# The Predictive Power of (only) Space Syntax Regarding Wayfinding and Cognitive Mapping

Saif Haq <saif.haq@ttu,edu >
Glenn Hill <glenn.hill@ttu.edu>
Adetania Pramanik <adetania.pramanik@gmail.com>

Texas Tech University, USA

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## Abstract

The role of spatial configuration in human exploration, wayfinding and cognition has been considered important by numerous researchers. In this regard, experiments have suggested that Space Syntax variables are a significant predictor of both. However, many of these experiments were done in *real* settings without sufficient control of extraneous variables and so 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, perceptual access, landmarks and so on. These call to question the experiment's internal validity. On the other hand, there have been a good number of similar experiments done in virtual realities (VR), and a similar conclusion regarding Space Syntax variables have been reached. But here, the question of ecological validity arises.

To answer these two categories of criticisms, a comparative experiment was undertaken that applied the same research methods in a real building, and in its VR counterpart. The VR was created in the same scale and layout as the real building; but here, all extraneous environmental variables were controlled. Two groups of participants drawn from the same age group with similar backgrounds carried out exactly the same tasks in both the settings. Analysis of the two data sets suggests that while they are different, the wayfinding and cognition data correlates with Space Syntax variables in a very similar manner. This highlights the strong predictive power of Space Syntax variables regarding exploratory movement, wayfinding and spatial cognition.

The first section of this paper provides a review of the experiment done in the real building. It then reports the processes and pitfalls of developing the VR system. It goes on to describe the wayfinding experiment in the VR including pilot study findings and modification to the experimental methods. Implications of this research in the light of broader environmental psychology concerns, and future considerations are also included.

# 1 Introduction

Human wayfinding has behavioral and cognitive components and is influenced by the environment in which it takes place. Carlson, Holscher et.al (2010) considers the spatial structure of the building, the cognitive maps, and the strategies and abilities of individuals as three contributing factors of wayfinding. They have proposed a three-set venn-model that depicts the inter-relationship of these components. (See Figure 1A) Additionally, they also describe the attributes of the overlap between each pair, and between all three. We propose a working model based on a similar concept. In this, we slightly modify Carlson, Holscher et.al's model and collapse cognitive map and abilities into 'internal processes'[1] and add 'behavior' as a new factor (see Figure 1B). We propose a 'connection' between a building's spatial structure and behavior, 'compatibility' between internal processes and behavior, and 'correspondence' between internal processes and the building's spatial structure. The spatial structure that we concentrate on is its layout complexity as derived from Space Syntax analysis of the floor plan. We hypothesize that syntactic variables will have a correlational 'correspondence' with cognitive map and a 'connection' with wayfinding behavior.

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 et.al 1990, (Hillier, Major et al. 1996), Haq and Zimring 2003) or their gaze directions and stopping positions noted (Conroy 2001). Cognitive components, being internal, are more difficult to categorize. Verbal descriptions of the environment (Lynch, 1960), sketch mapping (Lynch 1960, Kim 2001, Haq and Girotto 2003, (Lang, Baran et al. 2007)), pointing to unseen destinations (Dara-Abrams 2006, Siegel 1981, Sholl 1996, Haq and Girotto 2003), estimating distances (Evans and Prezdek 1980, Kirasic, Allen et. al 1984) etc. are some of the methods used to investigate the role of cognitive components. The third component in wayfinding studies -- environmental attributes -- is 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 and White 1975), relative locations (Kuipers 1978), topological relations (Kuipers, 1978). anchor points (Golledge 1978), visibility between destinations (Braaksma and Cook, 1980), visual access, architectural differentiation, plan configuration, (Weisman 1981), node-link network (Garling, Book and Lindberg, 1986), Interconnection density (O'Neill, 1991), and more recently, Space Syntax values such as integration (Peponis et al 1990, (Dara-Abrams 2006), Integration3, and connectivity (Haq 2003, Haq and Zimring 2003) etc. Theoretically, any or all of these environmental attributes should relate to internal landmark knowledge, route

[1] We also include such factors as spatial working memory, schemas (Gross and Zimring 1992), gender differences, age etc. in this group.

knowledge, or survey knowledge. These are considered the dominant theoretical framework in environmental psychology (Montello 1998).

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 (Holscher, Brosamle et al. 2009). 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, bringing up criticisms of ecological validity. On a more serious note, these reproductions do not allow the subjects to decide their movement i.e walk on self 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 2003), but these experiments can be criticized because they fail to control extraneous environmental variables – those that are not part of the study. Now-a-days Virtual Realities (VR's) are increasingly being used in wayfinding experimentations. These provide immersive computerized environments that can be 'navigated' by the subject, and where extraneous variables can be systematically controlled. (See for example Conroy 2001). In this way there can be reliable measures between the variables and greater internal validity of the experiment.

With regards to the model presented earlier, we are interested in the 'connection' between a building's configuraional structure as obtained through Space Syntax analysis, and wayfinding behavior in it, and the 'correspondence' between that structure and cognitive maps. For this purpose we report an extension to a previous study that was carried out in three real hospital buildings that indicated that Syntax configuration is a valid predictor of both wayfinding behavior and cognitive mapping (Haq and Zimring, 2003). In the extended experiment, one of the three hospitals is recreated in a VR model with uniform environmental conditions. 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 indicates that the spatial structure measured by Space Syntax has a 'connection' to wayfinding behavior and 'correspond' to the cognitive maps of the subjects.

