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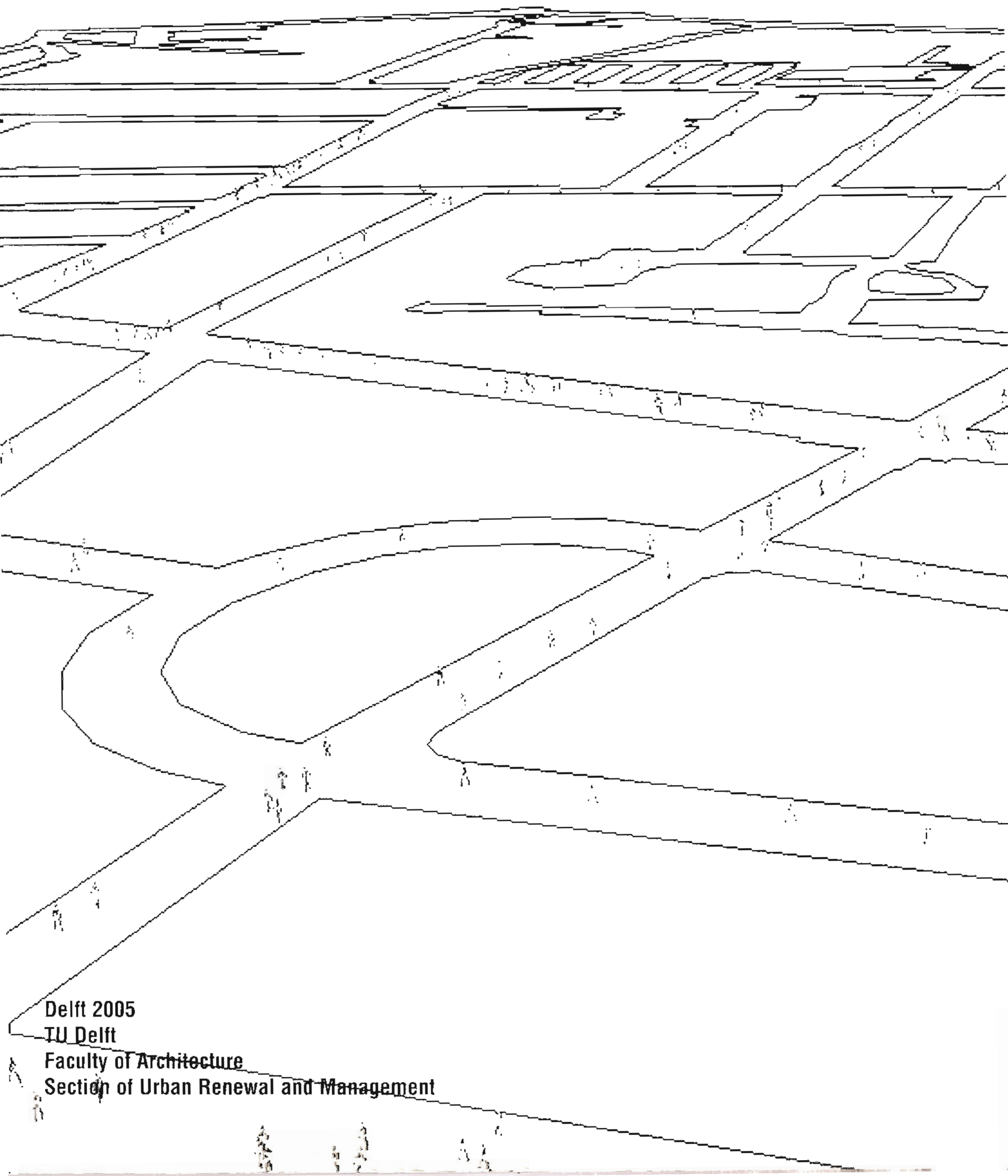

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Comparison of Configurational, Wayfinding and Cognitive Correlates in Real and Virtual Settings

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Abstract

The role of configuration in human cognition and wayfinding has been considered important by numerous researchers. In this regard, experiments have suggested that the topology based configurational analysis of Space Syntax is a significant predictor of both. However, these experiments were mostly done in real settings without sufficient control of extraneous variables. Observations of wayfinding behavior were measured by the number of times an axial space was used (Haq, 2003; Peponis, 1990), and cognitive understanding was measured (among others) by the number of times an axial line appeared in sketch maps (Haq and Girotto, 2003; Kim, 2001). These measures correlated well with syntactic values of the spaces, yet, the experiments can be criticized because they did not address the presence of, or the interrelationships with, other environmental variables such as signs and numbers, architectural differentiation and perceptual access (Weisman, 1989)

These drawbacks can be overcome with the evolving technology of Virtual Immersive Environments with User Controlled Movement (VIEUCoM). Such systems in experiments offer the possibility of controlling for all kinds of extraneous variables and introducing each one into the model in a systematic manner.

This was the purpose of the research that is reported in this paper. It uses data obtained from two wayfinding experiments: one done earlier in a real life hospital setting (67 subjects, Haq 2001) and the other done in a VIEUCoM model of the same environment where 32 users carried out the same tasks as the previous experiment which was in the real world. The first section of this paper provides a review of the earlier experiment. It then reports the processes and pitfalls of developing the VIEUCoM system. The paper then describes the wayfinding experiment that was carried out in this VIEUCoM. Pilot study findings and modification to the experimental methods are also reported. The most significant and final part of this paper compares movement and cognition data from the VIEUCoM system to that obtained earlier from the real setting.

Analysis of the two data sets suggests that wayfinding correlates with real world variables are remarkably similar to that of the VIEWCoM system. On one hand it brings out the dominant role of configuration, but on the other, it identifies a focused area regarding the relationships between configuration and other environmental variables including locational characteristics and scale. Such issues are discussed in the conclusion of the paper and possibilities of further experimentation are proposed.

