Proceedings of the Ninth International Space Syntax Symposium
Edited by Y O Kim, H T Park and K W Seo, Seoul: Sejong University, 2013

ON SPATIAL WAYFINDING:

Agent and human navigation patterns in virtual and real worlds.

079

Nicolas Orellana
University College London
e-mail: nicolasorellanac@gmail.com

Kinda Al Sayed
University College London
e-mail: k.sayed@ucl.ac.uk

Abstract

The paper is focused on the field of navigation and spatial wayfinding, based on the study of movement within an airport building, covering both real and virtual environments and at the same time attempts to find contributions from the field of agent-based simulations.

Over the last thirteen years research at Space Syntax Ltd. has demonstrated there is a strong relationship between the configuration of space and the pattern of human aggregated movement on buildings and urban areas. In this sense, this research includes analysis of virtual realities, where individuals might navigate through environments which only contain spatial information. Those results were compared with the data observed in a real building in order to find patterns of navigation not only at an aggregated level, but also at an individual spatial decision-making level.

The specific case under study is Terminal One, Paris Charles de Gaulle Airport. Observations of human behaviour were carried out and then the plan of the building was used to build three virtual environments, each of them with different three-dimensional characteristics, but based on exactly the same plan. These environments were tested in a total of 21 experiments, where people were asked to navigate through them and to resolve a wayfinding task. Also, participants were asked to sketch what they remembered from the navigation.

In conclusion, a strong relation between virtual navigation and human pedestrian movement is demonstrated; it is also argued that the variation of the three-dimensional properties of a place does not considerably affect the navigation, while the spatial configuration of plans is the main generator of patterns of movement. From the point of view of pause location, it is found that people tend to pause in specific spaces that offer maximum visual information and control of the environment. Also, a high correlation between the mental representation of the system and the level of integration of the spaces is found.

This research was presented by the author as a dissertation of the MSc Advanced Architectural Studies at University College London.

Keywords: *Space Syntax, wayfinding, navigation, agents, airport building, virtual reality, movement, Depthmap.*

Theme: *Spatial Cognition and Behaviours*

1.1 Research questions

To what degree are the strategies that people employ to navigate in an unfamiliar environment influenced by the spatial configuration of the plan? How do people navigate through the space? How do the three dimensional properties of a place affect the decision-making? And finally, is human movement analogous in real and virtual environments?

2.1 Spatial Wayfinding

When people are in an environment which is unfamiliar, they tend to rely on certain navigation strategies to complete their understanding of these new spatial settings and fill in the gaps, which might be a stressful experience. Some airports have a reputation for being particularly confusing (Fewings 2001); even finding one's way in a public building such as an airport terminal tends to be a frustrating task (Hölscher et al. 2006).

Looking at a general definition of wayfinding, Carpenter (1989) argues that it is about what people do in order to find a way somewhere. According to Fewings (2004), wayfinding is a human-centred approach which refers to how people use information-gathering and decision-making to orient and find their way or determine what direction to take through an environment to where they wish to go.

Some studies have shown a change in wayfinding behaviour when people are familiar with the environment (Hölscher et al. 2007). Fewings (2004) argues that it is possible to differentiate two main kinds of wayfinding; the "static choice problem", where people already know the environment they are to navigate and the decision is made knowing the possible results, and the "dynamic choice", where the decision-making is done in an unfamiliar environment by first-time visitors. In the case of airports, most of the visitors are in the building as a tourist, so they could be unfamiliar with the environment and perform a dynamic choice wayfinding.

It might be suggested that not only the architectural environment affects the wayfinding process. In the real context, buildings are composed of architectural boundaries plus, among other things, signs, texts, colours, textures, smells, vegetation, sounds and people. So people may not only use sight, but also smell, touch, sound, thermal perception and chronoception in order to interpret the external stimulus. There is a huge range of possibilities, but, as the objective of this research is to understand the relation between space and human performance, only spatial wayfinding will be analysed.

The definition of spatial wayfinding could be based on the evidence presented by Dalton (2001), who defines wayfinding as the act of travelling to a destination performing a constant process of decision-making, using the cognition to evaluate the previous and constant spatial environment. So, for the purpose of this research, spatial wayfinding is defined as the act of finding a way, processing the input obtained by the spatial properties of the environment, based only on visual cognition. This process is composed of a method of navigation and orientation-evaluation of decision-making.

2.2 Navigation

Based on the assumption that is the space which governs human movement, Mottram et al (1999) propose that just by controlling certain parameters, it is possible to recreate a computational agent performance similar to that observed in the real world. In this way, Turner and Penn (2002) argue that using the field of view, the isovist properties and the number of steps taken before reselecting a destination, it is possible to obtain a cumulative movement highly correlated to the aggregate human movement pattern.

But there is a discussion about what is the real relation between the aggregate movement and the individual performance. Some research has investigated the relevance of the space syntax model at an individual level (Hölscher et al. 2006; Emo et al. 2012). Turner (2006) discusses whether the internal axial structure actually correlates with the physical constraints of the map or with the internal structure of individuals. He carries out a set of agent-based experiments including the variable of the occluding edge, which gives a more human-like pattern of movement than in previous agent-based analysis. In conclusion, there is found to be a good correlation between agents and human performance in urban areas, so the author argues that the axial map is the embodiment of movement and as a consequence there is a relation to the environment and the agent structure.

2.3 Contribution of the research

Most of the research on spatial wayfinding covers the analysis of pedestrian movement at a cumulative level; also, agent-based models perform high levels of correlation to human behaviour, but again, only in an accumulative scale. It is recognised there is a need for understanding of pedestrian movement at an individual level, which is the generator of the aggregate result.

In the field of agent-based studies, there is previous research (Batty 2001; Turner and Penn 2002; Turner 2003; Turner et al. 2004; Turner 2007) that draws on encoding natural movement using agent-based models to find correlations with human pedestrian behaviour, but all of them have been carried out in urban areas or art galleries. There is a need for studies as to how this computational tool can be used in different types of building environments, such as an airport, the case studied by this research, where navigation is one of the main issues.

3.1 Theoretical approach

The configurational point of view of Space Syntax is based on the representation of systems in terms of patterns of connectivity between discrete spaces. The analytical Space Syntax approach allows us to generate topological representations of any spatial system at a local or global level (Hillier 1996). These representations are purely based on spaces rather than building geometric forms. The range of techniques developed by the Space Syntax community gives a more comprehensive and evidence-based approach towards understanding the built environment as a whole, looking at the emergent social phenomena related to the space and making the non-discursive socio-spatial structure a discursive one (Hillier 2006).

3.2 Spatial analysis

In order to understand the properties of the spaces and obtain a clear picture of the configuration of them, the syntactic computer software "Depthmap" was used to analyse the airport plans. This software has its origins in the Space Syntax theory and has been defined as a tool to "think with". The computational analysis has been done in order to test and discover patterns and relationships between human behaviour and space.

As the main issue in this research is to understand how people navigate through the space, the agent-based analysis is one of the most important tools. It works by reproducing the aggregate movement of agents in a plan, according to the rules of natural movement and a certain number of parameters: the number of steps before deciding to change the direction of navigation, the field of view and the timed steps performed in the system before disappearing.

3.3 Observation on real environments

In the interest of finding patterns of real human behaviour and to obtain a detailed picture and understanding of movement in the airport, spatial observations were carried out on Terminal One, Paris Charles de Gaulle Airport. The methods of analysis were "people following" and "dynamic snapshots".

A total of forty people were followed and their movements were traced through the airport, from the main entrance, until they changed their activity from walking to sitting or waiting in a queue. In order to differentiate patterns of navigation, people were classified as individual or groups. During this analysis, two factors were recorded; the time they spent walking between pauses, in order to obtain an overall walking speed, and the time they spent on the pause points.

3.3.1 Limitations on real environments

It is necessary to acknowledge this airport building presents some restrictions, as the time of observation and the area in which observation was allowed was limited by the permission given by the airport authorities. On the other hand, observation of human behaviour has some limitations in any case, because of the difficulty of recording where people are looking before making a decision or if the decisions are made because of spatial information observed or because of non-spatial information, for example, reading signs. For these reasons, observations in real environments are usually affected by a certain degree of inaccuracy.

3.4 Observation in virtual environments

According to previous research (Conroy 2001), a strong statistical correlation has been found between real world observations and virtual analysis of the replicated environment; in other words, people appear to navigate in an analogous way in both realities. In this sense, and understanding the field of new possibilities for testing different factors that technology could allow, this research is enhanced by experiments in virtual realities.

