COULD THE PERCEPTION OF INTELLIGIBILITY BE AFFECTED BY THE THIRD DIMENSION OF THE BUILT ENVIRONMENT?

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Abstract

Space Syntax research gives us a wide understanding of cities, pedestrian movement and use of space. However, all existing research refers to the study of the built environment in two dimensions as it appears in plan drawings of cities. This paper investigates whether the third dimension and architectural and urban scale affect the way people move in an urban environment and the way they use space. To investigate this issue, an experiment in an immersive virtual environment was set up to test how differences in scale are perceived by people moving in an urban environment. The participants were asked to complete a navigation task in six virtual urban environments which had the same configuration but different properties of scale or proportion. The differences were in building height, in the overall size of the environments and in scaling hierarchy. There were two groups of participants; one group had to navigate in an intelligible configuration and one group in a non-intelligible configuration. The participants had to fill in a questionnaire answering questions related to their perception of differences in the environments and to their perception of easier navigation. The results presented are based on the qualitative analysis of the questionnaires and on the correlation of the traces of the participants with syntactic values. From this study three hypotheses have been created: first, that perception of distance of a street is affected by the configuration of forms along this street; second that environments with the same topological properties but different properties of form are not perceived as the same; and third that same height environments are perceived as more ordered and easier to navigate than different height ones. All these introduce a new hypothesis for the definition of scale: scale is a relation of form to space. This scale called cityscape scale possibly affects the perception of intelligibility of the built environment.

The Problem of Scale in Architectural and Urban Theory

Space Syntax research has shown that human understanding of the built environment is closely related to the configuration of space as this emerges in two dimensions as in plans and maps (Hillier & Hanson, 1984). This derives from the high correlation between pedestrian movement and syntactic values in intelligible environments and the opposite in non intelligible ones (Hillier 1996; Conroy 2001). Therefore intelligibility, as this is defined by Space Syntax, as an attribute of the built environment is a good indicator of people's understanding of the built environment. This research questions whether people's understanding of the built environment is further affected by the image of the built environment as this emerges in three dimensions when someone walks down a street. The aim of this research is not however, to study only the height of buildings but the relations among dimensions of the built environment. This brings the issue of scale in the discussion.

Scale has always been an important issue in architecture. It has puzzled both practitioners and theoreticians as questions about form properties of buildings, the relation of part to whole, the proportions of forms and the size and proportion of public-open spaces. The most common approaches on scale in architecture were normative indicating norms like "human scale" or "in context" as appropriate, or talking about "in or out of scale", "harmonious scale" or "order".

Most writers coincide that scale is the relation of something to: either a standard (meter, foot, tatami, Modulor [Le Corbusier, 1948; Le Corbusier, 1958] etc.) in which case it is an external relation, or to the human body (Plato, Vitruvius, DaVinci, Modulor, foot) in which case it is an internal relation, or of things among themselves (Pythagoreans, Golden section, Fibonacci series etc.) which usually appear with mathematical relations. Therefore the question of scale brings back the philosophical question of relations in general and specifically the relation of parts to a whole.

Scale can be found in the literature as the issue of proportion (Proceedings of the Dresden International Symposium of Architecture, 1998; Padovan, 1999; Plato, 2000; Weber, 1995; Wittkower, 1949) or proportion systems (Le Corbusier, 1948; Le Corbusier, 1958; Van der Laan, 1983). It is sometimes defined as relative size (Licklider, 1965; Moore, Allen, 1976), sometimes referred to with its symbolic use (Mumford, 1961; Venturi, 1977; Zevi, 1978). Scale also appears in the literature in the discussion on context (Forty, 2000; Orr, 1985) or contextual architecture (Whitehand, 1992). There have also been attempts to quantify form (Krampen, 1979; Moles, 1966; Haken, Portugali 2003) and quantify space (Teller, 2003; Turner et al, 2001) which both approach implicitly the issue of scale. The issue of hierarchical scaling and how this is helping human understanding of the built environment is given in Mikiten et al (Mikiten, Salingaros, Hing Sing, 2000).