1. Introduction

Human wayfinding has behavioral and cognitive components and is influenced by the environment in which it takes place. In experimentations on wayfinding, behavioral data is relatively easy to collect. The paths taken by subjects may be traced in a plan drawing of the setting (Peponis, Zimring and Choi, 1990, Haq 1999, 2001, Haq & Zimring, 2003) or their gaze directions and stopping positions noted (Conroy, 2001). Cognitive components are more difficult to categorize. Verbal descriptions of the environment (Lynch, 1960), sketch mapping (Lynch 1960, Haq, 2001, Kim, 2001, Haq & Girotto, 2003) pointing to unseen destinations (Siegel, 1981, Sholl, 1996, Haq and Girotto, 2003), estimating distances (Evans and Prezdek, 1980, Kirasic, Allen & Siegel, 1984) etc. are some of the methods used to investigate the role of cognitive components. Additionally, cognitive scientists have studied the role of such factors as spatial working memory, schemas (Gross and Zimring, 1992), spatial ability, gender, age, etc. in wayfinding. The third component in wayfinding studies – environmental attributes – are the focus of this paper. Kevin Lynch (1960) was perhaps the earliest researcher who proposed environmental elements like paths, nodes, districts, landmarks and edges as important. This tradition was followed by later researchers who identified more complex variables as being influential in wayfinding. These include configuration (Seigel & White, 1975), relative locations (Kuipers, 1978), topological relations (Kuipers, 1978). anchor points (Golledge, 1978) visibility between destinations (Braaksma & Cook, 1980), visual access, architectural differentiation, plan configuration, (Weisman 1981), node-link network (Garling, Book and Lindberg, 1986), syntax integration (Peponis et al 1990), Interconnection density (O'Neill, 1991), Integration3, connectivity (Haq, 2001 & 2003, Haq & Zimring, 2003) etc. (see Haq, 2001 for a summary)

Typically wayfinding experiments are undertaken either in laboratories, where the environment is reproduced by various means or in real settings where there is little control of the environmental variables. As reproductions of the environment, photographs, slides, or movies are shown to the subjects (Heft, 1983). Depending on their resolution and size they may or may not create a sense of realism. On a more serious note, these reproductions do not allow the subjects to decide their movement i.e walk on selected paths - a crucial aspect of wayfinding. On the other hand, experiments that are conducted in real settings allow subjects to make decisions about their movement (Peponis et. al, 1990, Haq 2001), but these experiments can be criticized because they fail to control extraneous environmental variables - those that are not part of the study. Recently, some studies in wayfinding are being done with Virtual Immersive Environments with User Controlled Movement (VIEUCoM) (Conroy 2001).

This paper reports a new experiment where a VIEUCoM environment was created to replicate a real hospital building that was used earlier in a wayfinding study considering configurational variables. All the spaces in the VIEUCoM model was created with uniform environmental conditions and the layout was the only variable (see figure 164). Exploratory, wayfinding and cognition tasks carried out in this model were exactly the same as those done earlier in the real building. Comparison of the two experiments indicated that Space Syntax variables were very important in predicting wayfinding use of spaces. Also, these variables had significant presence in the cognitive maps of the subjects.

2. Background

Extending the procedures and concepts developed by Peponis et. al. (1990), Haq (2001) had conducted wayfinding experiments in three complex hospital buildings in a major city of the United States. Among them, work done in 'City Hospital' (figure 164) is directly relevant to this paper. In those studies the Space Syntax definition of topological variables of environmental units were considered and their relationship to exploratory and

Figure 164: Plan of City Hospital

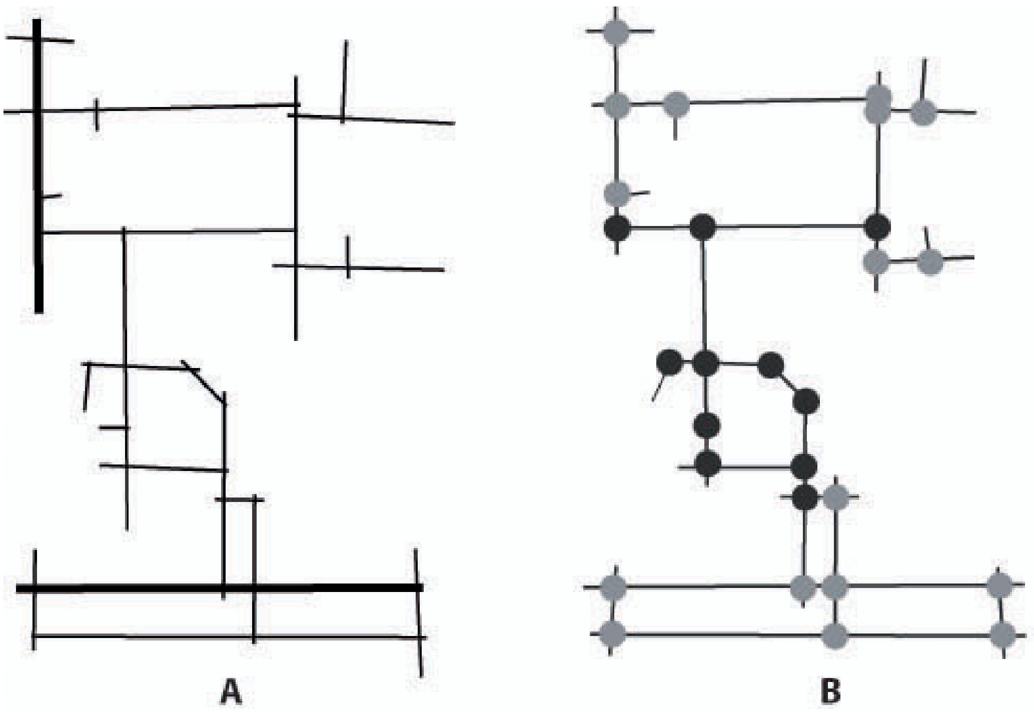

Figure 165: Syntactic analysis of City Hospital. A shows core of Integration-3 and B shows actual Node Integration.

wayfinding use of spaces and cognitive development was explored.

Analysis of settings began with identification of environmental units. These were developed from cognitive considerations and were understood as uninterrupted visibility lines and nodes[1]. Uninterrupted visibility lines were considered akin to 'vista' (Gibson 1979, Heft 1983) and were equated with Space Syntax axial lines. Their topological values were determined by Syntax methods (Hillier and Hanson 1984), specifically through the use of the computer program Spatialist[2] (figure 165). Nodes were considered to be 'transitions between vistas' (Heft, 1973) and were places of pause and spatial decision making. Corridor intersections were hypothesized to be such locations and were the 'nodes' of that study. Operationally, they were defined as intersections of axial lines. Therefore, their values were calculated by taking the average values of their constituent axial lines. Thus Integration, Integration3 and Connectivity were the calculated values of both lines and nodes. For nodes, additional variables were also developed. Among them, the one called Actual Node Integration was used in the study reported here. Actual Node Integration considered the direct connections of each node to all other nodes in the corridor system. The calculating formula was the same as proposed in Space Syntax theory (Hillier et.al 1984). Since AxmanPPC or Spatialist software only work with axial lines, a separate pro-

[1] Haq (2003) had also considered 'segmented' lines as units in wayfinding research.

