Effects of Urban Spatial Configurations and Physical Structures on Pedestrians' Perception of Subjective Duration

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Abstract. One of the less-noticed arguments associated with urban-space perception while moving is the pedestrians' subjective time perception. Indeed, in many cases, the pedestrians' perception of the time needed to travel a distance is shorter or longer than the actual time. The main objective of this paper—which has been neglected by many urban designers—is to determine the effect of the physical-spatial structure of a built environment on the pedestrians' perception of time. It is hypothesized that different spatial configurations and physical structures can have specific effects on the observer's subjective perception of time, while moving in an urban space.
Since this study needed to examine different types of physical-spatial structures from a time perspective, while preventing the possible involvement of other non-physical factors that affect people's time estimates, real urban environments received limited use in this study. Instead, the researchers used a virtual-reality technique to maximize the similarity between the observers' perceived conditions and the real environment. This makes it possible to make dynamic and continuous changes to the physical-spatial variables under study in a semi-real context, and to control other variables affecting the time variable.
In addition, to achieve a systematic and logical review, the researchers analyzed the effects of the physical-spatial structures in nine defined simulated tests on pedestrians' subjective time perception. The results supported the hypothesis of a logical relationship between certain physical-spatial configurations and the observer's subjective time perception while moving in an urban space. The logical relationships between the nine configurations studied in this paper were presented as part of the study's practical results.

Keywords: Time perception, subjective duration, physical structure, spatial configuration, virtual reality

1 Introduction

Different people have different perceptions of the three-dimensional (3D) space in which they move. One issue related to the perception of moving space, which has received less attention in urban-design literature, is that of pedestrians' perception of subjective duration [1]. In many cases, pedestrians may perceive their movement duration on a given path to be shorter or longer than the actual time needed to move thereon.

Indeed, a wide range of factors affects and can change the perception of time for an individual moving in an urban environment, including individual factors (gender, age, psychological state, etc.), social and cultural contexts, economic conditions, purpose and motivation for being in the space, knowledge of the given area, etc. However, the topic discussed in this study, which has received less attention in environmental psychology, includes the effects of the physical and spatial structures of the built environment on the pedestrians' perception of the moving duration in the urban space [2]. To investigate this relationship, this study attempts to analyze and explain the possible logical relations between different configurations of physical-spatial structures and the perception of subjective duration to find some physical design features that influence the time perception. It also attempts to delineate the temporal aspects of urban-environment perception in fluid spaces, e.g., roads.

2 Time Perception

Time perception, according to Fraisse's conception, is defined as "the attention to, or apprehension of, change through the integration of a series of stimuli, characterized by the ability to conceive of duration, simultaneity, and succession" [3]. It implies that perceived time bears no straightforward relationship to physical time [4]. Hence, the subjective duration experienced by a pedestrian may be different from the objective (real) time that has passed. So, even if all our senses were prevented from functioning for a while, we could still notice the passing of time through the changing pattern of our thought [5]. In this respect, [6] Gell posits that:

> *Perception is intrinsically time-perception, and conversely, time-perception, or internal time-consciousness, is just perception itself... That is to say, time is not something we encounter as a feature of contingent reality, as if it lay outside us, waiting to be perceived along with tables and chairs and the rest of the perceptible contents of the universe. Instead, subjective time arises as an inescapable feature of the perceptual process itself, which enters into the perception of anything whatsoever).*

Many personal experiences, as well as experimental studies, confirm that situations, and circumstances under which they occur, play an important role in time perception. Happy hours, for instance, are perceived by an individual as passing fast, but twenty minutes of waiting for a bus appears long, and one minute of pain much longer. Also, as one would intuitively expect, "interesting" time periods pass by more quickly [7]. The perception of time in a given period also closely connected with the number of new, unusual or remarkable events which take place in this period (see e.g. [8-9]). The periods which are filled with new things are momentarily seen as passing by quickly. Looking backwards they have made an impression, and now they seem much longer than less exciting periods of life. So, time has been coined as a "dimension of perception and experience" [7].

In this respect, James [10] believes that to experience time is to perceive change, to perceive events in succession. As he mentioned "In general, a time filled with varied and interesting experiences seems short in passing, but long as we look back. On the other hand, a tract of time empty of experiences seems long in passing, but in retrospect short".

3 Concept of Duration

Duration applies to the interval between two successive events [11] and is essentially a continuation of what no longer exists into what does exist (Bergson, 1999:33). The perception of temporal duration is crucially bound up with memory. It is some feature of our memory of the event (and perhaps specifically our memory of the beginning and end of the event) that allows us to form a belief about its duration [5]. Duration constitutes a judgment of temporal quantity and is related to our physiological subjective response to particular stimuli, rather than being an objective property of the stimulus events themselves [13].

Indeed, internal physiological states such as increased self-awareness in situations which are abnormally intense (as in solitary confinement, i.e., ‘empty’ intervals, or interpersonal violence, i.e., ‘full’ intervals) give rise to duration appearing to be protracted, vis-à-vis typical temporal awareness. Flaherty believes that “protracted duration is experienced when the density of conscious information processing is high and the subject is attending to more of the stimulus array and vice versa [14]. Flaherty also suggests that experiences which produce a lower density of information processing, and hence in which time appears to ‘pass more quickly’ (temporal compression), include those which involve routine complexity. This relates to the idea that activities, which while potentially complex, through routine practice give rise to “an abnormally low level of stimulus complexity brought on by the near absence of attention to self and situation” [15].

Craik, in his conceptual framework of environmental assessment, recommended that temporal characteristics, such as subjective duration, should be considered as fundamental attributes of places. Crick stated that "apparent duration… of journeys through different places at constant speeds may differ to a reliable and stable degree" [16].

4 Time-Based Urban Design Thoughts

As mentioned previously, few studies about time perception have been carried out in the area of environmental design and especially urban design. Moreover, application of findings of research in other disciplines, especially cognitive psychology, in affecting urban environments on perceived time has not received due attention. So, at the following, some of the most important viewpoints and studies finding in the area of time-based design is mentioned [1].

In the book "Aesthetics in Architecture" [17] notes that any movement takes time, and man will not be able to understand the environment without time. He believes that movement and especially time give urban space a dynamic nature. For Grutter, our perception of long time durations is limited. A duration of one hour is a specified concept for us, but that of several years is only a mathematical concept for us. When this duration increases, our time perception ability decreases until it totally disappears. According to Grutter, a rhythm is an important tool for making a path measurable.

Lynch, in the book "The Image of the City" [18], introduces “Motion Awareness” and “Time Series” as factors contributing to better perception of urban environment. According to Lynch, these qualities help the observer specify his/her direction and distance of movement, and through movement, forms become sensible for him/her.

