Stereopsis in the Design and Presentation of Architectural Works

by

Alan R. Cook

Associate Professor of Architecture,
Auburn University
Auburn, Alabama

Abstract

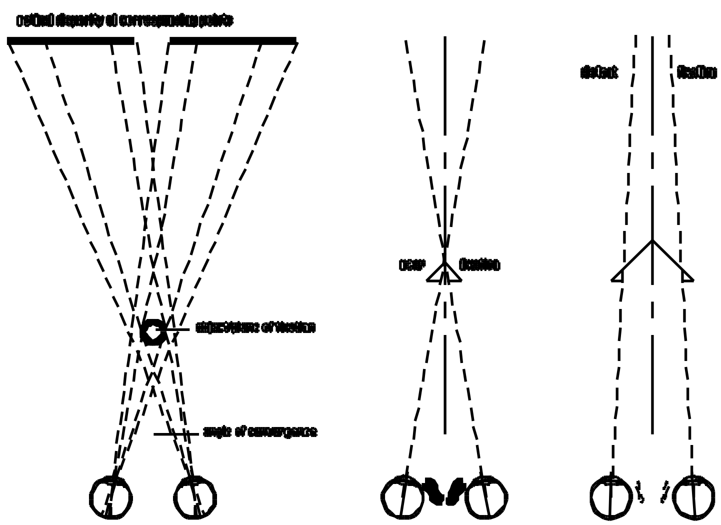
This article presumes the primacy of spatial cognition in evaluating architectural designs and begins by describing key concepts involved in the perception of spatial form, focussing on parallax and stereoscopy. The ultimate emphasis is directed at presenting techniques which employ computers with modest hardware specifications and a basic three-dimensional modeling software application to produce sophisticated imaging tools. It is argued that these techniques are comparable to high end computer graphic products in their potentials for carrying information and in some ways are superior in their speed of generation and economies of dissemination.

A camera analogy is considered in relation to controlling image variables. The ability to imply a temporal dimension is explored. An abbreviated summary of pertinent binocular techniques for viewing stereograms precedes a rationalization and initiation for using the cross-convergence technique. Ways to generate and view stereograms and other multiscopic views using 3-D computer models are described. Illustrations from sample projects show various levels of stereogram rendering including the theoretically 4-D wireframe stereogram. The translated perspective array autostereogram is presented as an economical and easily reproducible alternative to holography as well as being a substitute for stop action animation.

Introduction

Architecture in its most refined essence is necessarily a four-dimensional phenomenon, the experience of a volumetric place and a temporal occasion. In most cases, the representation of architecture is compressed into a mere two-dimensional instantiation requiring the viewer's imagination to bring it to life as a space-time entity, and then

Figure 1A, B, & C - Convergence, Corresponding Points, & Retinal Disparity: The visual contours of the object of fixation and the background features vary from the two eye positions. This is known as retinal disparity (see Figure 1A) The extrinsic muscles of the eye signal the brain as to whether the angle of convergence between the two lines of sight (ocular axes) is greater, as in the case of a near fixation; or slight, as in the case of a distant fixation.. When looking at models, the close fixation angle of convergence (Figure 1B) is significantly larger than the more distant fixations typical of observing architectural works at full scale (Figure 1C).



1A 1B 1C

often more as fiction than reality. Certainly there are times when this is appropriate and valuable. A novel, for example, by its abstraction from reality, has special qualities of ambiguity and a lack of specificity which draw from the mind of the reader those memories and yearnings which make the reading experience intimately personal and instantly connected to one's inner life. However, design documentation and interpersonal communication vehicles for negotiating what to build, often at great cost, require a clarity and precision not consistent with a highly abstract presentation and its inherent ambiguity and lack of specificity. The syntax of the artifact needs to be clearly understood so that the reading of its form, not that of its presentation, is the issue of focus. This article will discuss ways of making architectural modeling more focussed on the phenomenal aspects of spatial form and point of view by the use of computer generated stereoptical imaging. Included will be techniques which, it will be argued, ultimately involve aspects which are implicitly four-dimensional in nature. Many of the illustrations are cross-convergence autostereograms. For viewing them stereoptically see the section on Cross-convergence Stereopsis Initiation.

The co-existence of mass, space, time, and energy is an always and only physical proposition. Their separations exist only as categories of the mind. Within this context, the temporal dimension is perceived as a dynamic aspect of space. Without changes in the relative spatial positions of objects and viewers, time ceases to have meaning. The concept of parallax essentially involves seeing elements of the visual field from two discrete points of view which are mutually non-co-linear with the visual object(s). In this way visual elements or points at varied distances from the viewer appear to change their relative positions. They appear to re-constellate with different relative distances and angles

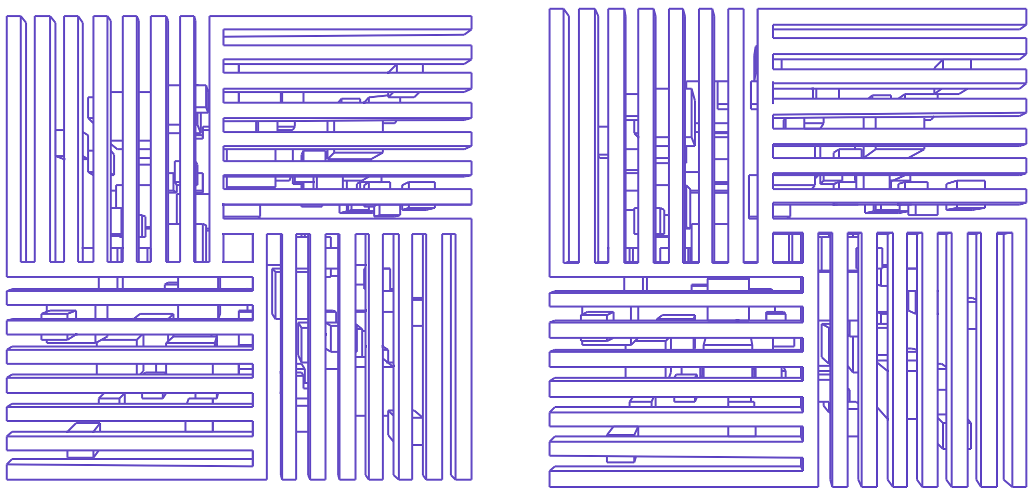


Figure 2 - Visual Dynamics:

When viewed stereoptically, this hyperconvergent autostereogram. the vertical sets of bars appear to effect a greater level of visual dynamics than do the horizontal ones. The verticals present the more edges subject to the discriminations of parallax due to the horizontal pairing of our eyes. Had the horizontal bars been articulated with textures or rhythmic devices, then they would appear to have increased visual dynamics due the greater number of fixation points relating through the parallax of varied planes of depth.

of displacement. Perceptual psychologists call the features common to a pair of binocular views corresponding points and the difference between the two perceived images is what is called their retinal disparity (see Figure 1A). Binocular vision is an example of a type of simultaneous parallax useful for interpreting spatial form, and relative distances of objects in the visual field from each other and the observer. Motion parallax is the temporal counterpart to binocular vision. It involves the observer's motion as a means of creating parallax and thus perceiving three-dimensional space, object distances, and their relative interpositionings. (However, in a subtle way, varying one's plane of focus by accommodation of the eye's lens or changing the object of fixation using the eyes' extrinsic muscles is also a temporal act even if the viewer and the objects remain stationary - see Figures 1B & 1C.)

Both of these types of parallax are biased in favor of horizontal discriminations. This is evidenced by the horizontal displacement of our two eyes and the relative ease of horizontal movement, versus vertical movement. Implicit in this bias is the phenomenal fact that vertical edges and overlaps are preponderantly more visually dynamic than are horizontal ones. The term visual dynamics, as used here, involves syntactical factors which imply the engaging of parallax discriminations. Of the incongruities of overlap cues due to parallax, there are relatively more instances of significant discontinuities of corresponding points (i.e. more retinal disparity) along vertical contours than along horizontal ones. With overlapping vertical edges there are often points only seen by one eye whereas with horizontal edges there are horizontal planes of shift but the same corresponding points are present in the views of both eyes whether the parallax is achieved by motion or binocular vision.