[2] Peponis J,Wineman J, Rashid M, Bafna S, Kim S H, 1998 Spatialist (Version 1.0) GeorgiaTech Research Corporation, Atlanta, GA

gram was used to calculate the actual node integration[3]. Unlike Syntax programs, this does not produce any colored representation and so they were manually drawn. This is shown in figure 166.

Data regarding wayfinding behavior was collected through an empirical experiment. The one conducted in City Hospital is described below. Sixty seven volunteers, 31 females and 36 males (mean age=19.2), completely unfamiliar with the environment and screened so that none of them had visited a large hospital complex more than once in the 12 months prior to the study, participated. In the floor that was accessible from the street entrance, the participants completed the following tasks: open exploration, directed searches or wayfinding, pointing to unseen but previously visited locations, estimating distances and sketch mapping. The first two tasks were used previously by Peponis et al. (1990) in their pioneering study of wayfinding and Space Syntax.

In open exploration, the participants were asked to freely explore the building and learn about the layout and locations as best as they could so that they would be able to carry out specific searches in the environment later. Open exploration was started from one of two pre-selected entry points of the hospital and the subjects were given 15 minutes. They were instructed not to talk to anyone but to try and fulfill their tasks making reference to the environmental cues only (including signage). It should be noted that most of the participants used less time than was allotted and insisted that they had become familiar with the building. During directed search, i.e. wayfinding, the subjects were required to find specific destinations. Four destinations were pre-selected with respect to their distribution according to the environmental variables considered in this study. The subjects were taken to one of the four and were asked to walk to another one. When the destination was found, they were asked to go to the next one. If the participants could not find their destination in the preset time period of ten minutes, estimated during pilot studies as sufficient, they were escorted to the destination by the researcher. The procedure was repeated until each participant had found, or unsuccessfully attempted to find, his/her way to and from all the selected locations. The searches were counterbalanced such that each task was completed in all possible orders to control for fatigue and learning effects. After each directed search, the subject was made to face west and asked to point to the out of sight locations that s/he had reached before. Each subject performed 13 pointing tasks at different times and with increasing familiarity with the setting. In total, the subjects did 871 pointing tasks. These were performed using a circular cardboard with angles marked on it in 10-degree intervals and a pointer attached to the center. Pointing tasks were previously found to be a highly successful test of orientation (Siegel, 1981, Sholl 1996). After all the tasks were done, each subject was asked to draw the plan of the hospital. They were instructed to draw all the paths/corridors that they could remember and to indicate all the locations that they could recall.

From open exploration the following data was collected. Total Use of Lines (TUL) and Total Use of Nodes (TUN). Additionally distribution of people, or People Using Line (PUL) and People Using Nodes (PUN) was complied. From directed searches the redundant use of lines and nodes were calculated. Redundant use was use of a line or node when it was not in the shortest path between origin and destination i.e use of a line or node when one was not required to do so. In this case also, Total Use of Redundant Node (TURN) and People Using Redundant Nodes (PURN) were compiled. Redundant

[3] Sonit Bafna, a faculty member in the College of Architecture, Georgia Institute of Technology, wrote this.

