Proximal vs. distal affordances in the optic array and their effect on spatial updating in urban environments

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1. Introduction

This paper elaborates on spatial updating research that was used in comparative analysis between the in situ environment and its mimetic Virtual Reality, VR. In this experiment, spatial updating, a component of spatial behavior, showed a pronounced influence related to visually perceived spatial configurations modeled by space syntax. These configurations, mapped as the isovist parameter maximum diametric (a surrogate for conventional axial lines) were influential in biasing landmark perception. The in situ environment offered the potential for using muscle memory and optical flow (termed proprioception) during translation (walking) between viewing waypoints, as well as true 3D binocular vision. The VR environment was devoid of all the previous benefits and further limited in field of view (15 inch diagonal CTR screen).

Spatial updating as defined by Loomis et al. (2002, p. 335), "refers to the ability of a moving person to mentally update the location of a target initially seen, heard, or touched from a stationary observation point." Spatial updating is used by wayfinders to keep track of occluded landmarks during travel. As such, spatial updating is a primary component of wayfinding, finding ones way, which becomes more robust with iterations. The beneficial aspect of the research conducted was that by providing similar results as in situ first exposure, VR would represent a cost effective way of improving wayfinding (at least initial exposure) for first responders, military and tourists.

The goal of the experiment was to ascertain how the changing ambient optic array present at viewpoints along a route influenced perception of global occluded landmark bearing positioning in both in situ and VR. This ambient optic array refers to the information contained in the reflected light observed at any point in time (Gibson, 1979) and is the basis for the ecological theory of visual perception. In this theory invariant features within the environment offer affordances for use at a subconscious level (e.g. a horizontal surface affords supportability). This novel experiment explored visual perception at a subconscious level in both environments. Angular error in the perceived occluded landmark bearing was measured from the true bearing azimuth. Group mean and standard deviation was obtained so as to compare the two environments. The subjects were required to gaze around each viewpoint before perceiving the bearing to the occluded landmark so as not to solely use cognition - reasoning the geometry and distance covered to triangulate an updated position (not requiring gazing the ambient optic array).

Beginning, the subjects initially perceived global landmarks by vision or spatialized language, SL, and at five subsequent waypoints along an occluded route were asked to point to where they perceived each landmark to reside. SL was given in situ by pointing out the direction and verbalizing distance, and in VR the verbalized distance emanated from the sound field provided by headphones. SL was used to test the amodal characteristics of landmarks, whether the different initial ways of sensing an object influenced how the internal representation was externalized in spatial behavior tasks.

In the experiment, three hypotheses were fundamental to ascertaining the importance of the ambient optic array and its mimetic quality across environments:

1. Bearing placement of occluded global landmarks is biased by attraction to the long corridors (modeled as axial lines) contained in the ambient optic array that provide the affordance of distance,

2. Occluded landmark perception during spatial updating is similar whether initial landmark perception was obtained visually or acoustically mediated with spatialized language, SL, and

3. Spatial updating in VR, devoid of proprioceptive translational movement between pause and gaze waypoints mimics in situ spatial updating of occluded landmarks.

The experiment was based on natural human "pause and gaze" wayfinding techniques. The first hypothesis evaluated how the viewed space around a vantage point (the ambient optic array) influenced (biased) perception of occluded landmarks in both physical and virtual environments. This hypothesis related directly to space syntax and as such is the focus of this paper. The third hypothesis compared the two environments. This hypothesis is referenced in support of subtle nuances of perception.

Determination of vantage point position and the measured error were obtained from parameters of Benedykt's (1979) Isovist maps - the polygon formed from the bounded view field of a vantage point. This isovist analysis is based on Gibson's ecological theory of visual perception, the assumption that humans directly use the perceived affordances provided by invariant features within the ambient optical array.

2. Background

The primary importance of space syntax has been to generalize a configuration of an environment, developing a model to understand how the open or free space correlates to spatial behavior within the environment (Jiang & Claramunt, 1999; Jiang et al., 2000). A person's mobility is a key factor in deriving human wayfinding behavior. Axial lines and their joining convex spaces developed within the field of space syntax, have shown correlation to mobility behavior. The type of VR developed for this research was based on pause and gaze strategies used during wayfinding, whereby a traveler scans a vista at a particular waypoint and precedes along a path to the next waypoint. Hillier (1996) promoted that behavior is linked to the convexity of this waypoint, its "fattyness". The VR structure used in this experiment contains a matrix of convex nodes (panoramic images) and paths connecting them.