In this investigation into virtual environments, participants were asked to navigate through a wayfinding task while their performance was recorded. Using the plan of Terminal One, Paris Charles de Gaulle Airport, three different virtual environments were built on a virtual three-dimensional architectural platform. All contained only walls, floors and ceiling. The idea was to avoid any distractions within this environment that could affect the decision-making of participants, such as colours, people, words or a strong differentiation of light.

"Model A" shows the purest spatial representation, where all walls are exactly the same height, in this case five metres. In addition, all elements in this model present the same texture, a grid formed by tiles of 120cm by 60cm. The presence of this grid helps to give a more realistic perception of the scale, the distance covered, the differentiation of the forms and the overall image of the environment (see figure 3.1).

"Model B", presents similar characteristics to the first one: exactly the same plan and same material in the vertical and horizontal elements, but including important variations on the height of the space. The ceiling is composed by a continuous nurb form, which changes its height from three metres at the lowest point to fifteen metres at the highest (see figure 3.2). This random ceiling tries to test whether an important change in the three dimensional form might affect the patterns of navigation of participants.

"Model C", which is also formed from the same plan, presents height variations, according to the real height, and includes transparency differentiation, according to the real material of the building (see figure 3.3). This model tries to include more realistic variables in order to see to what degree they might affect the performance of people.

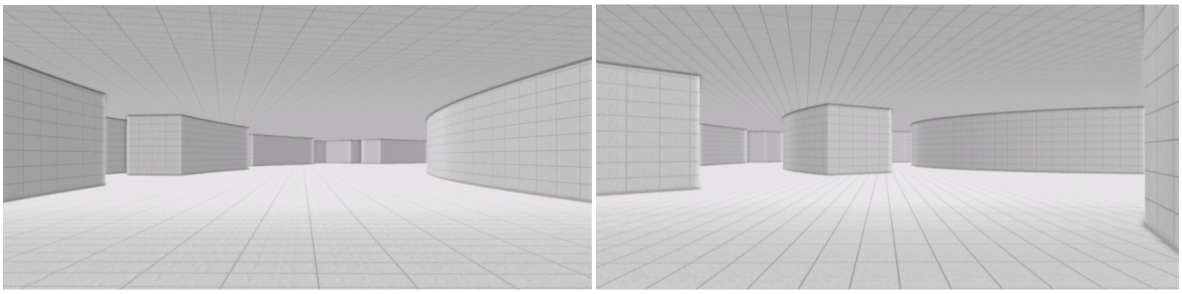


Figure 3.1: Model A, environment with a continuous height in the whole system.

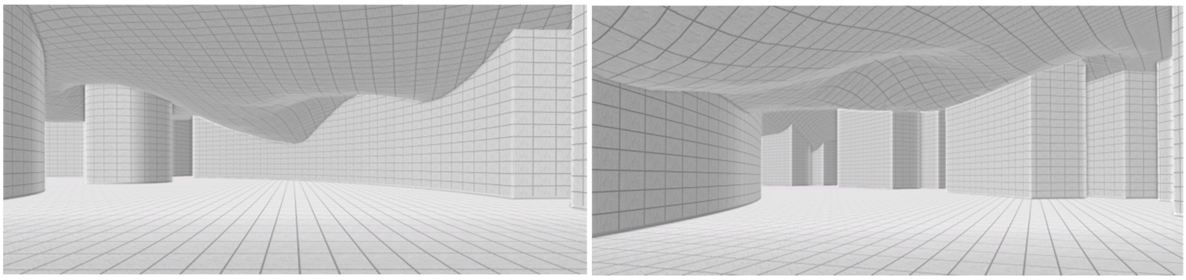


Figure 3.2: Model B, environment with a variable ceiling and random height.

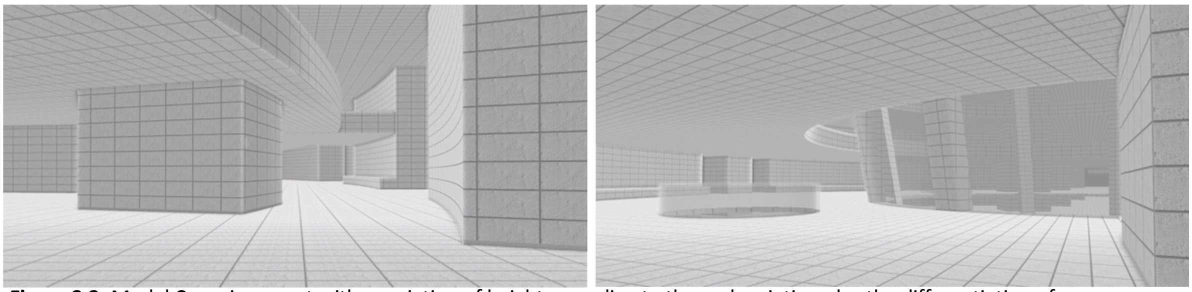


Figure 3.3: Model C, environment with a variation of height according to the real variation plus the differentiation of transparency in elements.

In total, twenty one experiments were carried out, divided into three speculative models. The ages of participants were between twenty six and thirty years old, with a mean age of twenty eight. Most of them were female, in a ratio of 3:1. All of them were right handed and had some or limited previous experience in virtual environments. Eighty percent of the participants did not present any known ocular abnormality. None of them had visited Terminal One, Paris Charles de Gaulle before.

Each participant was asked to navigate in the virtual environments in order to find a red door which was included in one of the walls. All participants were asked to start in the main entrance of the building, the same point where observations in the real building were made. In order to reduce the probability that it would be found by participants and so they could navigate for a longer period, the door was located in one of the most segregated area of the building. The time was tested for a maximum of ten minutes; if the participant had not found the door during the period given, the experiment was stopped.

Before starting the experiment, each participant was asked to navigate for about two minutes in a simple environment, with the aim of familiarising participants with the navigation control.

During their navigation, the point of view was situated at 1.60 metres from the floor, similar to the average real height of participants. The speed of navigation was 1.79 m/s, which is the normal walking speed tested in the real world observations, but with the possibility of slightly increasing this speed to 2 m/s. All walls in the system were represented by a physical mesh collider, with a rigid body so none of the participants were able to 'walk through' walls.

The space of navigation was composed only of the public area of the floor, avoiding access to offices, behind the scene areas and toilets. The lighting system used was pixel lighting with SSAO by Graphisoft BIM, which gives a uniform light to the whole system. Furniture was excluded in all models.

After the experiment finished, each participant completed a questionnaire in order to provide additional data as to age, physical condition, occupation, previous experience and also to answer some questions in relation to their experience during the experiment, for example, what degree of orientation they felt during the navigation in the environments; what, if any, strategies they employed in order to find the door and other comments.

Finally, each participant was asked to do a drawing task where they sketched the layout as they had experienced it. These drawings were used to analyse what elements they remembered from the environment and what relation could be found between what they remembered and the navigation performed in each environment, also to find the relation between the sketches and the axial properties of the plan. The number of times each area is drawn on sketches will represent a value that will be compared with the integration value of the axial line of this area.

3.4.1 Limitations in virtual environments

It is important to mention that the best environment to carry out this kind of experiment is the CAVE, which is a special room equipped with four projectors and devices to recreate the virtual reality. Unfortunately, this facility was not available during the period required; however, it was an opportunity to explore new technologies and programs in order to recreate an environment like the CAVE. A number of pilot experiments were done in order to find the best way to carry out the experiment, testing the usage of joysticks, kinect cameras, different softwares such as Unity 3d, Graphisoft Archicad, Blender 3D and JavaScript. Finally, the models were shown using projectors and joysticks.

The accuracy of results and correlation between navigation in a virtual reality and the experience performed in the real world could be affected by the intrinsic limitation of virtual experiments, where participants are not actually walking and the level of realism given by computers could affect the feeling of being in a real world. Despite of that, the possibility to reduce the number of variables present in the environments justify the usage of that kind of experiments.

It could be argued that the method taken could distort the results because people behave differently in real worlds, but as it will be shown in the results, the high correlation between the virtual experiment performance and real observations demonstrated that this experiment was carried out in an appropriate way and is a valid approach.