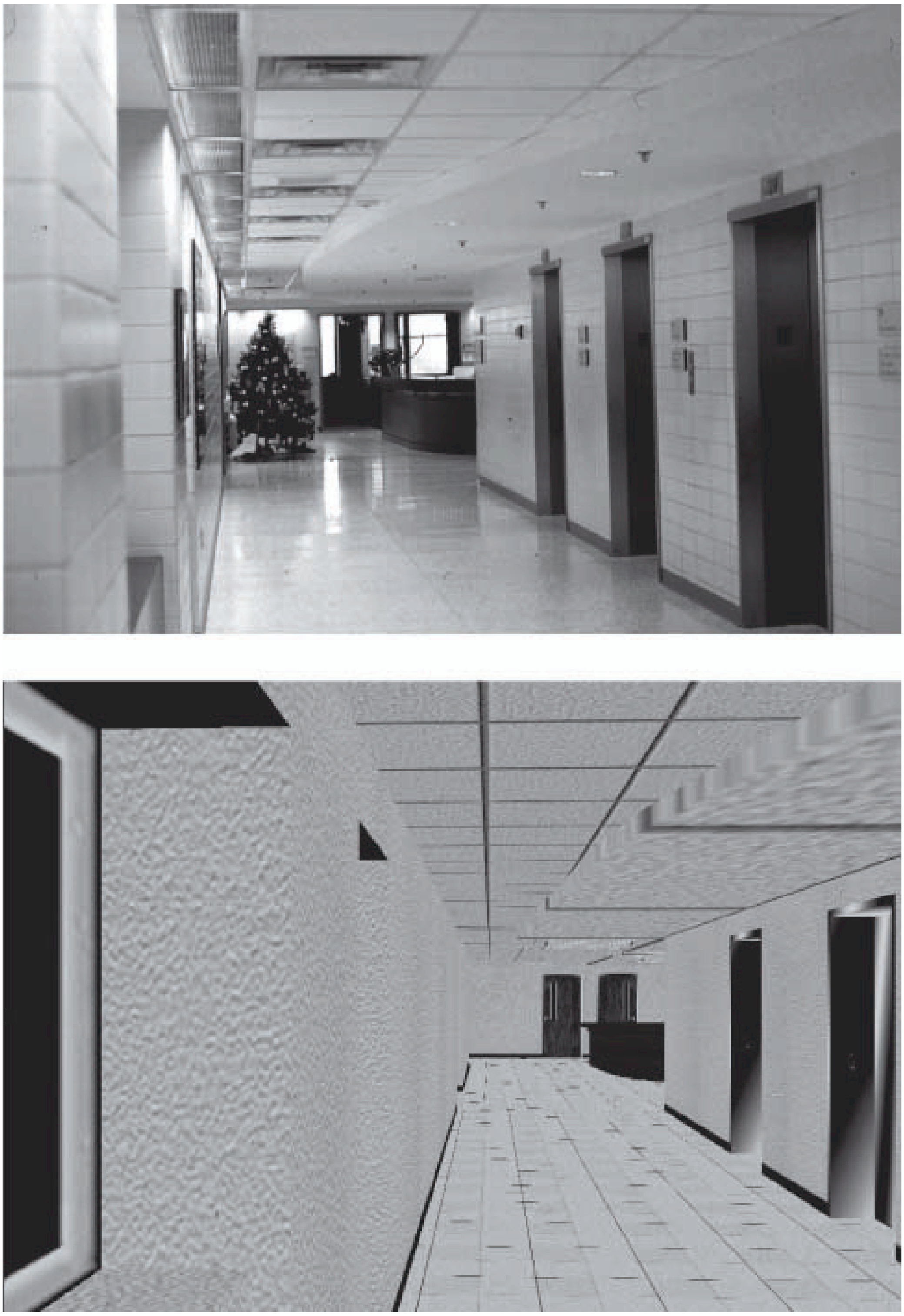

Figure 166: Comparison of real with VIEUCoM environment

use is important because it gives a measure of wayfinding difficulty. In environmental terms it provides an index of 'wayfinding attractiveness' of a space and in cognitive terms a sense of environmental understanding. Redundant node use was used earlier by Peponis et. al. (1990), Willham (1992) and Haq (1999) and redundant line use by Haq (2003). The distinction between total use of spaces and people using spaces should be emphasized. Whereas the former considered repeat visits, the latter value was obtained by counting the number of subjects who visited a line or a node.

The following data was collected from the cognitive tasks: pointing errors, lines appearing in sketch maps and sketch map accuracy. During pointing tasks, the angular deviations from the actual location were recorded and then averaged to produce pointing errors by person. The sketch maps were manually analyzed to determine the 'appearance' of lines. To make sure that the occurrences of lines in the maps were correctly accounted for, two independent raters judged a sample of the sketch maps. The researcher judged all of them. The two raters and the experimenter judged 25 maps which included 600 axial lines. Here they agreed 499 times, or 83.16% of the time (Cohen's k .= 0.6633). Sketch map accuracy was calculated by an independent rater not familiar with the building. To do so, the following procedure was used. First, the hospital was considered as three sections (the layout of the hospital 'afforded' this. Refer to figure 164). Each map was looked at by sections and then as a whole. After comparing with an actual plan, a grade from 0 to 25 was given to each third. A deduction of 5% was made for each error in each section of the map. The maps were also judged as a whole (0-25) and 5% was deducted for errors in direction or connection of each section in relation to the whole. The same rater also rated the cognitive maps done in the VIEUCoM experiment. It would have been preferable to have more raters evaluating cognitive maps. Unfortunately time and costs prevented this. However, there can be some confidence that maps from the two experiments were rated by the same person.

3. The VIEUCoM study

At the beginning, a distinction should be made between Virtual World or Virtual Reality (VR) and Virtual Immersive Environment with User Controlled Movement (VIEUCoM). Virtual world is understood as "an artificial environment which is experienced through sensory stimuli (as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment" (Merriam-Webster 2005). Sherman and Craig (2003), defines it as "a medium composed of interactive computer simulations that sense the participants position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation". The specific kinds of virtual reality where the user can decide on his or her own path and move in those paths are called Virtual Immersive Environment with User Controlled Movement (VIEUCoM). Such a model was produced for this experiment. This was a replica of City Hospital, created in a one to one scale. In it, all environmental variables, except the layout was controlled (figure 164)

3.1. Making the VIEUCoM

There were two main considerations in making the VIEUCoM model. First, appropriate software that allows both the creation of virtual world and user controlled movement