Though linear video could have been used so as to walk or flythrough the matrix, hyperlink connectivity was used to instantaneously jump between nodes. This offered a secondary test (hypothesis three) that was used to ascertain subconscious proprioceptive benefits in spatial updating. During physical navigation such as walking, the individual receives proprioceptive information in the form of vestibular sensing, kinesthetic sensing provided by the propulsion from their limbs and rotation of the body, and optical flow that provide velocity and heading information (Klatsky et al., 1998). Supporting the decision to remove animation from the VR portion of the study, Rieser et al. (1986) and Loomis et al. (1993) found that spatial updating over a route without linking optical flow with proprioceptive motion was poor.

The spatial behavior underpinning this research is Gibson's (1979) ecological visual perception based on "affordances and effectives" relating to the ambient optic array. This array can be thought of as the visual information contained in the ambient light surrounding a viewer at any point. Gibson theorized that the visual system developed evolutionarily within this ambient optic array and thus did not need reasoning to acquire direct knowledge from the environment. Further, he felt visual perception was directly linked to the action of the viewer and their effectives - the correlated abilities for action of the viewer (feet are used for walking, wings for flying). "There is, therefore, no need to invoke representations of the environment intervening between detection of affordances and action; one automatically leads to the other" (Bruce & Green, 1990, p. 382). Perception is directly linked to action and selecting some information over others (Allen et al., 2004). Effectives are linked to specific affordances offered by the invariant features (such as supportability, distance, and climbability) that the organism can use. Thus action dictates sensing the related invariant features present in the array which affords what the abilities of that organism can perform. Gibson (1979) stressed that affordances are specified by the structure of light reflected from objects, and are directly detectable.

Information contained in the ambient optic array is energy efficient. Shepard (1990) noted visual uptake is instantaneous; otherwise the organism would be unable to function, becoming overwhelmed with analysis. Norman (1993) argued that the hallmark of human cognition lays not so much in our ability to reason or remember, but rather in our ability to construct external cognitive artifacts and to use these artifacts to compensate for the limitations of our working and long-term memories. As noted by Alan et al. (2004, p. 218), "Seemingly lost in three decades of discussion on the problems of internal representation is Hawkins' (1964) insight that external representations can confer gains in thermodynamic efficiency." Summarizing this work, organisms "invest" by offloading information storage and processing to the environment itself and in turn reduce the biological costs associated with maintaining and processing the information (Alan et al., 2004).

An important concept of visual perception and one that relates to spatial behavior and its space syntax modeling is an understanding of how the visual system works. Paralleling Gibson, Shepard (1990, p. 168-9) promotes the automatic nature of visual perception even with two-dimensional drawings: "We do not first experience a two-dimensional image... The first thing we experience is the three-dimensional world - as our visual system has already inferred it for us on the basis of the two-dimensional input... Our visual experience evidently is the product of highly sophisticated and deeply entrenched inferential principles that operate at a level of our visual system that is quite inaccessible to conscious introspection or voluntary control." Gibson (1982) stressed we see the whole of the object - not an outline nor perspective image but the whole - we see the whole cat.

Gibson stressed an ecological approach to vision whereby visual perception of invariants is acquired involuntarily from environmental movement through an array. Within an evolutionary mindset Shepard (1990, p. 171) explains survival and reproduction were supported by "rapid and veridical (accurate and reliable) perception of the external world." Criteria based for example on the isovist's area, provides a perceived openness or concealing quality supporting a spatial grammar (Gibson, 1982).

The approach taken in this research was to use a viewshed analysis in spatial syntax. This approach, noted by Michael Batty and Sanjay Rana (2002, p. 7), used the maximum diameter of the isovist polygon to model the axial line. These authors felt view fields

