The impact of Different Building Height Configurations on Navigation and Wayfinding

Ref 072

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Keywords
three-dimensional scale; building heights; navigation; wayfinding; space syntax

Abstract
This paper is part of a wider research addressing the issue of the 3-dimensional scale of the urban environment as a missing element of the Space Syntax discourse. Investigating the three-dimensional scale through the Space Syntax theory will lead us to understand whether three dimensional scale affects movement in cities and how this knowledge can inform architectural design decisions. The question raised is whether 3-dimensional scale properties affect the navigation, wayfinding and intelligibility in urban environments. In order to investigate these issues an experiment in virtual environments was set up. The experiment is examining participants' performance in navigation, wayfinding and survey knowledge in four environments with exactly the same plan configuration but differences in buildings heights. The four environments are: first one with low buildings, second one with high buildings, third one with buildings' heights correlated to the integration of the street on which they are found and fourth one with buildings' heights reversely correlated to the integration of the streets on which they are found. In the third case the high buildings are on the integrated streets and the low ones are on the segregated while in the fourth case the low buildings are on the integrated streets and the high buildings on the segregated ones. However, in the fourth environment since the low buildings are on the integrated streets, these streets offer better 3d visibility, behind the low buildings, of the high buildings on the back alleys. In the present paper we report only an analysis of the last two models. The question is whether it is 3d visibility, correlatedness or syntactic integration that has the an impact on navigation and wayfinding. The main finding is that integration has the stronger impact on navigation but besides this, in regard of the third imension, correlatedness is having an impact on route choice and navigation is easier in the correlated environment. A possible explanation is that correlatedness is reinforcing established schemata of urban environment images where usually the high buildings are on more integrated streets (main streets) and low buldings are on the segregated streets (back alleys).

1 Introduction

In everyday life scale is mostly related to affective evaluations. People feel more affectionate towards a low scale, like in a picturesque village, or a high scale, like a downtown area with skyscrapers. However, the question that this research is aiming to address is whether scale is playing any role in navigation and wayfinding, in the intelligibility of the built environment and in the estimation of route distances. This paper is part of a wider research which is trying to look into a missing element in Space Syntax theory, that of the 3rd dimension or more precisely buildings' heights. The world around us is three–dimensional and even if all space syntax studies pinpoint to integration as the main factor for path choice, these studies always focus into two dimensional environmental properties of the urban environment. Although Space Syntax has a big contribution to the understanding of environmental cognition (Penn, 2003;) the lack of a three-dimensional approach has been part of its criticism the last years (Montello,2007) The question is then whether the third dimension, as building heights, is affecting the outcome of path choices; whether navigation and wayfinding is affected, by factors other than the configuration of space, by the buildings' height.

In order to examine this question an experiment in a virtual environment was set up which took place in the VR lab of the Centre for Cognitive Science in Freiburg. This experiment which will be presented in this paper is also based on the hypotheses that were created from a previous research in virtual environment on the participants' perception of differences in scale properties (Mavridou, 2006;Mavridou, 2007). The hypotheses created from that research were that the perception of length of a street is affected by the configuration of form heights along this street and that low height environments are perceived as easier to navigate than bigger height ones. The experiment is aiming to examine three themes:

- Whether the estimation of a route distance is affected by the scale of the buildings along the route.
- Whether navigation in virtual urban environments is affected by the scale of the buildings.
- Whether the navigation performance is affected by the buildings height when these are correlated to the syntactic integration, according to the space syntax term (Hillier and Hanson, 1984), and when they are reversely correlated.

This paper will investigate into the third question. More specifically it will investigate a "micro-navigation performance" based on the analysis of the participants' choices on each junction. The question to be tested is what are the "hidden" strategies for a wrong choice? In other words, what are the path choices that participants make on each junction affected by? In this respect and more relevant to the theme of this paper is the analysis of two models used for the experiment; the model where heights are correlated to the syntactic integration and the model where heights are inversely correlated to the integration.

