earlier for the task can now be replaced by an AR system showing the correct attachment locations of successive wires.

4.4. Telepresence

Telepresence applications form a link between robotics and VR issues. The main aim of telepresence systems being able to manipulate equipment at remote sites. Telepresence gives the user the feeling of actually being at the site and handling the controllers, thus providing highly intuitive interface for robotic control. A major problem in intuitive application is the time lag due to the transmission of signals over large distances (Boman, 1995).

The research at NASA Ames is based on being able to teleoperate vehicles for planetary exploration. These vehicles will be able to perform geological surveys besides traversing the terrain. One of the most difficult problems to be tackled in the research is providing operators on Earth the accurate control over these robots despite the long transmission delays (Boman, 1995).

Another research at MIT leaded by Ian Hunter is developing VR technologies for teleoperated surgical procedures. The researchers are initially working with a teleoperated microsurgical robot in experiments on eye surgery. The research team has developed a virtual model of the eye to practice teleoperated surgery under simulated conditions (Boman, 1995).

6. SUMMARY AND CONCLUSIONS

In this work the properties that distinguish virtual reality from other computer applications have been identified. The identification such as animation or computer generated models process has continued with a short overview on the historical development of virtual reality. During this phase, virtual reality components -software and hardware- have also been individually examined with the aim of being able to select from the wide variety of options, the respective combination that suits interior architectural activities.

Interaction with a virtual reality setup has been defined with respect to two alternatives. The first is a direct interaction resembling modeling with physical building blocks. The second relates to the involvement of the whole body causing intensified involvement with the task and in this way enhancing the designers productivity.

Interior architects have been treated as specialists and their working environments have been investigated, and the important requirements have been identified as: interaction with the environment being controlled by head, hands and vocal commands, an iterative design process, direct manipulation of three-dimensional objects, simulation of various lighting conditions, and rapid comparison ability with earlier design alternatives

According to former research, the effects of using virtual reality in education have been recorded as communicating his or her design to the student, enhancing the critiquing process, and speeding up the design finalisation process.

In relation with the issue, physical disorientations caused by the virtual reality technology under certain conditions with the aim of further helping to define the ideal working environment for the interior architect has been evaluated.

Virtual reality applications in other fields have been investigated and the outcome of the implementation in each field has been presented separately in this study.

Finally, this study has been concluded with the summary all of the gathered data, along with the evaluation of the results.

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