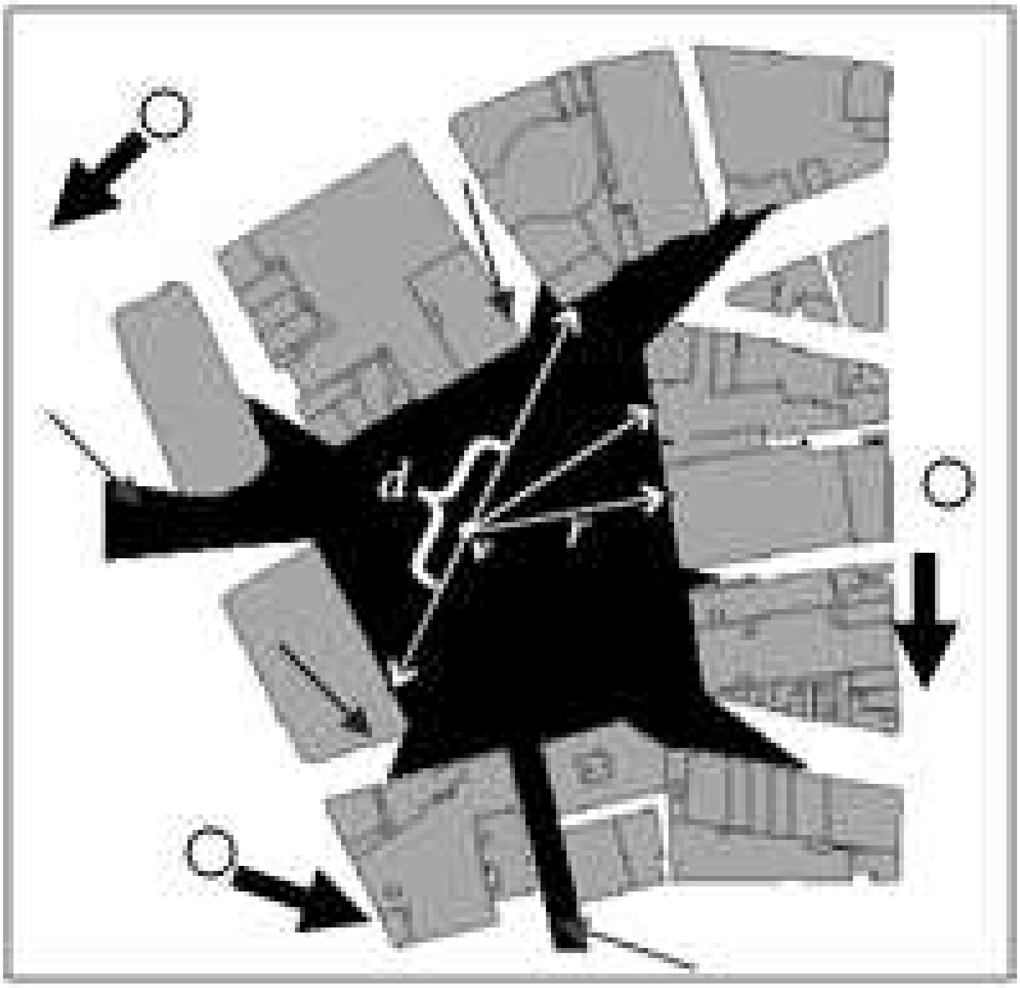

Figure 197: Map showing isovist polygon depicting radians of view corridors, thin arrows point to maximum diametrics and also denote occluding edges. Circles represent occluded landmarks and the thick black arrows represent the hypothesized biasing error in their spatial updating. (source: Rana, 2002)

provided a more scientific approach to using space syntax to model spatial behavior as they felt the current basic representational elements in space syntax were ill defined - not directly observable and measurable, and no agreed upon or unique defining methods. Even though isovists are not in general convex spaces, isovist analysis does provide a convex core (Hillier, 1996) in its parametric results.

Isovist parameters have been shown to correlate to spatial behavior. For example, past research conducted on parameter correlation to spatial behavior (Benedikt et al., 1980) substantiated that in situ initial recall of occluded landmarks is correlated to the radian distribution of the vantage point's isovist. They observed that occluded landmarks were placed towards the edges of occluding surfaces. Gibson had theorized that occluding edges were one of a number of invariant features offering the affordance of distance, thus the visual information gained from the environment, the perception of the occluded landmark bearing, is from the optical array in bounded space (Gibson, 1982). These results differ remarkably from blindfolded spatial updating results obtained in Loomis et al. (2003), whereby bearing error was correlated to path traveled (the landmark's perceived bearing moved forward with the path followed). The approach taken in this research was to use the maximum diametric as the generalized invariant feature offering the affordance of distance.

3. Methodology

The in situ and its mimetic VR course model were located on the San Diego State University campus, SDSU. The models were specifically designed to evaluate the appropriateness of vantage point position at a locale based on its isovist parameters. It was theorized that the parameter in the isovist related to the distance affordance, the maximum diametric and secondarily occluding edges, biased the spatial updating of global landmarks (initially perceived in reality or VR by vision or SL) by attraction, whereas the minimum diametric parameter affording proximity or occluding surfaces, biased the spatial updating of global landmarks by repulsion. Figure 197 (below) shows a theoretical isovist and how the bearing to occluded landmarks was hypothesized to err during spatial updating.

As mentioned, a primary importance in this research was to evaluate perception not cognition. A number of approaches were used to isolate and explore the subject's perception of occluded landmarks within the ambient optic array surrounding their viewpoint. This approach was markedly different then standard updating tests that explore cognitive supported updating relating to proprioception that is void of visual stimulus (such as blindfolded subjects). It was felt that emphasizing cognition, using a mental representation or map without regard for the surroundings, would overpower ambient occluded landmark perception at the waypoint.