In the book "Design of Cities" [19], Bacon also indirectly addresses time and states that adding the dimension of time to space creates a paradigm shift in our perception of the environment, so that our attitudes about the world and the way we define our relationship with the world and nature are changed and plans are influenced. Bacon says that road as an urban space can have sub-divisions in itself, which increases its measurement capability.

But the most important studies carried out in the field of subjective duration in urban design, which was discussed in this paper, include those by Bosselmann [20] and Isaacs [21].

Bosselmann, in his book entitled *Representation of Places: Reality and Realism in City Design*, compared the experience of a four-minute walk (about 350 m) through Venice, Italy, with walks of the same distance in a variety of other urban settings. In his work, Bosselmann investigates walking and shows how the perception of the passage of time in the distance traveled is different from reality; it is partly a function of the visual quality and experience of the environment in which the movement takes place. Since Bosselmann found that walking in Venice seemed longer, both in terms of time and distance, he investigated the time experience in 14 other cities with similar walking paths. He believes that 39 images from unequal distances could be taken to describe the four-minute walk in Venice, while walking in other countries could be illustrated with a much smaller number of images. He also argues that, although the walks are of equal length, they appear to take different amounts of time, suggesting that the spatial dimensions and the configuration influence an individual’s sense of time. He states that, by grasping this phenomenon, “designers thus have remarkable power to affect the perception of time by arranging objects in space, by setting dimensions, designing textures, selecting colors, and manipulating light” [20]

On the other hand, Isaacs’ test results suggest that the spatial-structural characteristics of urban environments affect the time perception [21]. In his valuable study of pedestrian experiences in urban places, 42 individuals were asked to estimate the time required to walk segments of three different paths in the central area of Dresden, Germany, which has a rich variety of urban patterns close to each other. Immediately after finishing the path, each individual provided qualitative responses to questions about the environment along the path. Next, Isaacs asked the subjects to estimate the time for each path. In his study, despite the effects of individual differences and simple and poor controls in the tests, the results showed statistically significant differences between the subjective duration estimates and the real time. In Table1 some findings from architecture, city & regional planning, landscape architecture and urban design researches about time-based urban design are mentioned.

Table 1. Some of the most important time-based design thoughts in architecture, city & regional planning, landscape architecture and urban design

Expert (s)	Key Viewpoints	Explanation
Lynch (1960)	*Motion Awareness and Time Series*	- They are factors which contribute to better perception of urban environment and help the observer specify his/her direction and distance of movement …
Bacon (1976)	*Time perception and role of designers*	- Designers can add the dimension of time to space… - Road as an urban space can have sub-divisions in itself, which increases its measurement capability.
Grutter (1987)	*Movement, rhythm and time*	- Movement and especially time give urban space a *dynamic nature*. - A *rhythm* is an important tool for making a path measurable. - Our perception of long time durations is limited. As this duration increases, our time perception ability decreases until it totally disappears.
Bosselmann (1998)	*Time perception and role of designers*	- Designers can manipulate the experience of individual's time perception appropriately for the overall design intent. - One design goal may focus on the immediate awareness of the passage of time in terms of `slower' or `quicker'. The other design goal is the reflective estimate of duration in terms of `shorter' or `longer', as tested in the two quasi-experiments.
Isaacs (2001)	*Spatial scale*	- Smaller spaces increase the subjective duration.
	Shift in directions	- The estimates for the paths with changes in direction are significantly longer than those for the straight paths.

Source: Shakibamanesh & Ghorbanian, [1]

5- Methodology

In this study, to investigate the relationship between a physical-spatial structure and the perception of subjective duration, the researchers used tests based on different arrangements of specific buildings and street layouts. Therefore, a cause-and-effect analysis (field experiment) and exploratory field research were used.

5-1- Virtual reality as a research technique

Since this research requires dynamic and continuous changes to the physical-spatial variables affecting the subjective duration, and it is almost impossible to bring a person to a real test field, we used a virtual-reality technique that can simulate perceptual conditions; e.g., providing a human with a dynamic three-dimensional field of view to the physical realm being studied and simulating path navigation.

In this research, a homemade laboratory head tracker with six degrees of freedom (6DOF) was added to binocular virtual-reality 3D video glasses (cinema glasses) to create a head-mounted display (HMD). The Unity 3D game engine was used to create interactive spaces. With these instruments, interactive perspectives of the space being observed were created, allowing the head (and to some extent, the body) to move in order to see different parts of the space, just as an individual (voluntarily or involuntarily) tends to see it.

Moreover, in this study, the researchers tried to take advantage of virtual-reality measures in the simulation space, e.g., maximizing the semi-reality of the test environments, simulating some of the events in virtual urban spaces, simulating a human's natural walking cycle on a sine wave, providing a semi-real navigation speed, dubbing in the real sounds of urban environments, and controlling the movement zones, to enhance the quality of the test results (See [22]).

5-2- Techniques to estimate duration

In this research, to assess the subjects' subjective duration, a combination of six different techniques was used[1], as follows:

A) *Time estimation via a reproduction technique.* In this study, the subjects were asked to go through each simulated path in a virtual environment and then replay it in their minds (reproduction method). Without observing the passage of time, they recorded their estimated start and end times for the path by simply pressing two buttons. The times were recorded with a digital clock (one-millisecond accuracy).

B) *Verbal estimation; time estimation based on the estimated duration (in metric).* In this method, the subjects were asked to estimate the distance traveled in the test path using a meter. Then, given the navigation speed of their avatars in the virtual tests in this study (1.27 meters per second)[2], the estimated distance figures were used to calculate the time.

C) The subjects were asked to determine the best time estimate by marking an *X* on the time-calibration chart (time-scaled chart).

D) The subjects were asked to identify the minimum and maximum time estimates by marking an *X* on the time-scaled chart and calculating the mean of the two values as a measure of the subjective duration.

E) The subjects were asked to determine the best time estimate via writing digits.

F) The subjects were asked to write the digital values of the minimum and maximum times and calculate the mean of the two values as a measure of the subjective duration.

Since the purpose of this study was to find the nearest-to-reality subjective-duration value, the final subjective-duration variable was obtained by averaging the above values.

5-3- Grouping subjects for tests

As the length of the simulated axes was high and it was time-consuming to respond to the questionnaires, all subjects could not be expected to pass all nine tests. Therefore, four subjects were assigned to each test group, and each subject was required to take three tests, as follows:

- First subject: Tests A1, A2, and A3;
- Second subject: Tests A1, C1, and C2;
- Third subject: Tests A1, C3, and S1; and
- Fourth subject: Tests A1, S2, and S3.

In this study, 20 groups of four subjects (total 80) participated in the tests[3]; thus, 240 questionnaires were completed. As can be seen, all members of a group were required to pass the control test, A1. In the sections below, to develop a background for investigating the effects of the spatial configuration and physical structure on the pedestrians' perception of subjective duration, the design of the nine tests and their simulation manner in a virtual environment are discussed.