# 2 Background

Extending the procedures and concepts developed by Peponis et. al. (1990), Haq and Zimring (2003) 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 2) is directly relevant to this paper. In those studies the Space Syntax variables of integration, integration-3 and connectivity were considered, and their relationship to wayfinding behavior was investigated by exploratory and wayfinding use of spaces, and to cognitive development by sketch-mapping and pointing to unseen destinations.

Analysis of settings began with identification of environmental units. These were developed from cognitive considerations and were understood as *uninterrupted visibility lines*[2] and *nodes*. Uninterrupted visibility lines were considered akin to 'vista' (Gibson 1979, Heft 1983) and were equated with Space Syntax *axial lines.* Their configurational values were determined by Syntax methods (Hillier and Hanson 1984), specifically through the use of the computer program Spatialist[3] (figure 3). Nodes were considered to be 'transitions between vistas' (Heft, 1983) and were places of pause and spatial decision making. In this case, corridor intersections were hypothesized to be such locations and thus were the 'nodes' of the study. Operationally, they were defined as intersections of axial lines, and their values were calculated by taking the average values of their constituent axial lines. Thus *Integration*, *Integration3* and *Connectivity* were the calculated values for both lines and nodes.

Data regarding wayfinding behavior in 'City' hospital was collected through an empirical experiment. 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, and sketch mapping. The first two tasks were taken as indicators of wayfinding while the later ones measured cognition.

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 (marked A and B in figure 2) 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 wayfinding, the subjects were required to find specific destinations. Four destinations were pre-selected so that they were located in all ranges of integration values. 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 wayfinding task, the subject was made to face west and asked to

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[2] Haq (2003) had also considered 'segmented' lines as units in wayfinding research.
[3] Peponis J,Wineman J, Rashid M, Bafna S, Kim S H, 1998 *Spatialist* (Version 1.0) GeorgiaTech Research Corporation, Atlanta, GA

point to the out of sight locations that s/he had reached before. These were performed using a circular cardboard with angles marked on it in 10-degree intervals and a pointer attached to the center. Each subject performed 13 pointing tasks at different times and with increasing familiarity with the setting. In total, the subjects did 871 pointing tasks. 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 on a 8 ½ inch by 11 inch sheet of unmarked white paper. 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 ubjects, 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 a 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 (Peponis et. al. 1990, Willham 1992). Redundant use is important because it gives a measure of wayfinding difficulty and also identifies lines or nodes where people go when they are lost. In environmental terms it provides an index of 'wayfinding attractiveness' of a space and in cognitive terms a sense of spatial understanding (because it is visited more). In this case, the following was calculated: Total Use of Redundant Lines (TURL), People Using Redundant Lines (PURL), Total Use of Redundant Nodes (TURN) and People Using Redundant Nodes (PURN). 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.

From the cognitive tasks the following data were collected: 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 2). Each map was looked at by sections and then as a whole. After comparing with an actual plan drawing, 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 VR experiment (explained later). 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 VR study

Virtual reality 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”. A specific kind of virtual reality is where the user can decide on his or her own path and move in those paths. Such a model was produced for this experiment. This was a replica of City Hospital, created in a ‘*one to one’* scale[4]. In it, all environmental variables, except the layout was controlled (figure 4). This is explained later.

## *3.A Software*

There were two main considerations in making a VR model. First, appropriate software that allows both the creation of virtual world and user controlled movement within it. Second, the required hardware to create a sense of immersion in that environment. Sherman and Craig (2003) have identified four key elements in Virtual Reality (VR). First is the virtual world. For this study it 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 that 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 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 physical movement (reproducing walking) and head turning. The former is the ability of carrying out open exploration and wayfinding in the VR and the latter is the ability of viewing the two sides of the subject (as if one is turning one’s head).

The virtual world was built from the drawings of the actual hospital. The model was a representation of corridors from the second floor of the hospital (figure 2). This was created using software that generated

[4] At this point it should be noted that Willemsen and Gooch (2002) had reported that “distances are not perceived the same in real and virtual environments”. However, in our case, since we were comparing real and virtual scenarios, we designed the VR in the same scale as the real building.

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, furniture and so on. Only the built-in reception desks were modeled because they restrict physical movement. Figure 4 illustrates the similarities and differences between the real hospital and the model. In the virtual environment, all the corridors had the same floors, same walls and same ceilings, and were given a similar luminosity everywhere. There were no other environmental elements, and so architectural differentiation was controlled. 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. The software provided objects of boxes, which were made invisible and inserted as collision boxes in the VR. 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 ‘walker’ in relationship to a particular reference frame (Kessler, 2002). In this particular experiment, the tracking device was used to report positions of the user in the environment in the range of time when the user ‘walked’ in that environment. The information recorded was time, and x-y coordinates.. This data was transformed back to the corridors’ floor plan as lines. These lines illustrated the paths that the walker completed in a period of time in relation with the building floor plan (Figure 5 inset B)

### *3.B Hardware*

User monitoring is real-time monitoring of a 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[5] was selected as a control device because it is simple to manipulate by people who might not have much experience with computers. The movement of the joystick was calibrated so that pushing it forward meant the user moved forward, tilting it to the left

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

while going forward was moving left and so on. Also the joystick simulated head movement. When it was turned to one side, the view rotated to display that particular side. Thus a person could actually be stationary and see around him or her.

Platform is the part of the VR system where the participant is situated. A platform can 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 5). Conroy (2001) has discussed the effectiveness of various display systems in the creation of immersive-ness. Although she considered the use of projection-based displays as less immersive than head-mounted display, she also acknowledged that both displays provided a similar pattern of movement. The VR in this experiment was projected on a wall to expand the use of regular monitor-based display. The 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 comparison, the projection-based display in our experiment produced 61 degree FOV (Figure 5).