4. Materials and Design

The waypoints in situ were mimicked in VR providing initial visual and acoustic mediated perception of landmarks, and subsequent occluded viewpoints of these landmarks. Panoramic images were taken of all physical waypoints and SL for the global landmark, the Parking Tower, was added to VR using Squamish SoundSaVRTM software. This allowed the SL in VR to emanate (in headphones) from a specific bearing within the panoramic image. In situ the subject observed the mediator directionally pointing and heard a stated

Figure 198: ArcView Isovist Analyst mapping of the test area, with highlighted parameters of second occluded waypoint overlain.

distance, i.e. "the Parking Tower is 1000 feet".

To obtain quantitative parameters relating to the waypoint's isovist the Isovist Analyst extension developed by Dr. Rana in ESRI ArcView (Figure 198 below) was used.

The landmark data obtained at each pause and gaze waypoint allowed analysis of the mean landmark bearing displacement and its variance to the isovist's maximum diametric angular offset from the true landmark bearing.

The pool of 36 physical subjects, acquired in two summer (2004) workshops, had no prior exposure to the SDSU campus. 40 subjects were tested in the virtual environment during 2004. They consisted of coffee house quests and acquaintances of the researcher, with no prior knowledge of the SDSU campus.

5. Spatial Updating Procedure

In starting the course, participants initially visually perceived prominent landmarks (the Green Door, the Cooling Tower, Hardy Tower, and the Quad Tower). As mentioned, the Parking Tower was initially perceived by SL and in actuality did not exist. To avoid continual visual updating in the physical environment to one specific landmark, shared attention between the subject and the mediator focused on the route foreground and the subject was distracted by irrelevant conversation. Once the subject was physically

Figure 199: Image showing first occluded landmark evaluation waypoint with arrows showing occluded landmark positions.

centered at the testing waypoint or had hyperjumped there in the virtual mode, the mediator informed the subject to gaze the viewpoint. Then the subject was asked to point to each occluded landmark. This procedure differs markedly from cognitively testing proprioceptive spatial updating where low emphasis is placed on visual perception of the subject's surroundings. In such cognitive tests the subject is expected to point with the "mind's eye", the focus being to evaluate vestibular and kinesthetic sensing during physical movement. This is not to say that there is no cognition present during this testing. The flux of cognition and perception exists concurrently within humans, but this research was designed to assess how visual perception influences occluded landmark perception, not the remembering of landmark position through cognitive reasoning correlated to physical body movement as in a blindfolded test.

In the physical test, the subjects pointed towards the landmark and a photograph was taken from behind the shoulder of the pointing arm. In the VR test a screen capture of the panoramic image was made when it was rotated and pointed directly at the occluded landmark. After all the data was recorder the landmarks azimuths were sighted from the adjoining rooftops. Compasses and GPS were not effective due to buildings limiting satellite signals and magnetic error produced by large underground metal pipes. Post test azimuth fixing limited any subconscious mediator biasing. The course route is shown in Figure 198 above (series of dark circles) and runs right to left. The participants had a total of five landmarks to update at five waypoints (the Green Door remained in view at the first two). The panoramic image below (Figure 199) is the initial testing waypoint and the dark dot represents the subsequent second testing point also highlighted in Figure 198.

Again care was taken to have the subjects visually pan their surroundings before asking them to perceive occluded landmark bearing.

6. Spatial Updating Analyses

In support of the first hypothesis, each participant's landmark bearing fix was tabulated within five-degree increments from the true bearing. A five-degree filter was used to allow for minor discrepancies. The group mean tendency of bearing perception and its standard deviation was acquired for each environment, VR or in situ.

Graphical depictions of group mean bearing perception and standard deviation were overlain on the isovist base map and regression analysis related to isovist parameters was used to test the first hypothesis. These long corridors are represented and classified in space syntax as axial lines and in isovist maps as the maximum diametric parameter. Mapping the group average perceived landmark bearing and associated standard deviation from mean for specific landmarks at each vantage point would graphically demonstrate if there was a propensity to incorrectly place landmarks, and if the ambient optic array was influential in biasing their placement positively towards these axial lines. Regression analysis was performed on the data to ascertain if the true angle formed from the isovist's maximum diametric and the true landmark bearing influenced perceived landmark bearing fixation.

7. Results

The group averaged occluded landmark perception bias was obtained as well as the standard deviation for each landmark at each of the five waypoints. Due to requirements on the number of illustrations for this publication, only biasing at waypoints 2, 4, and 5 in situ are provided. The VR environment produced similar results and this similarity supported the third hypothesis. In Figure 200 (below) bearing error for waypoint 2 is graphically portrayed. At the previous waypoint 40 feet back (Figure 199 above) the error was minimal, with the Quad Tower landmark bias at only 5 degrees counterclockwise in both environments. At this second waypoint, the Quad Tower landmark is drastically pulled towards the axial line denoted by the isovist maximum diametric portrayed in Figure 198 above.