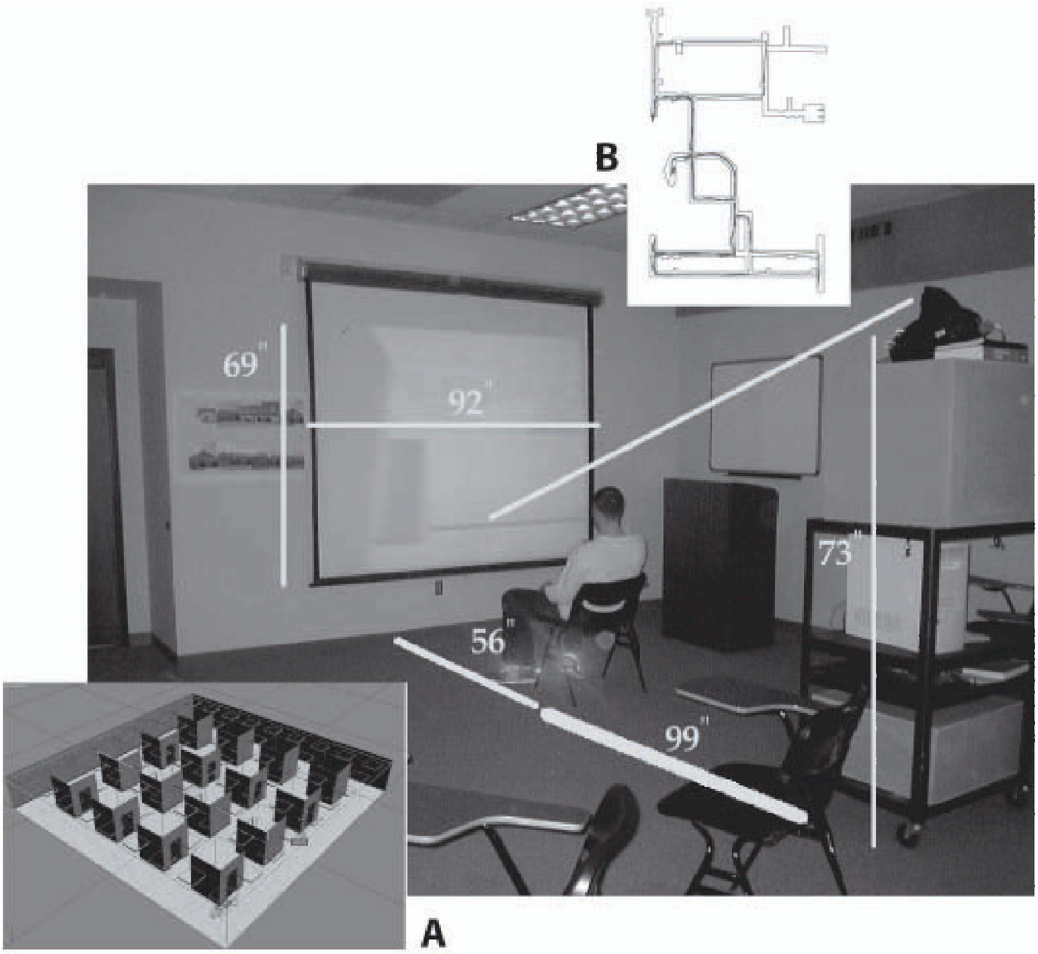

Figure 167: The platform with the VIEUCoM equipment. Inset A is the pre-training environment and B shows computerized recording of individual tracks

within it. Second, the required hardware to create a sense of immersion or being in that environment.

Sherman and Craig (2003) have identified four key elements in Virtual Reality (VR). First is a virtual world. The virtual world for this study was the representation of the continuous corridor environment of City Hospital that was used in the previous wayfinding research. The second element is physical immersion or the sense of being in the environment. Immersion can be achieved by providing the same visual senses as in the real world. A simple example is when an individual moves closer to an object in a virtual world, that object will appear bigger in the appropriate scale. In order to create immersion, the computational device needs to have a method for tracking an individual's movement and translating it to the virtual world. This method of computational tracking is the third element in VR called sensory feedback. The final element in VE is interactivity. The ability of an individual to interact with elements and move freely in the virtual world is regarded as interaction between the individual and the computer. In our experiment, interaction is taken to be the ability of movement, more specifically, carrying out open exploration and directed searches in the VR.

3.1.1. Software Components: Creating the Virtual Reality

The virtual world was built from the drawings of the actual hospital called City Hospital. The model was a representation of corridors from the second floor of the hospital (figure 164). This was created using software that generated the 3D VR content. For the purpose of having a smooth VR simulation, the use of low-primitive geometries such as polygons, lines, and text was used (Kessler, 2002). In addition, since the number of polygons has a significant effect to rendering time, this model contained as few polygons as possible (6083 polygon count).

To serve the purpose of this study, the model was created as simple as possible to limit any extraneous environmental variables such as signage, color, lighting, finish materials and furniture. Only the built-in reception desks were created to indicate where the reception areas were located. Figure 167 illustrates the similarities and differences between the real hospital and the model. In the virtual environment, all the corridors had the same floors, walls and ceilings and were given a similar luminosity. There were no other environmental elements. This model then was exported to software that acts as VR editor to provide interactivity. In this software, the walking speed of the user and the computational behaviors were programmed. The walking speed was obtained from North and Miller study (2000) as one meter per second.

Behavior in VR indicates how objects drawn in the model interact with each other and with the user. Two important behaviors applied in the VE model was collision and tracking.

The environment will obviously be more 'realistic' if the user cannot pass through the walls. This is called collision detection. The software provided objects of boxes, which were set up as invisible boxes and served as collision boxes in the VR. These boxes provided collision response when the user collided with the sides of the boxes. From the subjects' point of view, it prevented them from walking through walls.

Tracking devices are used to report the position and orientation of a "tracker" in relationship to a particular reference frame (Kessler, 2002). In this particular experiment, the tracking device is used to report positions of the user in the environment in the range of time when the user 'walked' in that environment. The tracking information recorded