A first hypothesis presents three factors that can affect path choice and will be examined. These factors are: 3d visibility, correlatedness and integration. Also, the idea of "when don't know, just go ahead" will be tested. The help that 3d visibility may offer for navigation is based on the extra information that can be gained from the fact that high buildings are visible behind low buildings. Correlatedness is an attribute of the model where the building heights are correlated to the syntactic integration. In this model the image of the 3d environment is reinforcing existing schemata of urban environments where usually high streets or main streets are having higher buildings while back streets or small alleys have lower buildings. Main streets are in general more integrated and back streets less integrated. Buildings heights then can give a hint about the street structure. Finally, integration is the main factor according to space syntax theory affecting route choice (Hillier et al, 1993). The other case that will be tested, "when don't know, just go ahead" is observed in (Conroy, 2001) according to which people tend to follow a close to linear direction when they are not sure about the correct route.

In what follows, in the methodology section, the participants, the layout, the buildings heights configuration and the procedure of the experiment will be presented, then the dependent measures of the analysis and finally the main findings of the experiment.

2 Methodology

2.1 Participants

Most of the participants were students who replied to an e-mail announcement. There were thirty two native German speakers. Sixteen of them were men and sixteen were women. They were 20-38 years old, with average age of 24. Most of the participants had a virtual environments experience at least once (n=17) and quite a few of them more often (n=11) and most of them (n=19) had video game experience at least once and many of them more often (n=12). Only four of them never had a virtual environments experience and only one never had video game experience.

2.2 Plan layout and building height configuration

Four different "virtual worlds" were designed for the experiment. The four worlds have all the same layout but each one has different buildings' height properties. The size of the world is approximately 680m X 705m. The variations of building heights configuration among the four models are:

- One model has high buildings, with 12m, 14m and 16m height.
- One model has low buildings, with 6m, 7m and 8m height.
- One model has heights correlated to the syntactic integration.

The height of the buildings is correlated to the integration values of each road. The axial map of the virtual world was drawn and the resulting integration values were sorted to three different ranges. The three ranges, corresponding to three colours, red for high integration, light blue for medium and blue for low, are shown in figure 1. The roads with higher integration are having higher buildings than the segregated ones. The heights for each range are: 4m, 5m and 6m for the low buildings, 10m, 12m and 14m for the medium height buildings and 19m, 22, and 25m for the high buildings.

- One model has the reversed correlation. In this case, the height of the buildings has a negative correlation to the integration. The integrated roads are having lower buildings than the segregated ones.

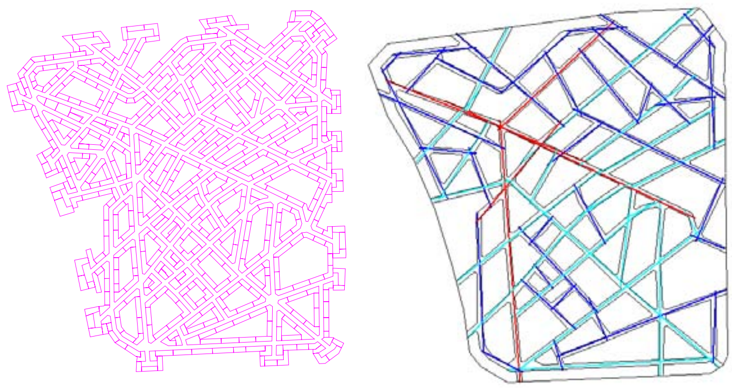

Figure 1

The plan layout of the models and the axial map with the 3 syntactic integration ranges corresponding to 3 different building height ranges

The hypothesis is that the correlated model (the third one described above) is expected to positively reinforce established schemata. It is usually the case in urban environments that higher buildings are situated on more integrated streets. In general, these streets have higher densities of visitors and therefore are in need of bigger areas. Therefore development in height can provide the necessary space. The fourth model described, the reversed correlated, is opposed to such established schemata. When an integrated street is perceived by someone as such, higher buildings are expected to be found on this street and then when turning back on some segregated alleys, low buildings are expected to be found. In this model this expectance is reversed, by having the low buildings on the integrated, type of high-street, road and high buildings on the segregated back alleys.