5-4- Determining the study paradigm in the estimation of subjective duration

The researchers argue that one of the key points in studies on the perception of time lies in whether the nature of the paradigm they use is retrospective or prospective [23, 24].

A. Retrospective Paradigm. In a retrospective research approach, after the test, the participants are informed that they will need to measure the duration [25]. Since we often do not pay attention to time cues, when we are asked to have a retrospective judgment on the subject of time, we use a certain amount of processed information or stimuli as the basis for inference on the perceived duration of an experienced event [26]. Research shows that in a retrospective paradigm, memory-based models are used.
(B) Prospective paradigm. In prospective paradigm, participants are informed that the purpose of the test is an estimate of the duration of their perceived time and that they are supposed to estimate the length of time experienced by a specific event or action [9, 25]. Measuring the length of time by the prospective paradigm depends on the amount of attention paid to the processing that occurs at the same time for non-temporal information. Hence, in this approach, the estimation of time occurs in a dual-task cognition context. This means that the individual's attention should be divided between processing temporal and non-temporal information [23] raising the issue of attention-based models in a prospective paradigm [26].
In the present study, the retrospective paradigm was used. The main reason for this choice is the high similarity of the conditions of perception in this approach to the real ones in which a person (often) estimate the duration of navigating in the urban environment, without a specific purpose. Choosing this approach can help to generalize the results of pseudo-tests of this study to possible conditions in perception of the real environment.

6- Designing the Research Tests

6-1- Physical conditions of the test environments
The formation of a physical-spatial structure in an urban context depends on many physical and formal parameters. A change in each leads to the formation of new and different types of physical-spatial configuration. Obviously, the physical structure and spatial arrangement of an urban space can take various forms, depending on various perspectives, tastes, architectures, design styles, etc. Thus, in this study, an attempt is made to provide limited but targeted tests to measure only the effects of specific changes in the physical-spatial structure on the subjective-duration perception. In this article, from among all the physical-spatial variables, the effects of only two macro variables are addressed.

6-1-1- Macro spatial configuration (scheme). In this study, the macro spatial configuration (scheme) is the pattern governing the space plan that can significantly affect the arrangement of the physical elements and the formation of the physical structures in an urban setting. Among all the design possibilities for macro spatial configurations, this study focuses on three macro arrangements, based on straight-line, curved, and spiral plans.

6-1-2- Physical layer of the space design. It is evident that in an urban axis, deliberate physical changes can be made in the different layers of space. Spatial layers include the ground-level layer, upper-ground wall layer, floor-wall layer, ceiling-wall layer (for indoor urban spaces), and the wall layer parallel to the movement axis. Moreover, as a general classification in this research, all physical layers in the design can be divided into two-dimensional (2-D) and 3D categories.

Indeed, avoiding various volumetric forms, e.g., extended, setback, and cut, can generally simplify the physical façade of each layer in the wall-design process. This results in the formation of a layer where 2-D surfaces dominate. Thus, this study contains a higher proportion of 2-D surfaces than 3D ones.

On the other hand, 3D physical structures can be created in different physical layers of an urban setting by using volumetric extensions or setbacks in relation to a shared building ground line, and by creating various surfaces that are not tangential to the street axis. In fact, 3D physical structures in different physical layers of a wall can be due to several reasons. Some buildings use these 3D surfaces in their initial design concept. Others apply extensions or setbacks in buildings to comply with urban regulations. Moreover, using special design elements, e.g., colonnades, arcades, arches, domes, and minarets, can contribute to the formation of such 3D structures. Thus, a variety of physical layers in an urban axis can be classified into the following 10 proposed categories:

a) Ground-level layer with a 2-D structure,
b) Ground-level layer with a 3D structure,
c) Upper-ground wall layer with a 2-D structure,
d) Upper-ground wall layer with a 3D structure,
e) Floor layer with a 2-D structure,
f) Floor layer with a 3D structure,
g) Ceiling wall layer (in indoor setting) with a 2-D structure,
h) Ceiling wall layer (in indoor setting) with a 3D structure,
i) Wall layer parallel to the movement axis with a 2-D structure, and
j) Wall layer parallel to the movement axis with a 3D structure.

6-2- Buildings modeled in the research tests

The following two types of buildings have been used to develop the research tests:

A) The first group of buildings should be extremely similar to each other, in terms of forms, volumes, materials, etc. They appear in three different types and are used in accordance with test requirements in simulated contexts (Fig. 1). These are:
- Buildings with full 2-D walls along the movement axis;
- Buildings with walls, including 3D ground-level layers and 2-D upper-ground wall layers, along the movement axis; and
- Buildings with walls, including 2-D ground-level layers and 3D upper-ground wall layers, along the movement axis.

B) The second group includes buildings where the ground-level layer and the upper-ground layer of the wall are two-dimensional, and are constantly used in all nine tests in the walls parallel to the movement axis.

It should also be noted that, in this study, to avoid unacceptable abstraction of the environment and to maintain the highest similarity of the simulated space to real urban paths, the design and forms of actual buildings in Tabriz, Iran, were used to model the virtual space.

6-3- Physical dimensions of the test paths

In this study, the longest simulated paths are considered to be 200 meters. The width of the simulated axes in all the tests is 34 meters and consists of sidewalks on both sides of the path, three traffic lanes on each side of the street, and a median in the middle of the path.

In this research, the effects of eight compound distinct configurations (layouts) of physical structures alongside the control test (A1 test) — described in Table 2—on the subjective-duration perception were examined. Tests with straight, curved, and spiral macro-spatial configurations are included in test groups A, C, and S, respectively.

