StereoCAD: Three Dimensional Representation

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Concepts of stereoscopic vision have been around for more than two thousand years. Despite this long history, its application to the field to architecture and design seems relatively unexplored. Synthesis of two technologies, the stereoscope and the computer, was the focus of the present study. The goal of the research was to determine if computer-generated stereoscopic pairs hold value for architectural design. Using readily available computer technology (Apple Macintosh) the research team modelled and rendered an existing project to verify the degree of correlation between the physical construct, the computer 3D model and resultant rendered stereo-paired representation. The experiments performed in this study have shown that producing stereo-paired images that highly correlate to reality is possible using technology that is readily available in the marketplace. Both the technology required to produce (i.e., personal computer and modelling/rendering software) and view (i.e., modified stereoscope) the images is unimposing. Both devices can easily fit in a studio or a boardroom and together can be utilized effectively to permit designers, clients and end-users to experience proposed spaces and projects. Furthermore, these technologies are familiar (clients and end-users have already experienced them in other applications and settings) and assume a fraction of the cost of more dynamic, immersive virtual reality systems. Working from this base, limitations of the process as well as future applications of computergenerated stereoscopic images are identified.

Keywords: stereovision, representation, computers, architects, design

1 Introduction

"The human brain is the most incredible virtual-reality machine anyone has ever discovered. Attempts through history to use technology to create three-dimensional illusions have tried to mimic artificially what the human perceptual system does naturally." [1]

As far back as 15,000 years ago in the caves at Lascaux, mankind was attempting to create three dimensional illusions. [2] Just before the birth of Christ, Euclid's Treatise on Optics [3] illustrated an awareness of depth perception. The illusion of three dimensions made great strides

"At the beginning of the Italian Renaissance, early in the 15th century, [when] the mathematical laws of perspective were discovered by the architect Filippo Brunelleschi." [4]

By providing a more accurate duplication of our perceptual systems (Figure 1), Brunelleschi's laws transformed the way architects, landscape architects, engineers, industrial designers, interior designers and artists represent their ideas.

Four hundred years later, in 1838, the stereoscope (Figure 2) was invented by Sir Charles Wheatstone. [5] Photography was invented the following year. Together, they allowed people to view places, people and events as they exist in three dimensions by creating a "heightened sense of reality, of actually being there." [6] Stereoscopic images were the forerunner to virtual reality, providing the viewer with a single moment of artificially created three dimensional experience. Its popularity faded in the early *1940's* with the widespread presence of television and film. Today many people do not even know what a stereoscope or stereo photography is.

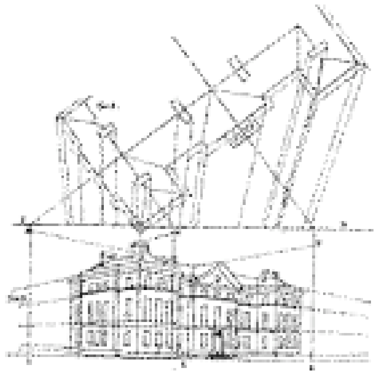


Figure 1. An illustration of Brunelleschi's laws of perspective. Source: Gwilt, Joseph. The Encyclopedia of Architecture. New York: Bonanza Books, 1982. 778.

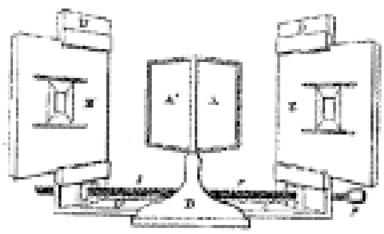


Figure 2. The original Stereoscope designed by Sir Charles Wheatstone. Source: Brewster, Sir David. The Stereoscope: Its History, Theory, and Construction. London: The Fountain Press, 1856. p6.

As the popularity of stereoscopes were fading the introduction of the computer was just beginning. Thirty years ago, computers were warehouse-sized machines that few people had access to. The introduction of a graphical user interface (GUI) made popular by the Macintosh in 1984 started a revolution in personal computing. The speed, affordability, and manageable size of today's computers allow designers to use them as tools for creating linear perspective drawings from any point of view. Personal computers are continually becoming more powerful and sophisticated. They are also becoming user-friendly enough for users to create photorealistic images (Figure 3). However, like an actual photograph, by themselves they still lack the depth that our experience of looking at an actual object gives us.