For example, let's compare a vertical bar screen to one with horizontal bars. The vertical bars will tease the viewer by revealing parts of the scene beyond to both eyes, other parts will be visible to only one eye or the other, while still other parts will be totally hidden. With the horizontal bars the situation is basically binary; i.e. you see some parts with both eyes and you don't see the other parts at all (see Figure 1). Regarding parallax, the vertical bars have more permutations of viewing and thus are intrinsically more perceptually dynamic. Granted, a landscape often has hills, rises and the like, which activate the dynamics of a moving viewer's experience of horizontal edges and overlaps, but in the built environment, where flat level floors predominate, these horizontal changes are much less abundant. And even these motions are viewed with a horizontal binocular parallax.

The anatomy of each human eye also shows a bias for horizontal discrimination. The macula lutea, that cone-rich part of the retina containing the focus of visual discrimination (the fovea centralis), is used for fine-grained acuity and has only about a three degree vertical angle of acceptance while horizontally it accepts from twelve to fifteen degrees of view; a ratio of at least 4:1.

The concept of motion parallax is similar to the multi-view system of presentation using orthographic views such that the different viewpoints provide redundancies and reinforcements for interpreting the lines of the drawings with correct spatial understanding. Motion parallax is also related to the idea of a serial vision presentation which involves a set of perspective views showing a spatial sequence. These and other multi-view presentations facilitate three-dimensional understanding but involve the distraction of splitting the viewer's attention with severe discontinuities; whereas a binocular view fuses the two views into a single perceptual experience. Orthographic views also do not usually provide a visual correspondence with an actual visual encounter with the object. Only a binocular view or a "camera motion" video can provide a visually convincing simulation of experience with real world encounters and its inherently intuitive spatial cognition. Since "camera motion" views of as yet un-built works have significant logistical requirements for production, reproduction, and viewing, this paper will focus on techniques which maximize economies in these areas.

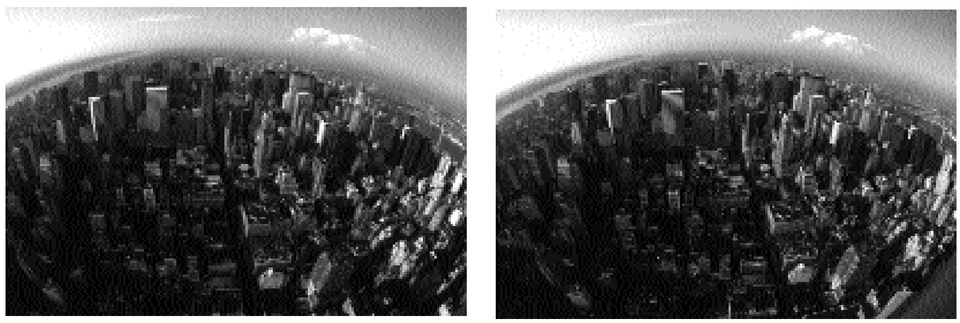
THE CAMERA ANALOGY: GIVING THE CYCLOPS DEPTH PERCEPTION

A materially three-dimensional scale model is a common and fairly effective method for presenting spatial information and allows both the viewer and presenter various degrees of control over it. This is both a strong point and its Achilles' heel. The biggest difficulty comes from the small size of the scale model which limits access to certain viewpoints while encouraging non-eye-level aerial perspective views unintentionally empha-

Figure 3 - Dome of San Carlo alle Quatro Fontaine. (cross-convergence viewing)
This Stereogram has about a five foot parallax which artificially enhances the stereopsis beyond the norm; but this is more expressive of an actual experience of being there in so far as the exaggerated stereoptic parallax simulates the depth appreciable with motion parallax.

Figure 4 - Stereogram of Mid-Town Manhattan. (cross-convergence viewing):

This stereo pair was taken with a parallax distance of about thirty feet using a fish-eye lens with a 160¯ diagonal angle of acceptance. The exaggerated parallax provides for appreciable stereopsis well beyond the typical thirty feet or so that is generally recognized as the practical limit of stereo effects for the natural parallax of human eyes. The effect however tends to give the subject matter a toy like character, as if it were a reduced scale model.



sizing the roofs. The key on-site views and the eye-level points of view are often left to conjecture and get de-emphasized. Also, due to the reduced scale, the parallax of the viewer is inappropriate for viewing the model at close range and will result in lack of coherent binocular fusion. Additionally, the accommodation of a human eye's lens is unable to simulate the relatively greater depth of field encountered with actual sized inhabitable environments. Thus squinting is required to form a pin-hole camera aperture with its profound depth of field; and winking is necessary to avoid the distraction of incoherent corresponding points from two overly diverse parallax views. Even where a model allows access to key viewpoints there is usually an inhibition about taking the often awkward postures necessary to access these views in front of a group of other people. So the winking, squinty-eyed, crouched-down awkwardness of it may prevent an effective realization of presenting the most desired points of view.

Using the solitary eye of a camera, one may document a model from some of the most propitious points of view under the best lighting conditions and use these images for presenting the model to best emphasize the architectural ideas. One drawback from this is that "photographs" are spatially more ambiguous than are physical models; they lack a parallax factor. Both the physical model and the "photographs" could be presented but then the attention is split and the control of emphasis is diminished. One way to control the views and still preserve binocular parallax, thus diminishing the spatial ambiguity, is to use stereography; i.e. make two images as stereo pairs with a left-image and a paired right-image, duplicating the natural effects of binocular parallax. In fact, the model may be made more believable by reducing, to scale, the parallax of interpupillary distance. By approximating the parallax of someone the same size as the model, the angles of ocular convergence are normalized (see Figures 1B & 1C).

Figure 5 - The Dynamics of Daylight and Wind at le Mont Saint Michele. (cross-convergence viewing):

This temporal stereogram has about a thirty second time differential during which the quick moving clouds dramatically shifted their shadows from the island to the foreground. Though the station point varies too little to reveal much spatial parallax between corresponding points of the solid elements, the clouds had sufficient motion during this interval to provide a pseudo-spatial impression. In some cases the shapes of the clouds have changed so much as to destroy the integrity of corresponding points.

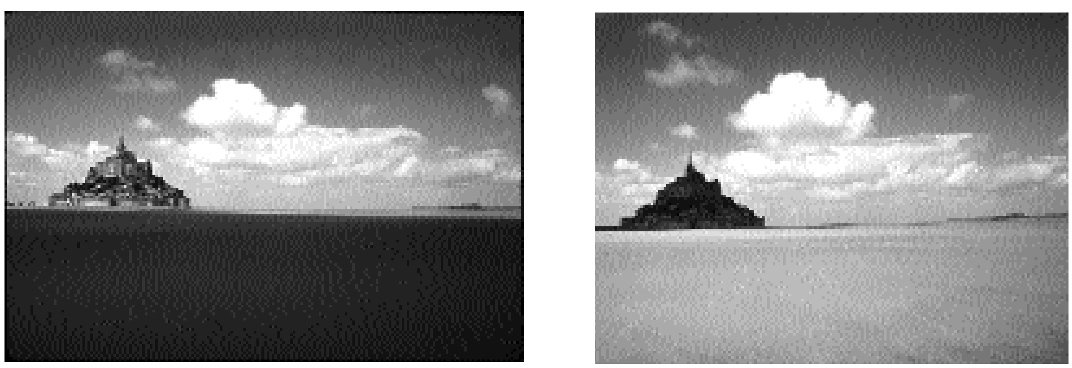


Figure 6 - Temporal Stereogram of the Water Tides at le Mont Saint Michele. (Cross-convergence viewing):

This stereogram view is looking towards the mainland from one of the towers on the east side of le Mont saint Michele. The temporal parallax is about eight hours. The spatial parallax has a slight vertical displacement as well as a lateral one.

A moderate exaggeration beyond the normal to-scale extent of parallax, may give the viewer a sense of personal aggrandizement and make the object being viewed seem more intimate or toy-like. It will also tend to enhance the perception of spatial depth (see Figures 3 & 4). Make sure if you employ such an exaggeration that you do not overdo the parallax. This would result in a loss of coherency by obliterating too many corresponding points in the binocular disparity. Particularly avoid pairs of views which present two opposite sides of the same planar element or object as this rarely occurs in the reading of environmental displays. Additional advantages of “photographs” versus physical models, include: ease of storage and portability; potentials for inexpensive multiple copies, and ease of inclusion into most portfolio formats.