4.1 Case study: Terminal One, Paris Charles de Gaulle Airport.

Paris Charles de Gaulle is the main airport in France. Terminal One, designed to handle eight million passengers, was inaugurated in March 1974 and presented as the most modern airport building at the time in terms of operations and design (Onnée 2004). It shows three levels organised within a circular plan. The distribution of spaces was thought to diminish the walking distance of all passengers. But, according to Onnée (2004), passengers are constantly being disoriented by the circularity of the building and the random way different areas are connected.

The area of study will cover all the public space of the floor, which is composed of more than 20,000 sq.m. This analysis excludes all the private offices, toilets, behind the scenes and security areas.

In order to make it easier to understand the following description of the area of study, it was divided into eight sub areas (Figure 4.1), which are three concentric rings, areas of connection between the rings and a sequence of peripheral convex spaces; peripheral ring, main ring, central ring, connection 1, connection 2, connection 3, connection 4 and twenty- two peripheral convex spaces.

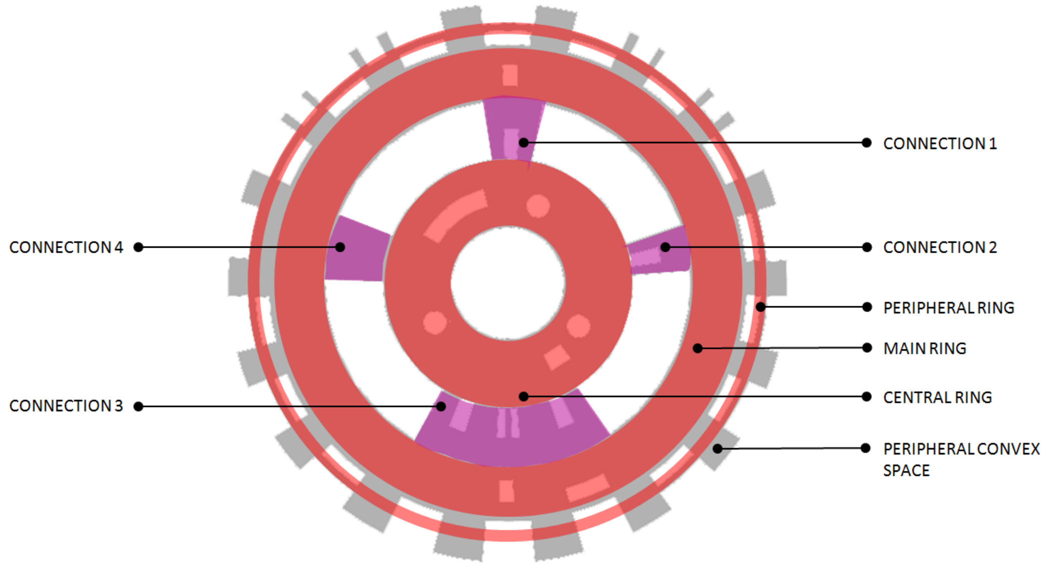


Figure 4.1: Distribution of main areas of the public areas.

5.1 Spatial configuration

The visual integration graph shows the core area of the airport, where it is possible to obtain a bigger field of view and be easily seen. In the wayfinding performance, these areas might be the locations where people tend to pause to evaluate their navigation. In this case, the most integrated areas are located in the main and central rings, with higher values close to the connection areas, especially the connection 3 and 4. The highest value is within the main ring, next to connection 4, reaching 12.2, while the average is 8.8 and the lowest values are 4.9, which are located in the peripheral convex spaces close to the connection 1.

The visual clustering coefficient (figure 5.1), represents a mix between convex and axial analysis. It is possible to suggest that blue areas, the convex-like, are more likely to be occupied by stationary activities; higher values areas, the more elongated, represent where people could perform more movement.

Finally, the through vision graph (figure 5.2) evidences the longer lines of vision with higher values. This graph is a finer representation of the segment choice analysis. It is a representation of the number of lines of sight passing through a pixelated location. Turner (2007) has demonstrated a high level of correlation between the through vision analysis and the pedestrian movement in a building (R2=0.68) and an urban scenario (0.62). In this case, the highest through vision values are in the main ring, especially near to connections 3 and 4, with a pick of 104775, while the average is 31868 and the lowest value starts at 0, around the peripheral ring and the sequential of peripheral convex spaces behind it.

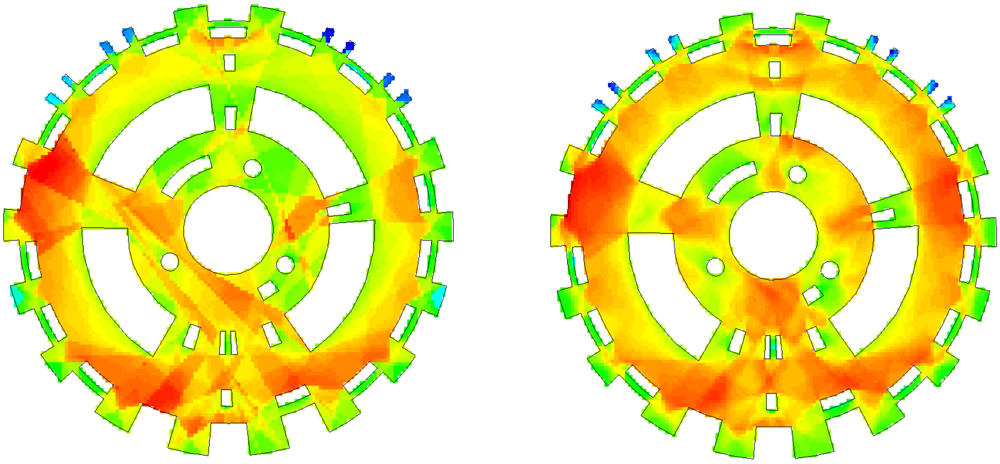


Figure 5.1: Left, VGA integration HH. Right: VGA visual control.

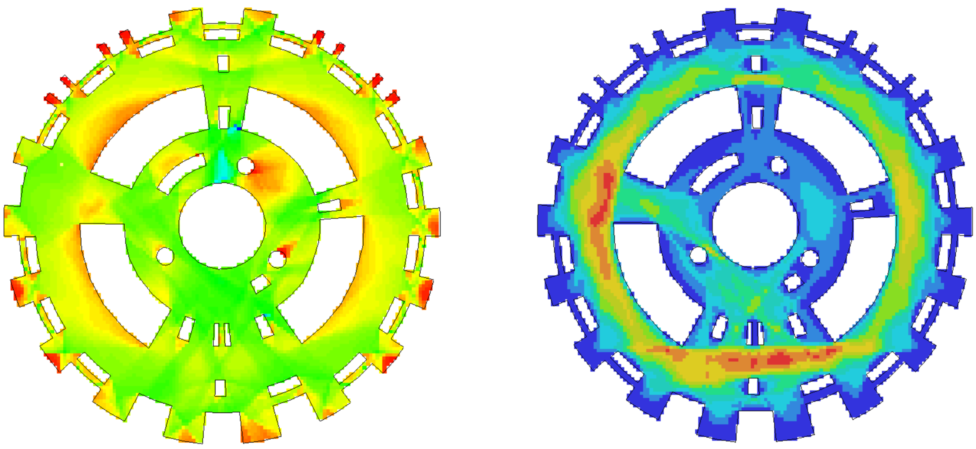


Figure 5.2: Left, VGA Visual clustering coefficient. Right: VGA Through vision.

5.2 Comments on spatial analysis

As a conclusion, according to the spatial analysis results, it is possible to suggest that the highest levels of movement within this building could be performed through the main ring, close to connections 3 and 4, with a tendency to use the central ring as well, near to these connection areas. In relation to the places which could be used as a pause point, where people could stop to evaluate the route in a wayfinding process, the most potential areas might be near connection 3, with a tendency to use the central and main ring nearby connections 2, 3 and 4. On the other hand, the peripheral sequence of convex spaces shows the lowest rates of potential "to move" and "through movement". The comparative table 5.3 of four visual analyses summarises these findings.

Table 5.3: Comparative table of overall, maximum and minimum VGA values.