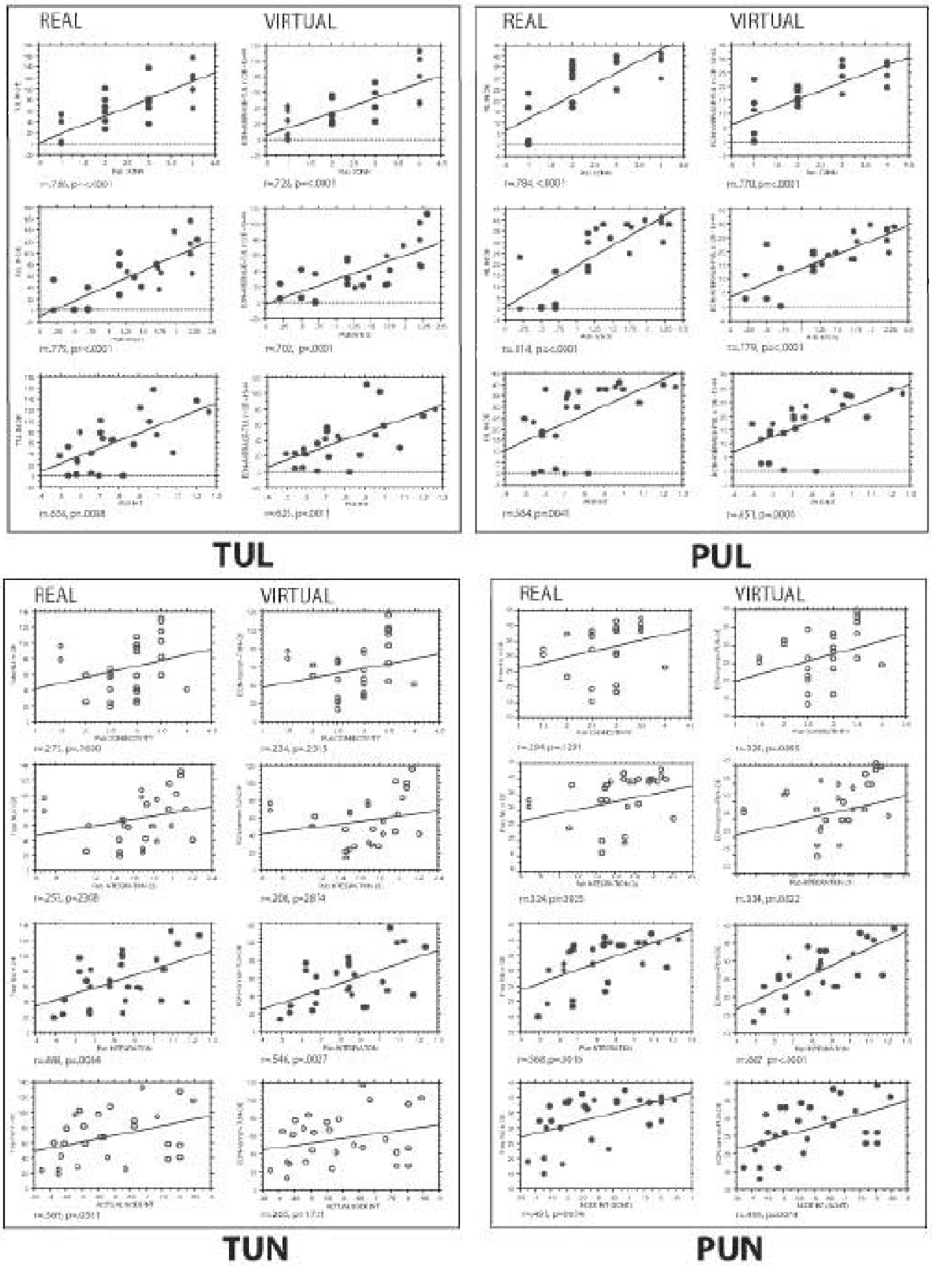

Figure 168: TOP: Correlations of Total Use of Lines, TUL and People Using Lines, PUL in Open Exploration with three syntactic variables in the real and virtual setting. BOTTOM: Comparison of Total Use of Nodes, TUN and People Using Nodes, PUN in Open Exploration with four syntactic variables in the real and virtual setting

was time, x-position, and y-position. This data was transformed back to the corridors' floor plan as lines. These lines illustrated the paths that the user completed in a period of time in relation with the building floor plan (Figure 168)

3.1.2. Hardware Components

User monitoring is real-time monitoring of the participant's actions in a VR (Sherman & Craig, 2003). Physical controls such as joystick, mouse, and keyboards are some of active ways for the user to input information into the systems. In this experiment, a joystick[4] was selected as a control device because it is simple to manipulate by people who are both familiar and not familiar with computers. The movement of joystick was calibrated so that pushing the joystick forward means the user moves forward, pushing it left is moving left and so on.

Platform is the part of the VR system where the participant is situated. A platform can be designed to mimic a real-world device such as a cockpit of a plane or it may simply provide a generic place to sit or stand (Sherman & Craig, 2003). In this experiment, a classroom was used as a generic platform (Figure 168 bottom).

The VR was projected on a wall to expand the use of regular monitor-based display. Conroy (2001) has discussed the effectiveness using various display systems and the creation of immersive-ness. Although she considered the use of projection-based displays as less immersive than head-mounted display, she also stated that both displays provided a similar pattern of movement.

The normal field of view (FOV) for humans is approximately 200 degrees, with 120 degrees of binocular overlap (Klymento and Rash, 1995). Displays that provide 100-120 degrees FOV begin to cover a reasonable portion of the human visual range. Monitor-based display has 44 degree FOV. In contrast, the projection-based display in the experiment had 61 degree FOV (Figure 168 bottom). Larger screen and rear projector are needed to implement the minimum 100 degrees FOV and will be considered in the next phase of experimentation.

3.2. Data Generation in the VIEUCoM model

Before conducting the experiment, a pilot study was undertaken with 12 undergraduate students and various configuration of hardware. Based on their performance and suggestions necessary adjustments were done. These included selection of the joystick, projection adjustments and corrections to the VIEUCoM model and the pre-training environment.

The experiment consisted of four phases. The first phase consisted of pre-training, i.e. getting comfortable using the joystick and navigating within a generic VIEUCoM environment for 5 minutes. For this purpose, a 72 feet by 72 feet virtual environment with 10 corridors (5 x 5) arranged in a grid pattern was created (see figure **??**).

The second phase was similar to the open exploration done in the real building. The users were taken to one of the two entry points (same as the real building) and were asked to navigate within the model for a maximum of 15 minutes. At this time, the users were also asked to pay attention to four colored doors that were placed throughout the hospital. The four colored doors corresponded to the four locations that were used for directed searches in the real building. After completion of the open exploration, each

[4] Although joystick as a controlling device was decided by the researcher, different types were tested before Logitech Wingman Attack 2 joystick was selected.