However, to gain photographic access to interior points of view would in most cases require special considerations in the construction of the model and in cases where views are desirable both to and from a certain point, it may be necessary to construct multiple model sections. By using computer generated perspective views from a 3-D digital model it is possible to maintain the geometric rigor of the stereo pair and still be able to position views in any manner within the virtual space model. The digital model could even be clipped as a bit map and imported into a digital image photograph of the context. If the context is photographed with lighting conditions, perspective cues, and parallax relationships matching the model, the composite collage images could be viewed stereoptically with the perceptual result conveying a seamless and convincing sense of reality.

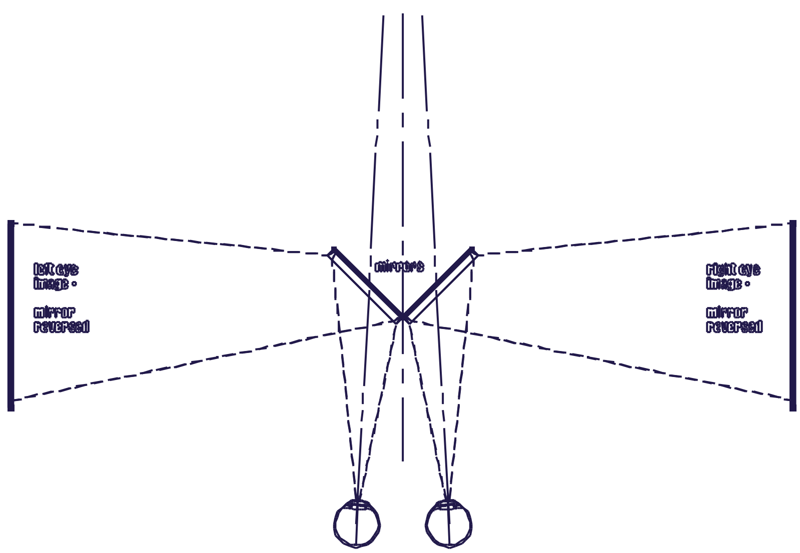


Figure 7 - The Wheatstone Stereoscope:

This is the diagrammatic essence of the original form of the first stereoscope (c. 1834) which allows for natural angles of ocular convergence and does not effectively limit the original image size. The rays from each image get laterally reversed in a mirror before reaching their respective viewing eye.

Now the obvious point to addressed is how to view stereoptical pairs to get a convincing 3-D effect. A few things must be kept in mind to assure success. First, the corresponding points of each image (left and right) must be laterally aligned, having no vertical displacements, with the image representing the left most point of view being the dominant central focus of the left eye, and the image representing the right most point of view being the focus of the right eye. The majority of the corresponding points of important spatial edges must not get eclipsed in either image. I have tested this to some spatial extreme. In one instance, I photographed a mountainous scene with approximately a one hundred foot parallax which made the layering of mountain ranges quite pronounced (but obliterated any coherency in the immediate foreground). Temporal displacements provide interesting four-dimensional images revealing the features of an environment that are relatively constant versus those that are more ephemeral (see Figures 5 & 6).

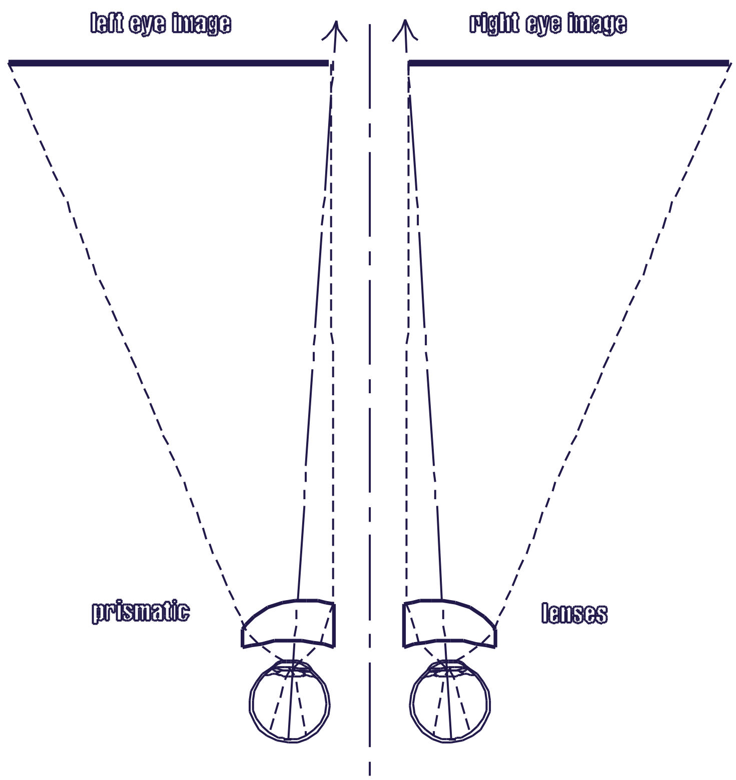


Figure 8 - the Lenticular Prism Stereoscope:

The diagrammatic essence of this device shows lenses that also act as prisms to both focus the images and to allow for divergent centers of vision thus providing for an increase in the maximum distance between corresponding points normally constrained by the interpupillary distance.

A preponderance of corresponding points relating the two parallax images must be visible so that the eyes may make typical convergence angles when resolving the parallax into the apprehension of spatial form. There must not be too much parallax or the retinal disparity will be incoherent and no binocular fusion will result. This is especially important in the consideration of foreground elements. Also, the two images should be virtually the same size.

Techniques for Binocular Viewing of Stereographic Pairs

The history of simulated stereopsis includes a wide variety of viewing techniques. The short listing which follows explains a few of the major ones.

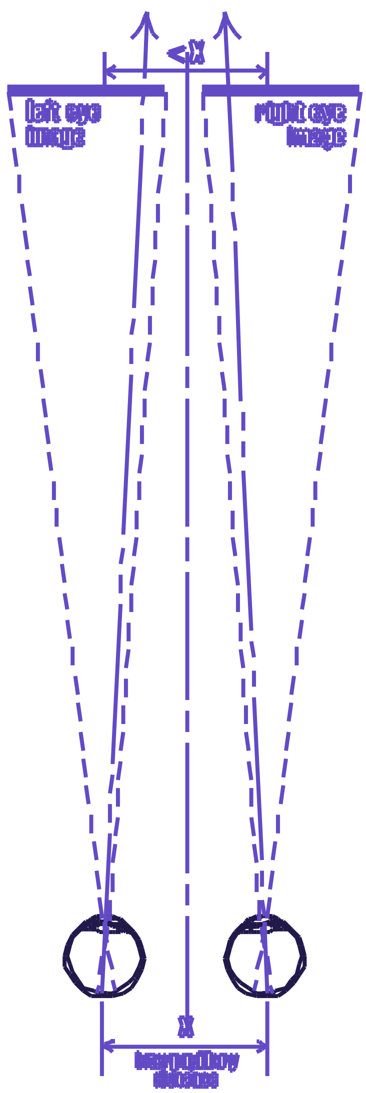


Figure 9 - Parallel Direct (Hypoconvergent) Viewing:
This illustrates that in this technique the corresponding points of the stereo pairs need to be closer than the inter-pupillary distance (indicated here as "X") to allow for ocular convergence.

1. The Wheatstone Stereoscope Viewer

First developed around 1833 by Sir Charles Wheatstone, this viewer is a double reflector, reversing the image once for each eye. The observer faces two mirrors which are joined in the center but tilt away at approximately 45 degrees. The two lines of sight with natural convergence angles, are re-directed in opposite directions; the left-eye-view to the left and the right-eye-view to the right. Terminating these reflected site lines are the stereo pairs at whatever scale is desired. Salvador Dali used this technique with several experimental works for which he painted stereo pairs on canvas. Since this method reverses both views, the final effect is a mirror image of the original (see Figure 7).