In the literature of the built environment three types of scale can be found: architectural scale, as it usually appears in architectural studies, urban scale, as it appears in urban morphology studies and spatial scale, as it appears in geography studies. It should be clarified that this paper is not dealing with any of these types of scale. Architectural scale is studying the scale of buildings, relations of their parts to wholes or relations of buildings. Urban scale in urban morphology is looking into relations of buildings in an urban environment and their relation to the space they create. This is similar to scale as a relation of form to space as it is presented in this paper, however, urban morphology is usually studying these relations either in city plans (as block structure) where the relation to the building's height is missing or in street sections where the relations among buildings is missing. Finally, spatial scale as this appears in the geography literature (Mansfield, 2005; Montello, 1993; Montello, 1998; Paasi, 2004; Sayre, 2005) is an abstract notion referring to the extent, either spatial or temporal, to which a phenomenon, physical or not, applies. In this sense there is the neighborhood scale, the city scale or the state scale. This paper is dealing with a more concrete sense of scale which is the scale of space and the scale of forms as they are apprehended through movement. This type of scale is relevant with Montello's categories of “vista” or “environmental” scale, as scales of a space apprehended visually from a single vantage point or through movement (Montello, 1998). However, “vista” and “environmental” scales refer only to the size, or scale, of space and does not take in to account the scale of forms.

Therefore, the main question that this paper attempts to investigate is how are differences in scale of an urban built environment perceived by people moving in it? There are two main points of this research. First is that the interest is on the perception of a moving and not static observer. Second, that the issue under examination is not the perception of distance or building heights or other metric properties of forms or of space, but the interrelation of all these and how changes in one metric property of the built environment may affect the perception of another metric property.

Investigating the question of the perception of scale is a step forward into trying to understand whether the way people perceive scale affects decisions they make about the use of space. Is the scale of the built environment an element of its configuration and as such does it affect people’s movement in cities? Or does the scale of the built environment affect the intelligibility of cities?

The methodology used to investigate the question is that of an experiment of navigation in an immersive virtual environment.

The experiment is presented in the next section of this paper.

Description of an Immersive Virtual Environment Experiment

The reason that this experiment was conducted in a virtual environment was because it’s hard to separate scale as an independent variable in a real environment.

Any virtual environment experiment brings up the problem of relevance of a real to virtual environment. Previous research investigating topological perception and wayfinding in real and virtual environments (Conroy 2001) has shown that movement patterns in real and virtual environments are very much alike, concluding that knowing the movement pattern in a virtual environment can lead to a prediction of the movement pattern in the same real environment. Research on the perception of metric properties of space, like distance, on virtual and real environments has shown that distances are not perceived the same in a real and in a virtual environment (Creem Regehr et al 2005; Willemsen & Gooch 2002; Witmer & Kline 1998). This may have an effect in experiments related to scale taking place in virtual environments. In the experiment presented in this paper the relevance to a real environment is not under investigation. The question is how varying properties of form and space are perceived by a moving observer in a virtual environment. T This differs from research on the perception of distance or size or other properties of form and space in an urban environment since what is examined is not perception of distance or size per se but how perception of one property is affected by the perception of changes of other properties.

The experiment presented was a pilot study. The experiment considers the configuration of space as being the invariant in six different environments while varying the scale and proportions of forms. Knowing that people’s perception of these environments is not affected by differences in the configuration, we can test the effect of scale on perception. However, since scale is not one specific property but depends on various relations among elements, different environments had to be recreated with each one approaching and examining a different kind of relation. So for example, in one case the forms have changed, the variant was the height of the buildings, in another the scale of the environment in relation to the observer, and in another the relation of parts to whole of the built environment by introducing hierarchical scaling (pavements, windows and doors).

The Experiment

Description of the method of navigation in an immersive virtual environment

The software used for the navigation in the virtual environment is called Candle (initially authored by Nick Dalton and next version by Chiron Mottram) and was developed in University College London. The head mounted display system used for the experiment is called Arthur AR Prototype Display system or AddVisor™ 150. This is a helmet like apparatus with two miniature flat panel displays. The displays are full color 1280*1024 pixel computer screens, one in front of each eye and each giving a slightly different view so as to mimic stereoscopic vision. The horizontal field of view is 54 degrees horizontal by 29 degrees vertical. The tracking system used was Motion Tracking by Ascension with an Inertia Cube by Intersense. The position and orientation measurement system was called The Flock of Birds. The participants were moving with the use of a 3d mouse.

The models were drawn in two dimensions first in “Autocad 2005, Autodesk” and then the three dimensional models in “3d Studio Max v.7, Autodesk”. The extracted data, which were the position of the object in the virtual world and the direction of the head, were saved twenty times per second as an ASCII text log file. These data files were then imported in Mapinfo Professional v7.5 in order to visualize and manipulate the data.