Because of the variations of heights from street to street the case is that when there are low buildings along a street, the higher buildings at the back are visible. This means that in the correlated model the 3dimensional visibility is better on or at the segregated streets. When you are on a segregated street you can see behind the low buildings on this street, the high buildings of the other sides of the blocks. The opposite is happening in the reversed correlated model; when you are on an integrated street you can see behind the low buildings on this street the high buildings at the back. So in the correlated model, the segregated streets with low buildings have better 3d visibility of the other sides of the blocks and in the reversed correlated model the integrated streets with low buildings have better 3d visibility. Taken together, this means that in the correlated model, there is a buildings height configuration that, on one hand, reinforces established schemata and, on the other hand, it offers better 3d visibility on the segregated streets than on the integrated ones. In the reversed correlated model, the building heights configuration is opposed to established schemata and it offers better visibility on the integrated streets than on the segregated ones. The question that arises from this situation is whether it is a) correlatedness or b) visibility that has the stronger impact on navigation and wayfinding, or whether it is c) integration per se, irrespective of building heights.

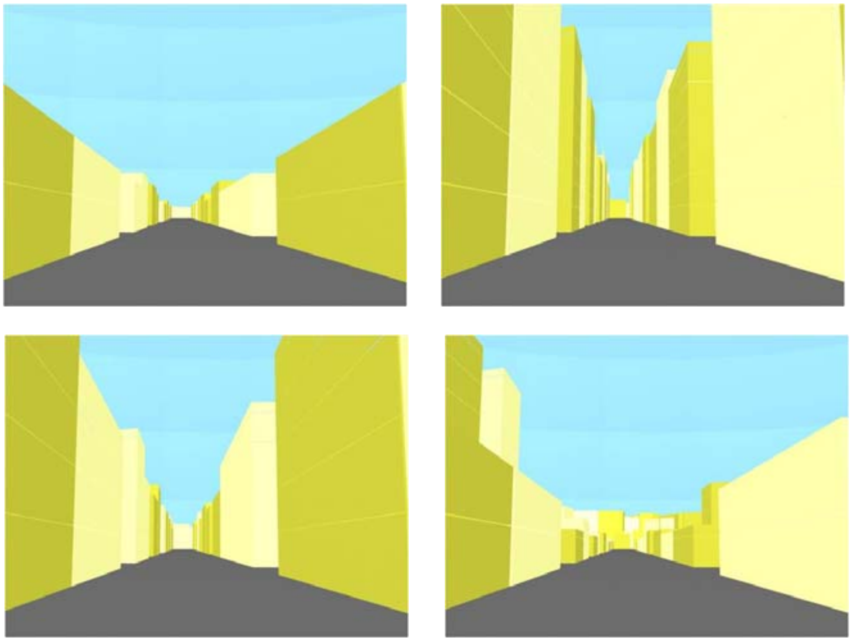

Figure 2
Aspects of the 4 models from the same point. Model with low heights (top left), with high heights (top right), with correlated heights (bottom left) and with inversed correlated heights (bottom right).