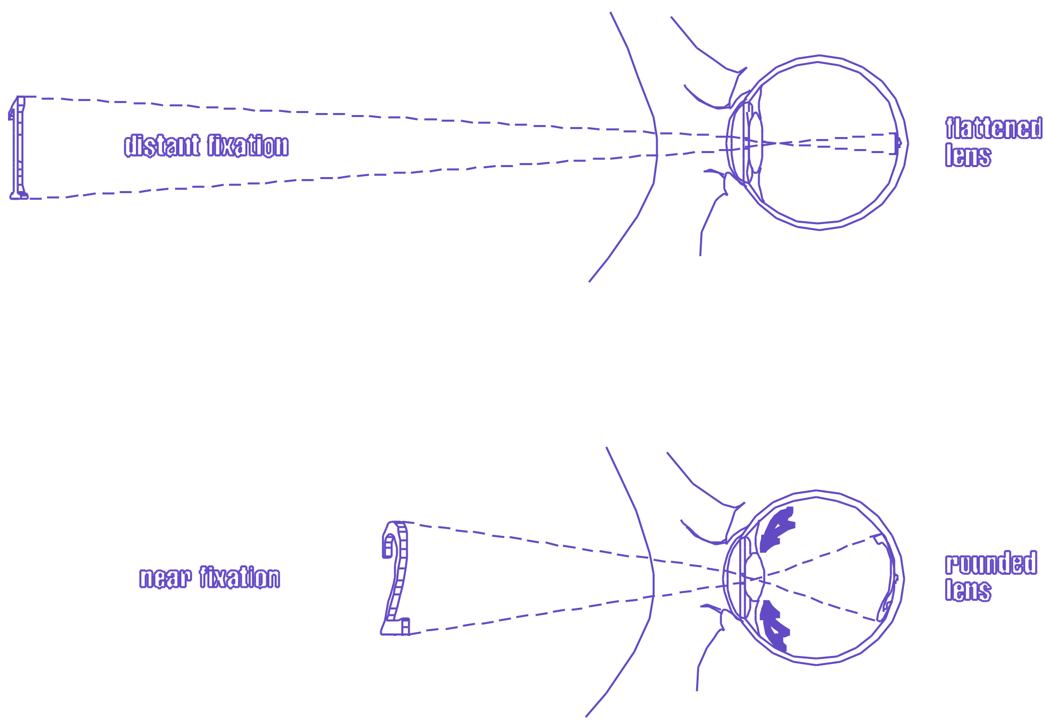


Figure 10 - Accommodation:

The top image represents a section through an eyeball showing the lens relatively elongated in section by the pull of the radial muscle fibers of the ciliary body. This decreases the convergence effect of the lens as well as signalling the brain as to the depth of focus. The lower image shows its lens accommodating for a close focussing distance. Note its plump relatively rounded shape. The ciliary body also has muscles that circumferentially constrict, reinforcing the lens' natural elastic tendency to thicken (much as a water droplet does due to surface tension) and thus cause a greater degree of refractive convergence. This second set of muscles also informs the brain as to the focal distance. (drawings modified from Christensen, Langley, & Telford. Dynamic Anatomy & Physiology. New York: McGraw-Hill, 1974. p. 318.)

2. The Stereoscope / Viewing with the Aid of Convergent Lenses

This technique employs the use of convergent lenses (i.e. magnifying glasses) interposed between the images and the eyes and thus simulating natural angles of convergence. This machine for viewing, known as a stereoscope, was first developed by the Scottish physicist David Brewster in 1849. One of his instruments, known as a lenticular prism stereoscope, had convergent lenses which were also prismatic, giving a slight divergence to the lines of sight. This allowed for a wider distance between corresponding points than in the direct viewing method and thus larger images could be used (see Figure 8). Coincident as this invention was with the advent of photography, it became a popular form of entertainment in 19th century Victorian parlors. The 3-D Viewmaster, its modern descendent, demonstrates that with the use of enlargement lenses and modern high resolution photography, images no longer need to be very large to effect a convincing display.

3. The Anaglyph (Red-Green Separation)

This common technique uses transparent color viewing aids (anaglyphoscopes) and stereo pair images reproduced with the superimposition of one image in red and the other in blue-green. The convention is to use a red filter for the right eye and a blue-green filter for the left eye (i.e. the right eye sees the blue-green image and the left eye sees the red image). The red filter makes the bluish-green lines appear dark and camouflages the red lines while the bluish-green filter plays the complementary role making the red ink appear dark and hiding the bluish-green graphics. This technique severely limits the chromatic palette of presentation but is satisfactory for line drawings and the so called random dot stereograms.

4. Freeviewing with Minimal Convergence (hypoconvergence - i.e. lines of sight near parallel)

With this paraphernalia-free technique you place the two stereo-pair images so that corresponding points align laterally and respectively with the left-eye-image being to the left and the right-eye-image being to the right. Make sure that the corresponding points are within the interpupillary distance of the viewer’s eyes; i.e. usually a 2 - 2 ´” parallax for an adult (see Figure 9). The viewer should relax and direct a general gaze towards the two images maintaining lateral alignment with the corresponding points (i.e. no sideways head tilt). Next the viewer’s focus should be directed as if looking into the distance; this will minimize the angle of convergence of the two eyes and will allow them to individually fixate on their corresponding points of the stereo pair images.

An alternate method of activating the proper viewing alignments is to hold the images close to your eyes so that the gaze of each eye is forced to relate to its respective corresponding points, and then gradually pull the images away from the face maintaining the same fixation points on the imagery. A third method is to gaze into the distance before interposing the imagery so that when the imagery is brought in front of your eyes, the eyes are virtually in parallel alignment with only slight convergence thus striking the respective corresponding points of the images. Many of the commercially available random dot stereograms use a gloss presentation surface so the viewer may concentrate on the reflected imagery thus simulating the minimal convergence of a more distant viewing plane than the image surface.

One major drawback with this technique is that the images are usually somewhat out of focus. The different muscles of the eyes physiologically give conflicting depth cues. The extrinsic eye muscles, those that point the eyes in different directions, signal a small angle of convergence consistent with a distant focus of view. But the viewer's intrinsic

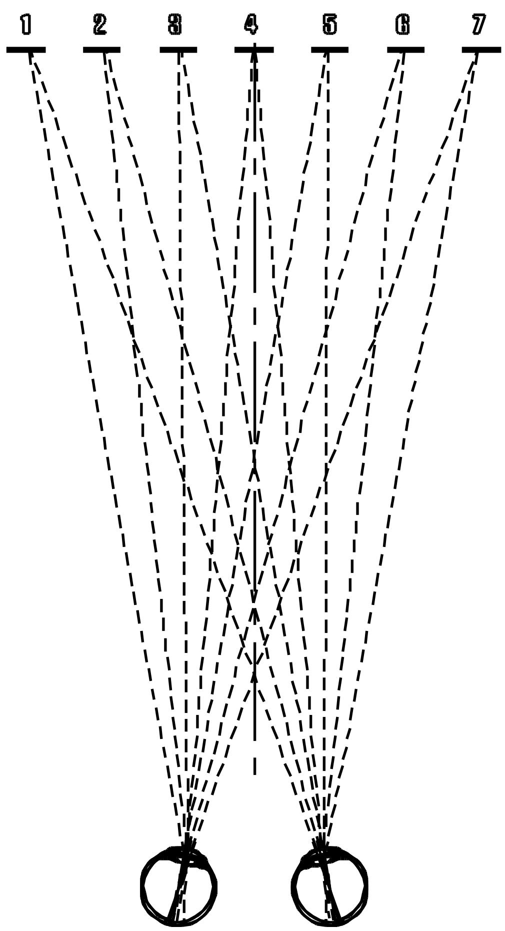
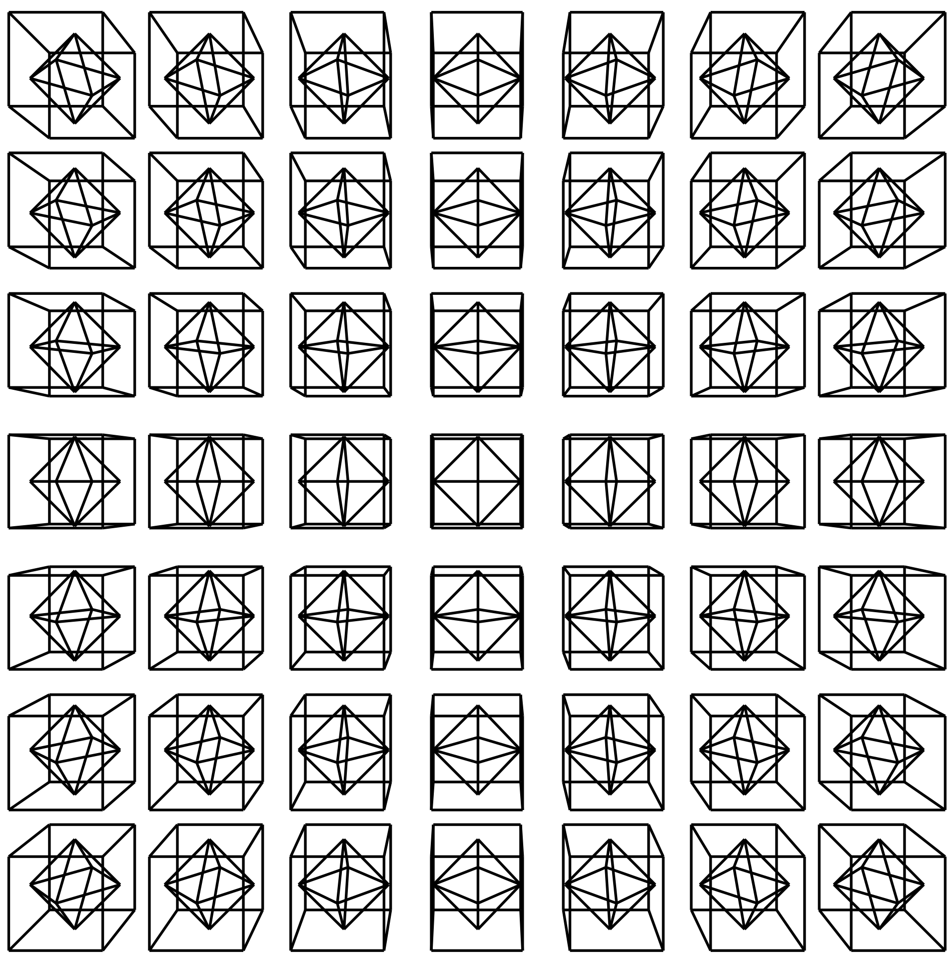