Description of the worlds (virtual environments)

The experiment consists of two groups of six virtual environments each. Both groups are based on two small urban layouts presented in the book “Space is the Machine” (Hillier, 1996). These two urban layouts are constituted by the same number and size of blocks but one layout is more intelligible than the other (Hillier, 1996). However, the layouts used for the virtual environments were slightly modified in order to make the world look more realistic. Extra blocks leading to dead-ends have been added to the edges of the worlds in the current experiment. Figure 1 shows the original and the modified worlds. The reason that an intelligible and a non-intelligible world were used was to examine if differences in intelligibility would have an effect on the perception of scale and, vice versa, if the scale differences would change the perceived intelligibility of space.

Two groups, one based on the intelligible layout and one on the non-intelligible, were created. The differences among the six environments were related to the scale, proportions and building heights. The diagram in Figure 2 sketches out the differences among the six environments. The code names were A1, B1, C1, D1, E1 and F1 for the intelligible worlds and A2, B2, C2, D2, E2 and F2 for the non-intelligible worlds.

In worlds A1 and A2, all the buildings had the same height which was 6 meters. There were no doors or windows on the buildings. In worlds B1 and B2, the buildings had different heights and these were 3, 6, 9, 12, an 18 meters. The height of each building was randomly chosen. Again, these worlds had no doors or windows. These worlds were designed to test perception of difference of heights and proportion.

In worlds C1 and C2, everything was double the size of worlds A1 and A2. As a result, all the buildings had the same height which was 12 meters. Width and length of roads were double than in worlds A1 and

A2. Worlds D1 and D2 were double the scale of worlds B1 and B2 respectively. Therefore, the heights of the buildings were 6, 12, 18, 24 and 36 meters. None of the worlds C1, C2, D1, and D2 had windows or doors. These worlds were designed to test perception of change of scale.

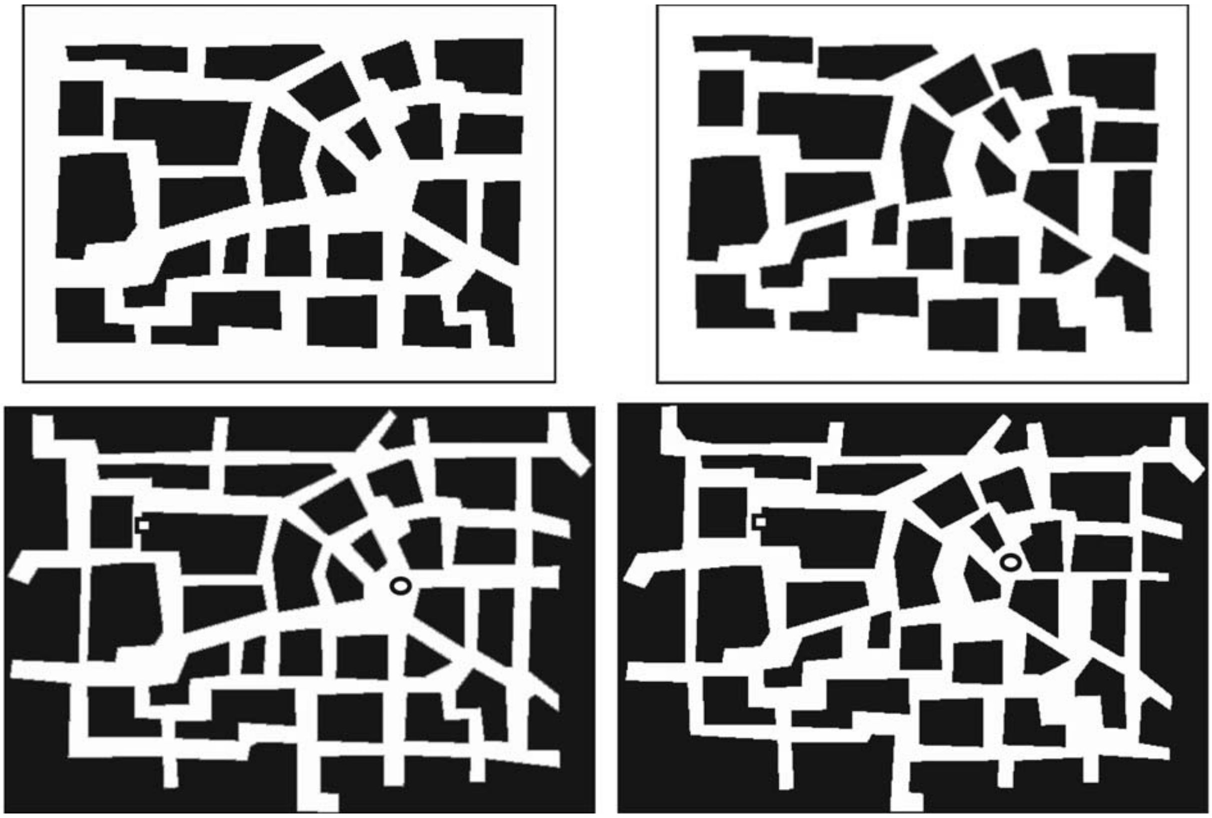


Figure 1:

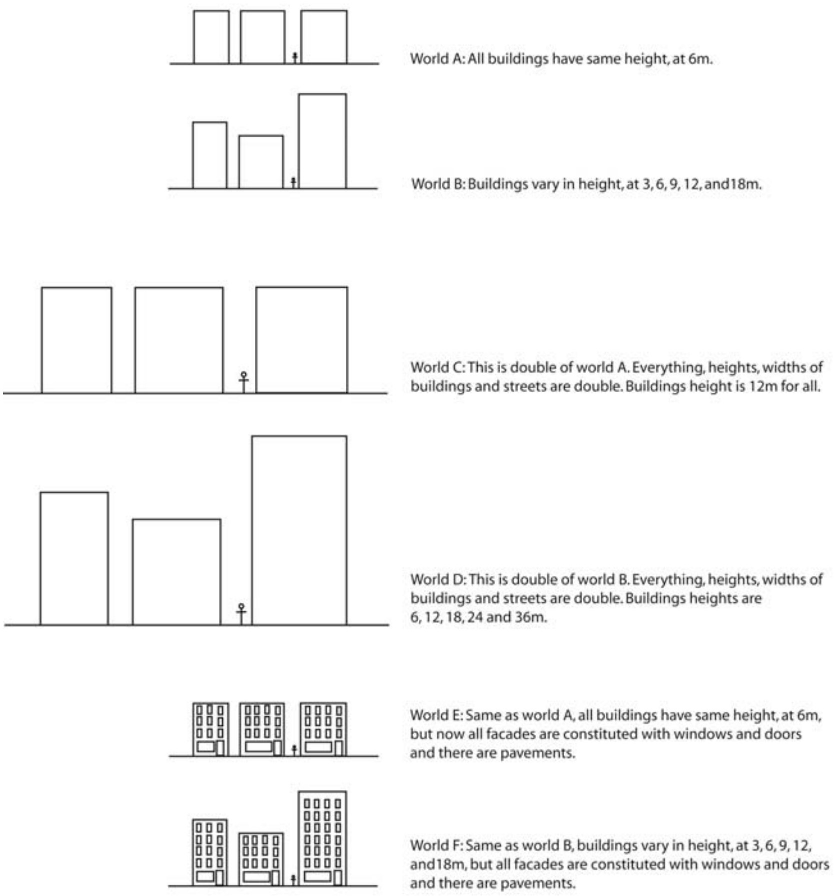
Plans of the original layouts (top), as presented in Space is the Machine, and the modified layouts (bottom) used for the virtual experiment. The small white square on the left side of each world shows the location of the object the participants had to find and the dot on the right side the starting point

Finally, worlds E1, E2, F1 and F2 were exactly the same as worlds A1, A2, B1 and B2 but they had also windows, doors and pavements. So actually, E1 and E2 had same height buildings and F1 and F2 had different heights. The doors, windows and pavements were designed to introduce hierarchical scaling as they were giving a sense of familiar size to compare to the buildings size. These worlds were designed to test perception of hierarchical scaling.

The size of each of the small worlds was around 260mx400m and the big 520mx800m. The participants were starting from the same point in all environments, which was in the centre of the small square, as it is indicated with the white dot on the modified plans of figure 1. The height of eyes of each participant was constant at 1.70m. The speed was always the same and approximated with normal walking speed at 7km/h. The task was to find an object on one of the buildings and if found to go back to where they started. The object is indicated in figure 1 with a small square and it was at the same place in all worlds. The participants had in the beginning a test navigation to get used to the apparatus and then had 10 minutes for each task. The collected data were the x, y, z coordinates of the position of the participant and the direction of the head. The participants completed also a questionnaire asking questions related to the differences they observed among different worlds and their perception of which environment was easier to navigate. The questions were answered some during and some after the experiment. In order to avoid any bias related to the order of the worlds and the participants' familiarity with the apparatus, the order was different for each participant. The participants in the experiment were twenty two unpaid volunteers. Eleven of them participated in the experiment with the group of intelligible worlds and the other eleven in the group with the non-intelligible worlds.

Figure 2:

Differences among different environments



Hypotheses Deriving from the Virtual Environments Experiment

The findings presented in this paper are based mainly on the analysis of the questionnaires and on the anecdotal comments the participants were making during their participation in the experiment.

