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Environmental Perception of Urban Spaces: Physical Versus Virtual Exploration

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Abstract The study aims to investigate virtual street view imagery as a tool for auditing and comprehending urban environments. The objective is to compare the physical and virtual exploration of urban spaces in terms of environmental perception. Previous research has been criticized for limiting itself to cognitive aspects of environmental perception. Accordingly, this study adopts a more holistic conceptualization of environmental perception and considers all cognitive, affective, interpretive, and evaluative aspects. A quasi-experiment was carried out in which 38 postgraduate and undergraduate architectural students were divided into two groups to explore sections of two different streets in Cairo, Egypt. Participants of each group explored a street section physically and, on another day, the other street section virtually through Google Street View. Data collection methods included perceptual sketches, cognitive maps, semantic differential questions, and paragraph writing. In relation to cognitive aspects of perception, results suggest that physical exploration permits a more complete and accurate reading and understanding of the urban environment than virtual exploration. In particular, it was found that, through physical exploration, participants tended to acquire a greater amount of information about the environment and had a better ability to estimate distances and heights than through virtual exploration. However, in virtual exploration, probably because of reduced amount of stimuli, participants were better able to notice some specific details such as, litter, and graffiti. In relation to affective, interpretive, and evaluative aspects of environmental perception, it was found that experiencing the environment in person allows capture the ambience of the place and form clear and strong impressions about the setting much more effectively than experiencing it virtually. Results showed that, during and after physical exploration, participants had a much greater tendency to express feelings and emotions about the environment and to formulate evaluations about its different components than during and after virtual exploration. In conclusion, it is suggested that virtual street view imagery exploration of the urban environment cannot replace actual physical exploration for a comprehensive and holistic audit of an urban space. However, virtual exploration could be used as a preliminary audit of an environment to acquire an initial understanding or as a more focused follow-up exploration to check or complete information about physical characteristics captured during a physical exploration.

Keywords Environmental Perception, Urban Environment Auditing, Physical Versus Virtual Exploration, Virtual Street View Imagery

1. Introduction

In recent years, there has been a significant increase in the use of virtual environment technologies to explore actual built environments, owing largely to the ease, convenience, and somewhat realistic simulation that they

provide in conveying a setting to observers [1], [2]. These technologies are increasingly used, for example, to conduct pre-design urban environment audits remotely, to evaluate proposed design alternatives, or to permit the visit of places or buildings not immediately accessible [2], [3]. Virtual street view imagery, such as Google Street View, is one of these virtual environment technologies most commonly used today by both professionals and students to conduct audits of urban environments [2]. Street view imagery relies on a 360-degree mosaic of still photographs to create a virtual representation of an environment that users can move through and explore remotely with a certain level of realism [4].

Of course, one can expect differences in terms of perception between the physical and virtual exploration of a particular urban environment. However, investigating the nature of the differences in environmental perception between the physical and virtual exploration of urban environments is important to better understand the true potentials and limitations of virtual audits [5].

To date, research that has investigated virtual street technologies has tended to show high levels of similarity in the perception of urban environments between physical and virtual explorations [5]–[9]. However, as further developed in the following literature review section, this research has been criticized for limiting itself to the perception of very specific elements of the urban environment and mainly cognitive aspects of environmental perception [5], [10]. As a whole, this research has failed to consider the urban environment comprehensively and to adopt a holistic understanding of environmental perception.

The study presented in this article aims to investigate virtual street view imagery as a tool for auditing and comprehending the urban environment. To address the limitations of previous research and rely on the theoretical work of Ittelson [11] on environmental perception, the objective is to compare the physical and virtual exploration of urban spaces in terms of the different aspects of environmental perception: cognitive, affective, interpretive, and evaluative.

2. Literature Review

2.1. Physical Versus Virtual Auditing of Urban Environments: Previous Research

A relatively large amount of recent research has investigated the use of virtual street view imagery as a tool for street-level auditing of urban environments in replacement of physical in-person modes of exploration and observation [5], [9], [10]. This research has tended to investigate levels of agreement between physical and virtual exploration of the built environment in relation to the perception of specific characteristics or elements of the environment.

In general, this research suggests that virtual street view imagery is suitable for assessing characteristics of actual urban environments [6], [12]–[14] and can be used to replace in-person observation [9]. Indeed, the studies have tended to show high levels of agreement between physical and virtual exploration for the majority of the built environment characteristics investigated [6]–[8]. According to Nesse and Airt [5], the level of agreement depends on the type of characteristics being observed. They concluded from their review of the literature that levels of agreement tend to be greater for large, permanent characteristics of the urban environment than for small, transient characteristics [5].

However, this previous research has been criticized for restricting itself to the perception of limited characteristics or elements of the built environment and for failing to consider the urban environment comprehensively [5], [10]. For example, in their study Pittam et al. [15] and Kelly et al. [16], compare physical and virtual exploration in relation to the perception of building characteristics – including building function, building height, and building façade design. Chiang, Sullivan and Larsen [17] restrict their study to the perception of different street characteristics such as street width, street intersection, sidewalk condition, signage, street lighting, and street furniture. Steinmetz-Wood et al. [18] investigated the perception of landscape features. Similarly Kepper et al. [19] look only at the perception of a number of characteristics related to the quality of the urban environment – building conditions, graffiti, and litter. In response to this criticism of previous research, the present study intends to compare physical and virtual exploration in terms of environmental perception by considering the urban environment more comprehensively including characteristics of the built environment, characteristics of the natural environment, people and activities, auditory and olfactory stimuli, and weather and environmental aspects [20].