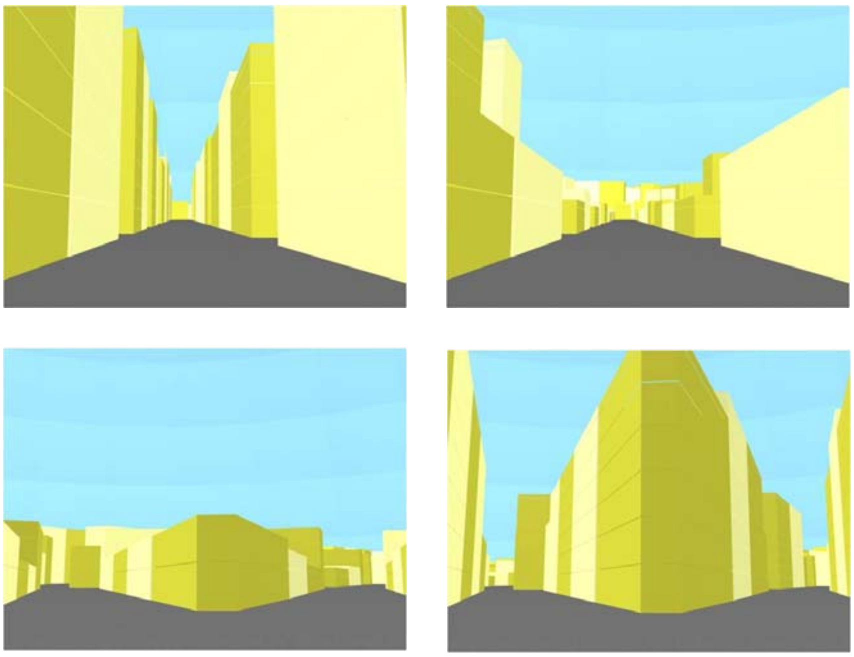

Figure 3
Aspects of the correlated (left) and inversed correlated model (right) from the same point on an integrated street (top row) and on a segregated street (bottom row).

2.3 Procedure

All participants had to navigate in all of the four models. The task was to learn the route in each one and to answer some navigation performance questions. In order to avoid learning the route between models there were four different routes but with equal attributes. Each participant travelled a different route in each of the four conditions. The conditions and routes were counterbalanced across participants. The attributes that were held constant across all routes were: total route distance, start to end survey distance, number of intersections en route, type of intersections (T type, cross (+) type, 5 streets or star (*) intersection), number of turns, type of angular properties of the turns (right angle, obtuse and oblique turns), and the sequence of syntactic property changes (integrated-segregated street) along the routes. The virtual worlds were projected on a 2.6m x 2.0m screen. The participants could navigate with the use of the arrow keys of the keyboard. The experiment consisted of a training phase, a learning of the route phase and the navigation tasks phase.

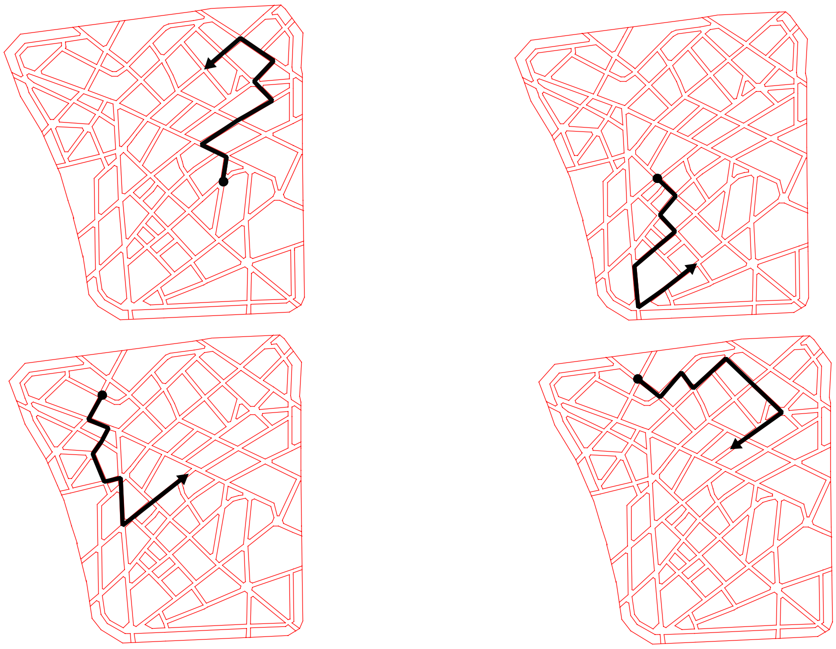

Figure 4

The four different routes.

During the training phase there was a distance training and a task training. For the distance training the participants were following a route with distance indication for every 50m in order to get a sense of distance in the virtual environment. For the task training they had to learn a route and complete the tasks in a world which was different from the worlds of the experiment.

After these two training sessions the actual experiment started. The route learning consisted of a passive and an active navigation episode. During the passive navigation the participants were watching a video of the route where the camera was stopping on each junction and was turning around to all streets of the junction. During the active navigation, the participants were walking along the same route following direction instructions given by the experimenter. With this procedure the participants experienced the route twice before performance was measured.