Based on the replies of the questionnaire the results of questions 1 and 2 are presented in the following tables. Table 1 shows the results of Questions 1 of the questionnaire asking for the differences between environments A and B. Table 2 shows the differences that participants who identified environments A and B as different, mentioned. Only building heights were different between environments A and B. Table 3 shows the results of question 2 asking for difference between environments A, B, C and D. Table 4 shows the differences that participants, who identified environments A, B, C and D as different, mentioned. It is reminded that the only difference was the double scale. The tables are summarised in the following paragraphs.

Table 1	Question 1: Similarity between environments A and B		
	Intelligible (N=11)	Non-intelligible (N=11)	Total (N=22)
Exactly the same	0	2	2
Different but cannot tell/remember what the difference was	3	3	6
Different	7	6	13
Other	1	0	0

Table 2: Differences recognized between A and B	Number of participants (out of 22 only 13 identified differences)
Heights of buildings	11
Layout of two world	5
Shapes of the buildings and blocks	4
B more irregular and confusing than A	3
Streets were narrower in B	3

Table 3	Question 2: Similarity between environments A, B,C and D		
	Intelligible (N=11)	Non-intelligible (N=11)	Total (N=22)
Exactly the same	0	0	0
Different but cannot tell/remember what the difference was	1	2	3
Different	8	9	17
Other	2	0	2

Table 4: Differences recognized between A,B,C and D	Number of participants (out of 22 only 17 identified differences)
Heights of buildings [i]	15
Streets and open spaces characteristics (length, width, bigger open space)	8
In size, just bigger and not double size	6
Layout of the worlds	4
Shape difference	2

The first hypothesis is that perception of distance of a street is affected by the configuration of forms along this street. Figure 3, on the top row, demonstrates three snapshots each one taken in a different virtual environment: one in A1, same heights environment, one in B1, different heights and one in E1, same heights with doors, windows and pavements. The snapshots are taken from the same point and towards the same direction in all three environments. The difference in the perception of the length of the road in each case can be noticed. The second row illustrates another two snapshots of the same street, one in an environment with same heights and one in an environment with different heights. The illusion that the length of the street is perceived as being different in each case though it is the same, can be paralleled to the Muller-Lyer illusion, also illustrated in figure 3.

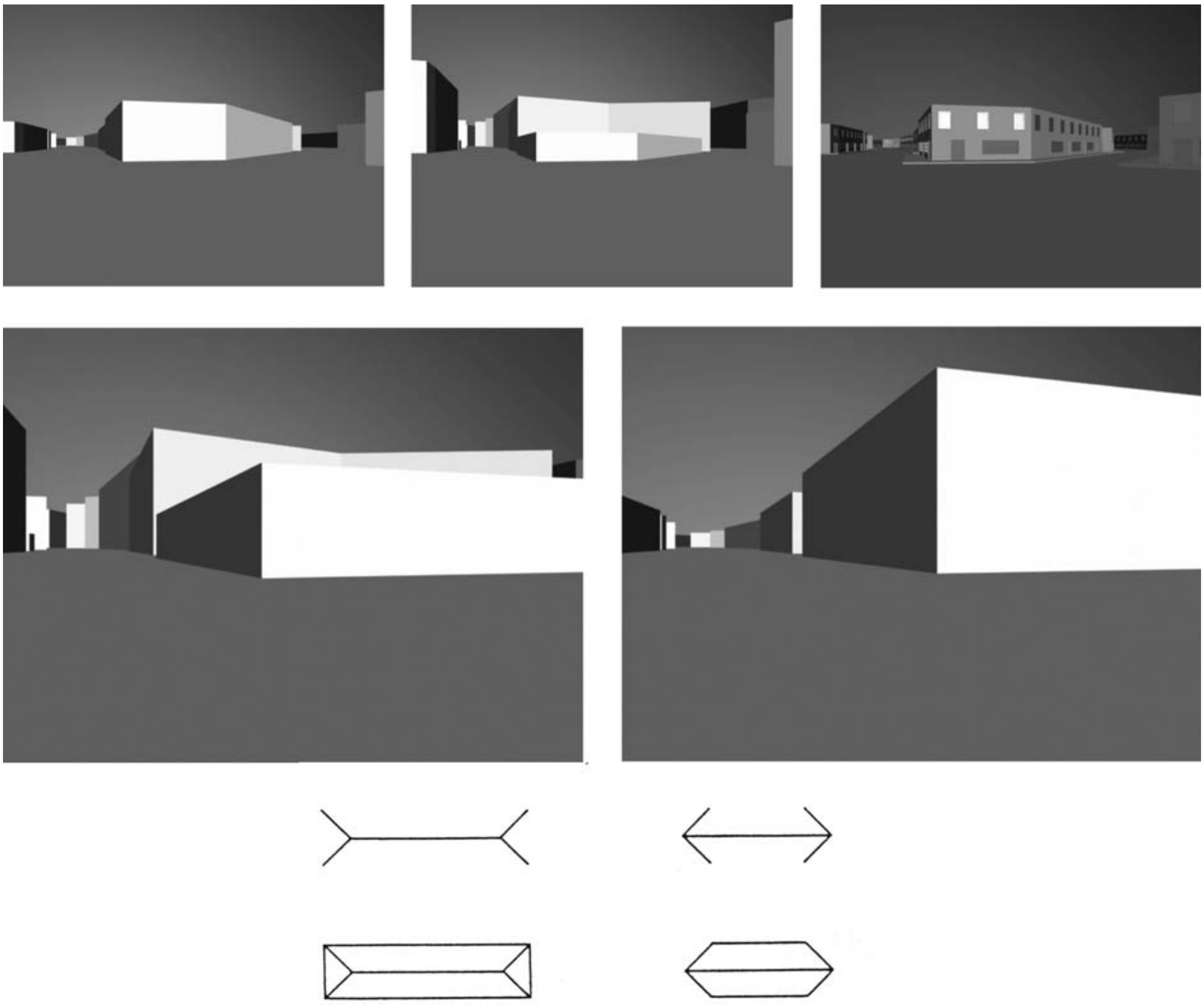
The way the perception of distance is affected by the geometrical properties of forms is illustrated in the participant's comments and replies. According to them the streets in same height environments were perceived as longer or as wider than in the different height ones. However, this difference does not apply in the big scale environments. Participants' comments were:

> “There was a distinctive broad alley” (mentioned by a participant as difference between A1 and B1, however the width was the same in both cases).
>
> “There were more narrow paths (in B1)”
>
> “Wider streets (in A1 than B1) made it sometimes easier to make your decision where to go and to navigate”

Something that initially may seem to be opposed to the above finding is that many participants mentioned that in different height environments they found the roads longer than they expected. This means a difference between perceived and traversed distance. A road perceived as short in same heights environments was assessed as longer than expected when the participant started actually walking along it.

Figure 3:

Top row, three views of the same street with different forms on each side. Middle row, two views of another street with different forms on each side and at the bottom the Mueller-Lyer illusion.



The second hypothesis is regarding the topological properties of the environments. The results of the questionnaires show that the environments are not perceived as the same when the geometrical properties of the environments are not the same. The six environments had exactly the same topological properties but they were not perceived as such.

The few cases that the environments were identified by the participants as the same were only when the buildings heights were the same; this is environments A, C and E. The same height enabled the recognition of the configuration as the same. Furthermore, in the case of environments with same height buildings being identified as the same, the participants had learned their way to the target. They were using the same route in all experiments to find the door and then go back to the starting point. Participants' comments were:

> "The second and fourth (A2 and C2) were exactly the same. The first and third (B2 and D2) could also be identical but it was too hard to tell"

> "The 1st, 3rd, and 5th (B1,D1 and E1) were more or less indistinguishable in terms of visual qualities" (we must remark that this participant didn't identify any differences related to the forms, like different heights or double scale)

The third hypothesis is that environments with same height were found to be more ordered and easier to navigate than experiments with different heights. This hypothesis derives both from the participants' comments and from a correlation of the integration values of axial lines (Hillier and Hanson 1984) to gates counts. The patterns of movement in each environment were studied. These patterns appear in figure 4. The number of pedestrians/participants crossing several "gates" was plotted against the value of the integration of the axial line crossing the same gate. This relation, as measured by the correlation coefficient of the graph, is very weak for this experiment and therefore cannot be considered statistically proved [ii]. However, it seems that environments with the same heights appear to have a stronger correlation than the ones with varying heights in both intelligible and non- intelligible environments. The exceptions to this are the intelligible double scale worlds (C and D) which have about the same correlation coefficient. This argument points to the direction of a hypothesis that environments with the same height may be more intelligible than environments with different heights. This argument also coincides with the perceived order and ease of navigation of these environments.