Building Types		
2-D Up & 2-D Down	2-D Up & 3D Down	3D Up & 2-D Down

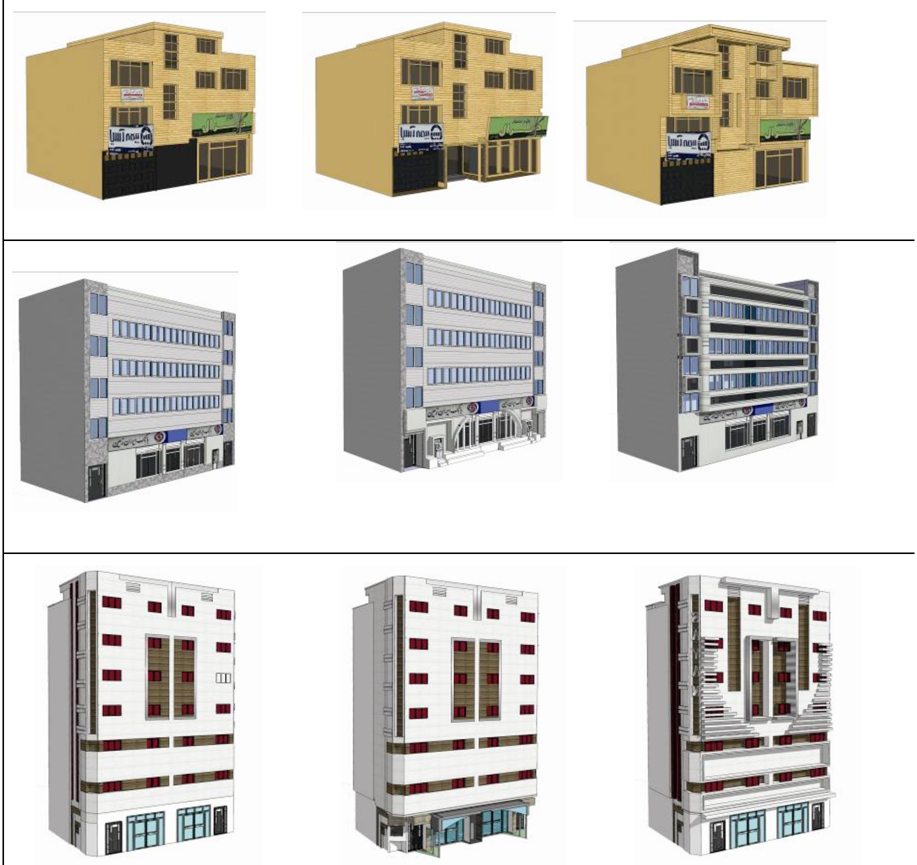
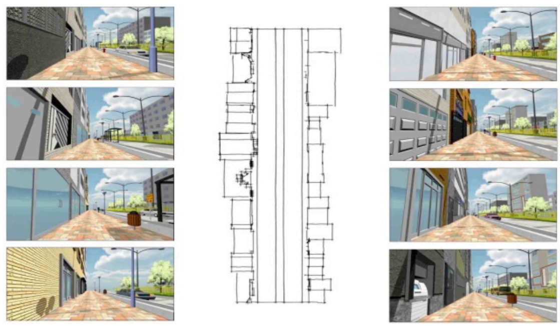
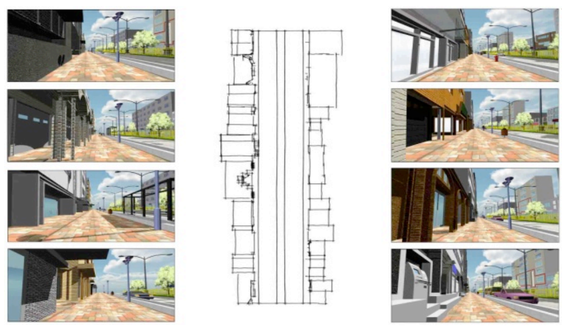
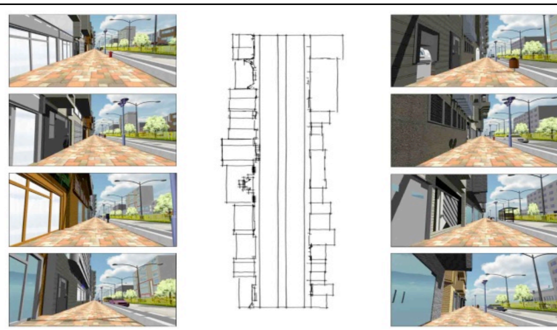
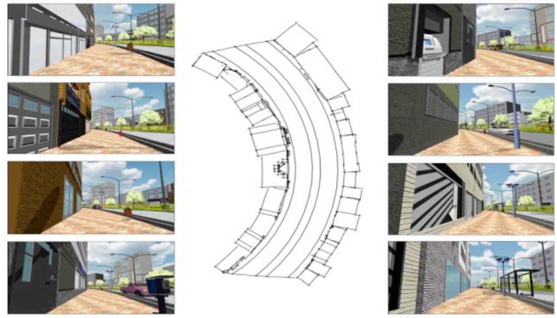
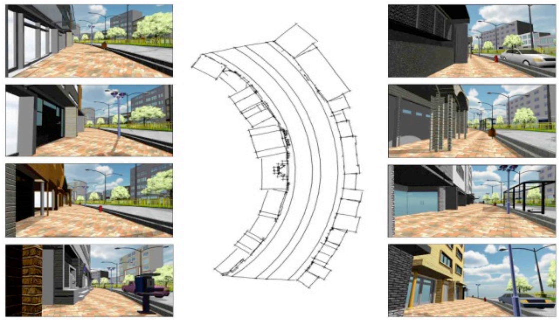
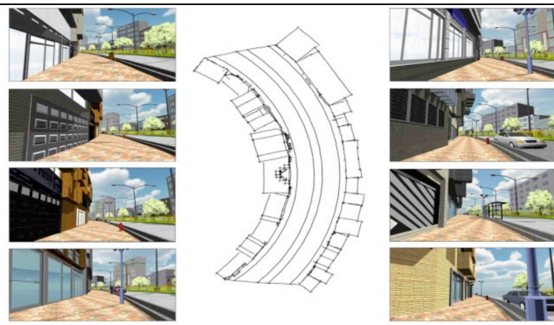
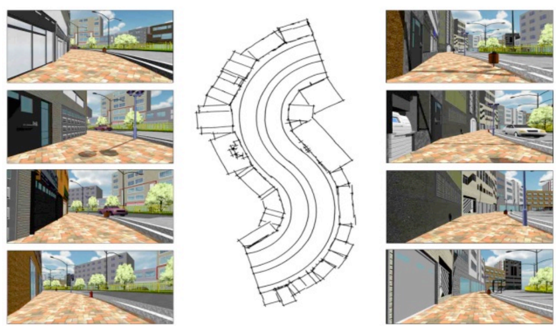
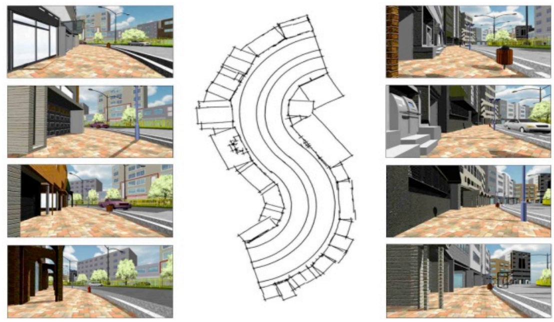
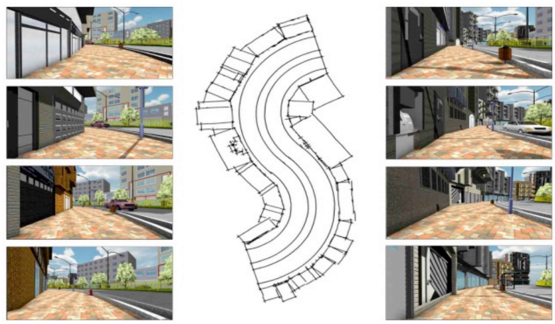


Fig. 1. Examples of buildings modeled along the movement axis in the virtual environment.