### *3.C Data Generation in the VR model*

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

The experiment consisted of five phases. The first phase was pre-training, i.e. getting comfortable using the joystick and navigating within a generic VR 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 5 inset A). 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 to match the four locations that were used for wayfinding in the real hospital earlier. Please note that these four locations were in all ranges of the Space Syntax values.

After completion of the open exploration, each subject was asked to perform a wayfinding task (third phase). For this, a VR model 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 that time, the destination could not be found, the researcher would stop the experiment, take control of the joystick, and virtually ‘escort’ the user to that destination. At the destination, another VR was opened which put the user in the same location. S/he was asked to face west and use a pointer on a graduated disc to 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 ½ x 11 white sheet of paper.

Thirty-two undergraduate students (9 males and 23 females) participated. Data from two students could not be used because they could not complete the experiment due to motion sickness. Biocca (1992) had reported earlier that individuals have the ability to adapt to some level of discomfort caused by motion. He also quoted 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 data, 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 VR. This result is important as it demonstrates that joysticks can be used as a tool of wayfinding studies in future VR's. 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 rotate themselves and walk 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 real and the similar virtual setting 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). The data from the two environments was compared through two-sample t-tests assuming unequal variances. The results are reported in table 1 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.

For the axial lines, three kinds of environmental variables were considered – Connectivity, Integration-3 and Integration-n. Two sets of scatter grams were done for TUL and PUL in Open Exploration (OE) respectively, and are shown in Figure 6 as a side by side comparison. This 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).

The node variables were the average values of Connectivity, Integration-3 and Integration-n of the constituent axial lines. In the case of TUN in OE, only Integration-n yielded good correlations in both the settings (figure F, TUN, row 3). Correlations of the rest were poor and insignificant. However in this particular case the poor correlations were 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 7). Thus, irrespective of good or not good correlations, they are all comparable across the two settings. In other words, exploratory behavior correlates with Space Syntax variables almost equally (both good and bad) in real and virtual settings.

Wayfinding tasks were quantified by redundant use of lines and nodes. Figure 8 shows the r-value comparison and scatter grams of TURL and PURL with the three syntax variables. As before, they are quite similar and comparable. 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. On a positive note, even these low correlations were similar and comparable between the real and the virtual environments.

## *4.A Discussion on exploratory and wayfinding behavior*

The t-tests reported earlier 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 settings, and this prediction is identical in a comparable virtual setting where layout was the only independent variable. The importance of configurational variables is not a new conclusion and has been reported before. (Peponis 1990, Haq 2003, Haq and Zimring 2003, Dara-Abrams, 2006) What is novel is the fact that the same experimental procedures when undertaken in a comparable 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 2). 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 VR environment. These numbers were *lower* in the real building -- 43% and 37% respectively (table 2). 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 configurational structure. 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 other words, the behavioral affordances in the VR was less (Montello 2007).

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 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 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 configurational variables as determined by Space Syntax analysis – 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

We begin by introducing the classic Piagian (1967) distinction of topological, projective and Euclidian relationships. Cognitive measures in this experiment were average pointing errors (in degrees), sketch mapping accuracy, and the correlation of corridors sketched to their syntactic values. The first two were considered measures of Euclidian learning while the last one indicates topological understanding.

Data from the real and the virtual worlds were compared using two-sample t-tests assuming unequal variances. This revealed a substantial difference between the two data sets (p-<.0079 for pointing errors and p=.0006 for sketch mapping accuracy, see table 1) 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%. Therefore it can be safely assumed that cognitive learning of Euclidean properties in the virtual environment was less than that in the real world. However, when we correlated the lines that were drawn in the sketch maps with their syntactic values -- connectivity, integration-3 and integration -- we found that in all the cases they have good correlations, and that those in the virtual environment are always higher than those of the real world. (figure 7 shows side by side comparisons). 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 this factor will be reflected in their sketch maps also.

The curious result that emerges is that the subjects in the virtual world had less Eucledian understanding, yet they demonstrated better learning of topological variables as calculated by Space Syntax analysis. One might say that in an environment devoid of all other cues except layout, topological learning is accelerated while Euclidian understanding developed slowly. But it did not affect wayfinding because the average wayfinding success (defined by the percentage of finding destinations) was 79% in the real environment and 76% in the VR. In this regard Peponis et. al's. (1990) earlier suggestion that configuration creates its own structure of wayfinding and exploration, is also relevant. The added caveat is that this also influences cognitive mapping. The topological 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 Implications

From an experimental point of view, this was perhaps the first attempt to compare data from exploration, wayfinding and cognitive tests in both a real environment and its virtual counterpart. The virtual world was developed in the same scale and geometry as a real building, but designed to control all kinds of extraneous variables so that layout remained the only independent variable. Further, the VR was not fully realistic, nor did it provide a full field of vision (FOV). Nevertheless, the results show that the two environments provided a similar correlation to Space Syntax variables. This theory begins with very simple concepts of connections and builds up to larger concepts of spatial relations in which each relations affect, and is affected by, all others. It seems almost unexpected that such simple concepts might have such predictive power. Yet this has been the case on numerous previous occasions and in our experiment also. Because we have concentrated on layout variables only, through a carefully controlled experiment, we can begin to get more specific about the predictive (and perhaps not explanatory) power of Space Syntax.

In terms of immersiveness, the virtual environment was not fully realistic, and it was navigated by manipulating a joystick. Yet, configurational variables predicted about 53% of wayfinding and exploratory behavior in it. Will higher immersive conditions change this? Regarding environmental factors, more tests and similar comparisons need to be carried out to understand the influences of global complexities such as scale, geometry and multiple levels[6] on one hand, and the effect of local environmental aspects such as color, lighting and other ‘landmarks’ on the other.