As we approach the 21st century, we find ourselves surrounded by innovative ideas and innovative uses of technology. A recent innovation is the autostereogram [7], a colourful image that appears as a set of random dots on a poster. When one stares into the poster, a three dimensional image mysteriously manifests itself -from within the page. The experience is not unlike looking at a hologram.

To experience a building in three dimensions (as opposed to a three dimensional representation on a two dimensional surface) before it was built, as one experiences an autostereogram, would be a useful tool in design. The present research into stereoscopic representation in architecture was conducted by Mark Thomas Ager (principle investigator) through a graduate level Special Topics course under the direction of Professor Brian R. Sinclair (Director, CADLAB, University of Manitoba).

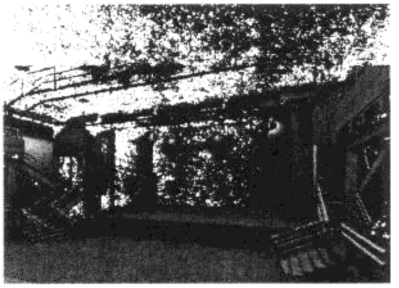


Figure 3. Radiosity rendered image of a design for a small theatre. Source: Mitchell, William J. & McCullough, Malcolm. Digital Design Media: A Handbook for Architects and Design Professionals. New York: Van Nostand Reinhold, 1991. 429.

2 Goals & objectives

The goal of the research project was to determine if computer-based stereoscopic images hold value for architectural design. The objectives were:

(a) to develop a method of producing stereo-paired images of computer models which can be created using readily available computer hardware and software;

(b) to illustrate the degree of correlation between stereo photographs of a built project and stereo computer-generated renderings from a three dimensional computer-based model of the same project; and

(c) to assess whether stereoscopic perception can be used as a tool for architects and clients to better understand the three dimensional nature of designed yet unbuilt spaces.

3 Premise

For many of us, computers are a part of everyday life. They are simply another tool which help us get our work done. In this capacity they reduce repetitive tasks; they cannot as yet reproduce our creative abilities, but can speed processes to free up time for designers to exercise their creative abilities; and, they have computational abilities which allow them to perform tasks which were not possible before such as photorealistic renderings and 'fly-over/walk-through animation.

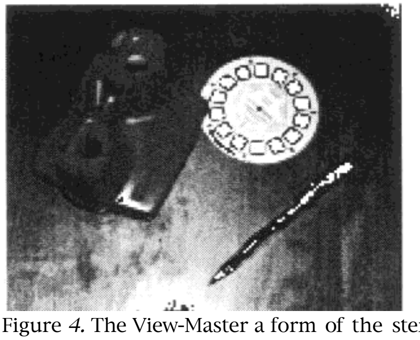


Figure *4.* The View-Master a form of the stereoscope that many people are familiar with. Source: Photograph by Mark Ager.

A tool which was as popular at the turn of the century as computers are today is the stereoscope. [8] A form of the stereoscope that many of us grew up with and may be most familiar with is the View-Master. (Figure 4) [9] The stereoscope was invented to take advantage of the fact that most of us have two eyes, which when coupled with some complex cognitive processing permit us to perceive depth in space. The technology of the stereoscope is relatively simple and has in fact been used in the field of geography for many decades to study aerial photographs.

In the last few years the computer industry has decreased dramatically its product pricing while concurrently increasing computing power. This combination now makes it possible for many people to own sophisticated computers and software, incorporating them into a broader range of daily activities.

The availability of personal computers and CAD software to model architecture in great detail and to create photorealistic renderings of computer-generated models creates a whole new context for architects. Traditional procedures and processes are challenged. The potential of synthesizing these two technologies, the computer (hardware and software) and the stereoscope raises many questions: Will it be useful to designers and their clients to be able to 'experience' an unbuilt project in 3D or will it simply be a novel effect? Can it be done affordably? What kind of equipment will people need to be able to view these 3D images? What other applications will this synthesis have?