Table 2. Nine physical-spatial tests measured in relation to the subjective-duration perception

Test Name	**Spatial Configuration and Physical Structure Conditions**		**Visual Description of Test Environments** (Successive Views From the Pedestrian's Viewpoint and Site Plan)
	Macro spatial configuration/ scheme	Condition of the designed physical layer	
A1 (Control Test)	Straight Line Path	- All wall layers are in 2-D form	
A2	Straight Line Path	- The ground-level wall layer is in 3D form - The other wall layers are in 2-D form	
A3	Straight Line Path	- The upper-ground wall layer is in 3D form -The other wall layers are in 2-D form	

C1	Curved Path	- All wall layers are in 2-D form	
C2	Curved Path	- The ground-level wall layer is in 3D form - The other wall layers are in 2-D form	
C3	Curved Path	- The upper-ground wall layer is in 3D form -The other wall layers are in 2-D form	
S1	Spiral Path	- All wall layers are in 2-D form	

S2	Spiral Path	- The ground-level wall layer is in 3D form - The other wall layers are in 2-D form	
S3	Spiral Path	- The upper-ground wall layer is in 3D form - The other wall layers are in 2-D form	

7- Statistical Results

7.1 Relationship between the nine physical-spatial structures and their estimated duration

The correlation between the independent variable, "type of physical test," and the dependent variable, "mean estimated duration (resulting from the mean of six separate methods)," shows that the Eta-squared correlation coefficient (η^2) is very low (equal to 0.047) and tends to 0. Therefore, the null hypothesis (H0) is accepted; i.e., there is no significant correlation between the type of physical test and the mean estimated duration. Moreover, the higher p-value level in the analysis of variance (ANOVA) than the specified significance level of 0.05 ($0.187 > 0.05$) indicates no significant correlation between the two variables.

However, an analysis of the correlation between the independent variable, "type of physical test," and the dependent variable, "estimated duration derived from the metric estimates," indicates that the ANOVA p-value is less than the specified significance level of 0.05 ($0.01 < 0.05$). Therefore, it can be assumed with a 99% confidence level that the H1 hypothesis (alternative hypothesis) is supported; i.e., there is a significant relationship between these variables. Similarly, the correlation between the independent variable, "type of physical test," and the two dependent variables, "best time estimate obtained from the time-calibration chart (time-scaled chart)" and "best time estimate obtained via writing digits," indicates ANOVA p-values of 0.028 and 0.047, respectively, which are both lower than the specified significance level of 0.05. Therefore, we can support the H1 hypothesis with a 95% confidence level; i.e., there is a significant relationship between the independent variable, "physical test," and both dependent variables studied.

Thus, it can be concluded that despite the lack of a reasonable correlation between the two variables, "type of physical test" and "mean estimated duration (resulting from the mean of six separate methods)," a reasonable correlation can still be observed between the variables, of "type of physical test" and "estimated duration obtained from three out of six methods," from the time estimation in the questionnaire. Based on these three methods, the hypothesis that various physical-spatial structures lead to different conditions for a moving pedestrian's subjective perception of time is supported.

7.2 Comparison of estimated duration in the nine physical tests

An independent sample t-test was used to investigate possible relationships between the mean estimated subjective duration in the nine physical tests. The results indicated a logical relationship between the "mean estimated duration" in some physical tests. T-test results are shown in Table 3.

Table 3. The possible logical relationship between the mean estimated subjective duration in the nine tests as investigate by Independent Sample T-test

Relationships	Significance	Confidence	Results
μ A1 > μ A2	Sig: 0.037	96%	With 96% confidence the mean of subjective duration in A1 test is more than A2.
μ A1 > μ A3	Sig: 0.012	98%	With 98% confidence the mean of subjective duration in A1 test is more than A3.
μ A1 > μ C1	Sig: 0.037	96%	With 96% confidence the mean of subjective duration in A1 test is more than C1.
μ A1 > μ S2	Sig: 0.048	95%	With 95% confidence the mean of subjective duration in A1 test is more than S2.
μ A1 > μ S3	Sig: 0.020	98%	With 98% confidence the mean of subjective duration in A1 test is more than S3.
μ S1 > μ A3	Sig: 0.047	95%	With 95% confidence the mean of subjective duration in S1 test is more than A3.
μ C3 > μ S3	Sig: 0.049	95%	With 95% confidence the mean of subjective duration in C3 test is more than S3.
μ S1 > μ S3	Sig: 0.044	95%	With 95% confidence the mean of subjective duration in S1 test is more than S3.

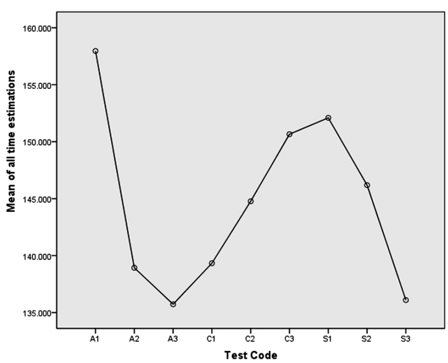


Fig. 2. Mean estimated subjective duration in the nine physical-spatial tests.

Fig. 2 shows the distribution of "mean estimated subjective duration" in the nine tests. As can be seen, path A1 has the longest subjective duration and S3 has the shortest subjective duration with a high margin.

7.3. Relationship between the "real navigation time in the test paths" and the "estimated duration"

7.3.1- Analyzing the correlation

The results of the Pearson correlation between the two variables, "real navigation time in the test paths (or real time)" and "mean estimated duration (from the mean of six separate methods)," show that the p-value is higher than the specified significance level of 0.05 (0.438 > 0.05). Therefore, the H0 hypothesis is supported with a 95% confidence level; i.e., there is no significant relationship between these variables. However, if the correlation between "real time" and "mean estimated duration of six methods" in the questionnaire is addressed separately, a significant correlation is only observed in a couple of variables, e.g., between "real time" and "estimated duration derived from metric estimates."

As in the Pearson correlation between "real time" and "estimated duration derived from metric estimates," the p-value is less than the specified significance level of 0.05 (0.003 < 0.05). Thus, the H1 hypothesis is supported with a 99% confidence level; i.e., there is a significant relationship between the above variables. A Pearson correlation coefficient of 0.21 was obtained. Therefore, the correlation rate is low, incomplete, and direct. This means that, in this study, when the real navigation time in the test paths increases, the estimated duration (derived from metric estimates) increases, and vice versa (Fig. 3).