Participants' comments that show that environments with different building heights were perceived as less ordered than the ones with the same height were:

> "The one with different heights was more confusing"

> "The street network structure seemed different, the first (the participant means A1 with same heights) was more regular and the second (the participant means B1,different heights) more irregular"

> "Last one (B1) had lots of irregular spaces"

Also, some participants thought that same height environments were easier to navigate. It is interesting that a couple of them found this opposed to their expectancy. They mentioned that they were expecting that different heights environments may be easier to navigate. The same height environments made them feel that the visual field was wider. Possibly this was due to the fact that the same height buildings were quite low as well (6m). Some comments were:

> "(E2) seemed easiest although there was little building height variation"

> "The very last one (E2) was easier, despite the wall height being constant, because there seemed to be more (longer) visibility available which somehow made it easier to navigate and remember the path"

> "The one with the low buildings was easier to navigate because you could see around better"

It is interesting to mention that the differences mentioned above, of geometrical properties and of order and ease of navigation, were only perceived as such in the small scale environments, A and B, and not in the big ones, C and D. A reason for this could be that in the big environments the buildings height differences were not in the close visual field of the participant and therefore were not strongly perceived. This could also be the explanation why big scale worlds are an exception to the fact that same height buildings have a better correlation of integration to pedestrian counts.

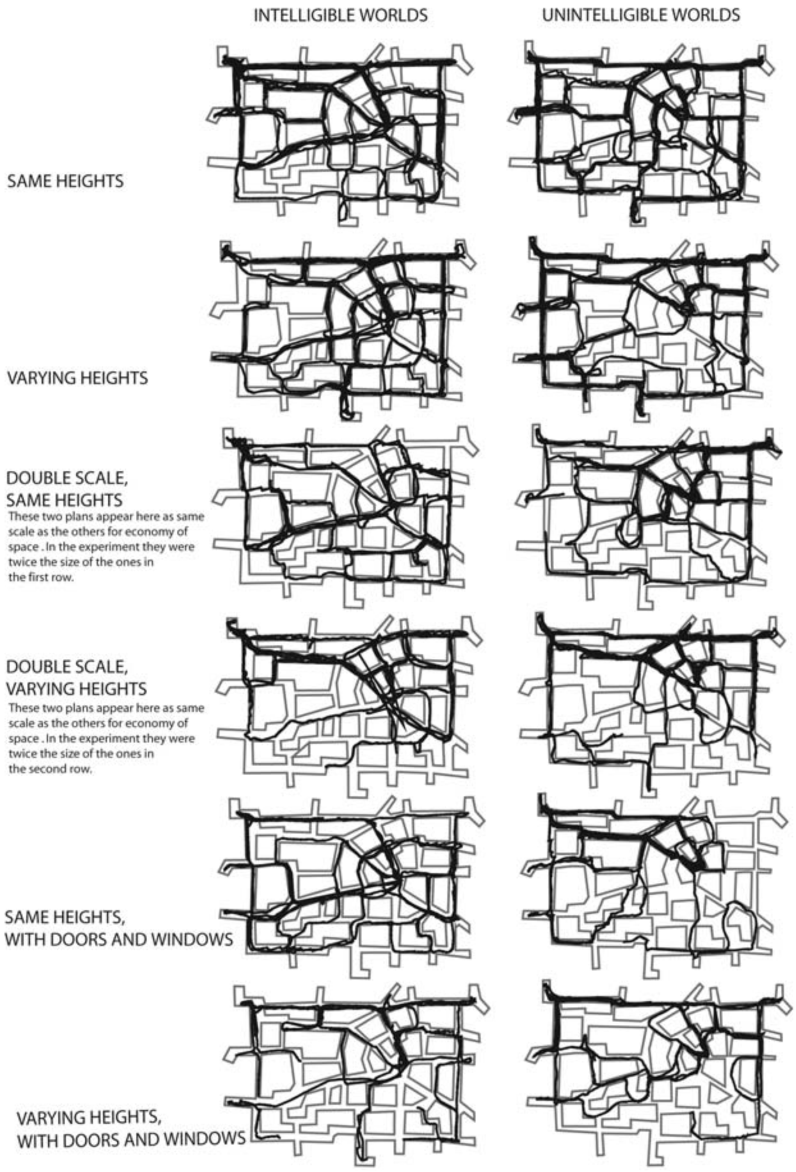


Figure 4:

The traces of the participants in each of the 12 wolds.

Some other findings that do not fit in the above hypotheses are presented here. The bigger scale (double) was mainly not recognized as such. In the bigger scale environments there was a perception of slower speed of movement rather than that the streets were longer. The difference between the small scale and the big scale environments was considered to be the slower speed of the apparatus. This wouldn't be expected to happen in a real environment but in a virtual environment it was perceived as such due to the lack of bodily effort. This is related to the issue of embodiment in virtual environments.