Figure 11 - the Wallpaper Effect:
This diagram shows how various angles of crossing the eyes may produce corresponding points from different parts of the visual field if that field consists of a repetitious array of a common unit. The various stereo-pairings will result in different degrees of ocular convergence (e.g. a minimal binocular parallax would occur in an adjacent pairing like the left eye viewing of #4 with the right eye viewing of #3; or in this example, the maximum parallax view would pair the left eye viewing of #7 with the right eye veiwing of # 1;) and slight retinal disparities due to the anamorphosis from the varied oblique angles of view.

Figure 12 - Pseudo-Hologram of the Polyhedral Duals of Octahedron and Hexahedron. (cross-convergence viewing):

This translated perspective array autostereogram is produced by setting up an array of identical units, orthagonally aligned and viewed in perspective as a related group. The various differing perspective angles provide an abundance of images that act as stereo pairs and may be viewed by crossing the eyes at various degrees matching corresponding points in the different images. The plane of “lateral” parallax may be shifted to view pairs along various directions of alignment other than just horizontal (e.g. vertical, diagonal, etc...).



eye muscles, the ciliary muscles which control the shape of the eye’s focussing lens (see Figure 10), must accommodate for close viewing. Since cues from the extrinsic eye muscles tend to dominate in this conflict, it is difficult to achieve a sharp focus unless the viewer is naturally very nearsighted. High level illumination is helpful in sharpening the focus by causing the pupillary apertures to constrict and thus function more like pin-hole lenses increasing their depth of field. (Squinting has a similar positive effect.)

The newest development in two-dimensional 3-D simulation is the random dot stereogram first produced by Boris Kompaneysky of the Russian Academy of Fine Arts in 1939. It was later re-invented and systematized at the Bell Laboratories in 1960 by the Hungarian, Bela Julesz who is generally recognized as its inventor. Subsequently, developments have lead to the autostereogram which requires no auxiliary viewing aids and which utilizes repetitive vertical bands of pattern elements with slight variations to encode spatial information through the implied parallax of retinal disparity. This development stems from Brewster's insight into what he called the "wallpaper effect" where, because of the repetition of pattern elements, it is possible to cross one's eyes and get various coherent yet non-identical corresponding points with a respective variety of convergence angles. Each different angle of convergence induces a different apprehension of spatial proximity (see Figures 11 & 12). It seems that now the most common type of autostereogram involves direct viewing with virtually parallel lines of sight, though many employ the viewing mode described in the following technique which I personally prefer.

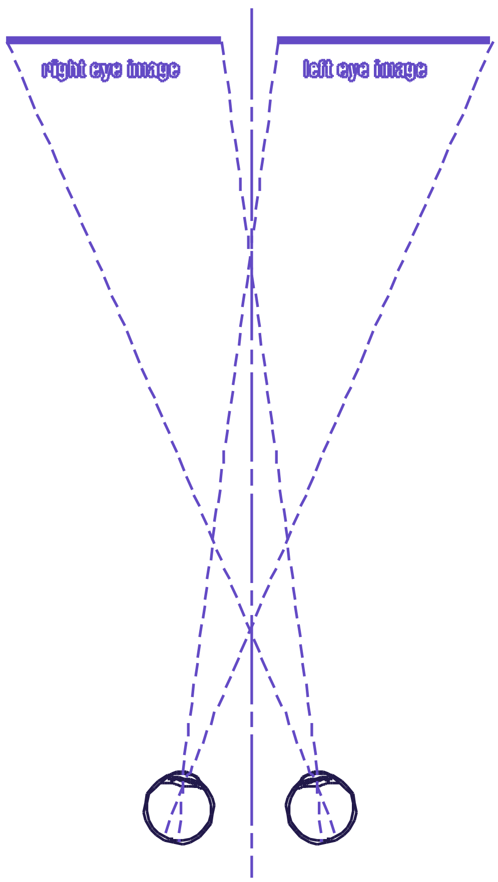
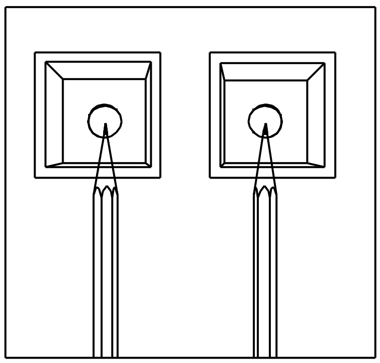


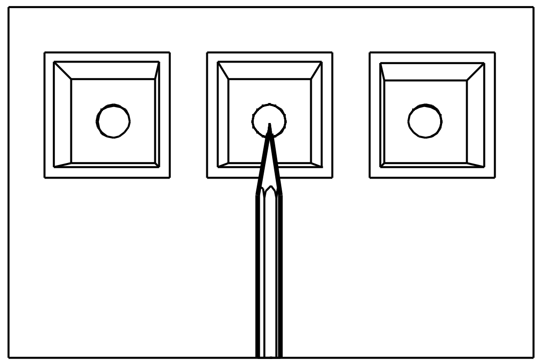
Figure 13 - Cross-Convergence (Hyperconvergent) Viewing: This shows that the left-right placement of the images is reversed so that when the eyes cross they will correct for the necessary correspondence. Also this demonstrates how the image sizes are not constrained by the technique.

5. Freeviewing with Cross-convergence (hyperconvergence - i.e. crossed-eyes)

Like direct viewing, this has the elegant virtue of not needing any accessory paraphernalia. But unlike direct viewing, this technique occasions virtually no focussing difficulties once it is learned. The technique involves aligning in parallel, the corresponding points of the two images with the plane of the eyes (i.e. no sideways head tilt). But contrary to the direct viewing technique, here you place the left-eye-image to the right and the right-eye-image to the left (see Figure 13). View these by crossing your eyes with the point of binocular convergence between you and the images so that your eyes focus on the corresponding points of the images on opposite sides (i.e. the right eye focusses at the left-most image and the left eye focusses on the right-most image). This allows images of virtually any size to be viewed and removes any interpupillary distance constraint between corresponding points; i.e. this technique may be effectively used on all scales of imagery from the size of small contact prints to large full-screen projections. With this method of viewing, the crossing of the eyes promotes ease of close-image



14A



14B

Figure 14 A - Setting up to View a Hyperconvergent Stereogram:

This shows a facsimile of what one would see looking at a stereo pair image of an open box with a round hole in the back side. Here you must focus on the plane of the paper where the images are printed and hold a pencil in the foreground between your eyes and the paper. Adjust the position of the pencil to align the centers of the holes with the pencil points and your corresponding centers of vision. Since both eyes are used, it should appear as if two pencils are present as transparent images.