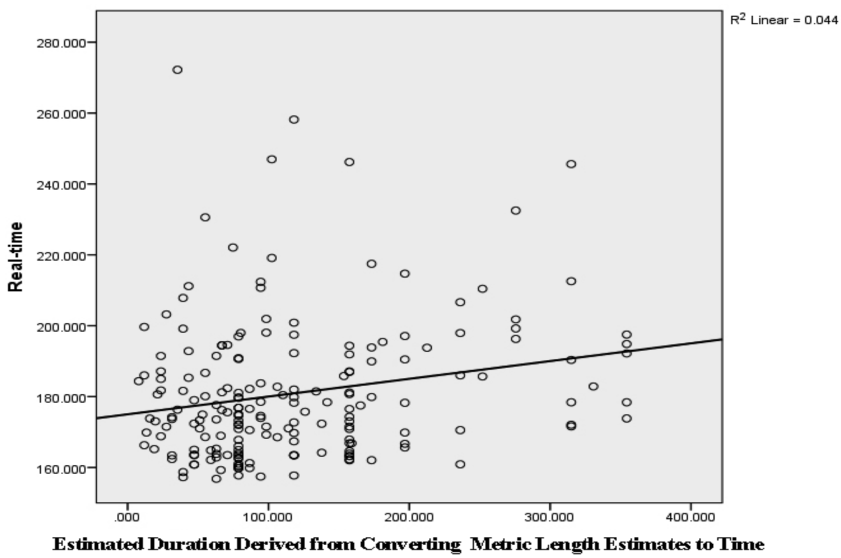


Fig. 3. Relationship between "real time" and "estimated duration derived from metric estimates."

7.3.2 Direct assessment and comparison between the real time and estimated duration

To directly assess and compare the "estimated duration" and "real time," the ratio of the two variables can be used. In this part of the analysis, the "mean estimated duration" for every subject is divided by the "real time." If the resulting value is equal (or very close to) 1, the real time and the estimated duration are equal. Values below 1 indicate that the subject underestimated the duration, and values greater than 1 indicate that the subject overestimated the time needed for navigating the path. Based on the data obtained from 240 questionnaires (completed by 80 subjects), the mean value for this ratio is equal to 0.815. This shows that, in general, the estimated duration for all nine tests was lower than the real time needed for navigating the test paths.

Table 4 shows the ratios for the nine tests in this study. As shown in this table, in all tests, the mean estimated duration was shorter than the real time. However, in A1, the numerical value was 0.917, which is nearer to 1. This shows that, in this test, the mean estimated duration was significantly close to the real time. The lowest numerical value was 0.635 in S3, indicating the greatest difference between the mean estimated duration and the real time (Fig.4).

Table 4. Descriptive statistics for "real-time", "mean estimated duration" and "ratio of real-time to mean estimated duration" in the nine tests

Test Code		Mean estimated duration	Real-time	Mean estimated duration/ Real-time
A1	Mean	157.96073	173.15518	**.91773**
	Std. Deviation	34.430676	11.508113	.215073
A2	Mean	138.93712	166.84467	.79898
	Std. Deviation	42.161565	10.069437	.199676
A3	Mean	135.73340	179.17320	.76480
	Std. Deviation	36.778424	22.576790	.197970
C1	Mean	139.33331	178.18867	.76961
	Std. Deviation	38.814190	7.433098	.203244
C2	Mean	144.77099	186.17733	.73705
	Std. Deviation	51.877234	15.087183	.254634
C3	Mean	150.65846	185.01706	.82115
	Std. Deviation	37.184017	13.499654	.186196
S1	Mean	152.09608	178.37588	.84430
	Std. Deviation	41.608406	10.145462	.246760
S2	Mean	146.18772	196.40006	.73871
	Std. Deviation	37.641024	24.425185	.202752
S3	Mean	136.10166	210.29100	**.63548**
	Std. Deviation	45.476061	29.038059	.209200

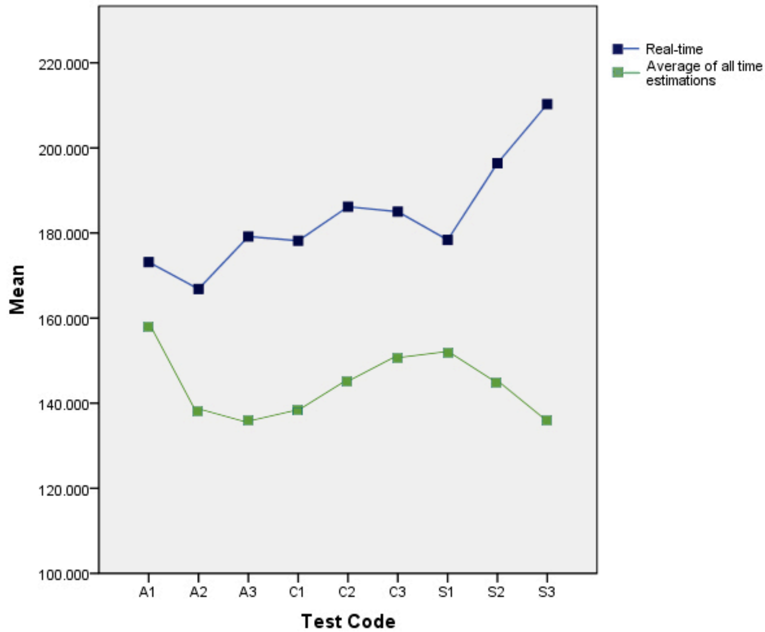


Fig. 4. Comparison between "real time" and "mean estimated duration" in the nine tests[4]

7.4 Correlation analysis between "familiarity with the test system" and "mean estimated duration"

The subjects were asked about their level of previous familiarity with the test system (based on virtual reality). Given the significance levels of Kendall's tau-b and Spearman's correlation coefficients (0.892 and 0.901, respectively) and the obtained value for the Eta-squared correlation coefficient (η^2) (0.010), which tends to 0, we can support the H0 hypothesis and conclude that there is no significant relationship between the "degree of familiarity with the test system (virtual reality)" and the "mean estimated duration." In other words, from a statistical point of view, the subjects' familiarity with the test system in this research did not have a significant impact on their time estimates.

7.5 Correlation analysis between "attractiveness of the test environments" and "mean estimated duration"

Kendall's tau-b and Spearman's correlation coefficients were used to investigate the relationship between the "attractiveness of the test environments" and the "mean estimated duration." The p-values of Kendall's tau-b and Spearman's were 0.035 and 0.036, respectively, which are less than the specified significance level of 0.05. Therefore, the H1 hypothesis, i.e. a significant relationship between the two variables, is supported. According to Kendall's tau-b (-0.105) and Spearman's (-0.136) correlation coefficients, the correlation rate between the two variables in question is low, incomplete, and inverse. Thus, it can be concluded that increasing the attractiveness of the test environment reduces the estimated duration, and vice versa.