Regarding the hierarchical scaling, addition of doors, windows and pavements, it is not clear if it was helpful or not. It was helpful for some participants and confusing for others. Some of their comments were:

> “too much detail”,
>
> “too cluttered with windows etc.”
>
> “windows and doors didn’t make any difference”
>
> “the fifth one (F2) was easier with pavements, doors and windows with colors and varying building heights”
>
> “the last two (E2 and F2) with doors, pavements and windows, seem to give more information about the form of the space”
>
> “the last two(F2 and E2) were probably easier because there were pseudo-real building elements rendered in the scene”

A final remark is that areas with very low buildings (3m) were considered as “squares”, like open spaces because they could actually see the buildings at the back. The participants were saying for example that:

> “in worlds B and D there were more squares”
>
> “low building in a square”

The worlds with very low buildings among higher ones were perceived as easier for navigation.

> “…look in the distance above lower buildings to think where to go and where I had been”

All the above findings can be summarized in a main finding: this is that changes of forms can affect the perception of both geometrical and topological properties of space. The perception of geometrical properties of space seems to be related to the forms creating this space. For example, it seems that the perception of the length of a road is strongly related to the heights of the buildings along this road, and to the width of the road etc. Therefore, in studies of perception, geometrical attributes of space, like distance, should not be isolated from the study of forms. The findings and hypotheses presented above lead to the formation of the main hypothesis of this paper. This is that the scale of an urban environment is a relation of form to space and not simply an attribute of form or an attribute of space. This scale is named cityscape scale [iii]. Cityscape scale defines the complex relation of what a human mind perceives when walking down a street. This is the relation of architectural forms, juxtaposed in a specific formal configuration which creates the urban form, with the spatial configuration created by these forms.

Conclusions

This paper has explored perception of the scale of the built environment and the effect it has on the intelligibility of cities. The paper has presented an experiment that took place in a virtual environment and the hypotheses that are formed from the findings of the experiment.

Scale is a very wide term in the literature of the built environment. This paper differentiates three types of scale: the architectural scale, the urban scale and the spatial scale and clarifies that it is not dealing with any of these three in particular. The interest is specifically in the perception of scale, as this unfolds in the relations of heights of buildings, length of streets, width of streets etc. and as this is perceived by pedestrians walking through cities.

In order to investigate the issue of the perception of scale, the method used was that of navigation in virtual urban environments. The environments had the same configuration but different properties of scale and proportions.

There are three sub-hypotheses deriving from the virtual environment experiment:

a. The perception of distance of a street is affected by the configuration of the forms along this street. The perception of geometrical properties of space like length and width of roads are perceived as different depending on the heights of buildings along a road being the same or not. This means that perception of distance of a street should be studied in relation to the forms along this street since perception of distance is affected by the configuration of the forms.

b. Environments with the same configuration but different form properties are not perceived as being the same. In the experiment, although all worlds in each group had exactly the same configuration they were not perceived as the same due to the differences in scale in each one of them.

c. Environments with the same height were perceived as more ordered and easier to navigate. In these environments the correlation coefficient between integration value of axial lines and pedestrian counts was higher than in environments with different height. This could mean that environments with the same height may be more intelligible than environments with different heights. This could be an intelligibility of scale as opposed to the intelligibility of space (Hillier 1996).

All these sub-hypotheses lead to the main hypothesis which is that scale is a relation of form to space, since the experiment has demonstrated that the perception of form affects the perception of both geometrical and topological properties of space. This type of scale defined as a relation of form to space is named cityscape scale. Cityscape scale defines the more complex relation of what a human mind perceives when walking down a street which is a combination of architectural forms juxtaposed in a specific formal and spatial configuration which creates the urban form.

It seems that scale properties of forms could affect the perception of the intelligibility of the built environment. If this is the case then the intelligibility definition (Hillier 1996) should be expanded to include scale relations, as relations of forms to space, as well. This paper sets and opens up many questions related to the issue of scale and suggests many hypotheses for further research.

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i. These participants mentioned as difference the heights of the buildings but they didn't necessarily grasp the correct relation of heights (double for example) among all four environments.

ii. The table presents the correlation coefficient between number of pedestrians/participants and integration value of the axial line for each world.

	World A	World B	World C	World D	World E	World F
Intelligible	0.20	0.16	0.10	0.11	0.17	0.10
Non Intelligible	0.10	0.01	0.13	0.10	0.31	0.01

iii. Thanks to Ruth Conroy Dalton for suggesting the term.