Area	C. Clustering			Integration			Through Vision			Visual Control		
	CC Av.	CC Max	CC Min	nt Averag	Int Max	Int Min	TV Average	TV Max	TV Min	C Averag	VC Max	VC Min
Connection 01	0.555	0.734	0.339	7.377	9.762	6.339	11217.83	25023	192	0.747	1.375	0.431
Connection 02	0.648	0.824	0.408	7.292	10.194	5.851	8948.731	16111	158	0.618	1.141	0.305
Connection 03	0.556	0.787	0.362	9.051	10.325	6.824	35321.79	99567	704	0.967	1.306	0.185
Connection 04	0.645	0.778	0.495	9.105	10.597	7.893	34766.34	60630	1519	0.946	1.272	0.763
Central Ring	0.563	0.983	0.367	8.713	11.342	5.952	19676.58	74983	36	0.972	1.425	0.281
Periph. Ring	0.633	0.947	0.399	7.867	12.223	5.081	6970.978	40345	97	0.825	1.615	0.141
Main Ring	0.631	0.871	0.438	9.314	12.181	6.158	50476.7	104775	348	1.127	1.535	0.210
Periph. space	0.736	0.989	0.459	7.387	11.189	4.939	3688.816	27462	0	0.580	1.358	0.092

6.1 Findings on pedestrian navigation

According to the tracing representation, it is possible to corroborate that the main ring is the busiest area of the building in terms of navigation. However, the behaviour of people might be highly influenced by attractors and the rules of the programme. They access the floor from one of the peripheral convex spaces of the system, the gate that connects with the train station terminal. From this location people usually move to the check-in desks, which are in the areas divided by the connections 1, 2, 3 and 4. This situation generates an accumulative number of tracings through the nearest 200 meters of the circumference of the ring and a diminution of movement near connection 3, an area that presented higher values of potential movement in the spatial analysis.

The overall distance navigated was 261 meters in an overall total time of 04:19 minutes, which includes the time they spend in pause points. The maximum number of pauses was 10, while the overall was 3 pauses. Most of these pauses do not have a relation to the spatial wayfinding, but they have relations to the programmed activities of the airport. Different reasons for pausing, were distinguished in the observations; those caused by people stopping to check directions, which would be categorised as spatial wayfinding, and pauses that are a product of people stopping by services, in which case they are programme-related.

6.2 Findings on virtual navigation

The cumulative tracing data of virtual and real performance is scattered. The manner of testing it is by using twenty three gates located in the building where was possible to register human movement. These gates cover almost half of the flow within the floor and are situated throughout the main, central and peripheral rings, connections 1, 2, 3 and throughout some peripheral convex spaces (figure 6.1).

As a result, a high statistical correlation of R square of 0.82 is found between virtual and real data sets, which means that both kinds of navigation are analogous in relation to areas where people move. The mathematically interesting result validates the usage of virtual reality as a powerful tool to examine human behaviour; with the advantage of testing purely the effect of spatial factors on navigation, even more, it will be possible to test isolated variables, such as the form factor, in order to distinguish their effect on space perception and wayfinding performance.

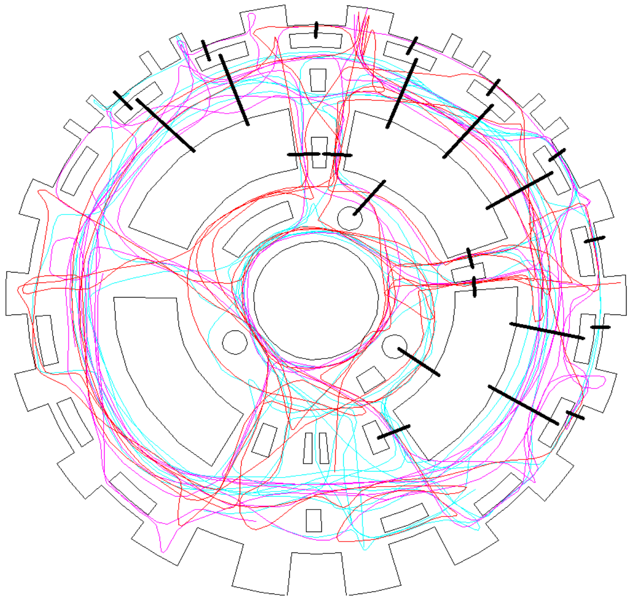


Figure 6.1: Location of 23 gates and the virtual navigation traced.

To assist the analysis of the relation between these two kind of navigation, real and virtual, with the properties of the space, the scatter plot between both navigations and the VGA Through vision analysis was run. As a result, both present high levels of correlation, confirming the assumption presented in chapter 5 which supports that segment choice and longer line of sight are highly correlated with the navigation process. It is important to acknowledge that the virtual navigation shows the highest correlation, achieving an R square of 0.83. This could be because in the virtual analysis the number of external factors are reduced, so the navigation is purely based on the spatial properties and the information that space gives.

6.3 Agent-based analysis

In the interests of finding the most proper way to simulate human movement using analysis based on Space Syntax theories, the agent-based analysis was tested, examining a complete range of different measures given by the Depthmap programme to find the best combination of parameters to obtain an agent behaviour similar to the human navigation at both an aggregate and individual level.

According to previous analysis (Turner and Penn 2002), the best combination of agent parameters in a building environment is composed of a field of view of 170° and a total number of three steps before evaluating the route navigated. With this combination previously tested, different analyses were run. In order to find the agent analysis that mainly represents the aggregated human movement, the more representative were correlated with the through vision analysis, including the Standard (R^2=0.80), the Line of sight length (R^2=0.65), the Occluded length (R^2=0.14), the Any occlusion (R^2=0.13), the Occlusion group bin 45 degree (R^2=0.21) and the Furthest occlusion per bin (R^2=0.13).

According to this correlation at an aggregate level, the highest correlated are the Standard analysis and the Line of sight length, the rest of the analyses show very low levels of correlation, so these two analyses will be used in further tests at an individual level, focusing on the tracing of agents and using the human navigation observed to find levels of correlation. Also, an exploration of different parameters will be presented, in order to find the most suitable agent-based tool.

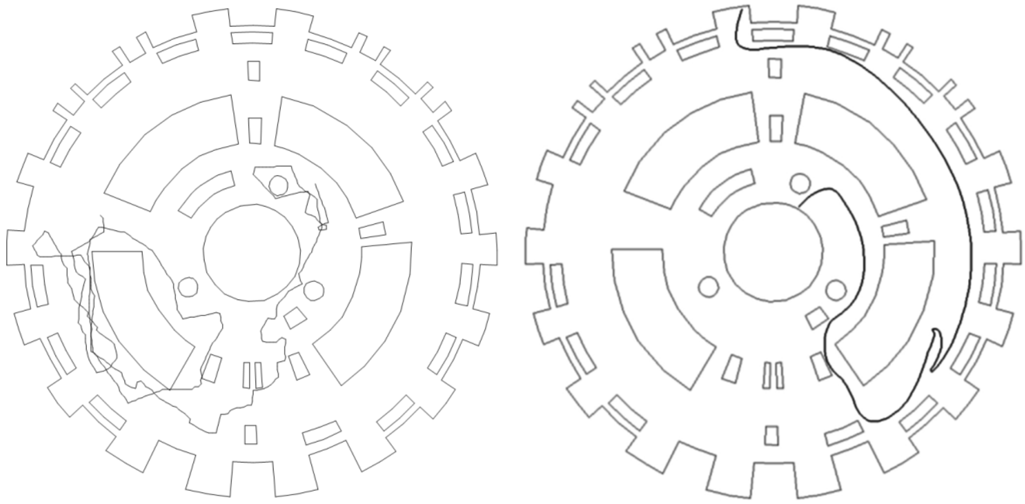


Figure 6.2: Left, Agent movement at three steps. Right, individual movement observed in real environment.

The first observation was based on the individual movement of each agent, which is the micro scale performance that generates the aggregate graph. Examining the Standard three steps and 170° combination, it is possible to see that the navigation is quite random and does not apparently represent the human navigation observed (figure 6.2). It could be argued that the three steps taken before evaluating the route is a short path and does not correlate with the real individual's performance. In order to define what is the number of steps that people actually take before re-evaluating the navigation route, the data obtained in the virtual experiment is examined. According to this, the overall distance navigated before pausing is 71.9 meters. A new analysis was run, using as a parameter a distance of 60 steps before re-evaluating the decision, as a result, an individual performance apparently more similar to the human one is performed, but at an aggregate level, the movement is very different to the human behaviour, showing a correlation of R^2=0.00.

According to the previous result, the number of steps given before re-evaluating the route apparently is not related only with the point where people pause or change their direction. It is possible to suggest that the evaluation is a continuous process, which is made evident when people pause or change their angle of view, but most of the time just the direct field of view gives enough information to evaluate if the route taken is the right one. In this sense, it should not be an issue of distances between pauses, but it seems to be correlated with the changes in the field of vision given by the environment. In order to test it, the segment lines are explored.