8- Discussion

While many studies have investigated subjective-duration estimation, there has been limited research on subjective duration and the impact of the physical-spatial components of the environment where the individual's temporal experience occurs, and the mechanisms behind it. Therefore, this study investigates the impact of the physical-spatial structure on the subjective duration. This can help urban designers use the most-often-theoretical results of perception psychology as a tool for applied urban-design approaches.

On the other hand, in urban-design literature, the concept of time has been observed from different perspectives than that of the present study. In fact, discussions on the time dimension in these resources are often limited to issues such as project reliability (stability or change of environmental components) over time, design semantics over time, use of the environment over time, design of time cycles and management of activities in urban areas, changes in the urban environment over time, etc. However, the practical use of subjective perception of time in urban-design projects has not received sufficient attention.

In fact, it seems that if the fourth dimension (time) is applied in the field of design, urban designers will be able to consciously sort and regulate spatial qualities in line with the overall design goals to manipulate the experience of movement in urban spaces. Designers can purposefully change the subjective duration from two perspectives in their designs. Thus, in a project, a major goal of the designer can be deliberate changes in individuals' immediate awareness of the passage of time. Thus, they may perceive a path's travel duration as slower or faster than real time. The designer can take measures to make individuals' retrospective estimated duration in urban areas shorter or longer than the actual time spent passing through these paths.

Based on title 4 (emerging time-based urban design thoughts) and in describing what distinguishes the present study from the similar ones, it is necessary to note the following points:

- Bosselmann [20] used a simple technique for noting different urban areas and compared the number of images able to describe the individual's experience as a walking observer from each of the places. In other words, his method is based on the observation and visual notation of urban scenes, and comparing them with the experience of a particular space (Venice).

  This study has three main shortcomings. First, in this method, the researcher is not able to control the influence of different variables that affect the perception of different urban scenes. Second, the researcher's conclusions are based on a technique that depends on the researcher's personal experience. The perception of ordinary people from the space is not considered. Third, based on Bosselmann's study, it was impossible to determine which physical-space qualities affected the perceptual time change.
- Similarly, in Isaacs' study [21], due to simultaneous changes of physical-spatial structures along the paths, it is not possible to identify which spatial-structural characteristics affected the estimation of perceived time. Moreover, because the study happened in segments of real urban spaces, the effect of other variables that influenced the subjects' estimated duration (e.g., street uses or facilities) could not be prevented.

The distinction between the present study and many previous studies in the area of subjective duration (especially in the field of perception psychology) is that most of these studies evaluate the time of controlled laboratory tests with very short time periods (up to

32 seconds). Therefore, the results of these studies cannot necessarily be generalized to the experience of walking in a realistic urban environment. To solve this problem, in the tests of the present study, the perception of time is evaluated based on carefully simulated paths with a fixed length of 200 m.

Table 5. Effects of different physical-spatial configurations on perception of subjective duration (with a retrospective approach).

Relationship between Tests	Changes in Physical-Spatial Structure	Practical Results
A1 > A2	The ground-level layer is changed to 3D	- In straight line paths, with a change of ground - level wall layer from 2-D to 3D (assuming other physical-spatial conditions as constant), pedestrians' subjective duration decreases.
A1 > A3	The upper ground wall layer is changed to 3D	- In straight line paths, with a change of upper ground wall layer from 2-D to 3D (assuming other physical-spatial conditions as constant), pedestrians' subjective duration decreases.
A1 > C1	Macro spatial configuration (scheme) of a path changed from straight line to curved shape	- With a change of macro spatial configuration (scheme) of a path from straight line to curved shape when in both paths, ground - level wall layer and upper ground wall layer are 2-D , (assuming other physical-spatial conditions as constant) pedestrians' subjective duration decreases.
A1 > S2	Simultaneous change of macro spatial configuration (scheme) of a path from straight line to spiral and change just the ground-level wall layer from 2-D to 3D	- With simultaneous change of macro spatial configuration (scheme) of a path from straight line to spiral and the change of ground – level wall layer from 2-D to 3D , (assuming other physical-spatial conditions as constant), pedestrians' subjective duration decreases.
A1 > S3	Simultaneous change of macro spatial configuration (scheme) of a path from straight line to spiral and change just the upper ground wall layer from 2-D to 3D	- With simultaneous change of macro spatial configuration (scheme) of a path from straight line to spiral and the change of upper ground wall layer from 2-D to 3D , (assuming other physical-spatial conditions as constant), pedestrians' subjective duration decreases.
S1 > A3	Simultaneous change of macro spatial configuration (scheme) of a path from straight line to spiral and change just the upper ground wall layer from 3D to 2-D	- With simultaneous change of macro spatial configuration (scheme) of a path from straight line to spiral and the change of upper ground wall layer from 3D to 2-D , (assuming other physical-spatial conditions as constant), pedestrians' subjective duration increases.
C3 > S3	Macro spatial configuration (scheme) of a path changed from curved to spiral	- With a change of macro spatial configuration (scheme) of a path from curved shape to spiral when in both paths, upper ground wall layer are 3D, (assuming other physical-spatial conditions as constant) pedestrians' subjective duration decreases.
S1 > S3	The upper ground wall layer is changed to 3D	- In spiral paths, with a change of upper ground wall layer from 2-D to 3D (assuming other physical-spatial conditions as constant), pedestrians' subjective duration decreases.

Based on the paper findings, the effects of different physical-spatial configurations on the subjective perception of time (with a retrospective approach) can be observed in Table 5.

It should be mentioned that the effect of temporal design and time perception on pedestrian behavior is not fully known. However, it is certain that a relationship exists between the environment and the subjective duration. However, the objective of urban-design studies is to determine how this will affect the behavior of people in urban spaces. In fact, the results of this study can be used to achieve many non-physical purposes in an urban-design project. Thus, an urban designer with the knowledge of how physical-spatial components affect pedestrians' subjective duration in city environments, will be able to make a short path with commercial, touristic, and cultural importance appear longer to observers than it is.

This can partly lead to more emphasis on the importance of the path, an increase in the likelihood of unconscious pauses in the path, and help form more lasting mental images and memories in pedestrians' minds. On the other hand, when an urban designer is forced to design a long corridor, he/she can use the knowledge of subjective duration to shorten the perception of the path, and decrease the mental fatigue, the desire to change the path, and the lack of attention to activities, physical functions, and structures located at the end of the path.