Previous research as a whole has also been criticized for considering only cognitive aspects of environmental perception [2], [5], [10]. To date, very few studies have considered subjective aspects of environmental perception. For example, Rundle et al. [21] have compared physical and virtual exploration of an urban environment in terms of perceived security. Bader et al. [22] focused on the perception of urban aesthetics. Dubey et al. [23] assessed perceptual attributes related to the appearance of the urban environment – lively, boring, wealthy, depressing, and beautiful.

To address the limited conceptualization of environmental perception inherent in most previous research, the current study intends to adopt a more holistic theoretical understanding. It intends to consider the different aspects of environmental perception proposed by Ittelson [11].

2.2. The Different Aspects of Environmental Perception

Environmental perception is regarded as one of the main

processes through which humans interact with the environment and according to which they behave within the environment [24]. It is through environmental perception that people comprehend the environment and the process generally refers to acquiring, organizing, and storing information about the environment [25]. Environmental perception is a complex phenomenon that involves capturing stimuli and environmental information through the senses. This information is selected, arranged, and stored, generating an internal representation of the environment as a result of cognitive mechanisms [26], [27]. However, theoretical developments of environmental perception emphasize that the process does not stop at cognitive aspects of perception. The process also includes the association of meanings to the information captured, the formation of feelings and emotions about the environment, and the formulation of judgments about it, all of which play an important role in guiding behavior, decisions, and choices [11], [25], [27]–[29].

In particular, Ittelson [11] (see also [30]–[32]) in his theoretical framework, articulates four aspects of environmental perception operating simultaneously: (1) the cognitive aspect – involving the capture, organizing, and storing of information about the environment, in essence, allowing to make sense of the environment; (2) the affective aspect – involving human feelings which influence the perception of the environment; (3) the interpretative aspect – encompassing the meanings or associations derived from the environment; (4) the evaluative aspect – incorporating values and preferences and the determination of good and bad elements in the environment.

3. Method

3.1. Research Design

As previously mentioned, the objective of the study is to compare physical and virtual exploration of urban spaces in terms of the different aspects of environmental perception. The study relied on a quasi-experimental research design adapted from Meenar et al. [2]. Participants were randomly divided into two groups, group A (n=18) and group B (n=20). Participants of group A first explored a section of a street (ST1) physically and then explored a section of another street (ST2) virtually through Google Street View. On the other hand, participants of group B explored first ST2 physically and then explored ST1 virtually. The two street sections selected for the study, ST1 and ST2, are quite different in character. This is not considered to be a problem as the study does not compare perceptions of the two street environments. On the contrary, differences between ST1 and ST2 are viewed to contribute to the strength of the research design. Indeed, the research design adopted minimizes the potential impact of the particular characteristics of the environment explored on results and ensures greater validity in comparisons between physical and virtual exploration. The research design also minimizes the impact of potential differences between the two groups. To compare physical and virtual exploration, for each of the explorations performed by participants, environmental perception was assessed in terms of (1) cognitive aspects and (2) affective, interpretive, and evaluative aspects using several methods of data collection. These included perceptual sketches drawn by participants during the exploration. Following each exploration, participants were also asked to draw a cognitive map of the setting explored and answer a number of semantic differential questions about perceptions of the atmosphere of the setting. Finally, after completing both explorations, participants were asked to write a short paragraph describing differences in experiences and impressions of both physical and virtual exploration.

3.2. The Two Settings Selected for the Study

The very limited number of streets in Cairo for which Google Street View was available at the time of the study greatly limited possible choices. Furthermore, streets in historical, touristic, and popular destination areas of the city were not considered to limit possibilities that some of the participants could be familiar with the settings selected. In addition, for selection, potential street sections had to be checked for similarity between the actual current conditions and the Google Street View representation of the setting. Ultimately, sections of two different streets in Cairo were selected for the study, ST1 and ST2.

ST1 is a 1.2 km section of the Nile Corniche Street by the Old Cairo District (see Figure 1). The Nile Corniche Street is considered to be a main artery in Cairo. This particular section of the street is about 55m wide and is divided by a narrow median strip. It is characterized by heavy vehicular traffic most of the day. The sidewalk on the Nile side of the street is relatively wide and features planted areas along with seating opportunities. A number of docked boat function as restaurants. On the other side of the street, the sidewalk is much narrower. Buildings on this side of the street are one to twelve stories in height. Most of these buildings are residential buildings with lower floors typically dedicated to commercial or administrative functions. As shown in Figure 1, there are also car workshops, schools, hospitals, a police station, and two historical mosques.