Focusing on the Quad Tower landmark (lower right corner), the reader will find large discrepancies with placement as noted by the standard deviation bars. Note the true location is not contained within these standard deviation bars. An example of what this error looks like in situ is shown in Figure 201.

Though the actual bearing to the Quad Tower landmark is at the far right of the image, the average perception for both environments is closer to the center of the image. In comparative T-tests between the in situ and the VR groups at the waypoints 1 and 2, all bearing placement supported the third hypothesis of similarity between in situ and VR. Additionally, comparative T-tests between the initial visually perceived Hardy Tower and the initial SL perceived Parking Tower supported hypothesis two.

At waypoint three only one of the five-paired bearings (in situ to VR) failed to support the third hypothesis. The trend at waypoint three in bearing placement was a similar continuation of the trend shown at the second waypoint (Figure 198 above). The only noticeable change was for the in situ environment where the Quad Tower was pulled counterclockwise even further towards the maximum diametric.

At waypoint 4 (Figure 202), an intersection of isovist diametric areas occurs (refer to Figure 198 above).

This secondary affordance of distance had a drastic influence on the perceived bearing to the Quad Tower landmark. With the change in the ambient optic array at waypoint 4, as mapped in Figure 198 above, this secondary maximum diametric offered an affordance of distance closer to the true landmark bearing. The resultant average error is now slightly offset clockwise. The other landmarks continue their bias trend as shown in Figure 200 above. At this waypoint the Cooling Tower data between the two environments failed to support the third hypothesis (T stat = 1.8). With 36 in situ participants and 40 VR participants the T Critical value for one-tail was 1.66. Of interest is the difference between the two environments. The VR environment did not contain a recessed roofline in line with the landmark as the viewer cropped it. Instead, though the landmark is inline with the secondary maximum diametric (a corridor similar to a tunnel) there would seem to be a