4 Context

Computers are convenient and useful because they allow us to do more than we are able to do with traditional tools and to also do things that we never could have done before. This may seem like a benefit, but many professionals have seen it as a curse -- a curse because it creates certain expectations. Architects were once seen as the professional you would engage if you wanted a building designed. As people become more and more computer literate, they feel that they can design with the machine, in essence replacing or sidestepping the Architect. After all, anyone can readily go down to their local computer store and purchase a copy of Home Designer, Office Designer, or similar off the shelf applications for less than $50. They can draft a house or office space if they are ambitious enough to learn the software and save hundreds of dollars in architect's fees for the effort.

Architects must be able to convince clients and the general public that their services are essential. In recent times, the architectural profession has met with an increasing crisis of confidence and image problem with these constituents. [10] While a lay person may be able to draft their own house and even create perspectives of it, an architect can draw on his/her experience and knowledge to go beyond the limitations of the computer program and provide a better design which meets more user needs. Architects are trained in much more than drafting. They have a knowledge of materials and the way they are put together. They know how to create spaces that convey a certain feeling or mood. They understand the complex relationship between the built environment and human behaviour. All these skills take years to develop and cannot be "acquired" through the purchase of a $50 software package.

Involvement is another expectation that clients have. If a client decides to hire an Architect, he/she often wants (or expects) to be included in the design process, from the first conceptual sketches through to the finished product. Computer applications allow the designer to quickly develop conceptual models and visualize various possibilities for a design. Three dimensional modelling software allows the designer to create perspective views of the model, a method of visualizing that permits clients to understand the design because it simulates their real experience. This allows the client to then offer their own suggestions (i.e., feedback) as the design progresses, rather than trying to guess or create their own mental visualization of what a design might look like.

The origins of the word "perspective" tell of its very limitations. The Latin word is "perspectivus, from perspicere, to look through, to view." It was perhaps Dürer (Figure 5) and his perspective instruments that "may have led to the idea of looking into a picture, instead of looking at a picture." [11] When we look at the real world, our eyes are constantly converging on a single point. From a young age we learn that sometimes our eyes converge on points close to us and sometimes on points far away from us. This is one of the ways we know that we are not simply looking at a photograph. When we look at a Photograph, our eyes converge on a plane whose points are all a similar distance away from the viewer.

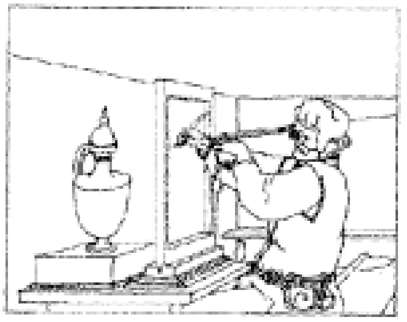


Figure 5. Draughtsman drawing a vase. After Albrecht Durer, 1538. Source: Redrawn in Forsyth, Kevin. Glide Projection: Lateral Architectural Drawing. York: Van Nostrand Reinhold Co. mc, 1984. 25.

Architects have been using various tools such as linear perspective for centuries to visualize their designs, but ultimately it is the client who must critically be able to visualize the design. Drawing techniques such as plans, elevations, axonometrics, and perspectives have all been developed as conceptual devices which help explain an idea and as communicative devices intended to explain how a design is constructed. What stereoCAD (i.e., the term used by the investigators to describe stereo-paired image processing with a CAD/rendering system) offers is the ability to not only see what a building will look like in three dimensions but also to perceive the proposed space as if it actually existed in the third dimension. In essence, the stereoCAD process provides a much stronger simulation of reality than is available in 'flat or planar representations.