ST2 is a 0.4km section of a residential street in Maadi District, Street No.9B. The street is about 15m wide. The sidewalks, which, in some parts of the street section, are very narrow, tend to be occupied by parked cars. Large numbers of motorcycles and tuk-tuks share the pavement with a heavy pedestrian traffic. In the southern half of the

street section, buildings are one to six stories in height. In the northern half, they are three to twelve stories. Most of these buildings are apartment buildings. For few of them, the ground floor is occupied by commercial establishments or other types of uses (such as mosques, nurseries, a gym, an internet cafe, and two educational centers). The street section also features several schools (see Figure 2).

Figure 1. Map and photographs of ST1, adapted from Google Maps and photographs taken from Google Street View

Figure 2. Map and photographs of ST2, adapted from Google Maps and photographs taken from Google Street View.

3.3. Participants

For participants, the study targeted postgraduate and upper-level undergraduate students in the Department of Architecture at the Arab Academy for Science and Technology (AAST), Cairo. The reliance on university students was thought to be beneficial to the study, becauseaccording to the literature [33], [34], they are often pioneers in the use of new technologies and, thus, they were not expected to experience much difficulty in the use of Google Street View. In addition, the choice of architectural students was justified by the fact that they are trained to audit urban environments as part of their studies. Furthermore, the selection of the particular university (AAST) was thought to be appropriate because it is quite distant geographically from the two street sections chosen for the study, thus also reducing chances of participants' prior familiarity with the two settings.

A total of 42 prospective participants volunteered to take part in the study in response to in-class announcements. For the undergraduate students, the announcements were restricted to classes of the Urban Design Course taught at the Department and the students were offered course credit by course instructors for participation.

All prospective participants were clearly informed of the purpose of the study and of the tasks they will need to complete prior to participation. One of them was excluded because he indicated that he was familiar with the settings selected. Three others did not complete the experiment. Ultimately, 38 participants completed the study, 24 females and 14 males. Their ages ranged from 22 to 28 years (23 undergraduate students and 15 postgraduate students). As mentioned above, participants were randomly assigned to the two groups of the study, group A (n=18) and group B (n=20).

3.4. Data Collection and Procedures

Data collection methods were tested through a pilot study conducted in September 2020. The pilot study led to a few adjustments to the instruments and procedures used for the study proper. The main data collection sessions were held in November and December 2020. The following sections detail the methods of data collection used (perceptual sketches, cognitive maps, semantic differential questions, and paragraph writing) as well as the procedures adopted for both physical and virtual explorations.

3.4.1. Perceptual Sketches

The drawing of perceptual sketches by participants during their physical and virtual explorations of the settings was one of the methods used to investigate differences in environmental perception between physical and virtual urban exploration (see for example [35]). Perceptual sketches are a very useful data collection method to understand how a particular setting is perceived by participants [36]. This method allows participants to organize information and process their experiences and thoughts. It encourages them to represent relevant aspects of their perception of the environment including feelings and preferences [36]. Participants were asked to describe through free-hand sketches the nature of the environment of the street section to someone who is not familiar with the location. At the start of the street section exploration whether physical or virtual they were given an A4 booklet that included several pages on which to draw their sketches. These pages featured, on the margin, a base map of the street section to allow participants to link their sketches to a specific location. Participants were instructed to draw as many sketches as possible. They were also asked to annotate their sketches to clarify the features they meant to show and/or the feelings they meant to express.

3.4.2. Cognitive Maps

Cognitive mapping was used to investigate potential differences between physical and virtual exploration in relation to participants' overall cognition of the environment. This method is commonly used in investigations of the perception of urban environments [37]–[40]. By aggregating together the cognitive maps of several individuals, it is possible to determine their shared level of knowledge about an environment and what elements of the environment are most salient [41]. Following each of their physical and virtual explorations, participants were asked to think of their street inspection and draw from memory a cognitive map of the street section as accurately as possible, including all elements or details they could recall. They were briefly explained what a cognitive map is and were shown various examples. They were given a plain A4 sheet of paper to draw the map on. They were not allowed to view the previously drawn perceptual sketches.

3.4.3. Semantic Differential Questions

Semantic differential questions were used to determine whether there was a difference in the subjective perception of the environment between physical and virtual exploration. This method is frequently used to investigate participants' feelings and judgments [42]. Following the drawing of the cognitive map, using five-point scales, participants were asked to rate the setting in terms of six dimensions defined by opposing word pairs (exciting – boring, dynamic – static, pleasant – unpleasant, attractive – unattractive, ordered – chaotic, secure – insecure) [43].

3.4.4. Paragraph Writing

The paragraph writing task was used to explore participants' perspectives on using virtual street view imagery as a tool for auditing and comprehending the urban environment. According to the literature, this method allows participants great freedom to externalize their thoughts and feelings [36]. Following the virtual exploration, at the end of their participation, participants were asked to write a paragraph describing their impressions about the difference between the virtual and physical exploration of an urban environment. They were specifically instructed to reflect on the exploration experiences rather than on the settings they explored.