If the evaluation of the route is related to the visual information given by the environment, the length of the segment lines should play an important role in the navigation. If it is right, the overall length of segments could be used as the variable to evaluate the number of steps between evaluations. But some areas present long segment lines, and at the same time do not present a high level of movement, as for example the peripheral ring of the airport. In this sense, the "value of movement" should be multiplied by the length of segment, in order to give more value to segments which show highest values of movement. As a result, an equation is proposed in order to obtain a distance which comes from a segment length multiplied by its "value of movement", in this case the segment choice value. This distance, divided by 0.70 meters, which is the overall length of walking step observed, gives the total number of steps before evaluating the route of navigation (equation 6.1).

$$s = \frac{\sum_{i=1}^{n} l_i c_i}{0.7Nm}$$

Equation 6.1

In this equation, "s" is the number of steps that each agent walks before re-evaluating its route, "l" is the length of each segment, "c" is their corresponding segment choice value, "m" is the overall segment choice value of the system and "N" is the number of segments in the system.

According to the calculation over all the segments of the system, 6.23 is the number of steps which will be included in the following agent-based analysis. As a result, the individual navigation of one single agent looks similar to human navigation (fig. 6.3). What is more, the correlation between the agents and the real observation is an R square of 0.66, which is almost the same as the correlation between the real observation and the standard analysis, which presents a correlation R square of 0.69. The correlation with the virtual navigation is much better, showing a R square of 0.82, which is the highest correlation found so far.

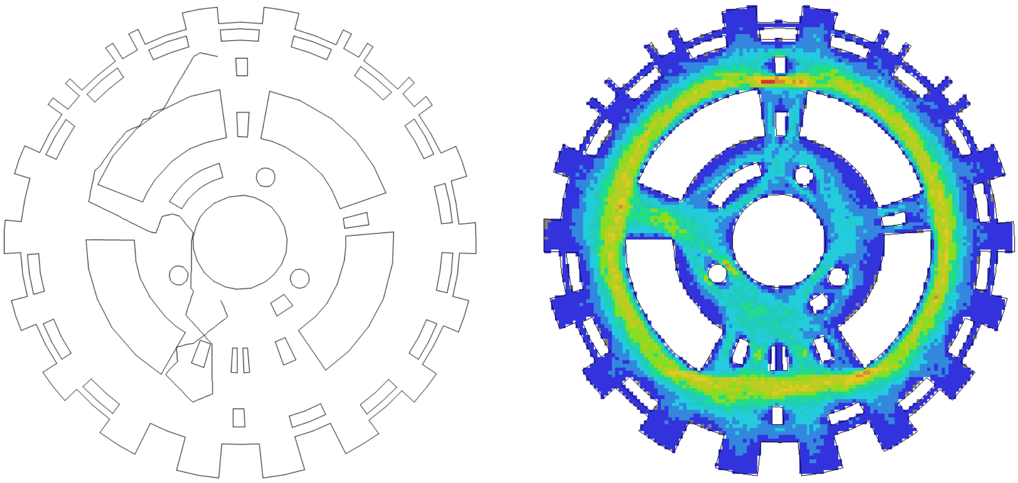


Figure 6.3: Agent-based analysis of Line of sight length with eight steps. Left, tracing of one agent. Right, gate count.

In order to corroborate this finding with other buildings, St Pancras International Station is analysed, where the author has carried out observations over forty four gates, obtaining a clear picture of the overall navigation within this building (Orellana 2012). Calculating the equation of segment properties in its ground floor, 5.6 is the number of steps that agents should walk between decisions. Accordingly, a high correlation is obtained between agents' performance and real observation data, with a R square of 0.72. This result reinforces the implementation of the equation proposed, which is based on the particular properties of each building.

Discussion Between Virtual Realities

7.1 Comparison of navigation

In order to find a detailed representation of the movement flow (fig.7.1), a total of fifty four gates were included in the area of study; with this it is possible to completely cover the flow of movement and use this data to explore the correlation between experiments (fig. 7.2).

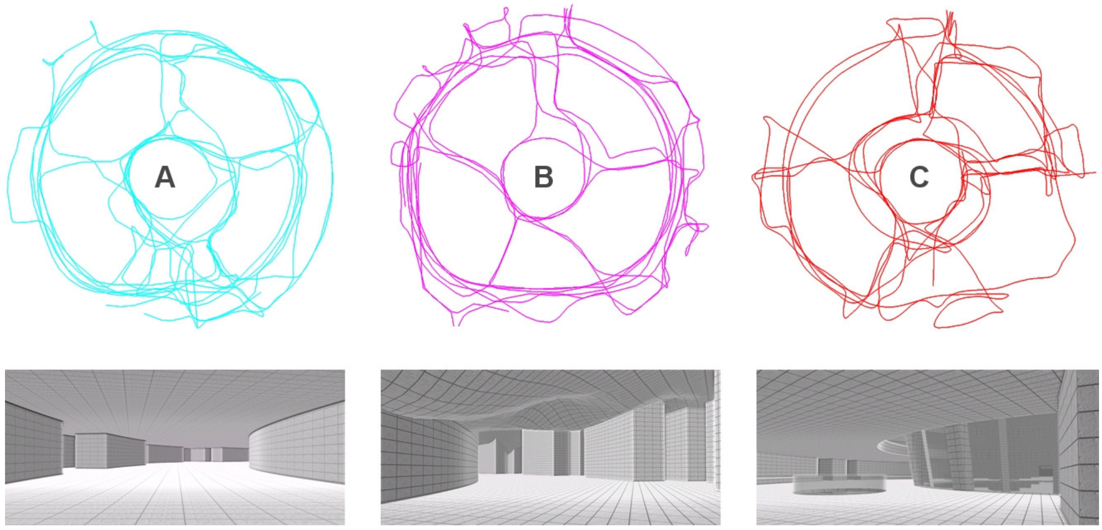


Figure 7.1: Three different virtual models and the navigation performed within each of them.

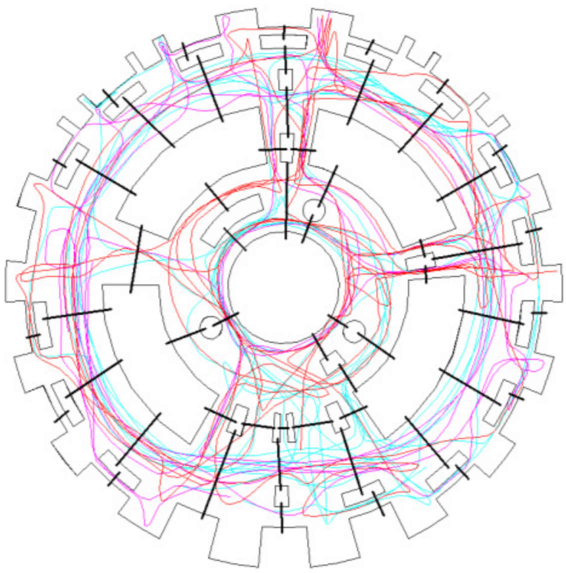


Figure 7.2: Fifty four gates that cover the overall flow of movement.

An important correlation between the models A (R^2= 0.65) and B (R^2= 0.62) with the real navigation is found (figure 7.3), which means that in these three-dimensionally different models the navigation is performed in a similar way. This finding reinforces the Space Syntax theory which supports that is the spatial configuration rather than the building form which generates the rules of human navigation. In this sense, it might be suggested that important changes in vertical shapes do not affect the patterns of navigation. It allows architects to be explorative in form issues without affecting building performance because the plan configuration is the generator of human movement.