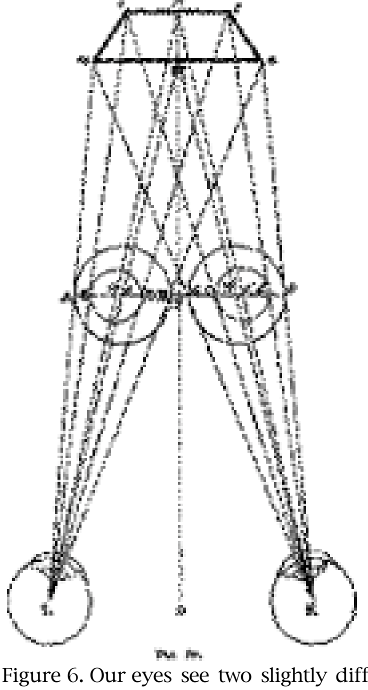


Figure 6. Our eyes see two slightly different views or the same object, creating the perception of depth. Source: Brewster, Sir David. The Stereoscope: Its History, Theory, and Construction. London: The Fountain Press, 1856. 84.

By providing our brain with two slightly different views of the same image (Figure 6), we fool it" into an experience of depth. StereoCAD goes a step beyond even the most highly realistic painting or rendering by providing our brains with another point of view. How is this different from so called virtual reality? It is actually a single moment in virtual reality at a fraction of the cost. Instead of costing several hundred thousand dollars or more for powerful immersive VR technologies, stereoCAD images can be produced for a few dollars each with software that is readily available and in wide use in many architectural firms around the world.

The technique of producing stereoscopic pairs on the computer is not new. "Virtual image" stereograms were initially devised by Kenneth Snelson. [12] However, minimal research has been done with computer-generated stereoscopy in the field of architecture. Snelson (and other artists) have produced stereo-paired images on the computer which, when 'fused" by crossing ones eyes and creating a single image, produce a three dimensional simulation. Those fortunate enough to be able to perceptually fuse images experience a truly unique phenomenon -- the image mysteriously rises out of the paper and is perceived as existing in three dimensions. This scenario highlights a great limitation if the experience of stereo-pairs is to be useful as a tool and not just an art form that produces interesting and exciting effects. For this reason the current study explored the idea of the 'reconfiguring" the stereoscope for use with ordinary slides (both conventional and digitally produced) as this is a common method of output for many computer users.

5 Historical Background

The concept of stereoscopic vision were documented before Christ's birth. Euclid, in the 26th, 27th, and 28th theorems of his Treatise on Optics [13] showed how each eye sees different portions of a sphere. Leonardo Da Vinci was also aware of the concept of stereoscopic vision and describes it as the reason why "a painting, though conducted with the greatest art, and finished to the last perfection, both with regard to its contours, its lights, its shadows, and its colors, can never shew a relievo equal to that of the natural objects, unless these be viewed at a distance and with a single eye." [14] Brewster described the process of stereoscopic vision with Victorian precision in his history on the subject:

"Since objects are seen in relief by the apparent union of two dissimilar plane pictures of them formed in each eye, it was a supposition hardly to be overlooked, that if we could delineate two plane pictures of a solid object, as seen dissimilarly with each eye, and unite their images by the convergence of the optical axes, we should see the solid of which they were the representation. The experiment was accordingly made by more than one person, and found to succeed; but as few have the power, or rather the art, of thus converging their optical axes, it became necessary to contrive an instrument for doing this." [15]

When photography was in its infancy, Sir Charles Wheatstone built a device for "uniting two dissimilar pictures, and thus reproducing, as it were, the bodies themselves," [16] which he called the STEREOSCOPE. Wheatstone had the first pairs of stereo photographs made in 1841 and exhibited the device at the 1851 Exhibition at the Crystal Palace in London.

Many varieties of the stereoscope were produced in the following 80 years. People had a fascination with being able to "see the world" in three dimensions and man places, events, and people were recorded in stereo views. *"At the turn of the twentieth century few homes (in America] were without a viewing instrument and a small of assortment of cards'* [17] with stereo views. After 1920, there was a gradual decline in the excitement of stereo views due to the rising popularity of motion pictures, radio and people's ability to travel more freely (i.e., heightened mobility).