When the participants reached the end point of the route in the active navigation they were asked to complete the performance tasks. They were asked to give an estimation of the route length, of the Euclidean distance (survey distance) from start to end and to point to the starting point. Finally, they were asked to go back to the starting point following exactly the same route. The participants' wrong choice on a junction was corrected by invisible barriers that were obstructing movement. So the participants could not move forward if they had taken the wrong turn on a junction and they had to correct their choice. If the task was not completed after 5minutes they were asked to stop. After navigating all four routes, the participants were given a questionnaire to fill in.

3 Dependent measures

The objective dependent measures, testing navigation performance, are:

- The detour behavior. The number of wrong choices per route will be estimated. If people are better orientated in the low height environment then they are expected to perform less wrong choices.
- Total time to complete the task.
- Total distance until the task is completed.
- Speed (total distance divided by total time).
- Success to find starting point.

The subjective measures tested were based on the questionnaires that were given to the participants at the end of the navigation to reply. The questionnaire consisted of some questions regarding the level of difficulty of the environments and the navigation and of the type of environmental changes they noticed in the four different environments. Also in order to measure their sense of direction, selected items from the Santa Barbara sense of direction scale questionnaire (SBSOD) (Hegarty et al, 2002) and the Questionnaire of Spatial Representation (QSR) (Pazzaglia et al, 2001) were given to them to answer.

The analysis presented in this paper is focused on the micro analysis of the participant's performance in models 3, correlated to heights model, and 4, reversely correlated to heights. Specifically in what is called participant's performance on each junction and is based on the study of the path choice on each junction of each route in each model for each participant. All four routes have 11 junctions which are exactly the same in both models, the correlated and the reversely correlated, in plan view and the environmental properties which deal with the two dimensions. They differ however in the 3-dimensional properties, in building heights. All the junction properties, both two-dimensional and three-dimensional, registered for the analysis were:

- Type of junction. There are three types, T- type junction with three path choices, (+) cross-type junction with four path choices and (*) star-type junction with five path choices.
- Mean integration of the junction. An integration value was assigned to each junction which was the mean integration value of all axial lines crossing the junction.
- The integration value of each path choice of a junction.
- The height of the buildings of each path choice of a junction.
- The length of the isovist from the junction for each path choice of the junction. The navigation performance was measured with three dependent variables, separately for each individual junction along each route:
- Number of attempts to find the correct route; whether the participant chose the correct path on first attempt, second, third and so on.
- Whether the first choice was correct or incorrect.

The reason that only the initial choice is tested separately from all the rest is because every other choice, after the first, is dependent on the new position of the participant due to the first choice. For example, there are three choices on a junction, left, ahead and right and the participant first chooses left which is wrong then the new path choices are again left, ahead and right but now ahead is what in the first choice was right. In this respect, every path choice after the first has to be tested both in regard to the initial position when entering a junction and to the new position the participant has after every choice. For subsequent path choices it is a matter of future research to establish a comparison to random (chance level) performance.

3. Initial choice corrected: initial choice performance was corrected for the type of intersection, given that T-intersections are easier than star(*)-intersections (by 27.3 %). Also, cross(+)-intersections are easier than star(*)-intersections (by 8.9%), conceivably due to the number of possible choices. The differences of error probabilities for the different junctions were calculated and the performance of the initial choice was adjusted by the error probability due to the type of the junction (effectively "partialling out" the effect of junction type).

The research questions that are examined by analyzing the above mentioned dependent variables are:

- Whether there is a general performance difference between model 3 and 4.
- Whether there is a difference between model 3 and model 4 regarding the height of the buildings of the wrong options.
- Whether there is a difference between model 3 and 4 regarding the height of the buildings of the correct option.
- Whether there is a difference between model 3 and 4 if ahead is the correct option. Finally, it is tested if there are any correlations between any of the dependent variables and any of the environmental properties for each of the two models.