Layout complexity of the physical (real) environment has been identified as an important aspect of cognitive mapping (Weisman 1981; Garling, Book et al. 1986), yet, ‘what constitutes a complex layout in a psychological sense is a question of ongoing research” (Montello 2007). To this distinction (between real and psychological) we include the Piagian (1967) ideas of topological, projective and Euclidian properties as playing a role in both conditions. This was hinted at by the results shown in this paper. Also, the larger question of what properties plays a more dominant in what stage of wayfinding is of added interest.

What is important to note is that layout complexity as measured by Space Syntax, and hence topological, has both a physical and a cognitive counterparts. If so, then theories like Space Syntax (including isovist studies) which are concerned with measuring the physical aspects of layout complexity can become more useful in testing new layouts for ‘cognitive friendliness’.

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[6] The research of Holscher, Brosamle, et al. (2009) is noteworthy in this regard.

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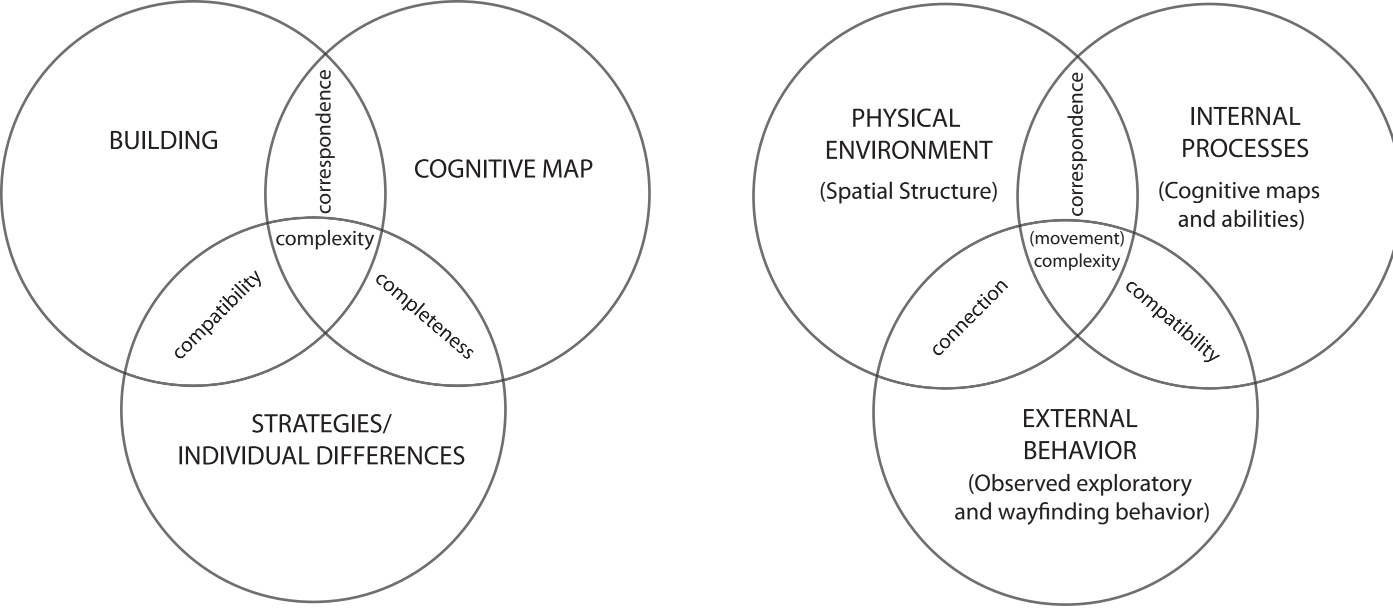


A: Redrawn model for wayfinding/navigation as proposed by Carlson et. al. (2010)

B: Proposed wayfinding model

Figure 1: Comparison between the proposed wayfinding model with Carlson et.al.'s (2010) proposal.