"Perhaps the next major advance in the field (of stereovision] was the invention of the random-dot stereogram." [18] Working at the Bell Institute in the 1950's and 60's, Bela Julesz introduced the concept of computer-generated, random-dot stereograms. [19] Julesz explains his discovery, "I was originally a communication engineer working with radar. Everybody in the field thought it to be common sense that camouflage could be broken in the stereo photo, and that shapes which could not be visible monocularly could jump out in depth.' [20] His work created quite a stir in the field of perceptual psychology and "by the early 1970's enormous energy was being poured into the development of the stereo ram on the philosophical, artistic, and technical levels." [21] His work also lead to the development of 3D movies with red/green glasses that viewers wear to achieve a three dimensional

effect. Juleszs ideas were also developed by Christopher Tyler [22] into the single image autostereogram, a craze that is sweeping the shopping malls in the form of colourful posters. If one stares at the poster a three dimensional object will mysteriously emerge from the paper.

The principles of stereovision have thus been understood for thousands of years, but it is only in the past hundred years since the introduction of the photograph that these principles have been meaningfully applied. It is only recently with computers becoming more affordable and powerful, that stereoscopic ideas have been used to actually simulate proposed objects and environments [23], instead of just representing what already exists.

6 Research Paradigm

The present research of stereographic representation was structured to verify the correlation between computer renderings of a built project and the actual project itself. To verify that the stereoCAD process is valuable to designers, the investigators deemed it critical to assess 3D perception as measured against an actual constructed project. Having the physical construct as the benchmark, the research then assessed the validity of both photographic stereo-pairs (Figure 7) and computer-generated stereo-pairs (Figure 8). While simple models are relatively easy to produce, realistic renderings can be very time consuming for both man and machine.

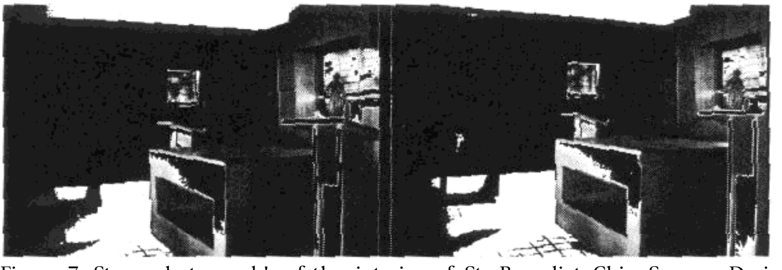


Figure 7. Stereophotograph's of the interior of St. Benedict Chip Source: Design, Michael Boreskie Architect Inc. Photographs, Mark Thomas Ager.

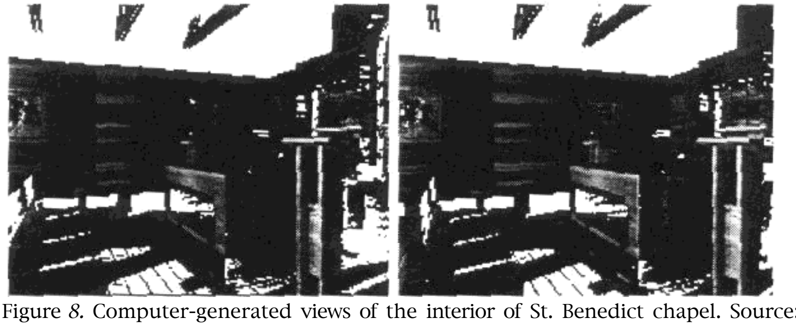


Figure *8*. Computer-generated views of the interior of St. Benedict chapel. Source: Design, Michael Boreskie Architect Inc. Modelling & Rendering, Mark Thomas Ager.

The paradigm further suggests that the computer modelling could be carried out in a time frame that would be reasonable; that the computing power required to execute the renderings would be within the range typical of a small architectural firm; and that the output, whether paper or slide, would be clear enough to be able to experience the depth perception (a major factor in spatial experience) effectively.

7 Methods

7.1 Literature search

In initial literature searches, very little information was discovered regarding stereoscopic vision. Brewster's history and theory of the stereoscope proved a strong historical and reference book. Much of the research that has been done in the field of stereoscopy can be found in the field of perceptual psychology. Some historical examples are found in books and magazines on photography. Due to the special equipment needed by most people (the general public is largely incapable of "fusing" images without a stereoscope), 'it has remained little more than a curiosity.' [24] Many books [25] have come out in recent months illustrating the potential of stereoscopy (specially autostereogram images) in the fields of art.