3.4.5. Physical and Virtual Exploration Procedures

The physical exploration of the two settings was conducted on several days but always in the morning time and under similar weather circumstances to approximate as much as possible the conditions in Google Street View. At an agreed date and time, groups of two to four participants were met by one of the researchers at the start point of the street section to be explored. On the days in which the weather was not appropriate, raining for example, the exploration session was postponed to another date. Participants were handed a booklet that included an instruction sheet, a demographic data form, and pages on which to draw the perceptual sketches. They were also given the needed sketching tools. Participants were first asked to read the instruction sheet which explained in detail the different tasks they will be required to perform and ask for clarifications if they needed any. They were also asked to complete the demographic data form which included questions about age, gender, and academic background. Then, they were asked to individually explore the street section without wandering out of the boundaries. While there was no imposed time limit, the exploration of the setting along with the drawing of the perceptual sketches took about 45 minutes. Following the physical exploration, the drawing of the cognitive map and the filling of the semantic differential questions took around 15 to 20 minutes. At the end of the physical exploration session, participants were given an appointment for the conduct of the virtual exploration session.

Virtual exploration sessions were conducted in a computer laboratory at the College of Engineering AAST, Cairo with groups of two to four participants. Each participant was assigned to a computer and given the same material distributed for the physical exploration. Again, they were first asked to read the instructions for the different tasks and fill out the demographic data form. Then, the researchers introduced the participants to Google Street View through a brief explanation and a short online video. After that, participants were asked to practice the use of the tool in a different virtual environment than the one they had to explore for the study until they felt comfortable moving around in and interacting with the virtual environment. After this practice session, participants were asked to begin their actual virtual exploration of the selected street section. For the two settings, the starting point was the same as the starting point of the physical explorations. The virtual exploration along with the drawing of perceptual sketches took around 45 minutes. Following the virtual exploration, participants completed successively the cognitive mapping, the semantic differential questions, and the paragraph writing tasks. Participants completed the entire session within 90 minutes.

3.5. Data Analysis

Data analysis was conducted to identify differences between physical and virtual exploration in relation to environmental perception, both in terms of (1) cognitive aspects and (2) affective, interpretive, and evaluative aspects. First, for each of the two street sections explored by participants (ST1 and ST2), physical and virtual exploration data collected through perceptual sketches, cognitive maps, and semantic differential questions was comparatively analyzed. Then, differences identified for each of ST1 and ST2 were compared to confirm similarities.

Perceptual sketches were analyzed through a content analysis process adapted from [44]. Content analysis is a tool used to determine the presence of certain words, themes, or concepts within qualitative data. Through it, researchers can analyze qualitative data and quantify the presence of concepts and meanings and investigate relationships between them [45]. Using an emerging coding system, each of the sketches was individually coded to identify the type of information featured whether information related to cognitive aspects of perception or related to affective, interpretive, and evaluative aspects. This process permitted to compare sketches drawn during physical and virtual explorations in terms of type of perceptual information featured as well as amount and detail of information. It also permitted to identify discrepancies in the information included.

Cognitive maps drawn by participants were analyzed in terms of map style (see for example [41], [46]), map accuracy (see for example [37], [41]), and map complexity – or amount of details included (see for example [37]).

Answers to the semantic differential questions were analyzed statistically using IBM SPSS v.25. T-tests were conducted to investigate the significance of differences between physical and virtual explorations.

Finally, paragraphs written by participants were analyzed through a qualitative thematic analysis [47]. The paragraphs were first read and re-read to gain familiarity with the contents. Then, the paragraphs were individually coded. Finally, the codes were reviewed and analyzed to identify emerging themes.

4. Results

Results for the different methods of data collection used are successively presented in the following sections.

4.1. Analysis of Perceptual Sketches

Information featured in perceptual sketches drawn by participants, whether in drawing form (such as layout, section, elevation, or perspective sketches) or in the form of annotations (see Figures 3 and 4), was coded for both cognitive aspects of environmental perception and affective, interpretive, and evaluative aspects. The coding categories developed for the coding of information related to cognitive aspects were adapted from the list of components of urban physical space proposed by Piga and Morello [20]. They included five main categories: (1) built environment, (2) natural environment, (3) people and activities, (4) auditory and olfactory stimuli, and (5) weather and environmental aspects. The particular codes used for each of these categories emerged from the analysis of the perceptual sketches (see Table 1). Information related to affective, interpretive, and evaluative aspects of perception was coded in terms of (1) affective aspects – information related to emotions and feelings about the environment explored, (2) interpretive aspects – information related to meanings or suppositions, speculations, and inferences made about the environment, and (3) evaluative aspects – information about preferences and likes and dislikes [11].

Table 1. Coding system for the analysis of perceptual sketches (adapted from [20])

A. Cognitive aspects		
1. Built environment		
• Building function	• Street width	• Parking
• Building height	• Street condition	• Signage
• Building condition	• Street intersections	• Street lighting
• Building façade design	• Median strip	• Street furniture
• Building setback from the street	• Vehicular traffic	• Street litter and garbage
• Vacant lots	• Transportation	• Landmarks
• Bridges	• Sidewalk width	• Nodes
• Graffiti	• Sidewalk condition	• Edges
2. Natural environment		
• Vegetation	• Nile river	• Animals
3. People and activities		
• Number/density of people	• People characteristics	• People activities
4. Auditory and olfactory stimuli		
• Noises	• Smells	
5. Weather and environmental aspects		
• Weather	• Shade and shadow	
B. Affective, interpretive, and evaluative aspects		
• Affective	• Interpretive	• Evaluative