Figure 2: Floor plan of hospital

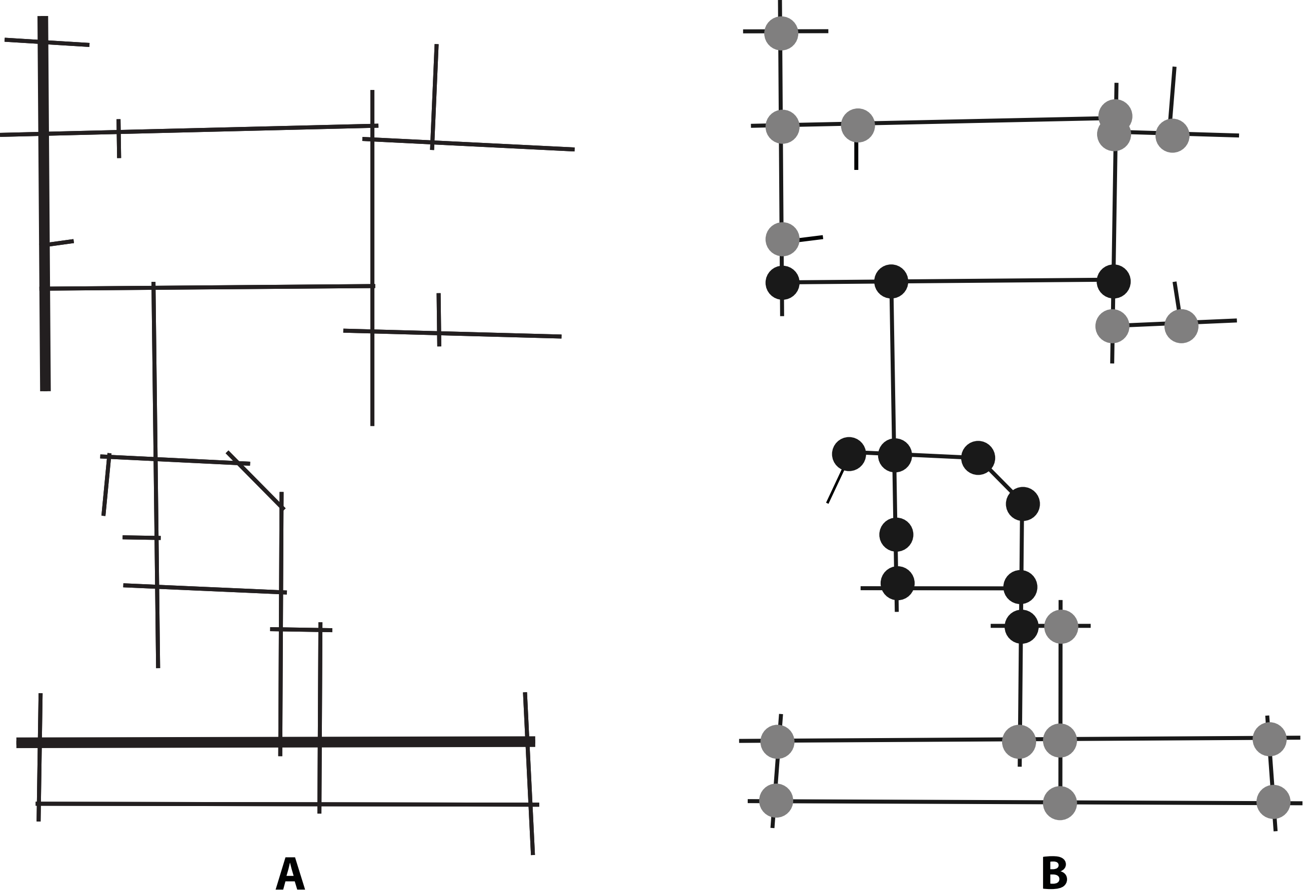


Figure 3: Space Syntax analysis of City Hospital.
Dark areas show more integrated sections (lines and nodes)

Fig 04: Comparison between the real hospital and the VR model

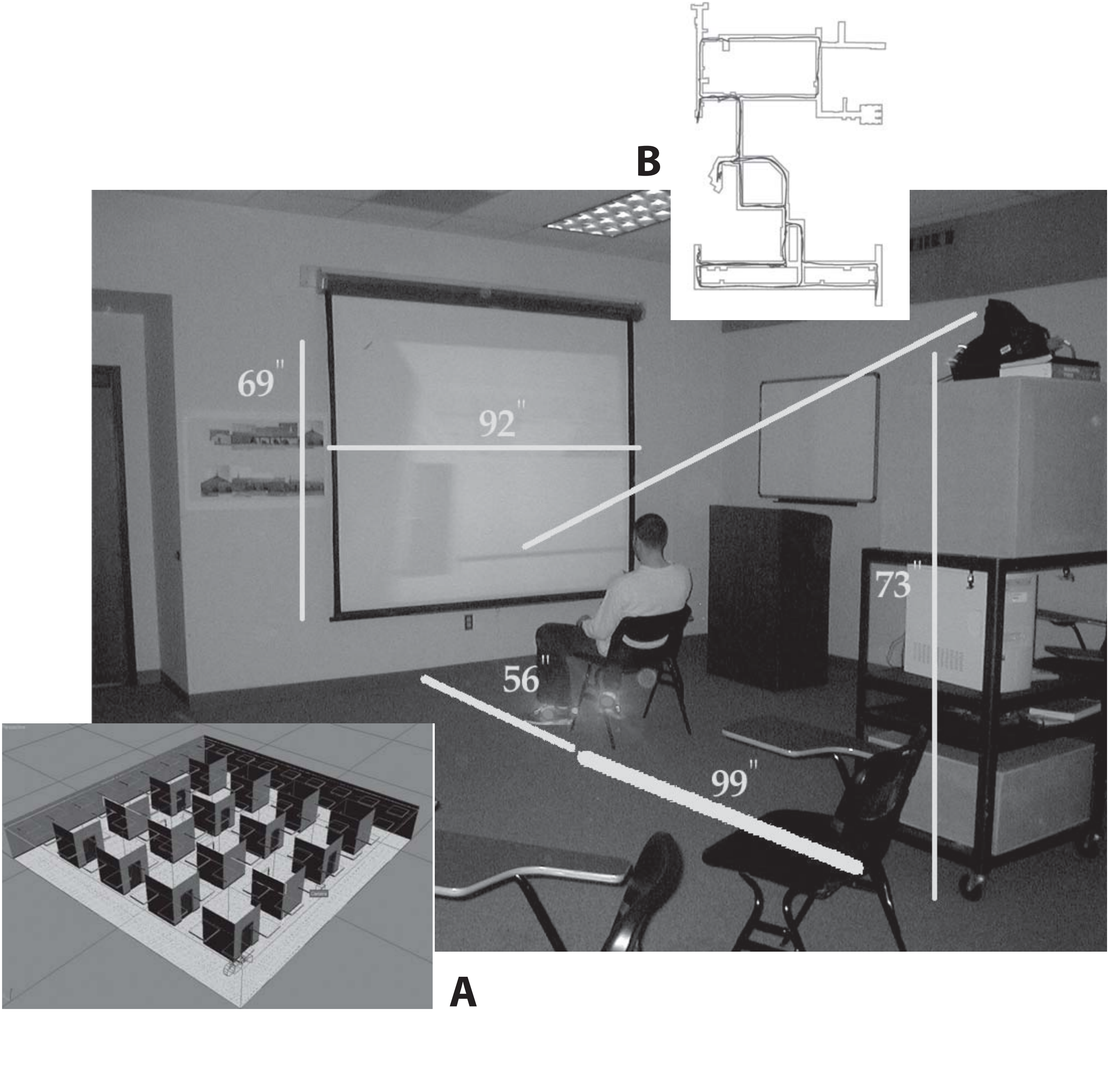


Figure 5: The platform with the VR equipment.
Inset A is the pre-training environment and B shows computerized recording of individual tracks