7.2 Representational paradigm

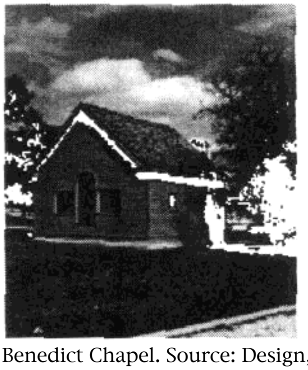
While virtual image stereograms such as Snelson's showed that a three dimensional effect could be produced, they represented conceptual and often fantastic environments; hence they could not be compared to the physical construct (i.e., real environments). The present investigators decided that a built environment (e.g., constructed architectural commission) would be chosen to be modelled on the computer. The physical construct could then be compared with the subsequent computer model to verify the correlation between the two.

St. Benedict's Chapel (design: Michael Boreskie Architect Inc., Figure 9) in Holland, Manitoba, Canada was chosen to be modelled on the computer for several reasons:

(a) It is a built project, so working drawings of the project existed. Located near Winnipeg, the site could readily be visited, experienced and photographed by the investigative team.

(b) It is a small enough project that it could be computer modelled /rendered in detail in three dimensions.

(c) The building is an intimate, meditative chapel used by Trappist monks in the summer. Its interior qualities provide a "quiet, contemplative atmosphere" as described by the monks. It was seen as a further challenge to the investigators to see if this somewhat "mystical" quality could be conveyed in computer-generated stereoscopic views of the space.



Benedict Chapel. Source: Design, Michael Boreskie Architect Inc. Photographs, Mark Thomas Ager.

7.3 Available technology

Modelling, rendering and image processing activities were executed using an Apple Macintosh Quadra 900 equipped with a maximum of 20 megabytes RAM. Software used for modelling was form •Z (auto.des.sys), a three-dimensional solid modeller. Form 'Z is a powerful yet intuitive program which allowed the chapel to be modelled in great detail and with great precision, including the bevels in the wood siding. The model was then imported via DXF into StrataVision 3D (Strata Inc.) where textures were applied.

Renderings were then executed in pairs, producing images with approximately 2-1/2 viewpoint offset (the same distance as the average person's eyes.)

8 Findings

The implications of stereovision in the field of architecture are significant. Architects have been formally visualizing and communicating unbuilt projects for hundreds of years since the development of perspective drawing. StereoCAD affords viewers the feeling of being IN a space or looking INTO a space as opposed to looking AT a space. Limited testing of the early stereoCAD prototype viewers and associated computer generated images lead to anecdotal comments like "Wow, *Ifeel like I am in the chapel!* ,"The beams seem to float and the podium really jumps out at me." Others conveyed disbelief that the images were computer-generated.

8.1 Modelling

The chapel was "constructed" in approximately 32 hours in form•Z. It took approximately 26 hours to apply and fine tune the textures and lighting within Strata Vision 3D. The final images required 6-10 hours each (at a resolution of 72 dpi [dots/inch]) of computer time to generate. The time taken to model St. Benedict's Chapel and the time required to render screen resolution (72 dpi) images were considered reasonable by the investigators. High resolution images (300 dpi) required much greater amounts of computing time to produce (over 50 hours each). Due to the ability to temporarily "suspend" rendering activity, it is possible for designers to use machines for design activities during peak business hours and relegate intensive rendering work to off-peak (e.g., through the night) times.

8.2 Output

The low resolution images were printed on a 300 dpi dye-sublimation printer. The results were pixelated and somewhat blurred. Images were also output to 35mm slides, producing much better colour saturation and reducing pixelization. To be commercially viable, the quality would have to be much higher; however, for the purpose of demonstrating the stereoscopic effect, the low resolution slides were adequate.