4 Findings

The main findings from the analysis sketched in the previous section are presented here. A global comparison of model 3 and 4 across all junctions revealed no reliable difference between the correlated and reverse-correlated conditions. Similarly, no global difference could be established within or between models for a comparison of junctions based on the mean integration values of each junction (all $p>.20$). There are substantial inter-individual differences in task performance and local route choice that may obscure some effects of the models. But more importantly, participant's path choices are sensitive to local properties of the junctions, namely the relative building height and integration both for the correct choice at a junction as well as the spatial properties of the other path choice options that can (erroneously) attract movement decisions. Once these factors are taken into account in the fine-grained analysis, differences between the models also become statistically visible.

Model		No. of attempts	Initial choice	Initial choice corrected
3	More low-building options	1.25	0.79	0.67
	More high-building options	1.40	0.64	0.52
4	More low-building options	1.38	0.68	0.55
	More high-building options	1.31	0.73	0.61

Table 1

Performance measures compared for building height of the wrong options (Note on "Initial choice" measures: 1= correct choice, 0= wrong choice, i.e. high values indicate good performance. On the opposite, on No. of attempts high values indicate bad performance)

Building height of the wrong options

In model 3 there is a slight tendency to make more mistakes (number of tries) when the wrong streets involve more high buildings whereas in model 4 they make more mistakes when the wrong options involve more low buildings (statistical interaction of factors model * height: $F(1,414.82)=2.138$; $p=.144$; see table 1). More importantly, in model 3 there is a tendency to make more errors of the first choice (initial errors) when the wrong options involve more high buildings whereas in model 4 they make more initial errors when the wrong options involve more low buildings (again, interaction model * height: $F(1,434.21)=4.144$;$p=.042$). This interaction effect is most prominent for the variable "initial errors corrected by the type of the junction" ($F(1,433.10)=6.389$;$p=.012$).

Streets with high buildings in the correlated model 3, means that the streets are integrated and offer low 3d visibility while streets with low buildings in inverse correlated model 4 means that, again, the streets are integrated but now they offer high 3d visibility. In both cases though, when streets with these properties are available as erroneous choices the participants have a bad performance. Since visibility is not a constant factor in both cases, while integration is, it can be concluded that the wrong choices are based on the syntactic properties of the streets. This means that when the participants don't know which the correct route is, they follow the more integrated path option.

Building height of the correct option

The previous finding is also supported by the fact that there is a statistical trend in model 3 for the participants to make more mistakes, when the correct street is with low buildings and in model 4 they make more mistakes when the correct street is with high buildings (interaction model *height: $F(1,522.36)=2.391;p=.093$). Again, in the correlated model 3, the streets with low buildings are the segregated streets which also have high 3d visibility while in the inverse correlated model 4, streets with high buildings are also the segregated ones which though offer low 3d visibility. It seems again that visibility is not the crucial factor for the participants' choice while integration has an important effect on their performance. When the correct street is segregated their performance is hampered. Taking into account the building height of the correct option also reveals a direct difference between models 3 and 4. For the "initial choice" and "initial choice corrected" measure we observe a marginally significant effect of model ($F(1,542.636)=2.944;p=.087$ and $F(1,542.588)=2.638;p=.105$). In model 3 participants make fewer erroneous initial wrong choices (21,6 %) than in model 4 (28,3%).