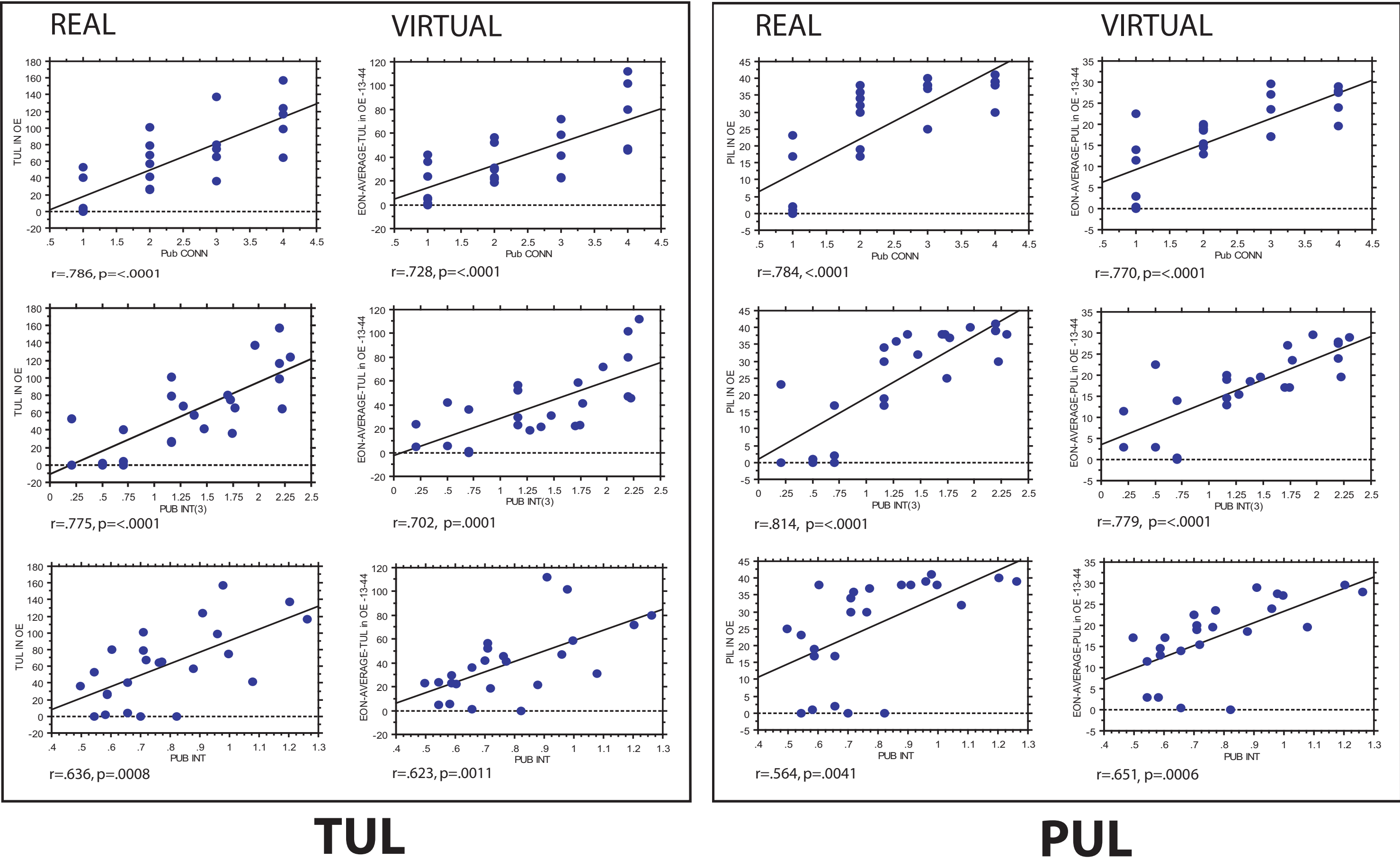


Figure 6: Correlations of Total Use of Lines, TUL and People Using Lines, PUL in Open Exploration with three syntactic variables in the real and virtual setting.