The perceptual sketches drawn during physical and virtual explorations were first analyzed in terms of "type of information featured". While a total of 37 different codes were used (see Table 1), for physical exploration, the average number of different codes featured in perceptual sketches of ST1 and ST2 were 15.11 and 13.75 respectively. For virtual exploration, the averages for ST1 and ST2 were 13.20 and 10.94 respectively. The comparative analysis of physical and virtual exploration perceptual sketches did not actually reveal great differences as they tended to feature the same type of information. It should be noted however, that certain specific types of information were not found to be featured in virtual exploration perceptual sketches such as "nodes", "people characteristics", "animals", and "weather". Furthermore, due to the nature of the Google Street View tool, information about auditory and olfactory stimuli was featured in virtual exploration perceptual sketches only in the form of interpretive information and that, for only a limited number of participants (25% of participants for ST1 and 5.5% of participants for ST2). The perceptual sketches suggest that these participants used information available in the virtual environments to make inferences about auditory and olfactory stimuli. For example, the presence of a car workshop led to the assumption that the place was noisy, and the presence of garbage led to the assumption that the place was smelly. In contrast, for physical exploration, information about actual auditory and olfactory stimuli was mentioned by a greater percentage of participants (55.5% and 55% of participants for ST1 and ST2 respectively).

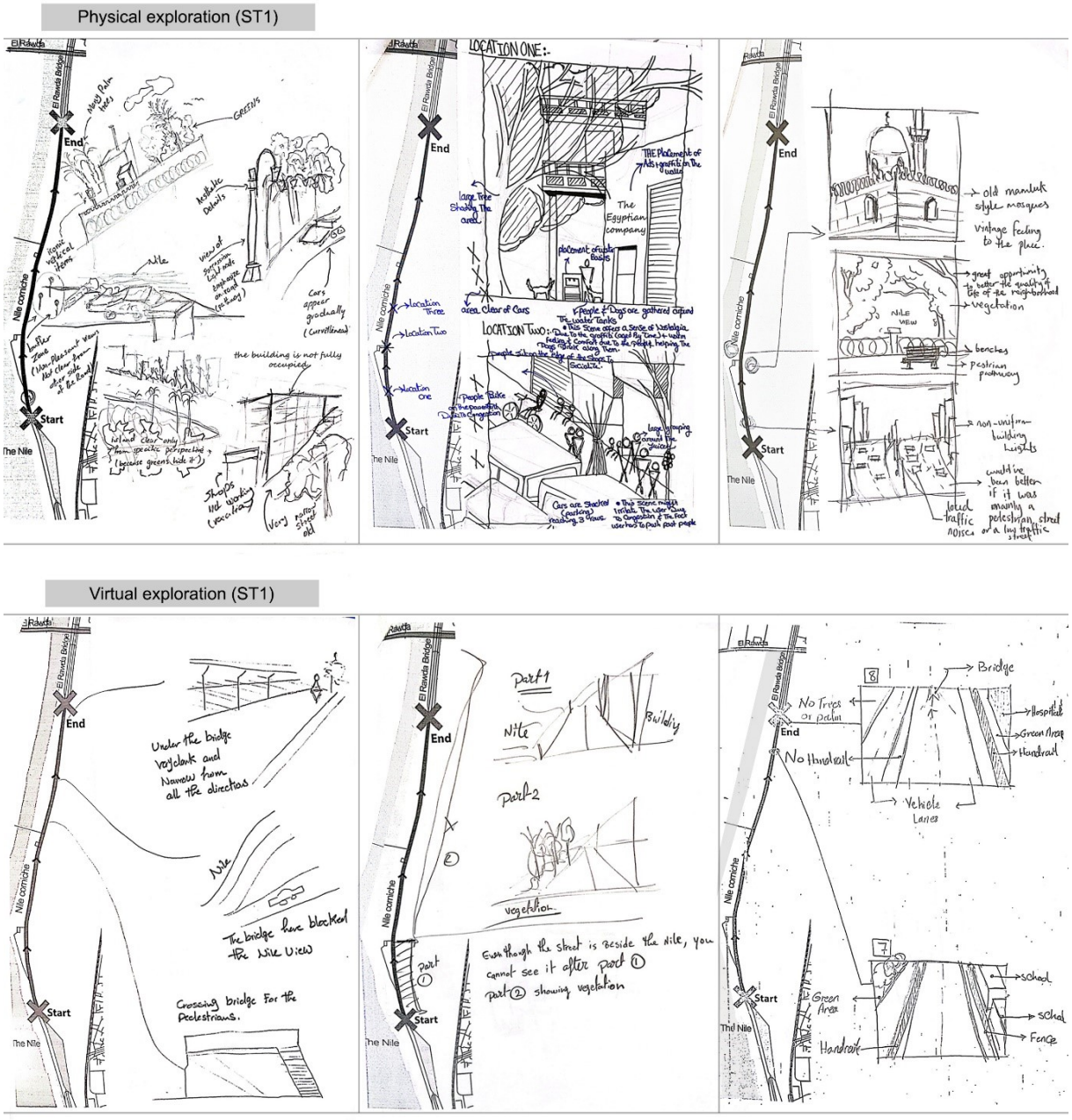

Figure 3. Examples of participants' perceptual sketches for ST1.