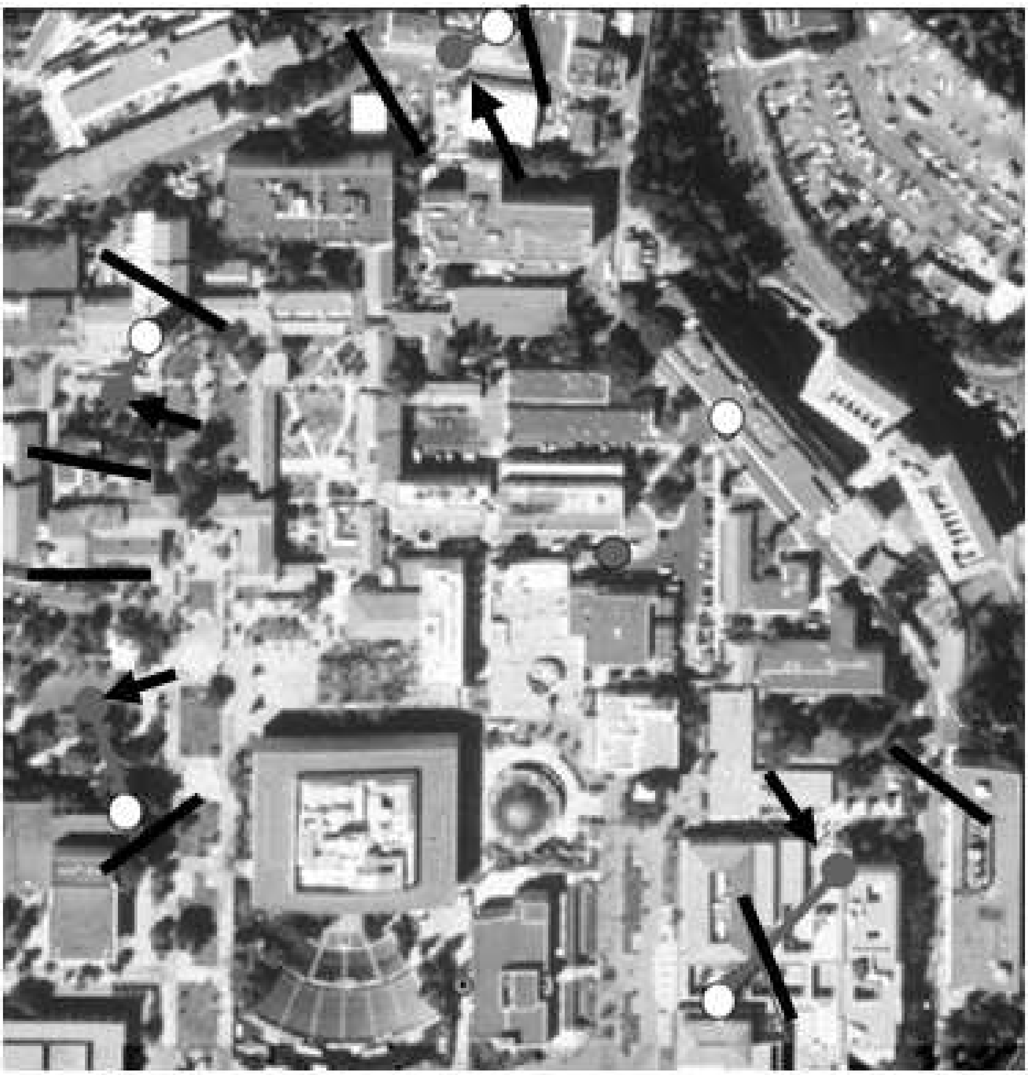

Figure 200: Image showing in situ perceived bearing and group standard deviation at viewpoint 3. Black lines bound the standard deviation of group perception and black arrows denote its mean placement.

Figure 201: Image of second waypoint with average perceived bearing to occluded landmark "Quad Tower" at the center. The actual bearing, which was correctly perceived at the first waypoint (40 ft away at the curve in the concrete as shown in the image) is towards the black dot on the wall at right at this waypoint.

limited affordance of distance (Figure 203). The VR mean bearing was offset 5 degrees clockwise while the in situ bearing was correct.

At the fifth and final waypoint (dot in Figure 203) the western component of the isovist maximum diametric comes to an end. Thus the route directional information present within the ambient optic array affords proximity not distance (comparable to the southern occlusion wall at the second waypoint in Figure 201). This occluding wall effected the bearing perception of the two western most landmarks; the Hardy Tower and the fictitious Parking Tower (see Figure 204).

Note in this image the drastic change in perceived bearing of these two landmarks and the return of the Quad Tower to counterclockwise biasing. Two minor corridors face north and south at this waypoint. It is speculated that they act as a secondary maximum diametric offering enough of an affordance of distance to facilitate placement of the global landmarks. The primary maximum diametric draws the Quad Tower toward its affordance of distance. Results are strikingly similar in the VR environment, again supporting the third hypothesis. Lastly, it is theorized that the lack of error in positioning of the Cooling Tower was caused by its bounded position between the two adjacent landmarks on that side of the course, the Green Door and the Hardy Tower and its internalized memory. These two landmarks thus helped center the landmark and possibly avoided its perceived bearing from duplicating the systemic error the Quad Tower went through.

A test of significance (F-test) felled to support the first hypothesis when the Cooling Tower was included - results were no better than chance. Excluding the bounded Cooling Tower, F significance (prob(F) $<$ .05) was significantly better than would be expected by chance for both environments (VRmean = .00017; VRstandarddeviation = .0021; InSitumean = .00013; InSitustandarddeviation = .0072). Thus bearing perception of landmarks and group variability increased proportionally (larger angles resulting in greater pull and variance) to the maximum diametric at the four remaining landmarks.