9.3 Viewing

An early prototype stereoCAD viewer was constructed at a cost of less than $10. (Figure 10) A more elaborate, durable version designed for gallery display (or for office application) was manufactured for less than $100. (Figure 11)

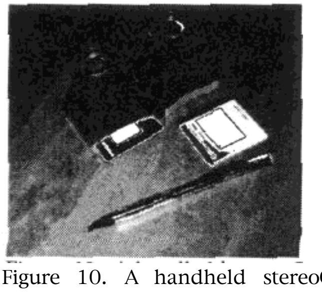


Figure 10. A handheld stereoCAD viewer produced for less than US$10. Source:Design, Mark Thomas Ager & Brian Sinclair. Photographs, Mark Thomas Ager

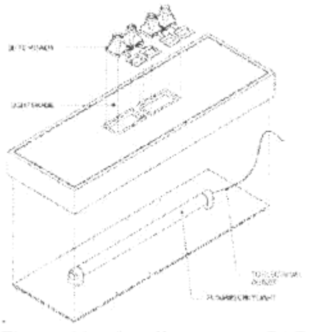


Figure 11. A gallery stereoCAD viewer produced for less than *US$100.* Source: Design, Mark Thomas Ager & Brian Sinclair. Isometric drawing, Mark Thomas Ager.

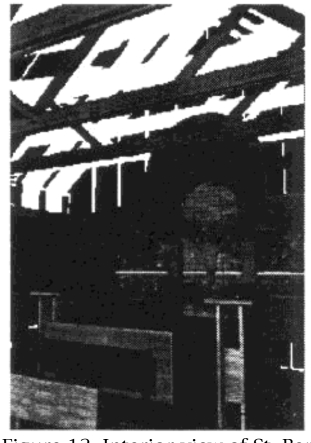


Figure 12. Interior view of St. Benedict Chapel, looking west.Source: Design, Michael Boreskie Architect Inc. Photographs, Mark Thomas Ager.

9.4 Limitations

The computer generated model (Figure 12) created in the present study was not an identical construct of the actual building. It would be very difficult and time consuming to completely mimic the complexity of the wood grain, the reflection differences created by surface imperfections, the perturbations in the stained glass, etc. These shortcomings aside, the views generated indicate that there is a strong correlation between the built environment and the computer simulation. If this technique is used in visualizing future projects it would be important to note that the inverse is true as well. When a project is built it will not look exactly like the computer-generated images. It will however, e a close and valuable proximation.

The stereoscopic views of St. Benedict's Chapel provide a good feeling of what it might be like to be in the space, but they have several limitations. Our real experience allows us to see things in both foveal and peripheral vision. The stereo views provide a limited viewpoint (largely foveal). Our real experience of a space is a complex interaction of all our senses, not just vision. As we experience the built environment we are constantly moving, shifting, looking around, smelling, listening and touching. To simulate this complexity would, require much more than a personal computer and some 35mm slides. Computer-generated stereoviews of an environment are not meant to completely recreate reality. StereoCAD was conceived as a vehicle to better understand, design, and communicate architecture.

The rendering process is another limitation. Renderings can often take enormous lengths of time, especially to create photorealistic results. This is continually changing as computers become faster, but at the moment it still is a big concern. Near the end of the present study, CADLAB (research unit at University of Manitoba) acquired a suite of Apple PowerMacs based on RISC chip architecture. Planned testing of stereoCAD on the this platform should significantly improve performance. In large design firms with man computers, perhaps computers would be designated as rendering devices. Small firms wit limited computer resources would best render their images during off hours.

9 Conclusions

The experiments performed in this study have shown that producing stereo paired images that highly correlate to reality is possible using technology that is readily available in the marketplace. Both the technology required to produce (i.e., personal computer and modelling/ rendering software) and view (i.e., modified stereoscope) the images is unimposing. Both devices can easily fit in a studio or a boardroom and together can be utilized effectively to permit clients and end-users to experience proposed spaces and projects. Furthermore, these technologies are familiar -- clients or end-users have already experienced them in other applications and settings. Having this base to work from, potential applications are numerous.

9.1 Future Applications

The most obvious application is using this technique to experience spaces in projects which have not yet been built Our perception of spaces from a plan or section or even a perspective is enhanced by the addition of depth and will be very useful in both the design phase and the production phase of an architectural project. Presentation and communication, whether to financiers, approving authorities, contractors or potential users, can be facilitated through stereoCAD. Accompanying enhanced awareness of projects before construction should help alleviate problems downstream.