The perceptual sketches drawn during physical and virtual explorations were also comparatively analyzed in terms of "amount of information and detail". In general, physical exploration perceptual sketches were found to include more information and a greater amount of detail than virtual exploration perceptual sketches (see Figures 3 and 4). In fact, for physical exploration, the average number of coded items per participant was 40.05 for ST1 and 37.05 for ST2. For virtual exploration, the averages were only 26.04 for ST1 and 22.66 for ST2. In terms of cognitive aspects, the specific types of information particularly associated with a greater amount of detail in physical exploration perceptual sketches included: "building condition", "building façade design", "street intersections", "median strip", "parking", "landmarks", and "people activities". On the other hand, "vacant lots", "signage", "street litter and garbage", "shade and shadow", and "edges" were associated with a greater amount of detail in virtual exploration perceptual sketches. In terms of affective, interpretive, and evaluative aspects, "affective" and "evaluative" information was clearly associated with more detail in physical exploration perceptual sketches. However, "interpretive" information was associated with more detail in virtual exploration perceptual sketches. Interestingly, perceptual sketches show that participants had a better sense of scale and

could better estimate distances and heights during physical exploration than during virtual exploration. Indeed, in physical exploration perceptual sketches, information and detail about "building height", "building setback from the street", and "street width" tended to include distances in meters. But in virtual exploration perceptual sketches, this information tended to be more strictly in evaluative form, high or low, narrow or wide, etc...

Figure 4. Examples of participants' perceptual sketches for ST2

The analysis of perceptual sketches revealed discrepancies between some of the information featured in the sketches drawn during physical exploration and those drawn during virtual exploration. These discrepancies were primarily related to the absence of certain environmental information in the virtual environment of Google Street View and the tendency of participants to make suppositions and inferences about this information in their virtual exploration perceptual sketches. As a result, information about "vehicular traffic", "number/density of people", "people activities", and "noises" often showed discrepancies between physical and virtual exploration perceptual sketches. Furthermore, also as a result of suppositions or inferences made during virtual exploration, there were clear discrepancies between the "affective" and "interpretive" information featured in each of the physical and virtual exploration sketches. For example, virtual exploration perceptual sketches of ST2 tended to feature such affective comments as "comfortable", "calm", "relaxing", and "peaceful". On the other hand, many of the physical exploration perceptual sketches of ST2 featured negative affective comments such as "not safe", "scary", and "oppressive".

4.2. Analysis of Cognitive Maps

4.2.1. Map Style

Cognitive maps drawn by participants were first analyzed in terms of map style. They were classified into five different types: (1) sequential diagram, (2) single line linear map, (3) double line linear map, (4) single line pointed map, and (5) double line pointed map [46], [48]. As shown in Figure 5, sequential diagrams were line diagrams with annotations rather than actual maps. On linear maps, the street section explored was represented with a single line or double lines with annotations to indicate landmarks and other noticed elements. On the other hand, on pointed maps, buildings bordering the street section were indicated in the form of blocks.