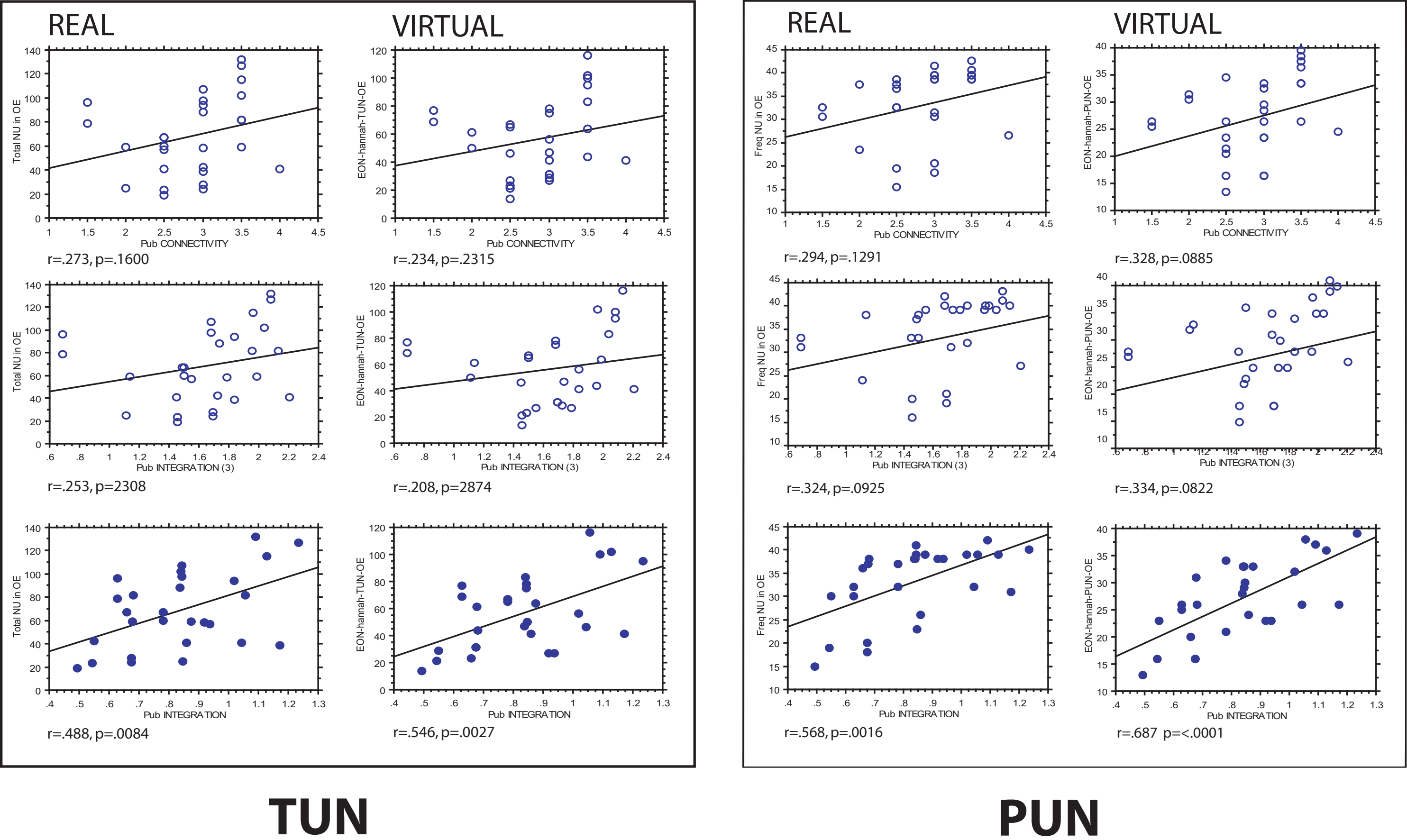


Figure 07: Comparison of Total Use of Nodes, TUN and People Using Nodes, PUN in Open Exploration with four syntactic variables in the real and virtual setting