The type of technique used in this study, which enabled the researchers to simulate physical-spatial conditions is another important issue. Through this simulation, key variables could be changed while keeping other physical variables constant, and also environmental variables that could change the test results could be controlled to help improve the result accuracy. On the other hand, in this paper maximizing the semi-reality of the test environments, simulating some of the events in virtual urban spaces, simulating a human's natural walking cycle on a sine wave, providing a semi-real navigation speed, facilitating the subject's movement in the scene to find a preferred perspective, dubbing in the real sounds of urban environments, preparing high levels of immersion in virtual environment by HMD and controlling the movement zones, have been used to enhance the quality of the test results.

However, despite all the advantages and strengths of using virtual reality in urban design, there are questions and issues in this regard to be investigated and answered in the form of future studies and researches. Among these, the following points and questions can be mentioned:

- In this study, from the different senses that could be used to perceive time when moving in an environment, only the sense of vision was selected and analyzed, because of its importance in the perception of an environment, its greater power and ability to collect data, and its higher controllability compared to the other senses. Obviously, if it had been possible to evaluate the subjective perception of time with regard to all the main senses, the results and arguments would have been more powerful and reliable. However, given the existing limitations in terms of the technological facilities available for including other senses in a virtual environment (as the technical basis for this study), and in terms of time and cost, only the results based on vision were taken into account.
- Are the perceptual errors in virtual environments a level that allows the results of studies in these environments to be generalized to the real ones? For example, it has been observed that moving in a virtual environment while wearing a binocular virtual reality 3d video glasses may induce slower displacement due to the lack of orientation in the virtual space. Possibly this is an aspect that may affect the interpretation of the collected data. So can the errors caused by perception of depth in virtual space be

considered negligible? Furthermore what techniques can be used to decrease, to a reasonable extent, these errors in such studies?

- How much do charm and appeal of the masses and spaces built in the virtual environment help attract the users' attention and makes the perception in the virtual environment distinct from the real space?
- Obviously, conducting all studies in an urban context without the presence of its major players, i.e. people, lacks scientific value. Thus the line of studies can be done to show how presence of people's avatars can be facilitated and also to provide real-life conditions for simulating social interactions in the real world and virtual environments [22].

It goes without saying that answering the above questions can allow for the implementation of scientific techniques of virtual reality in urban design studies and help this area compete with other scientific advancements.

9- Conclusion

This paper examined the effects of the physical and spatial structure of a built environment on the time perception of pedestrians moving in urban spaces. The general hypothesis was that a relationship existed between specific physical-spatial variables and the subjective perception of time by moving observers. Moreover, in this study, an attempt was made to take advantage of a virtual-reality approach and techniques to apply dynamic and continuous changes to the physical-spatial variables in a realistic context, while controlling other variables that affected the time.

On the other hand, since the analysis and evaluation of the effects of a physical structure on the subjective perception of time can include a very wide range of physical and spatial conditions and layouts, the researchers designed nine classified tests to measure the changes in subjective duration using a systematic and logical investigation of physical-spatial structures.

According to the statistics mentioned in the previous section, based on three different methods, the hypothesis of a logical relationship between specific physical-spatial variables and the subjective perception of time by moving observers was supported.

Other important findings of this study are as follows:

- Increasing the attractiveness of the test environments reduced the estimated duration, and vice versa.
- The subjects' "mean estimated subjective duration" in a path of form A1 (a straight-line path with 2D physical layers) was longer than the other simulated paths in the tests. On the other hand, changes in tests A3 and S3 decreased their mean subjective duration compared to the other tests in the study.
- Based on statistical results, the general estimated duration in all tests was less than the real time spent navigating the simulated paths. However, the numerical value of the estimated duration in test A1 closely approached real time. Unlike A1, in a setting with an S3 physical-spatial structure, a significant difference was observed between the estimated and real times.
- The estimated duration (derived from metric estimates) increased with an increase in the real navigation time in the test paths in this study, and vice versa.
- A lack of correlation between "familiarity with the test system (virtual reality)" and the "mean estimated duration" showed that the first variable did not affect the second one. This could partly affect the validity of the results in this study.

In this study, the researchers tried to present a scientific and practical investigation of logical relationships between the physical structure of the environment and the perception of time. One of the most important implications of this study that distinguishes it from previous studies is its emphasis on analyzing the physical-spatial structure of the environment, assuming the subject is in a semi-natural environment with a three-dimensional structure. The purpose of the authors in this paper was to increase the practical understanding of the concept of time in a three-dimensional urban space, and show the relationship between a physical-spatial design and the perception of time.

Endnotes:

[1] - The reason for using six techniques to estimate time in this research is to achieve results that are more reliable and closer to scientific reality for estimating the perceived time of the subjects being tested. In fact, each of these techniques has already been used in the perceptual psychology and cognitive psychology studies. But in this paper, it is expected to achieve a certain number as the basis for calculating perceived time in a way that is more precise, and based on the informed integration of previous evaluation techniques.

[2] - The respectable reviewer mentioned a very important point. Certainly, in scientific terms, the more and the better we can simulate the physical conditions of individuals' natural movement in a quasi-realistic environment, the more reliable results will be achieved. Hence, if the speed of the avatar is variable and at the discretion of the person being tested, better scientific results will be obtained. Assuming a constant speed for avatar is due to the technological limitations of the research and the complexity of defining the necessary motor protocols in the software used. However, this study attempted to obtain an acceptable scientific result by simulating the movement of the avatar on the sinusoidal wave of natural human motion at a speed close to reality and from a viewpoint similar to the human field of view. On the other hand, in this study, the possibility to stop and move along with the possibility to move in a simulated environment and achieve a Preferred Space is provided for the subjects' avatars.

[3] - The point noted by the honorable reviewer is absolutely correct. Certainly, if there is a possibility in this article that each super group consists of 8 individuals to perform double tests assuming the test A1 is constant ((A1-A2), (A1-A3), (A1-C1), (A1-C2), (A1, C3), (A1, S1), (A1, S2), (A1, S3)), then it will be reasonable to expect more scientific results from this research. However, because of the difficulty of doing the tests in the virtual environment, their timeliness, and the limitations of the sample, there was no possibility to extend the tests in this manner.

[4] - As mentioned in the methodology section of the manuscript, in order to obtain a single number as the estimated subjective duration of the subjects tested, in this study, 6 techniques were used in parallel. The important point is that what is shown in Fig. 4 is the ratio of the estimated time obtained as the "average of 6 techniques" and the "real time" rather than the correlation between these two variables. In fact, the only logical correlation occurred between the "real time" and the "estimated time derived from the metric estimation" rather than between the real time and the average of all time estimation. On the other hand, though the correlation between the two variables is accepted with an error of less than 1%, based on the Pearson coefficient, this correlation can be considered small, incomplete and direct. Certainly Fig.3 and Fig.4 cannot be fully supported by each other and do not explain the same concepts, because each represents a tentative rather than a definitive mathematical interpretation of the statistical data.

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