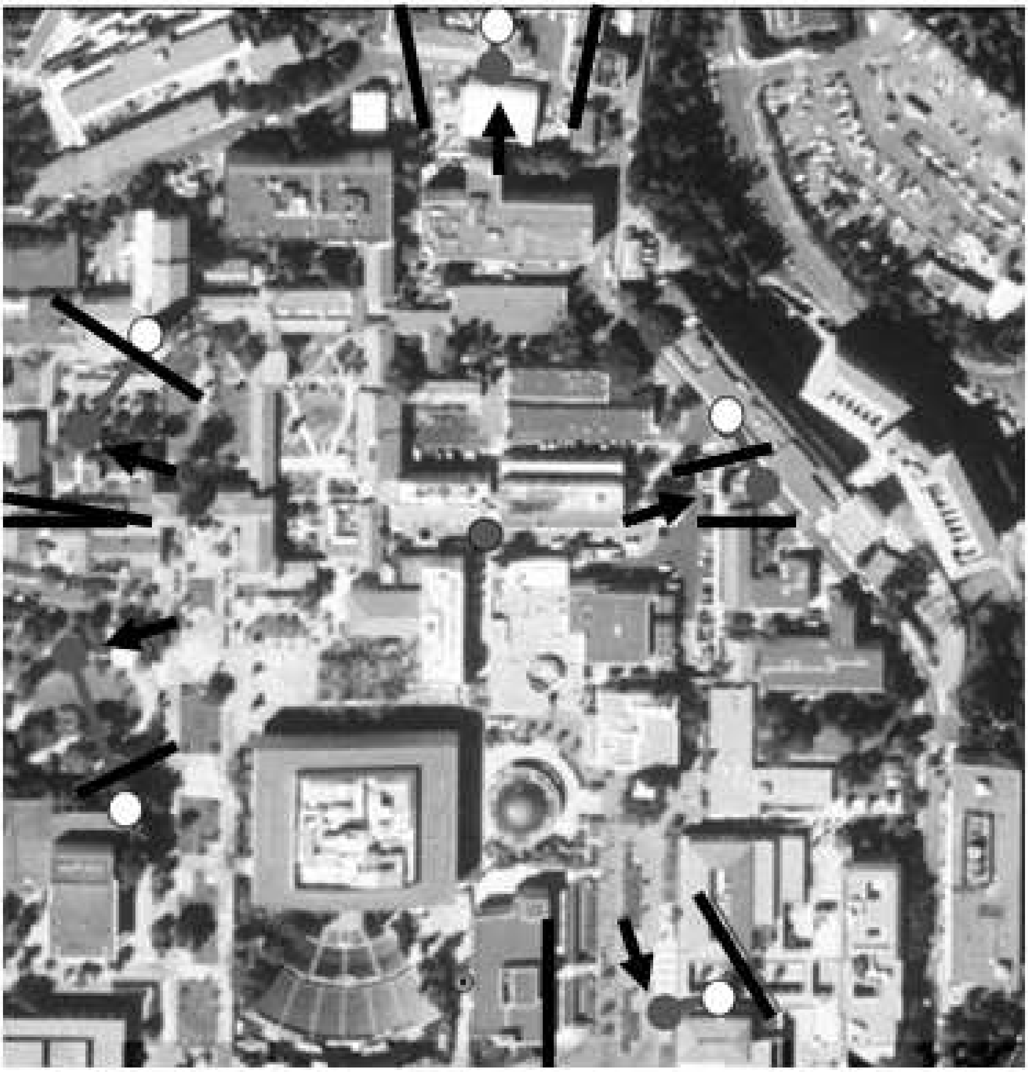

Figure 202: Image showing in situ perceived bearing and group standard deviation at viewpoint 4. Black lines bound the standard deviation of group perception and black arrows denote its mean placement.

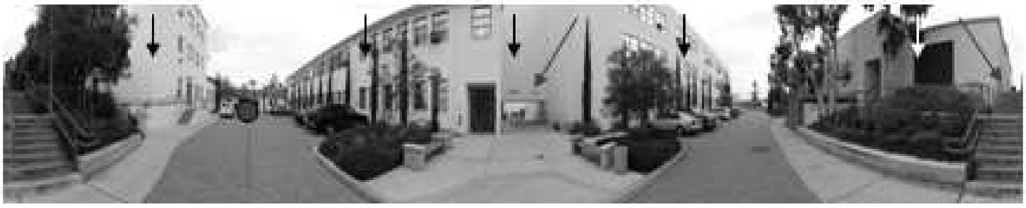

Figure 203: Image showing southern and northern corridors within the occlusion walls with black and white arrows showing landmarks. Dark arrows denote new secondary axial or maximum diametric lines. Image center is north towards the Cooling Tower.

8. Conclusion

This experiment pertained to the topic of spatial behavior and its relationship to spatial configuration, the ambient optic array, and how space syntax might represent these topics. Two approaches were taken to analyze the first hypothesis, a qualitative graphical depiction of updating error for trend analysis and a quantitative correlation analysis relating to increased angular discrepancies between the maximum diametric and true landmark bearing to the group mean and error in landmark perception. Sixty percent of the variance in the model of either environment was explained by the regression analysis, when the Cooling Tower was removed. The inclusion of other invariant features offering the affordance of distance might improve this predictive model. The maximum diametric only provides a general structure to correlate distance to. Gibson classified numerous secondary invariants, occluding edges, figure ground, and texture gradients, which were noticeable at affording distance. Results supported the robustness of VR for testing spatial updating. Control of the environmental configuration through VR might help isolate specific invariants offering affordances of distance. For example it is easy to remove the north corridor at waypoint 4 through image editing software.

The results visualized in the graphic portrayal of biased spatial updating supported that space syntax could qualitatively model the spatial behavior of updating. Already space syntax configurationally models mobility tasks such as driving or walking with axial lines and convex nodes (even as noted by Batty and Rana, 2002, the mapping of these is somewhat suspect). An important space syntax theory concept is its convex interpretation of areas. The convex area within space syntax has been portrayed to confine behavior based on perception, one contained within the convex limits. Occluded landmarks reside outside of these limits and yet this experiment seems to support that we readily perceive them in the convexity of the view field and place or link them to appropriate areas.