Figure 14 B - Controlling Convergence and Attention:

Now, without moving the pencil or your viewing position, converge your centers of vision (i.e. cross your eyes) to fixate on the pencil point. Now the pencil should appear opaque and you will be aware of three images beyond the pencil. Your eyes are now positioned with the correct angle of convergence to fuse the two stereo pair images. Next shift your attention to the middle images without changing the angle of your ocular convergence. When you have come to visualize the three-dimensional image then remove the pencil so it will no longer obstruct your view.

focussing since the convergence of the eyes by their extrinsic muscles is conditioned to correspond with close-focussing accommodation of the eyes.

One minor drawback of this technique is the self-consciousness that may be experienced when crossing one's eyes in view of the public. Another shortcoming is the possible fatigue of the extrinsic eye muscles and possible mild headache sensations that may result with prolonged viewing if the degree of binocular convergence is extreme. To prevent this, maintain a close juxta positioning of smaller images for short viewing distances; or a long viewing distance if larger images are used. The ratio of the viewing distance to the distance between corresponding points should be kept relatively large. A minimum ratio of at least 3:1 or larger is desirable. With a little practice, the eye muscles adapt and the technique becomes second nature.

Cross-convergence Stereopsis Initiation

There is something special about educated adults learning a new way to use their eyes. It is akin to a right of passage and represents continued growth and maturation. The adept initiates the neophyte into a new world of visual possibilities. The architect may confer this perceptual gift, as it were, to the client, who later as an initiate, may impart this knowledge to others wishing to experience the (client's) stereogram .

Step 1: Position the images as shown in Figure 13. With your attention and depth of focus centered on the plane of the stereo pair images, hold the tip of a pencil (or your finger) between your eyes and the images. Due to the binocular disparity, you will see what appears to be two quasi-transparent pencils. I recommend that you use a sharp pencil instead of your finger the first time you try since this provides greater assurance of acuity in accurately aligning the corresponding points.

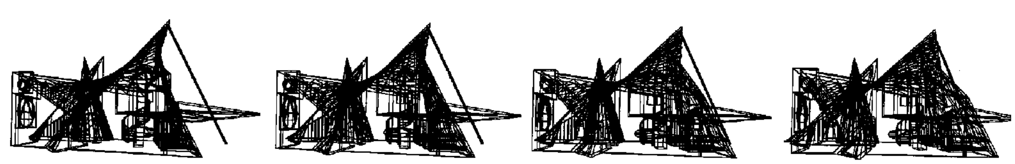


Figure 15 - Ritual House Wireframe Pseudo-Hologram - North Elevation. (Cross-convergence viewing):
The fourth dimension is loosely implied here by the incorporation of memory; the wireframe diagram is a topological drawing providing strong memory cues for the arrangement of spaces and surfaces normally only encountered by temporally moving through the spatial score.

Step 2: While still focussing on the stereo images, adjust the position of your pencil so that the tip appears to overlap corresponding points on the two stereo images (see Figure 14 A). Be careful to avoid tilting your head sideways and creating a vertical misalignment of corresponding points.

Step 3: After positioning your pencil so that a particular set of corresponding points are respectively aligned, shift your focus to your pencil (or finger) so that the angle of convergence of your eyes is increased. You will now see one pencil and three laterally aligned images of the subject matter of the stereo image (see Figure 14 B). The center one of these images should appear in 3-D.

Step 4: Possibly the most difficult part of the initiation, shift your attention to the 3-D image without also changing your angle of ocular convergence. Once you have successfully shifted your awareness to the 3-D stereo image, you may remove the pencil to unobstructed your view. Maintaining the correct angle of ocular convergence you may now scan the image for detail.

With a little practice you should be able to control the crossing of your eyes to the extent that you will be able to instantly apprehend the desired view without using a pencil or your finger. Be persistent if you don't at first succeed. The sense of accomplishment is often directly proportional to the perceived magnitude of the challenge which has been overcome.

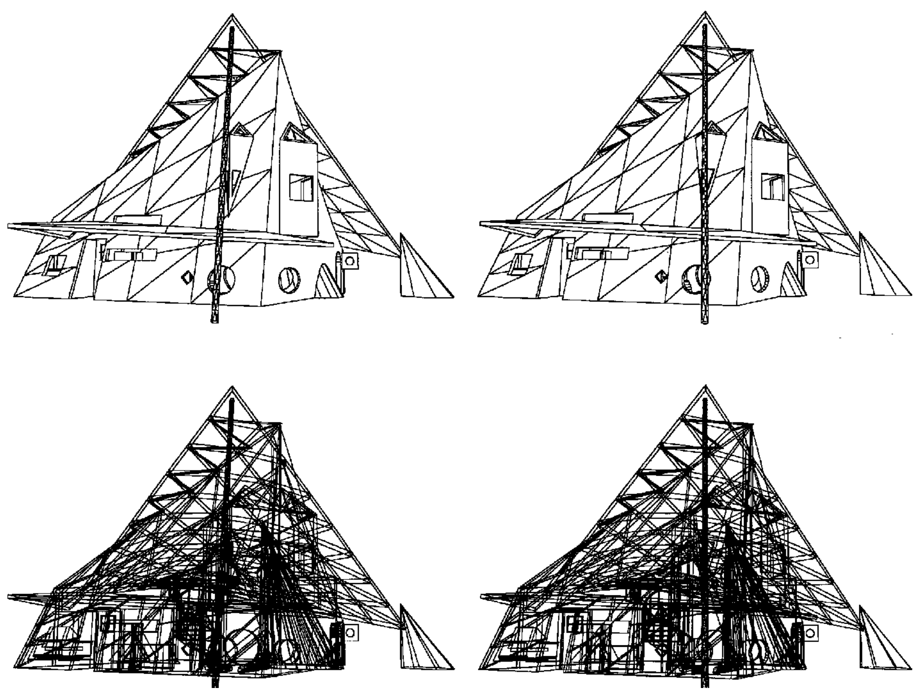
Computer Modeling in Four-Dimensions (low-high tech)

The computer has come of age as a commonly accessible and efficient tool for modeling objects in three-dimensions. However, as stated in the outset of this article, architecture is at its essence a four-dimensional entity. It is possible to develop virtual interactive realities where expensive state of the art technology transports some helmet-wearing, manually digitized cybernaut into realms of architectural imagination. But, what I wish to present here is a way of modeling architecture in four-dimensions which is modest in its technical requirements.

There are many different rendering applications with abilities to map a myriad of material textures onto complex geometries with compound illumination simulations, but nearly all 3-D computer modeling programs utilize wireframe diagrams as a base for modeling and visualization. This type of model usually requires a less complex program, less memory, and less generation time than hidden line or surface rendered modeling. I contend that the wireframe diagram can be developed as a four-dimensional model. Perspective wireframe diagrams structure the visual field so that it may be

Figure 16 - Comparative Parallel Presentation of Wireframe and Hidden-line Points of View - Southwest Elevation:

Here a wireframe view with an extreme amount of layered lines makes the wireframe image extremely confusing until they are viewed stereoptically. When that is done, the lines are perceived to be organized networks precipitating much less confusion. The hidden-line stereogram aligning with the wireframe stereogram allows them to be seen simultaneously thus facilitating a comparison between what is seen by an observer as the exterior form and what is known by the observer as the total volummetric organization.



understood in three-dimensions. In addition, the fact that they are transparent reveals things that are beyond, within, or in other ways eclipsed by elements of the foreground. The typical problem with wireframe diagrams is that since they show the edges and surface meshes of everything, they often appear as a chaotic confusion of line segments. But if you take a complex wireframe model and look at it stereoptically, much of the confusion melts away and the wireframe diagram model becomes a very penetrating design evaluation tool (see Figure 15).