Another application would be to "rebuild' projects that no longer exist. Producing stereoCAD images would allow viewers to "experience" what it must have been like stepping inside of the Parthenon, for example. One could "visit" other projects of significant historical value like some of Frank Lloyd Wright's buildings which have been destroyed by fire or demolition.

This study concentrated primarily on the areas of interior architectural spaces. Future studies could explore architecture in the landscape, using image processing techniques to "graft" computer-generated stereo images into stereo photographs of the natural landscape within which a future building is to be sited (or was sited, in the case of destroyed projects).

The investigators foresee useful application in a broad range of design and planning activities, from product design to urban design. Applications to design and planning education also hold much promise.

10 Endnotes

[1] Horibuchi, S., (ed) Stereogram. San Francisco: Cadence Books. 1994, 6.

[2] ibid.

[3]Brewster, D., The Stereoscope: Its History, Theory, and Construction. London: The Fountain Press. 1856, 6.

[4] Encyclopedia Britannica. 15th (ed) s.v. "Perspective.".

[5] Kinglake, R., Introduction to The Stereoscope: Its History, Theory, and Construction. (London: The Fountain Press. 1856.) NY: Morgan & Morgan 1971.

[6] Horibuchi, S., (ed) Stereogram. San Francisco: Cadence Books. 1994, 36.

[7] C Tyler was one of the early innovators in creating device-free stereograms while working at Bell Labs with B Julesz who had previously developed the random-dot stereogram. Tyler, C., In Stereogram. San Francisco: Cadence Books. 1994, pp 83-88.

[8] The stereoscope works on the same principles as our own eyes. When we look at things, each eye sees a slightly different view of the same object. These views are united in our brain. A simple illustration: Place your index finger about 4" in front of your nose. While looking at your finger, close one eye, then open it and close the other. The two views

of your finger will be slightly different. Stereovision, linear perspective, atmospheric perspective and experience allow us to interpret how far and close things are to us. Stereo paired photographs are photos taken from two points of view 2-1/2" apart (the same distance apart as the average persons eyes).

[9] View-Master is a registered trade mark of View-Master Ideal Group, Inc., Portland, Oregon 97207. A subsidiary of Tyco Toys, Inc.

[10] Sinclair, B. R. 'Design in an Uncertain Realm'. WAREHOUSE. (Faculty of Architecture, University of Manitoba: Winnipeg, 1994) Volume 3, pp 34-37. Concurrently published in Digital WAREHOUSE (WorldWideWeb/Internet URL: http: / /cad9.cadlab.umanitoba.ca).

[11] Schaarwachter, G., Perspectives for Architecture. New York: Frederick A. Praeger, Publishers. 1964, 8.

[12] Burder, D., Foreword in Superstereogram. San Francisco: Cadence Books. 1994, 4.

[13] Brewster, D., op cit 6.

[14] ibid., 9.

[15] ibid., 52.

[16] ibid., 18.

[17] Darrah, W. C., Stereo Views: A History of Stereographs in America and Their Collection. Gettysburg, Penn: Times and News Publishing Co. 1964, v.

[18] C. Tyler was one of the early innovators in creating device-free stereograms while working at Bell Labs with B. Julesz who had previously developed the random-dot stereogram. Tyler, Christopher. In Stereogram. San Francisco: Cadence Books. 1994, 83-88.

[19] Julesz, B., Foundations of Cyclopean Perception. Chicago: The University of Chicago Press, 1971.

[20] Shimojo, S., An interview with Bela Julesz. in Superstereogram. San Francisco: Cadence Books. 1994, 86.

[21] Horibuchi, S., (ed) Stereogram. San Francisco: Cadence Books. 1994, 22.

[22] ibid., 74-75.

[23] The work of computer artists like Kenneth Snelson and Seiji Yoshimoto are testimony to the power of the computer and its ability to produce photorealistic results.

[24] Horibuchi, S., (ed) Stereogram. San Francisco: Cadence Books. 1994, 36.

[25] Brelinski, M. & Herber, P., Holusion Art. NVision Grafix, Inc. 1994.

[26] Kunoh, H. & Takaoki, E., 3-D Planet. San Fransisco: Cadence Books. 1994.

[27]D. Dyckman. Hidden Dimensions. New York: Harmony Books. 1994.

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