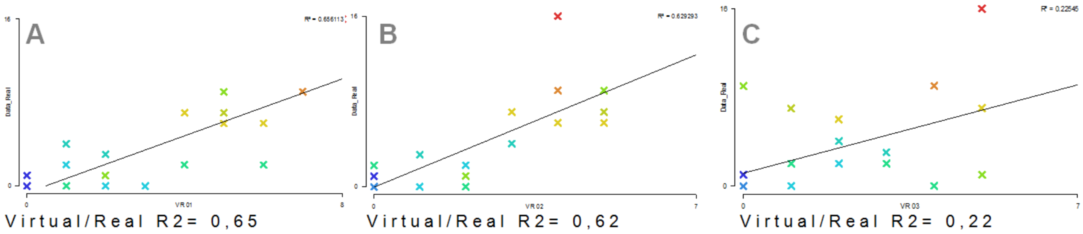
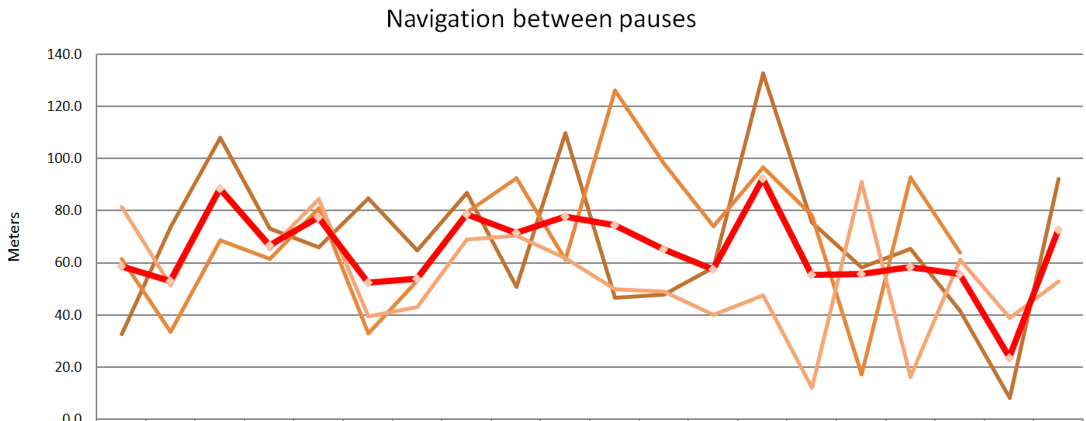


Figure 7.3: Correlation between each virtual model navigation and the real navigation.

In relation to the distance navigated between pauses (fig. 7.4), it is possible to see a similar performance in all models during the first 10 pauses, where the overall distance is 71.9 meters. However, the length of these routes has a relation to the area navigated, while the overall distance between pauses in the main ring is higher than the distance observed in the central ring. This finding also reinforces the idea that navigation distances have a relation to the metric length of segments rather than a fixed value. On the other hand, after 10 pauses, each model presents different distances between pauses. It could be explained by the tendency of participants to explore different areas after certain distances, while during the first 10 pause lapses, the navigation is mainly through the main ring.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	32.8	74.0	108.3	73.4	66.2	85.0	65.1	87.0	51.0	110.0	46.9	48.0	58.4	133.0	75.7	58.6	65.6	41.8	8.3	92.5
B	61.7	33.6	69.0	61.7	81.2	33.2	53.3	79.6	92.7	61.3	126.3	98.3	74.2	96.7	78.3	17.5	93.0	64.1		
C	81.8	51.6	88.5	65.6	84.8	39.6	43.1	69.1	70.7	61.9	50.0	49.3	40.2	47.7	12.4	91.2	16.5	61.3	39.2	53.2
Overall	58.8	53.1	88.6	66.9	77.4	52.6	53.8	78.5	71.4	77.7	74.4	65.2	57.6	92.5	55.4	55.7	58.4	55.7	23.7	72.8

Figure 7.4: Distance navigated between pauses in each model.

7.2 Comparison of pauses

The place where people pause is not the only location where they evaluate the route choice, but if the navigation is interrupted, this location should have a more important effect on the wayfinding than other places. The pause areas are examined, with the aim of finding correlation between these locations and their spatial properties.

In the interest of finding a general spatial pattern of pause point locations, the overall picture was analysed, identifying eleven clusters where, in a radius of twenty metres, it is possible to find at least ten pause points (figure 7.5). With this finding, these areas were compared with the levels of integration and visual control.

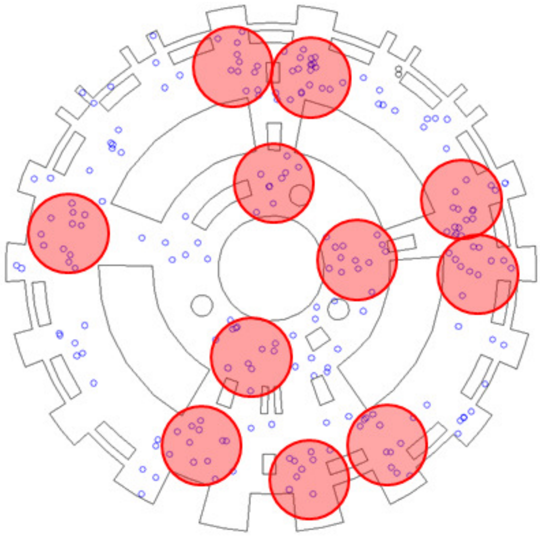


Figure 7.5: Overall cluster locations. At least 10 pauses in 20 m. diameter.

The cluster points present a clear relation with the integration HH properties of the space (figure 7.6). Apparently people tend to pause in places where the integration value is higher than average; in this case, the average value where people pause is 9,6, while the overall integration HH value of the system is 8.8. Also, there are no clusters located in places where the integration values were less than 8.4.

According to the relation between visual control and pause clusters (figure 7.7), it is demonstrated that this property of the space presents the strongest relation to the pause points. While the overall visual value of the system is 1, the overall value of this measurement in pause clusters is 1.3; what is more, there are no clusters with a visual control value lesser than 1.2. This means that all pause clusters are concentrated where the visual control of the environment presents the highest levels.

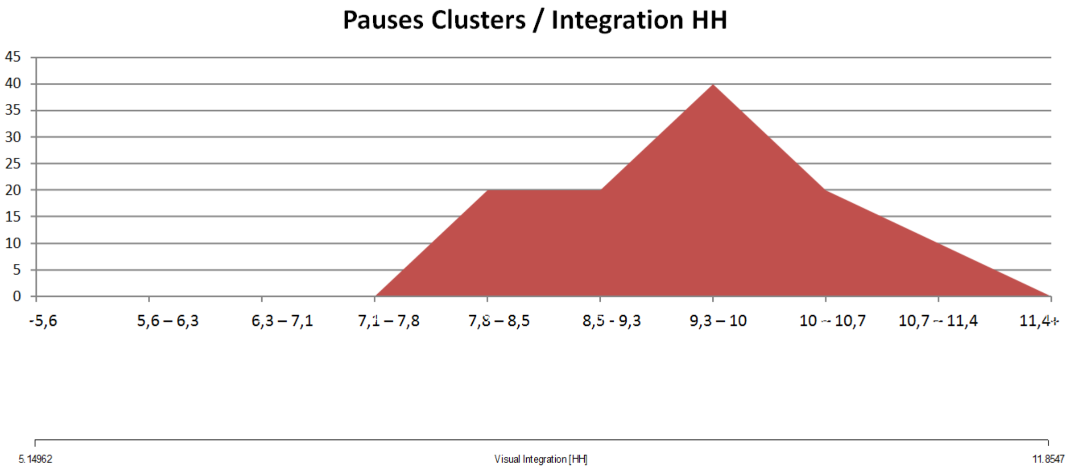


Figure 7.6: Relation between pause clusters and integration HH properties.

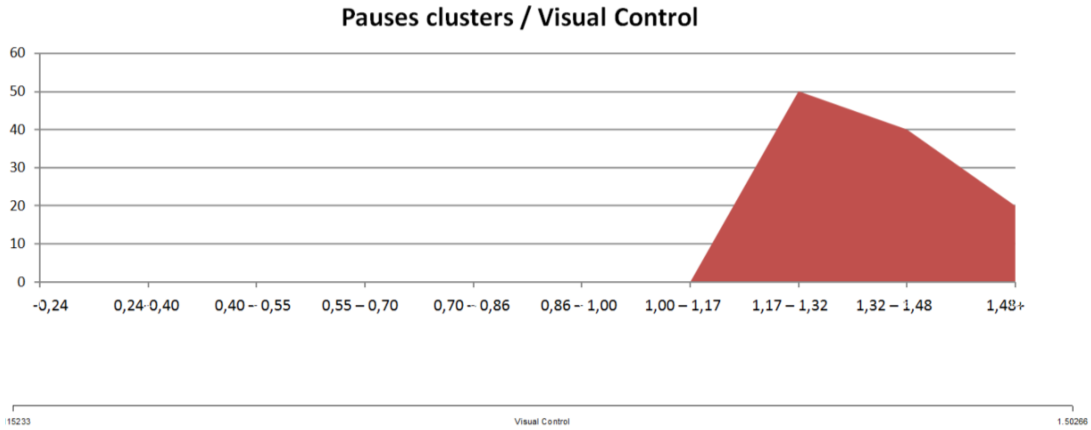


Figure 7.7: Relation between pause clusters and visual control properties.