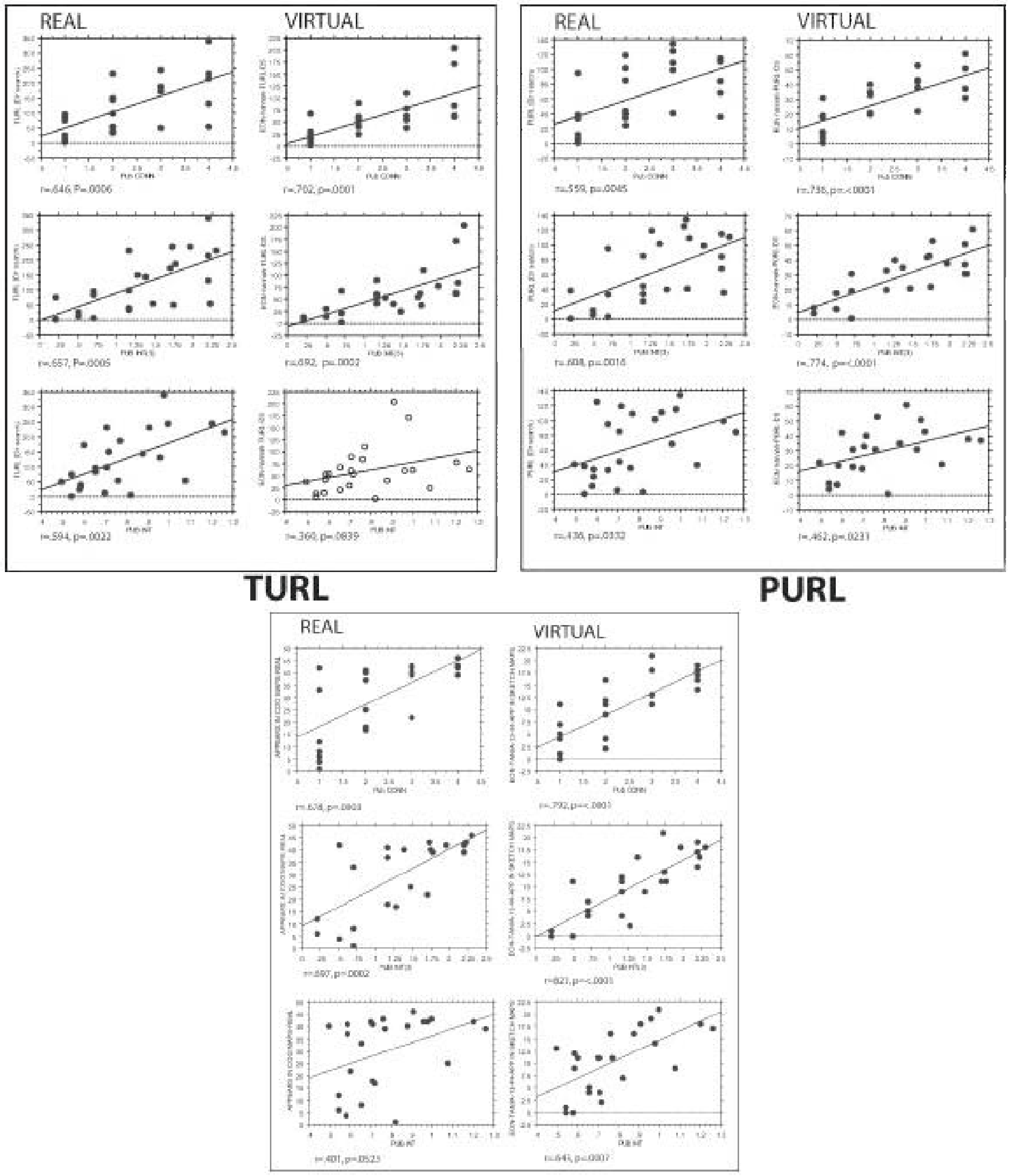

Figure 169: TOP: Comparison of Total Use of Redundant Lines, TURL and People Using Redundant Lines, PURL in Directed Search (wayfinding) with three syntactic variables in the real and virtual setting. BOTTOM: Comparison of lines appearing in sketch maps with three syntactic variables in the real and virtual setting

subject was asked to perform a directed search (third phase). A VIEUCoM was opened which positioned the user in any one of the four colored doors and then was asked to walk to another colored door. Like the real experiment they were given a maximum of 10 minutes. If after 10 minutes the destination could not be found, the researcher would stop the experiment and escort the user to that destination. At the destination, another VIEUCoM was opened which put the user in the same location. S/he was asked to face west and point to the location that s/he had come from and those that s/he had visited before. This procedure was repeated four times until the user had walked to all four colored doors.

Finally, the user was asked to sketch the hospital corridors as s/he remembered it on an- 8 $\frac{1}{2}$ x 11 white sheet of paper.

Thirty-two undergraduate students (9 males and 23 female) participated. Data from two students could not be used because they could not complete the experiment. This was mainly caused by motion sickness. They reported feeling nauseous when navigating in the VR. Biocca (1992) reported that individuals have the ability to adapt to some level of discomfort caused by motion. Biocca also reported from Tyler and Bard's (1949) study that "...as many as 5% of those who are susceptible to motion sickness never adapt..."(p. 341). Based on this theory, the two that dropped out (6%) was not unexpected.

Twelve of the subjects never had previous experience of using a joystick. Nevertheless, they could all complete the experiment. Therefore one can say that the skill level in using joystick does not affect the ability to navigate in a VIEUCoM. This result is important as it demonstrates that joysticks can be used as a tool of wayfinding studies in VIEUCoM.

Additionally, an informal observation demonstrated that the subjects seemed to 'walk' and navigate in a similar manner as in the real world. This observation supports Conroy's assertion (2001) that there are similarities in people's movement in VR and in real environments. However, we must also report that two subjects behaved differently. There were times when they 'walked' backward rather than rotated themselves and walked forward. In future experiments the joystick will be calibrated to prevent this.

4. Comparison of exploratory and wayfinding behavior in real and virtual settings

Exploratory behavior in both settings was characterized by the use of lines and nodes (TUL, PUL, TUN and PUN) and wayfinding behavior by the redundant use of lines and nodes (TURL, PURL, TURN and TURL). Behavior in the two environments was compared through two-sample t-tests assuming unequal variances. The results are reported in table 20 and show that in all the cases the p-values are much less than 0.05. Therefore it seems that there is a substantial difference between the two datasets. In other words the exploration and wayfinding behavior between the real and virtual environment were statistically different.

Next, the effects of the syntactic variables on exploratory and wayfinding behavior were calculated through correlational analysis.

Table 20: Results of two-sample t-tests (assuming unequal variances) showing the relationship between various experimental procedures in the real and the virtual world.

		t values	P values (one tail)
Open Exploration	TUL	1.889	0.0332
	PUL	2.323	0.0129
	TUN	3.392	0.0007
	PUN	7.012	<.0001
Directed Search	TURL	2.866	0.0035
	PURL	3.808	0.0003
	TURN	3.014	.0023
	PURN	4.053	0.0001
Cognitive Tests	Pointing accuracy	-2.503	0.0079
	Sketch map accuracy	3.402	.0006
	Appears in Cog Maps	5.957	<.0001

4.1. Exploratory behavior

4.1.1. Open Exploration and Lines

For lines, three kinds of environmental variables were considered in this study - Connectivity, Integration-3 and Integration-max. Two comparative charts of scatter grams were done for TUL and PUL in Open Exploration (OE) respectively, and are shown in Figure 169 and table 20. A side by side comparison shows that they are not only statistically similar, i.e. their r values are very close, but also, the scatter pairs are very comparable (in all the cases). This resemblance is especially apparent in the scatters between TUL and Integration and PUL and Integration in Real and Virtual settings (compare the two scatters in the last rows in Figures 169 and table 20.

4.1.2. Open Exploration and Nodes

The node variables were the average values of Connectivity, Integration-3 and Integration of the constituent axial lines. Also a fourth variable, Actual Node Integration was selected. In the case of TUN in OE, only Integration yielded good correlations in both the settings (figure 169, bottom row 3). In the case of PUN, both Integration and Actual Node Integration gave good results (figures 169, bottom rows 3 and 4). Correlations of the rest were poor and insignificant. However in this case poor correlations are not unhelpful. Just like the good correlations, the poor ones are actually similar in the real and virtual settings, both in the r-values and the scatter forms (see figure 169 bottom. Thus, irrespective of good or not good correlations, they are all comparable across the two settings. In other words, exploratory behavior correlates with syntactic variables almost equally in real and virtual settings.