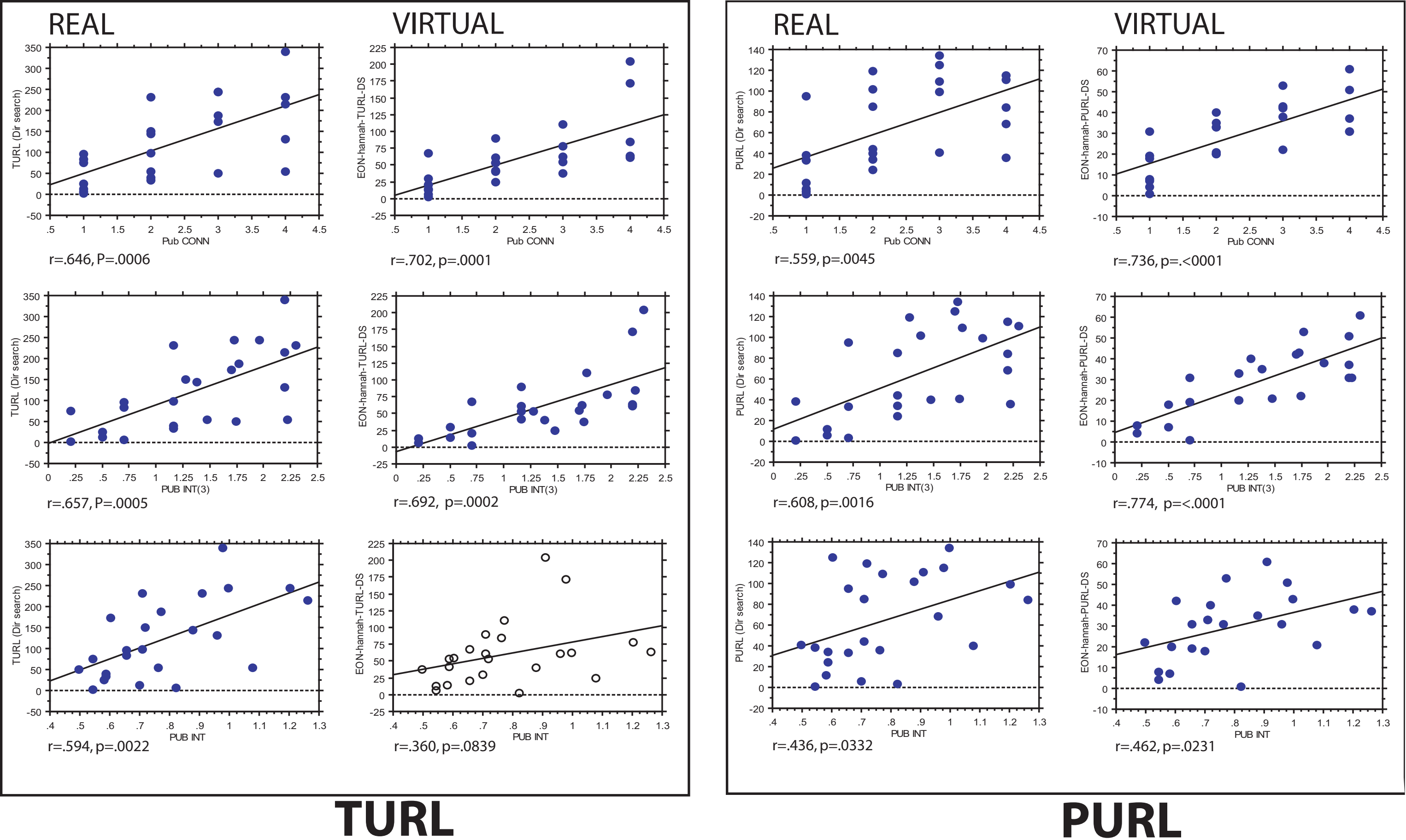


Figure 08: Comparison of Total Use of Redundant Lines, TURL and People Using Redundant Lines, PURL in Directed Search (wayfinding) with three syntactic variables in the real and virtual setting

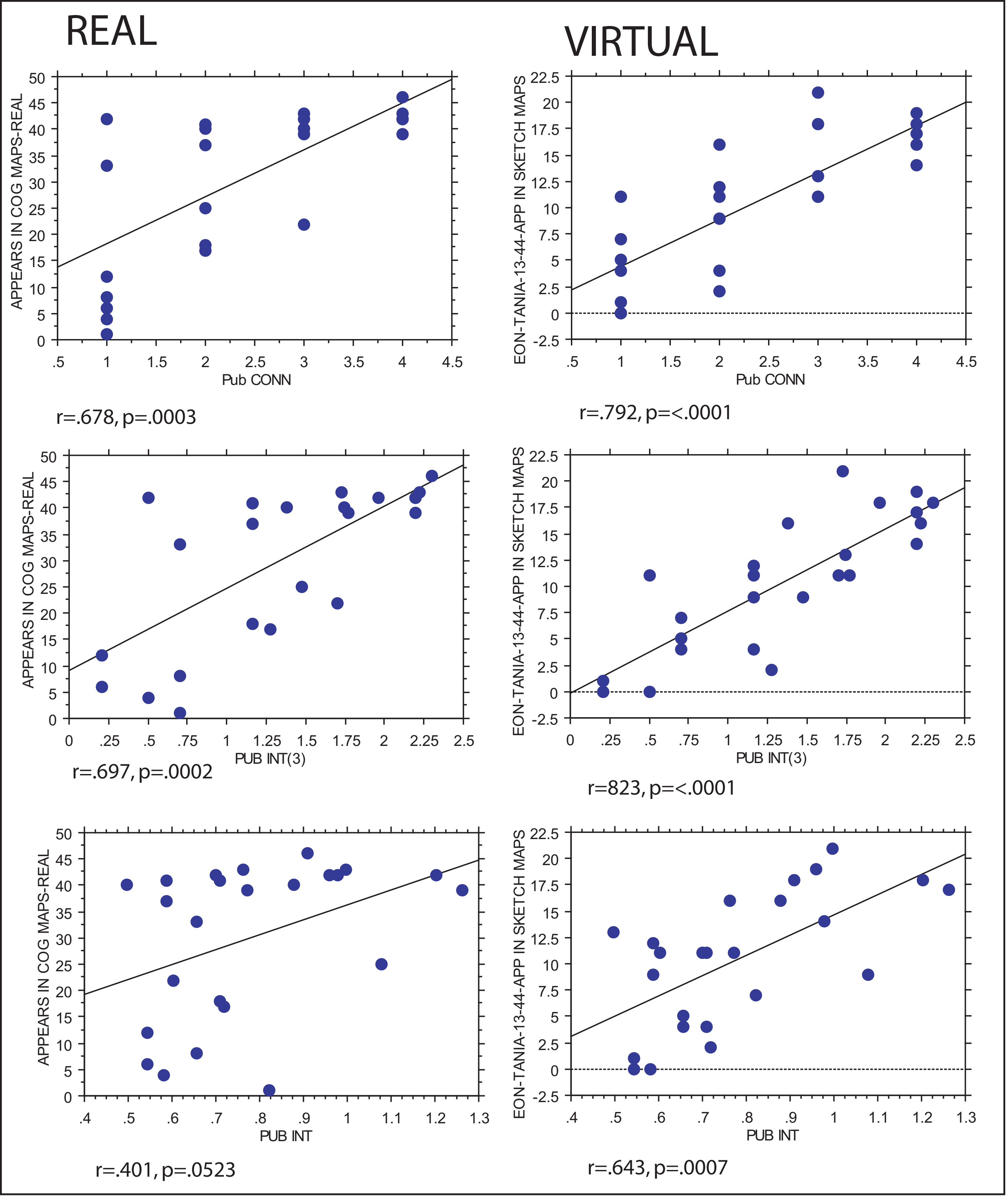


Figure 09: Comparison of lines appearing in sketch maps with three syntactic variables in the real environment and the VR