According to the volume of space visible from the pause clusters (figure 7.8), it is possible to see all of them cover the three rings and different areas of the building. In relation to their isovist properties, all clusters present higher areas, perimeters, occlusivities, drift angles and minimal radials than the average values of the building, while the most remarkable is the minimal radial of cluster, which is more than double the average for the whole building (table 7.9).

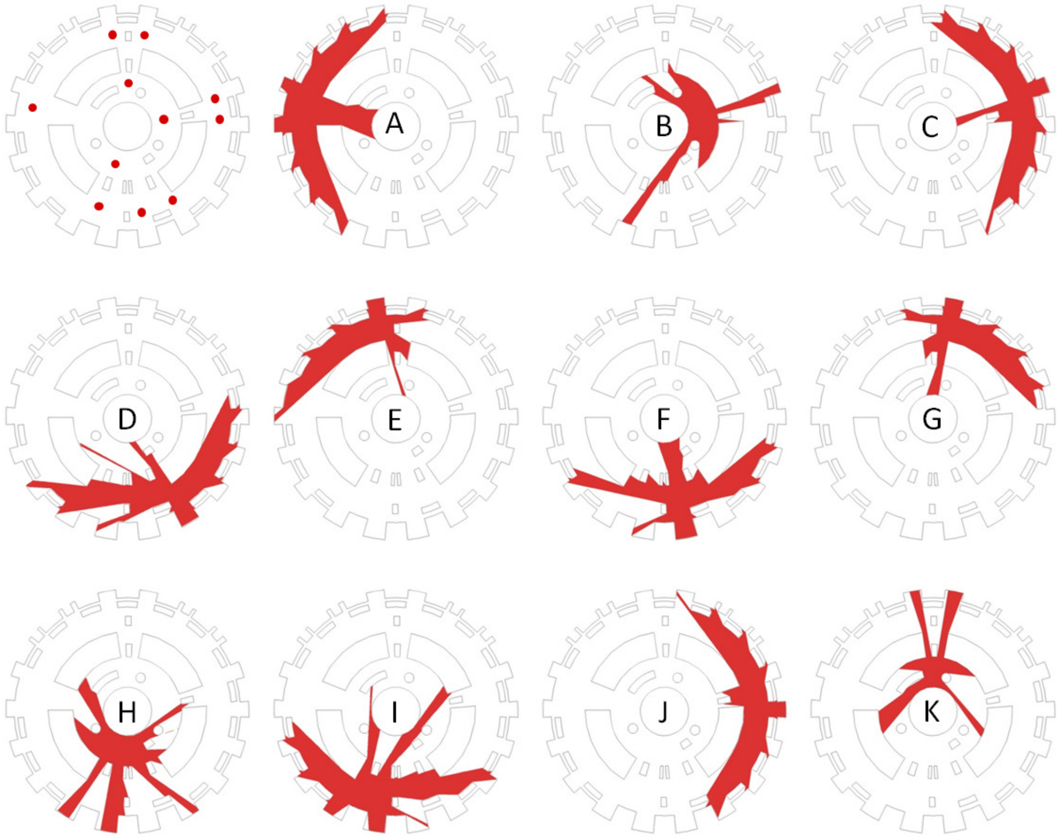


Figure 7.8: Isovits from the centre of the eleven clusters.

Table 7.9: Comparison between the pause clusters and the total system in relation to different isovist properties.

	Compactness	Drift Angle	Drift Magnitude	Max Radial	Min Radial	Occlusivity	Perimeter	Area
Average Clusters	0.10	195.68	17346.59	105475.25	9768.69	394522.08	688797.76	3767.02
Average building	0.12	183.35	19598.00	101235.00	4594.00	323523.00	557956.00	3031.67

7.3 Comparison of mental representations

How people remember spaces could relate to the intelligibility of the system. In these three experiments, where the plan is the same, what people remember from the space should therefore be something similar. Sketches drawn by participants are examined in order to test this. As a methodology, the number of spatial areas included in each sketch will be assessed by a value, areas which have been most drawn obtained highest values. Each element was assessed with a value of between 0 to 1, according to the accuracy of the sketch (table 7.10). These values are then correlated with the integration values of each area. This methodology is based on the principles presented in the research of Kim and Penn (2004), but this time in a building context.

Overall, participants of the three models drew the elements of the system with a similar average frequency. The main ring is the most popular, followed by the central and the peripheral rings (fig.7.11).

The average interpretation of sketches shows a high correlation with the maximum integration value HH, with an R square of 0.60. According to the individual interpretation of each experiment, models B and C show high levels of correlation as well, with R squares of 0.51 and 0.77 respectively. It could be argued that by introducing differentiation in the general three dimensional identity and by adding unique features it is possible to obtain deepen long term spatial memory of layout features.

Table 7.10: Analysis of frequency of drawing of each element.

Area	MODEL 01							MODEL 02								MODEL 03								TOTAL
	A	B	C	D	E	F	overall	G	H	I	J	K	L	M	overal	N	O	P	Q	R	S	T	overall	overall
Connection 01							3.5								2.5								2	2.7
Connection 02							2.5								2								3	2.5
Connection 03							2.5								1.5								3	2.3
Connection 04							2.5								1.5								3	2.3
Central Ring							5								3								4	4.0
Periph. Ring							3								3.5								4.5	3.7
Main Ring							4								6.5								7	5.8
Periph. spaces							2								2								4	2.7

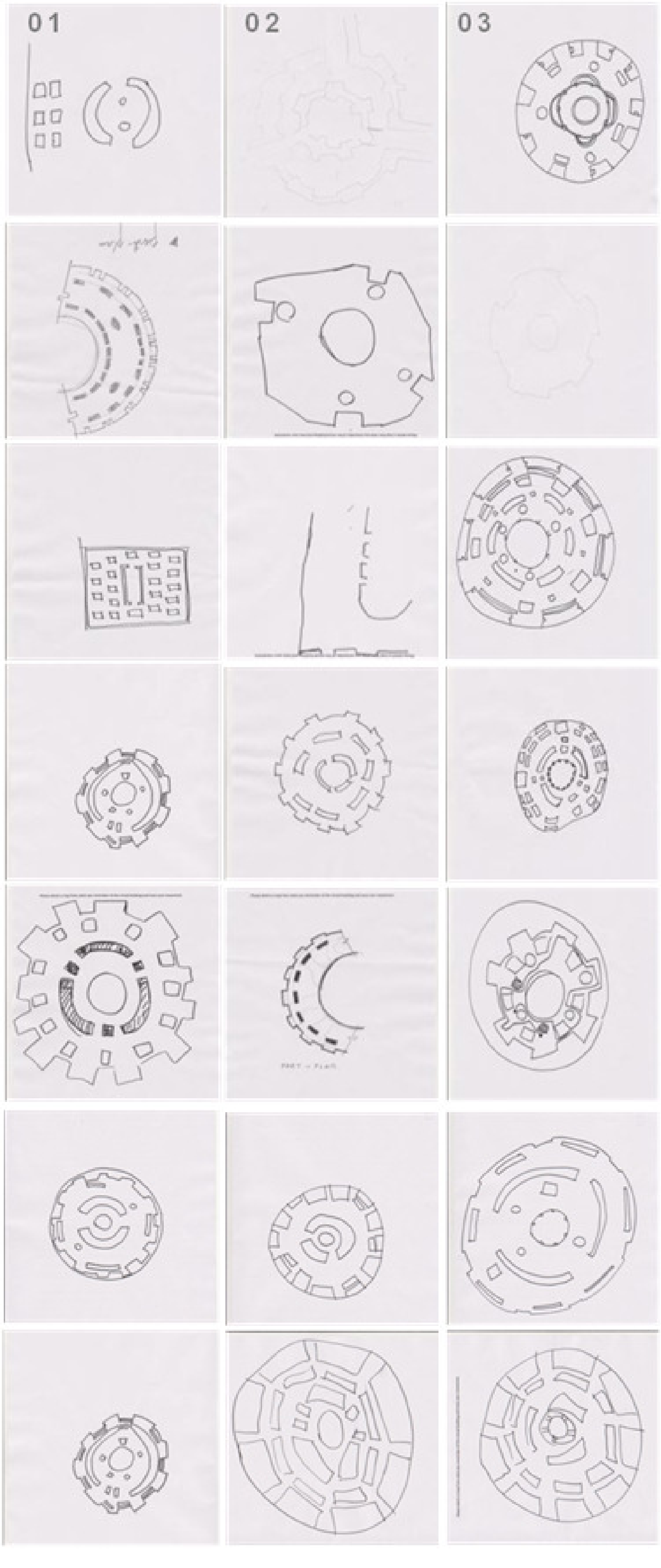


Figure 7.11: Sketches drawn by participants

In order to understand the least and the most accurate sketches of each model, the navigation performed by their authors is analysed. According to this, it is demonstrated that some participants, even though they do not navigate through the whole system, sketched a complete figure. Tversky (1992) argues that human mind spontaneously reorganize the information entirely to make the mental representation, in this sense, people include spatial elements in order to generate spatial inferences of the whole. On the other hand, some sketches just present a limited number of elements, while the author navigate through most areas of the system. It could be argued that some participants have more familarity with virtual realities and have more drawing abilities than others, so it could affect the quality of sketches draw.