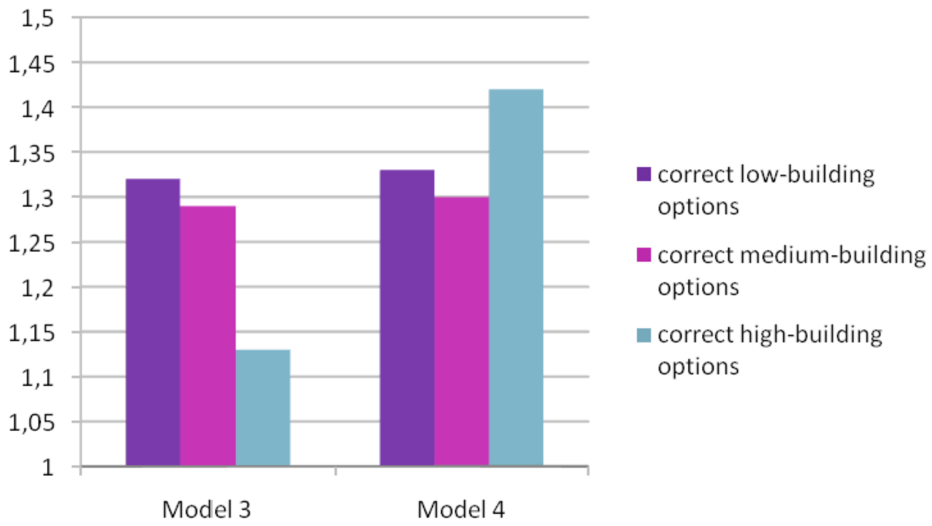

Figure 5

No. of attempts compared for building height of the correct option.

Direction of the correct option (ahead: yes/no)

Participants make significantly more mistakes if ahead is the incorrect choice ($F(1,503.40)=22.848;p<.001$) and they also make significantly more "initial errors" if ahead is incorrect ($F(1,525.20)=22.614;p<.001$) and the same for "initial errors corrected by the type of the junction" ($F(1,525.477)=8.135;p=.005$) (Table 2). This indicates that one of the navigation strategies when people don't know the route is to go ahead and when this is not the correct option, performance suffers badly.

	No. of attempts	Initial choice	Initial choice corrected
Ahead incorrect option	1.429	0.663	0.573
Ahead correct option	1.166	0.830	0.660

Table 2

Performance measures compared for direction of the correct option.

Statistically controlling for whether or not ahead is the correct option again helps to reveal some global difference between the models 3 and 4. In this analysis participants tend to have a better performance in model 3 than in model 4 regarding the number of attempts ($F(1,506.51)=2.06;p=.152$)

and regarding the "initial error" (F(1,542.125)=2.09;p=.149) as well as the "initial error corrected by the type of the junction" (F(1,542.09)=2.08;p=.149). This provides further evidence that model 3 is easier than model 4.

Correlations with environmental properties

The findings for the correlations of number of attempts, "initial errors and "initial errors corrected by the type of the junction" with environmental properties are presented next.

Model		Low buildings at wrong choice	Medium buildings at wrong choice	High buildings at wrong choice
3	number of attempts	-0.302 (*)	0.498 (**)	0.099
	initial errors	0.313(*)	-0.437(**)	-0.241
	initial errors corrected	0.261	-0.325(*)	-0.325(*)
4	number of attempts	0.074	0.231	-0.069
	initial errors	-0.084	-0.344(*)	0.101
	initial errors corrected	-0.175	-0.253	0.089

Table 3

Correlations with environmental properties (=p<.05; **=p<.01).*

Model 3: In model 3 there is a significant correlation of number of attempts (R=.498, p=.001) and the number of "initial errors" (R= -.437, p=.003) with the proportion of wrong streets being of medium height. This correlation remains in the same pattern even in the case of "initial errors corrected to type of junction" (R= -.325, p= .031). This means that the more medium height streets are wrong, the more mistakes the participants make to find the correct way and the more initial mistakes they make. Also, in model 3 there is a significant negative correlation of number of attempts to the proportion of wrong streets being of low height (R= -.302, p=.046) and of "initial errors" to the proportion of wrong streets being of low height (R= -.313,p=.039). The more low height streets are wrong, the fewer initial mistakes and the fewer subsequent mistakes the participants make. This is also supported by the correlation of "initial errors corrected according to the type of the junction" with the proportion of wrong streets having high buildings (R= - .325,p=.032). The more high buildings streets are wrong, the more initial mistakes the participants make.

So participants show worse performance when the wrong streets are of medium or big height and better performance when the wrong streets are of low height. The low buildings streets are the segregated streets in model 3 and it seems that when the segregated streets are wrong the participants are enabled to find the correct route since their choice is towards the more integrated. This finding is also pinpointed by the trend that is noticed in model 3 for a negative correlation between number of attempts and integration of the correct option (R= -.284, p=.076). The higher the integration value of the correct way is, the less mistakes the participants make. It is concluded that when the participants don't know the route they pick the more integrated path choices.