By its abstraction from reality, a wireframe stereogram, like a novel, presents a basic structure within which the specifics of the surface imagery are left to the observer's imagination. But by its transparency it necessarily acts in a more general context of geometry and form. An observer can be virtually placed at a very poignant viewpoint, composing not only the nearest enclosing space but an entire sequence of contiguous spaces and objects. The transparency serves as a mnemonic device enhancing associative activity of visual form. It's like the distillation of a whole series of serial vision drawings without the imperfections of memory that occur with the opaque occlusions of traditional drawings. One well-chosen transparent wireframe stereogram view may show a complex of spatial entities which otherwise might require four or five separate images to even begin to show the same extent of spatial relationships. Of course this multi-view serialization would present the various perspective distortions and alignments inherent in the environmental encounter; but the wireframe stereogram view holistically consolidates the topological relationships between the spatial elements into one view.

Wireframe stereograms may be very effectively used in conjunction with more traditional modes of presentation like rendered surface perspectives and sectional views so that they complement each other. The rendered surface drawing would reveal the user's typical visual encounter from a designated perspective station point, while the wireframe stereogram would present the memory factors of past and/or future serially encountered elements. One could develop a progression of serial vision views redundantly presented in both surface rendered and wireframe stereogram images. With these redundant views positioned one above the other the two stereo pairs could be examined and studied simultaneously in a single field of view. This would initiate the viewer into a clear understanding of the experienced view, as shown by the rendered surface stereogram; and its temporal-mnemonic context of movement through space, as revealed in the wireframe stereogram (see Figure 16).

The abstraction provided by the wireframe diagram may provide additional benefits. By removing the complexities of a more fully simulated reality, it is easier to direct focus to a more limited set of concerns. Particular to the wireframe diagram, the issue of potential viewing apertures and object alignments in the architecture could be very efficiently studied since all the elements of the model in a particular perspective cone of view are locatable in space.

Stereogram Generation

One of the easiest ways to produce a stereogram is to start with a three-dimensional computer model and print two perspective views taken from station points with appropriate lateral parallax displacement. The images may be wireframe diagrams, hidden line views, or rendered images. Place the hard copy images next to each other using the cross-convergence technique for viewing. This side-by-side placement automatically allows hyperconvergent stereopsis of the two images as long as the perspective points of view (station points) are selected with appropriate lateral positioning and are not so far apart as to create images with excessive retinal disparity.

Anaglyphic stereograms may be modeled on a computer screen monitor by copying the model next to itself, making the left eye image bluish-green and the right eye image red. Then view the models in a perspective display with the red-green 3-D glasses. Cross-position the two images so that the bluish-green image is shifted to the right and the red image is shifted to the left. This insures ocular convergence and avoids the problem of corresponding points being too far apart requiring divergent lines of sight. Keep the two models on separate layers so they may be easily selected separately in case their colors or placements need adjustment. Attune the colors to insure minimum visibility with the same colored lens and maximum visibility with the complementary colored lens. Adjust the placements to assure good lateral alignment of corresponding points. Usually if the two models overlap, the second model generated on the screen takes precedence in the pixel array leaving the first generated image incomplete. This shortcoming may be avoided by plotting the images with pens using appropriate colors (though finding the right pen colors may not be so easy). The places where the two plotted colors overlap will be visible through both lenses.

Cross-convergence freeviewing may also be utilized with on-screen displays by copying the modeled objects next to each other and viewing them from a line of sight perpendicular to the direction of displacement of the two copies of the model. The relative distance of view must be considerable or binocular rivalry will result from excessive retinal disparity. With this technique the two models need to be discretely separate but may be presented with color surface rendering. Another related technique is described below which has many attributes common to holography and stop-action animation.

The Pseudo Hologram: Translated Perspective Array Autostereograms - The Multiscopic Display

Holography uses an expensive and complex setup of laser light, split into direct and reference beams, special emulsion plates, etc., to reproduce images that may be observed stereoptically and with motion parallax. Their reproduction is not easy which is attested to by their incorporation into the manufacture of premium credit cards to discourage counterfeiting. However it is possible to approximate the choice of view options and the stereoptic qualities of holography by using a more modest and accessible technology, the multiscopic display I call the translated perspective array autostereogram. When dealing with 3-D computer models of relatively minor complexity, it is quite feasible to make a multiple copy array such that the copies form alignments on a two-dimensional grid. When this array is presented in perspective from a point of view frontally facing the 2-D grid, each copy of the model presents a different viewpoint thus providing parallax information.

Using the hyperconvergence viewing technique (i.e. crossing the eyes to converge in front of the image plane) various viewing combinations creating stereo pairs can be seen. If adjacent copies of the model are fixated in cross-convergent lines-of-sight then the minimal parallax is observed. But if non-adjacent copies are concurrently fixated then the amount of parallax is greater. This may be extended to the point where excessive retinal disparity arrests binocular fusion. An additional feature of this array is that the parallax need not be limited to only horizontal pairs. Vertical or diagonal pairs may provide parallax in whichever direction is most informative or otherwise desirable. In fact the whole situation becomes one of interactive potential. The viewer (within the limits of the multiscopic display) may choose the point-of-view to the object, the degree of parallax, and may even scan the array while maintaining approximately the same angle of ocular convergence and thus move from one stereo view to another in quick succession (see Figures 12, 17, 18, & 19). And even though the movement is not continuous, the effect is somewhat like a stop-action animation in that the views simulate a sequential path of movement relative to the observer and the object/space, much the same as the effect of someone observing a hologram. But unlike the hologram, the translated perspective array stereogram may be reproduced on regular paper with no more that a copy machine. Also, using translated perspective array autostereograms, object color may be represented, and in that regard this technique surpasses all but the most advanced and expensive holographic imagery. This technique also has the virtue of being infomationally significant to those who are stereo-blind, particularly since all of the views are coordinated in perspective maintaining the viewer's orientation with the object.

Ultimate Design Benefits

Certainly the possibilities for stereo-imaging are not limited to the kinds of things which have been mentioned. For example: the construction end of the profession of architecture could benefit from ad hoc applications of stereography to visually clarify details and problems in the field. Electronic digital imaging cameras could capture two photographs forming a stereo pair to be transmitted to remote locations for examined by experts. Or details modeled in 3-D on computers could be faxed as stereograms from the office to the field, etc... But for the designer, I think the investigations with stereo imaging will yield at least two valuable insights.

The first insight is intra personal. It lies in the designer's cultivation of a generalized and profound understanding into the nature of parallax. This should enhance the designer's ability to recognize situations during the design process with potentials to powerfully influence spatial perception and the expression of spatial dynamics. With