4.2. Wayfinding behavior

4.2.1. Directed Search and Redundant Lines

The wayfinding variables for directed search were quantified by redundant use of lines and nodes. Table 21 show the r-value comparison and scatter grams of TURL and PURL with the three syntax variables. As before, they are quite similar and comparable.

4.2.2. Directed Search and Redundant Nodes

The correlations of TURN and PURN with environmental variables were not significant and had low r-values in the real building. They were similarly low in the virtual setting. However, these low correlations were similar and comparable between the real and the virtual environments.

4.3. Discussion on exploratory and wayfinding behavior

The earlier results reported here indicate that wayfinding and exploratory movement in real environments is not similar to movement in its virtual counterpart. The later results aggregate to the conclusion that configuration, as understood through Space Syntax theory is an important predictor of both exploration and wayfinding behavior in real and virtual settings. The importance of configurational variables is not a new conclusion and has been reported before. (Peponis, 1990; Haq, 2003; Haq & Zimring, 2003) What is novel is the fact that the same experimental procedures when undertaken in a virtual environment have produced very similar results.

On an average, in the virtual environment, integration -3 values of axial lines accounted for 55% of the variance in exploratory behavior and about 54% of the variance in wayfinding behavior (in the latter case the values were the average of the constituent lines). This is especially significant when we remember that these results were obtained in a setting where all kinds of extraneous environmental variables were controlled and layout was the only predictor.

In exploring the virtual setting, Integration-3 predicted about 49% of the repeat use of lines and 61% of the distribution of people (see table 21). In the real building, these numbers were higher - 60% and 66% respectively. In the wayfinding condition, this result was reversed. Integraton-3 predicted 48% of repeat use of redundant lines and 60% the redundant distribution of people in the VIEUCoM environment. These numbers were lower in the real building - 43% and 37% respectively (table 21). In other words, in the virtual building, layout had lesser effect in exploration but higher effect in wayfinding. Of course, one setting cannot be used to make conclusive comments, but a reconsideration of the experimental procedures could help shed some light on this phenomenon. In the real building the subjects were told to try and learn about the environment as much as they could. Naturally they looked at signs for that purpose and perhaps did not visit all corridors because they thought that they knew beforehand (through signs) what could be found there. Additionally, the signs in the real setting generally corresponded to its configuration. All of these could have had a multiplier effect. On the other hand, while wayfinding in the virtual setting the subjects only knew that there were four colored doors. Since there were no signs or any other environmental cues, the subjects' only option was to explore as many corridors as possible and therefore they were more affected by the layout.

In a study considering three real hospital buildings that included City Hospital, the counterpart of this virtual model, Haq (2003) reported that "when repeat visits was considered, then connectivity emerged as the strongest predictor, but when number of people who visited a line was considered, integration-3 gained prominence" (pp 853). Although this statement was based on the findings of all the three hospitals and on reports of other

Table 21: r2 values of Integration-3 and the exploratory and wayfinding use of lines

		Real		Virtual
Open Exploration	TUL	60	>	49
	PUL	66	>	61
Directed Search/ Wayfinding	TURL	43	<	48
	PURL	37	<	60

researchers, this was exactly correct for City hospital. Interestingly, the same result was obtained in the virtual environment- total use of lines was best predicted by connectivity (r=.728) and distribution of people was best predicted by integration-3 (r=.779).

Among the behavior studied in the three real hospitals studied earlier, all the specialties and peculiarities observed in city hospital were recreated in the virtual world. This is especially interesting. Other hospitals have to be recreated virtually to see if they too produce the same nuances in behavior. At this moment, we can state that layout - independent of any other variables - is a strong predictor of exploratory and wayfinding performance. But does it also relate of cognitive learning? That is discussed next.

5. Cognitive Correlates

Pointing to previously visited but unseen destinations and sketch mapping of the corridors were taken as indicators of cognitive learning. The average pointing error inside the real building was 39.52 degrees while inside the virtual environment it was 56.03 degrees. Sketch mapping accuracy in the real building was 57.92% and in the virtual environment was only 37.5%. Furthermore, two-sample t-tests assuming unequal variances revealed a substantial difference between the two data sets (p-<.0079 for pointing errors and p=.0006 for sketch mapping accuracy, see table 20). Therefore it can be safely assumed that cognitive learning in the virtual environment was less than that in the real world.

The final test considered the lines that were drawn in the sketch maps. This data, called 'appearance in sketch maps' was correlated to all the syntactic line values - connectivity, integration-3 and integration. The corresponding r-values are shown in figure 169 with side by side comparisons with the correlations in the real environment. In all the cases, the drawn sketch maps has good correlations with space syntax values and those in the virtual environment are always higher than those of the real world. We have also seen that in directed search, the subjects' reliance on syntactic variables was higher in the virtual model. Thus it is not unexpected that it will be reflected in their sketch maps.

The curious result that emerges is that the subjects in the virtual world had more pointing errors, yet they demonstrated better configurational learning. This recalls the classic Piagian (1967) distinction of topological, projective and Euclidian relationships. One might say that in the absence of all other environmental cues except layout, Euclidian understanding develops slowly. On the other hand, Peponis et. al. (1990) had suggested that configuration creates its own structure of wayfinding and exploration. This structure is learned more rapidly and based on this experiment, it can be assumed to predict about 55% of the exploration and 54% of wayfinding.

6. Final Comments

This is perhaps the first attempt to compare data from exploration, wayfinding and cognitive tests between a real environment and its virtual counterpart. Furthermore, the virtual world was developed to control all kinds of extraneous variables and layout was the only common element between the two. The results show that the two environments produced similar behavior when considered from the point of view of layout. Not only that, layout as understood from a Space Syntax perspective predicted about 53% of wayfinding and exploratory behavior in an environment that had layout and nothing else. Admittedly more tests and similar comparisons need to be carried out; perhaps in more immersive virtual environments. As the results stand now, configuration remains the strongest predictor of both exploratory and wayfinding movement. This message has to be delivered to the design community.

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