The research conducted here supports a convex containment of perception and this might support rethinking some principles relating to wayfinding. Jiang et al. (2000) promoted that small-scale perception (not meaning map scale) relating to the convex core principle of space syntax analysis is a prerequisite for large-scale perception (geographic space). Small-scale spaces are continuous (not discrete) and interconnected. Thus, when walking along a street, our surrounding environment is perceived as a small-scale space. Garling (1969) promoted that judgement of whole spaces might be predicted from averaged judgements of their parts. But cognitive mapping studies have not supported this assumption, though there is initial improvement related to iterations. No matter how of-

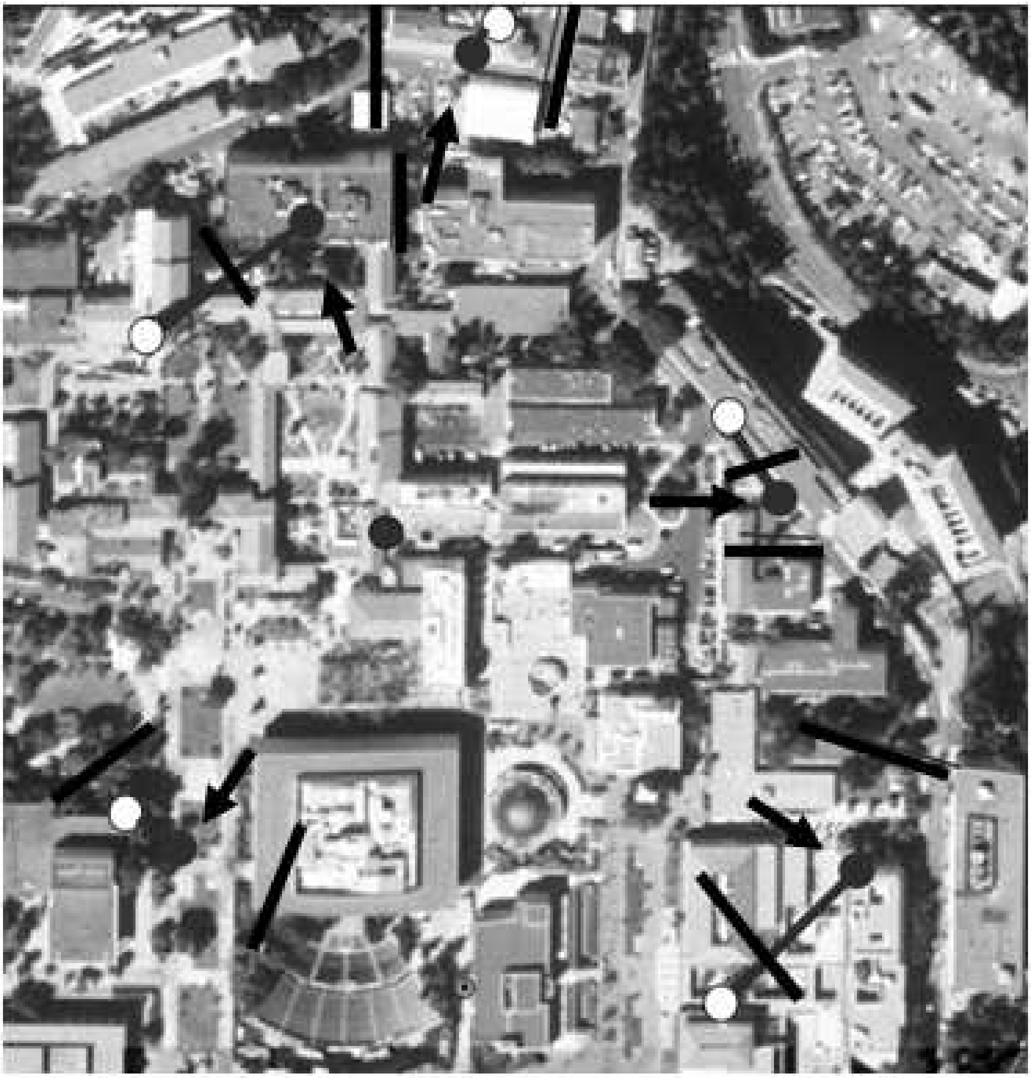

Figure 204: Image showing in situ perceived bearing and group standard deviation at viewpoint 6. Black lines bound the standard deviation of group perception and black arrows denote its mean placement.

ten a subject is exposed to an environment, they still have gross errors in representing the area (Golledge, 2002). At some level the continued familiarization of the parts does not improve the whole. Likely it is for the same reasons expressed in the background theory and supported in this experiment, mental energy efficiency dictates landmarks being placed in the convex view - a place holder. Thus perception of local and geographic space is occurring simultaneously. By externalizing the approximate locations of global landmarks into areas affording distant within the ambient optic array, the wayfinder is freed from internal reasoning landmark bearings. This process produces continuous error in wayfinding behavior but is still generally efficient for finding ones way.

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