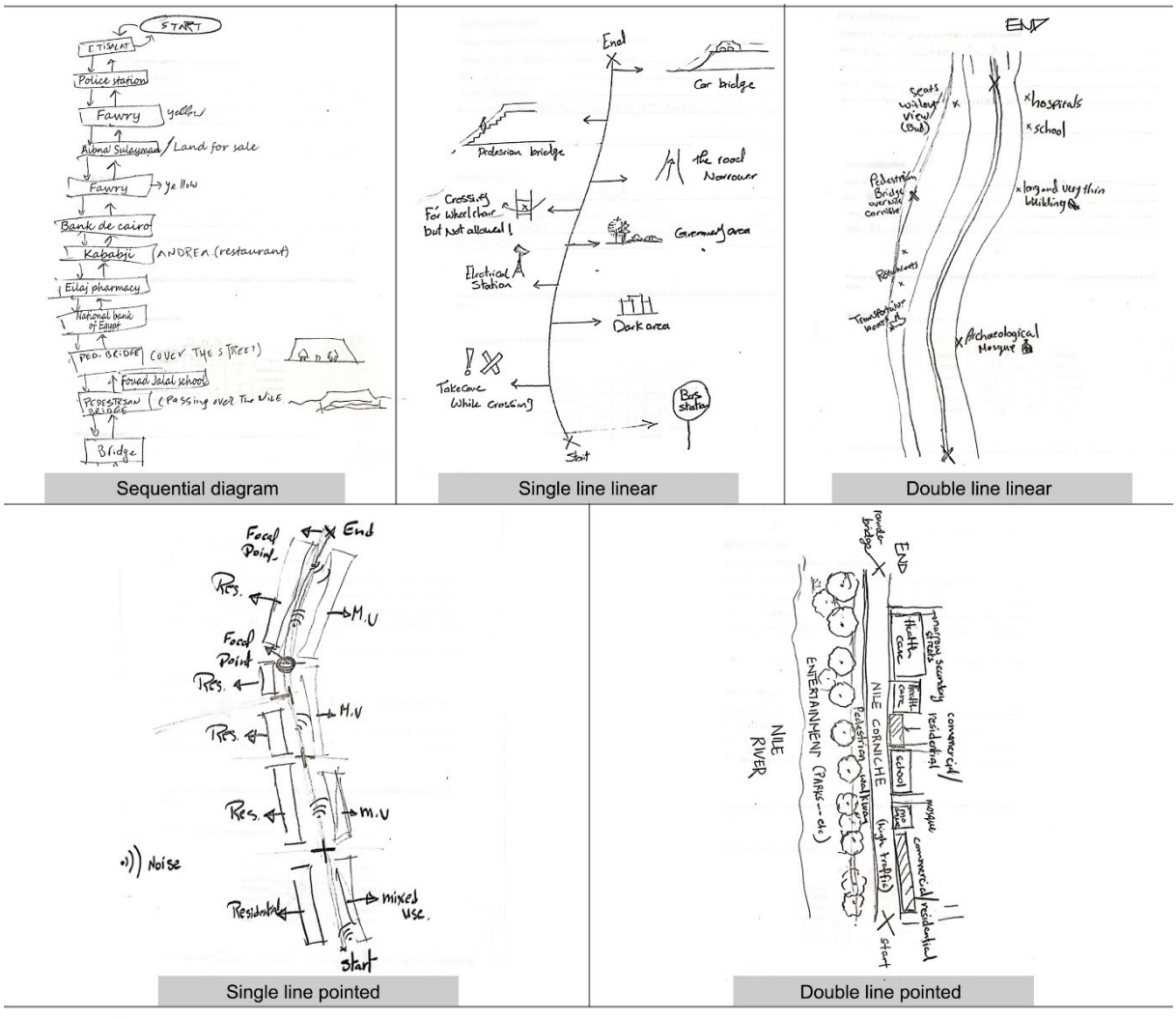

Figure 5. Map style categories used for the analysis of cognitive maps (adapted from [46], [48]).

Table 2. Analysis of cognitive maps in terms of map style

Map style	ST1		ST2	
	Physical Expl. Group A (n=18)	Virtual Expl. Group B (n=20)	Physical Expl. Group B (n=20)	Virtual Expl. Group A (n=18)
No map	0 (0%)	1 (5%)	0 (0%)	0 (0%)
Sequential diagram	2 (11.1%)	0 (0%)	0 (0%)	2 (11.1%)
Single line linear	4 (22.2%)	2 (10%)	1 (5%)	4 (22.2%)
Double line linear	3 (16.6%)	1 (5%)	3 (15%)	4 (22.2%)
Single line pointed	0 (0%)	1 (5%)	2 (10%)	0 (0%)
Double line pointed	9 (50%)	15 (75%)	14 (70%)	8 (44.4%)

Table 3. Analysis of cognitive maps in terms of map accuracy

Map Accuracy	ST1		ST2	
	Physical Expl. Group A (n=18)	Virtual Expl. Group B (n=19)	Physical Expl. Group B (n=20)	Virtual Expl. Group A (n=18)
Low accuracy	4 (22.2%)	8 (42.1%)	1 (5%)	9 (50%)
Moderate accuracy	9 (50%)	6 (31.5%)	14 (70%)	8 (44.4%)
High accuracy	5 (27.7%)	5 (26.3%)	5 (25%)	1 (5.5%)

The analysis of the cognitive maps in terms of map style did not reveal clear differences between maps drawn after physical exploration and those drawn after virtual exploration (see Table 2). Actually, the analysis suggests that differences in map styles were more related to differences in map drawing skills between group A and group B than to the type of exploration. For example, for group A, double line pointed maps constituted 50% of the maps drawn after physical exploration and 44.4% of the maps drawn after virtual exploration. In contrast, for group B, the percentages were 70% and 75%.

4.2.2. Map Accuracy

For the analysis of cognitive maps in terms of map accuracy, both map style and amount of detail on the map were ignored. The focus was on the accuracy of changes in street section direction and of placement and relative positioning of features represented such as street intersections and landmarks [37]. The maps were classified into three categories: (1) low accuracy, (2) moderate accuracy, and (3) high accuracy. Low accuracy maps were those that did not at all represent the reality of the built environment explored. In moderate accuracy maps, the street section represented could be recognized but they were characterized by distorted relationships and a relatively high number of inaccuracies. In contrast, high accuracy maps were those judged by the researchers to more accurately represent the built environment with no or minimal distortion and relatively few inaccuracies.

The analysis of cognitive maps in terms of accuracy revealed clear differences between physical and virtual exploration. As shown in Table 3, for both settings, cognitive maps drawn after physical exploration tended to be higher accuracy than those drawn after virtual exploration. For instance, moderate and high accuracy maps constituted 77.7% and 95% of the maps drawn after the physical exploration of ST1 and ST2 respectively. In contrast, they constituted only 57.8% and 49.9% of the maps drawn after the virtual exploration of ST1 and ST2

4.2.3. Map Complexity

Map complexity was assessed in terms of the amount of details represented on the cognitive maps. The cognitive maps drawn by participants were classified into three categories: (1) low detail, (2) moderate detail, and (3) high detail. Low detail maps did not depict more than the street section and some of the surrounding buildings. Details depicted on moderate and high detail maps (in the form of annotations or drawings) included, for example, trees, lighting posts, street furniture, car parking areas, and sources of noise and smell (see Figure 6).