Model 4: Generally, in model 4 we observe much lower correlations between error patterns and building height than in model 3. In model 4 there is a correlation for «initial errors corrected by the type of the junction" to the wrong streets being of medium height (R= -.253, p=.098). The more medium height streets are wrong, the more initial errors the participants make. For model 3, the "initial errors corrected by the type of the junction" are correlated to the wrong streets having high buildings (R= -.325,p= .032, see above). The more high buildings streets are wrong, the more initial errors the participants make. It seems that in model 3 for initial choice the participants pick the high buildings streets, which are the most integrated, but in model 4 they pick the medium height streets which are of medium integration. If integration was the factor with the most impact on choice it would be expected that in model 4 participants would pick the low height streets, which are the most integrated. However, the fact that the integrated streets are opposed to existing schemata must be confusing them, leading them towards a more mediocre choice, the medium height and medium integration streets. Therefore it is not integration per se that has an effect but correlatedness also plays a role.

Taken together, model 3 appears to be overall easier than model 4 which is detailed up when considering the building height of the correct options and the case when ahead is correct. This is not directly apparent in the global analysis because of the noise of the different building heights but since it is taken into account then the difference becomes visible. Also, looking into the global performance of all models there were five participants lost in model 1, seven lost in model 2, seven lost in model 3 and eleven lost in model four. This also points to the direction that model 3 is easier than model 4.

5 Discussion and Conclusions

This study was designed to systematically test whether differences in building heights affect navigation, wayfinding performance and route distance estimation. The issue of the 3 dimensional scale is examined as a missing element in the Space Syntax theory. The experiment that was set up in virtual environments was an attempt to examine if buildings heights configurations play any role, main or additional to integration, in navigation. Specifically in this paper the case of two models was examined; one model with building heights correlated to the syntactic integration of each street and one model with buildings heights negatively correlated. The initial hypothesis was that there can be three factors affecting navigation performance and these are: the 3dimensional visibility, the correlatedness of heights to integration, and integration per se. From the analysis of the participants' performance on each junction and the study of the path choices they made in relation to environmental factors, it is found that integration is indeed a crucial factor affecting the participants' path choices irrelevant of buildings heights. The case is that when people are lost they follow either of two strategies a) "when don't know where to go they to go to integrated places", found in Peponis et al (1990) or b) "when don't know just go ahead", found in Conroy Dalton (2001), and it is not affected by buildings heights.

What is furthermore added by this research to the above finding is that it is easier to perform wayfinding in the correlated world than in the reversely correlated. The fact that it only gets visible in the detailed micro-analysis and not on all variables is an indicator that correlatedness has a smaller impact than integration of a path choice. The explanation that is suggested to the observation of the effect of correlatedness is that the correlated model corresponds with established schemata of urban environments. These schemata usually follow the pattern of integrated streets (usually main streets) having higher buildings and segregated streets (usually back alleys) having lower buildings. Future research will be necessary to further untangle this potential explanation.

The main aim of this research is to effectively use the obtained knowledge in order to inform the discourse on 3dimensional design and building heights in architecture. The discussion on building heights in architectural design is still focused on issues like population densities, view restrictions or aesthetic quality and more important lately on the environmental sustainability of high buildings. Such a discussion has never taken place at the level of the three-dimensional intelligibility of the city, at the level of navigation and wayfinding. This research is throwing light into the question whether scale could be important on navigation in the city or whether it should always derive, as until now, from policies, technology, aesthetic rules and other environmental factors?

The present paper can give a hint on the direction that architectural design could proceed regarding building heights and easiness of navigation in urban environments. It could be concluded that if the same structure that applies on the spatial configuration on the two dimensions could be reflected on the three dimensional configuration, navigation would become easier. In this way the three-dimensional image of the city would support the underneath two-dimensional structure and would bring to surface and make more apparent what people seem to already perceive about two-dimensional spatial configuration.

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