8.1 Conclusion

According to this research, it is possible to conclude that is the spatial configuration which generates the most important effect in the patterns of movement of people. From the agent-based analysis, it is confirmed that it is possible to predict human movement, according to a number of predetermined parameters, the angle of vision (170º) and the number of steps before evaluating a change in direction. It was demonstrated that this number of steps is not a fixed number, but depends on the metric characteristics of each environment to analyse it, that is, obtained by the relation between the length of segments of the systems and its segment choice value. It is proposed that more flexibility should be introduced to the agent model, in order to include a variable according to particular properties of the segments of the system. According to that, in Paris Charles de Gaulle airport a total number of six steps was obtained from the metric analysis and was highly correlated with both real (R^2= 0.66) and virtual navigation (R^2= 0.82).

It was also demonstrated that pause points in a navigation have a relation to location where the environment gives high levels of information. People tend to pause in locations which show higher isovist areas, perimeters and minimal radial properties. Also, these pauses have a relation to spaces with important levels of VGA visual control, in fact all of them were in the higher quarter of the range. This finding could be useful in a wayfinding design, in order to identify locations for allocating information or certain attractors.

In relation to the analysis of different virtual environments, taking into consideration the limitation of using new technology and virtual models to analyze the performance of people and the benefit of reducing the number of variables present in the environment, it was demonstrated that the three dimensional form of the environment does not significantly affect the patterns of navigation. Between the three dimensionally different environments, the correlation between the real navigation and the model A is 0.65 and with the model B is 0.62, which are positive correlations and confirm that the configuration of the two dimensional space is the most relevant in relation to the movement generated.

In relation to the mental representation of the spaces, a high correlation is found between the maximum levels of integration and the frequency in which people remember them, or in this case, what people drew, obtaining a R square of 0.60. It is possible to suggest that highly integrated spaces are easier to remember and also easier to navigate.

References

Arthur, P. and R. Passini. 1992. *Wayfinding: People, signs and architecture.* New York: McGraw-Hill Publishing Company.

Batty, M. 2011. "Agents-based pedestrian modelling." *Environment and Planning B: Planning and Design* 28: 321–326.

Brettel, A. 2006. "The effects of 'order' and 'disorder' on human cognitive perception in navigation through urban environments." MSc diss., Bartlett School of Graduate Studies, UCL, London.

Carpenter, E. 1989. "Wayfinding: Design breakthrough or trendy buzzword?" *Print* 43(1): 92-163.

Carpman, J., and M. Grant. 2006. *Design that Cares. 3rd edition.* Chicago: American Hospital Publishing.

Conroy, R. 2001. "Spatial navigation in immersive virtual environments." PhD diss., Bartlett School of Graduate Studies, UCL, London.

Cutting, J. 1996. "Wayfinding from multiple sources of local information in retinal flow." *Journal of Experimental Psychology: Human Perception and Performance* 22:1299-1313.

Dalton, N. 2003. "Fractional configurational analysis and a solution to the Manhattan problem." In *proceedings of 3rd International Symposium on Space Syntax*, Georgia, Institute of Technology, Atlanta.

Emo, B., C. Hölscher, J. Weiner, and R. Dalton. 2013. "Wayfinding and spatial configuration; evidence from street corners." In *Proceedings of 8th International Symposium on Space Syntax,* Santiago, Chile.

Evans, G. and M. McCoy. 1998. "When buildings don't work: The role of architecture in human health." *Journal of Environmental Psychology* 18:85-94.

Fewings, R. 2001. "Wayfinding and airport terminal design." *Journal of Navigation* 54(2).

Gibson, J. 1979. *The Ecological Approach to Visual Perception.* Boston: MA.

Hillier, Bill. 1996. *Space is the Machine.* Great Britain: Cambridge University Press.

Hillier, Bill. 2006. "Studying cities to learn about minds: how geometric intuitions shape urban space and make it work." In *proceeding of Space Syntax and Spatial Cognition, proceedings of the workshop held in Bremen*, 11-31.

Hillier, Bill. 2009. "Spatial sustainability in cities: organic patterns and sustainable forms." In *proceedings of the 7th International Space Syntax Symposium,* Stockholm, Sweden: Royal Institute of Technology.

Hillier, Bill, and J. Hanson. 1984. *The social logic of space.* Great Britain: Cambridge University Press.

Hillier, Bill, A. Penn, J. Hanson, T. Grajewski, and J. Xu. 1993. "Natural movement: or, configuration and attraction in urban pedestrian movement." *Environment and Planning B: Planning and Design* 20:29-66.

Hölscher, C., R. Dalton, A. Turner. 2006. "Space syntax and spatial cognition." SFB/TR 8 Monographs.

Hölscher, C., M. Brösamle and G. Vrachliotis. 2006. "Challenges in multi-level wayfinding: A case-study with Space Syntax technique." *Space Syntax and Spatial Cognition - Proceedings of the Workshop held in Bremen,* edited by C. Hölscher, R. Conroy Dalton, and A. Turner. 24th September 2006, Bremen: University of Bremen.

Lynch, K. 1960. *The Image of the City.* Cambridge: MIT Press.

Meilinger, T., M. Knauff and H. Bülthoff. 2006. "Working memory in wayfinding – a dual task experiment in a virtual city." In *Proceedings of the 28th Annual Conference of the Cognitive Science Society.*

Mottram, C., R. Conroy, A. Turner, and A. Penn. 1999. "Virtual beings: emergence of population level movement behaviours from individual rule-sets." In *Proceedings 2nd International Symposium on Space Syntax.* Brazil: Universidad de Brazil.

Onnée, J. 2004. *Airport systems planning, design and management.* Paris, Charles de Gaulle Airport, France.

Orellana, N. 2012. "Patterns of movements through St Pancras international station." MSc diss., Bartlett School of Graduate Studies, UCL, London.

A. Penn and N. Dalton. 1994. *The architecture of society: Stochastic simulation of urban movement, Simulating Societies: The Computer Simulation of Social Phenomena.* London: University College London Press: 85-25.

J. Peponis, C. Zimring, Y. Choi. 1990. "Finding the building in wayfinding." *Environment and Behaviour* 22:555-590.

Turner, A. and A. Penn. 1999. "Making isovits syntactic: isovist integration analysis" In *Proceedings 2nd International Symposium on Space Syntax.* Brazil: Universidad de Brazil.

Turner, A. 2003. "Analysing the visual dynamics of spatial morphology." *Environmental and Planning B, Planning and Design* 30:657-676.

Turner, A. 2006. *The Ingredients of an Exosomatic Cognitive Map: Isovists, Agents and Axial Lines?* Great Britain: Bartlett School of Graduate Studies, UCL.

Turner, A. 2007. "To move through space: Lines of vision and movement." *6th International Symposium on Space Syntax.* Istanbul: Istanbul Teknika Universitesi.

Turner, A., C. Mottram, and A. Penn. 2004. "An ecological approach to generative design." *Design Cognition Computing* 94:259-274.

Turner, A. and A. Penn. 2002. "Encoding natural movement as an agent-based system: An investigation into human pedestrian behaviour in the built environment." *Environment and Planning B: Planning and Design* 29: 473-490.

Tversky, B. 1992. "Distortion in cognitive maps." *Geoforum* 23:131-138.

Weisman, J. 1981. "Evaluating architectural legibility: Way-finding in the built environment." *Environment and Behaviour* 13:189-204.