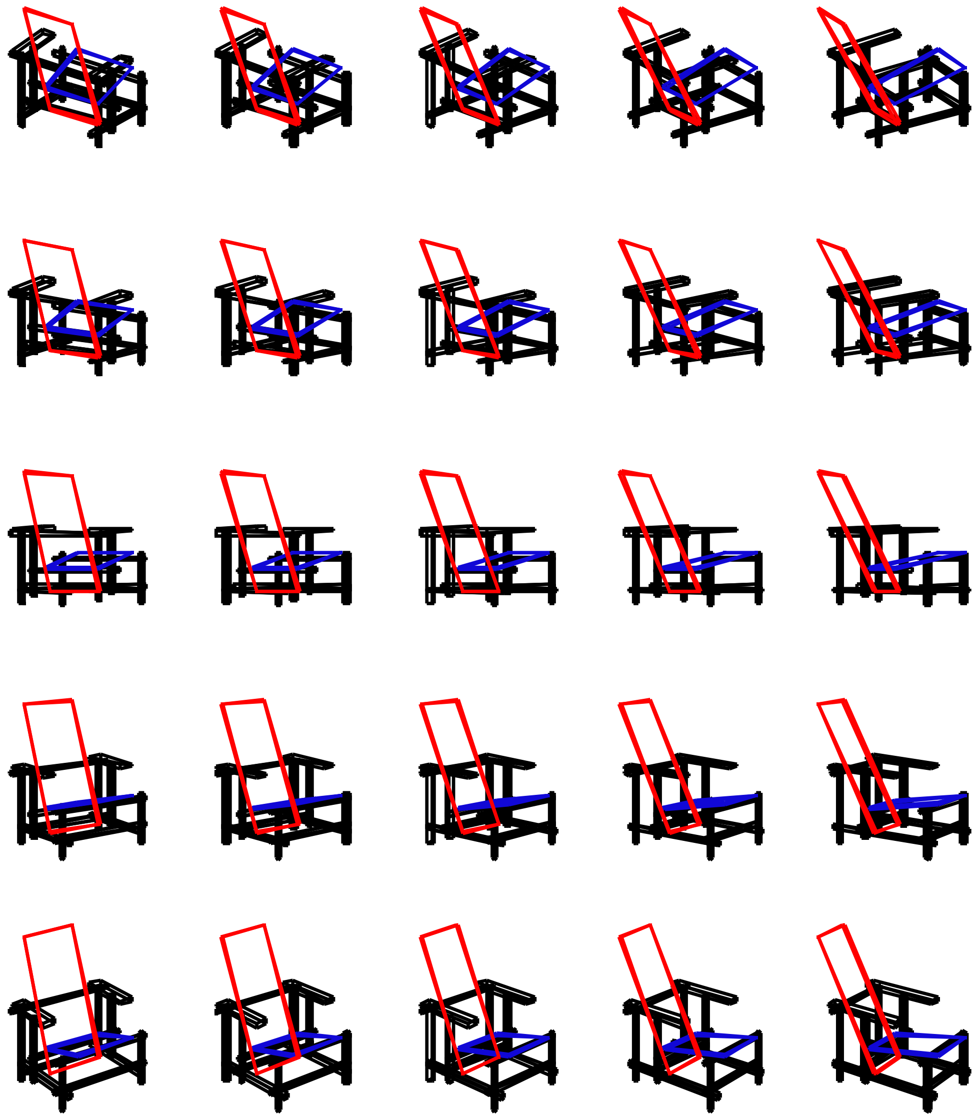


Figure 17 - Pseudo-Hologram of Rietveld's Red & Blue Chair. (cross-convergence viewing):

Here the viewer may choose the angle of view as well as the direction and degree of parallax.

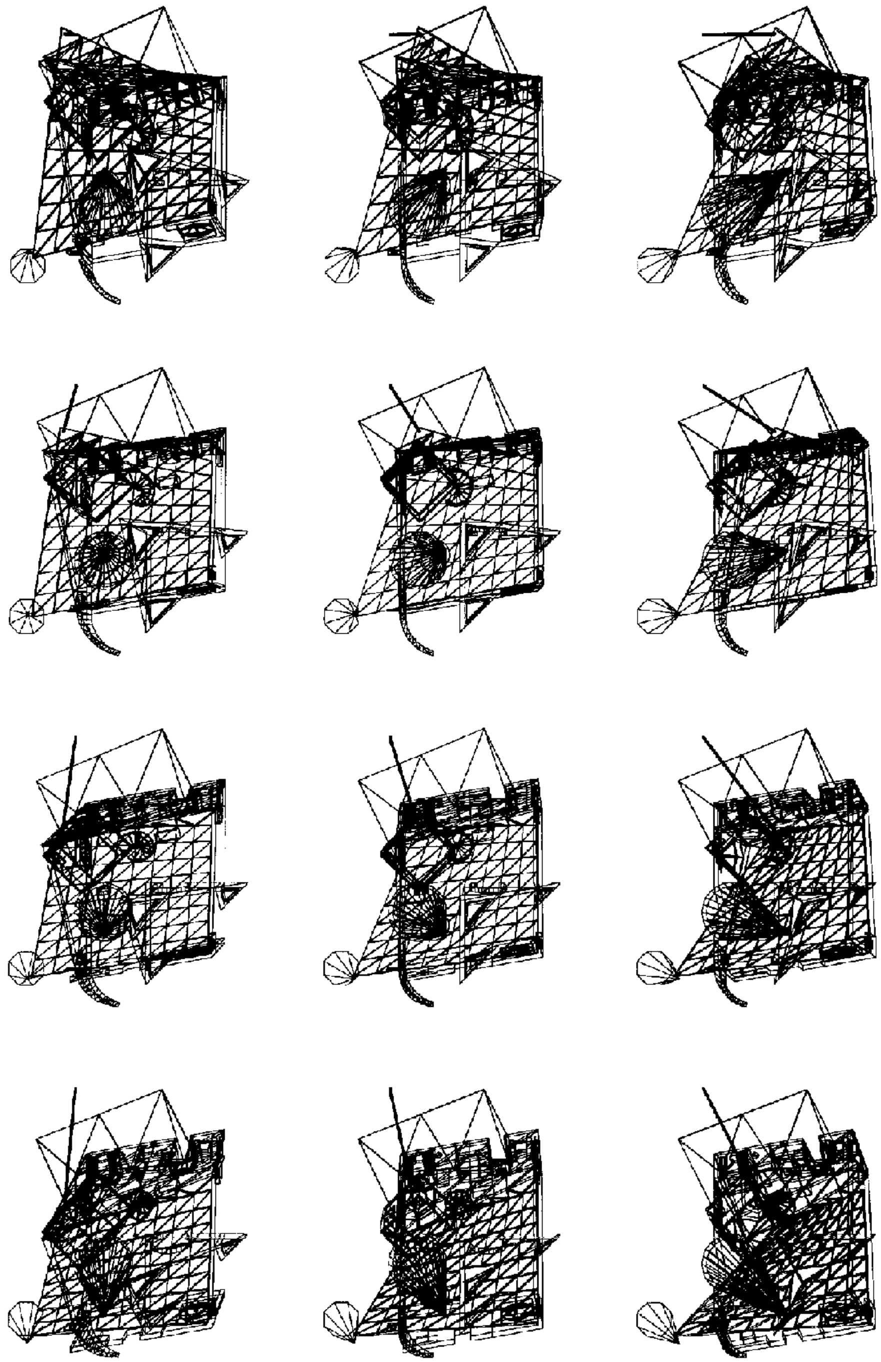


Figure 18 - Ritual House Wireframe Pseudo-Hologram - Aerial View. (cross-convergence viewing):

Here is a three-by-four array of copies of the wireframe model of the Ritual House seen from above. Stereograms may be viewed using various angles of alignment pairing different separate models and thus producing varying directions and degrees of parallax.

this insight gained, issues of spatiality become more outstanding and thus are more likely to be integrated and emphasized early in the design process. Instead of aesthetic space-time issues being merely residual effects of other design requirements, they may take their fitting place as essential considerations fundamental to our human nature.

The second insight is interpersonal. It allows intended visual qualities of spatial form to be unambiguously demonstrated to a client, user, critic, or other concerned party. It also allows the stimulus of this demonstration to be permanently archived. This may include the communication of spatial sensations as demonstrated by surface rendered stereograms, or the choreography of memories, and anticipations that are perceptually embedded in transparent wireframe stereograms.

A spatial sequence with a complex of screens, windows, overlapping layers, other types of viewing apertures, etc... may be configured so that the observer's spatial cognitive needs (i.e. his or her need to understand the form and constraints of the environment) may be fulfilled by following a designed serial vision path. A deep understanding of the potentials of choreographing the motion parallax trajectory may allow the designer to optimize the user's opportunities to aesthetically experience and appreciate the architectural form. Matching the observer's cognitive and aesthetic needs with the lines-of-desire for accessing other motivating goal destinations is a most elegant strategy for realizing programmatic intentions. The ability to inexpensively provide the client or other critics with stereoptic serialized views, binocularly to scale, from the most propitious points of view, assures the designer of obtaining accurate and informed criticisms and affirmations leading to superior spatial design resolution.

ENDNOTES:

1. Hall, Edward Twitchell, *The Hidden Dimension*, New York: Doubleday & Co, 1966, p. 71.
2. Gulick, W. Lawrencw, Lawson, Robert Human *Stereopsis: A Psychological Analysis*, New York: Oxford Press, 1976, p. 17.
3. Gregory, Richard L. *TheIntelligent Eye*, New York: McGraw-Hill, 1970, p. 26
4. Tyler Cristopher, "The Birth of Computer Stereograms for Unaided Stereovision," *Stereogram*, San Francisco: Cadence, 1994, pp. 83-84.