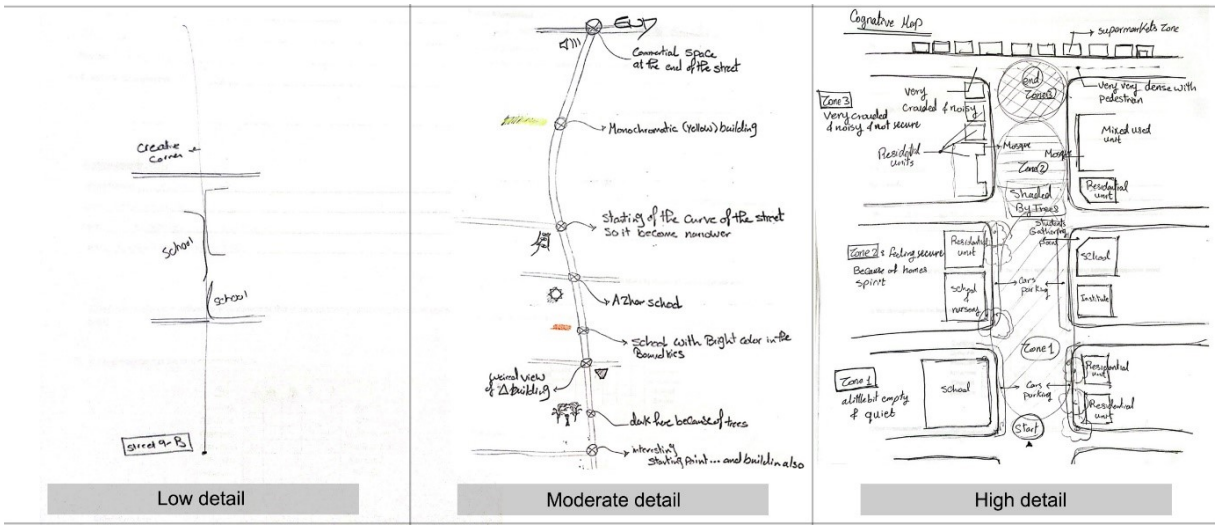

Figure 6. Map complexity categories used for the analysis of cognitive maps

Table 4. Analysis of cognitive maps in terms of map complexity

Map complexity	ST1		ST2	
	Physical Expl. Group A (n=18)	Virtual Expl. Group B (n=19)	Physical Expl. Group B (n=20)	Virtual Expl. Group A (n=18)
Low detail	4 (22.2%)	8 (42.1%)	2 (10%)	6 (33.3%)
Moderate detail	4 (22.2%)	6 (31.5%)	9 (45%)	7 (38.8%)
High detail	10 (55.5%)	5 (26.3%)	9 (45%)	5 (27.7%)

As for accuracy, the analysis of cognitive maps in terms of complexity revealed differences between physical and virtual exploration. Table 4 shows that, for both settings, cognitive maps drawn after physical exploration tended to feature a greater amount of detail than those drawn after virtual exploration. Indeed, moderate and high detail maps constituted 77.7% and 90% of the maps drawn after the physical exploration of ST1 and ST2 respectively. On the other hand, they constituted only 57.8% and 66.5% of the maps drawn after the virtual exploration of ST1 and ST2.

4.3. Analysis of Answers to Semantic Differential Questions

For ST1, t-tests did not reveal any significant difference between physical and virtual exploration in answers to the semantic differential questions (see Table 5). In contrast, for ST2, as shown in Table 6, differences between physical and virtual exploration in answers to the semantic differential questions were found to be significant for three of the six dimensions: dynamic – static, ordered – chaotic, and secure – insecure.

Table 5. Differences in answers to semantic differential questions after physical and virtual exploration of ST1

	Physical exploration Group A (n=18)		Virtual exploration Group B (n=20)			
	Mean	Standard deviation	Mean	Standard deviation	t-value	Significance
Exciting – boring	3.61	1.037	3.05	1.356	1.420	Not significant p = 0.164
Dynamic – static	3.89	1.231	3.25	1.517	1.415	Not significant p = 0.166
Pleasant – unpleasant	3.50	1.098	3.40	1.188	0.269	Not significant p = 0.790
Attractive – unattractive	3.50	0.985	3.80	1.056	-0.902	Not significant p = 0.373
Ordered – chaotic	2.78	1.309	3.15	0.988	-0.996	Not significant p = 0.326
Secure – insecure	3.22	1.353	3.85	1.309	-1.453	Not significant p = 0.155

Table 6. Differences in answers to semantic differential questions after physical and virtual exploration of ST2

	Physical exploration Group B (n=20)		Virtual exploration Group A (n=18)			
	Mean	Standard deviation	Mean	Standard deviation	t-value	Significance
Exciting – boring	3.00	1.026	2.72	1.364	0.714	Not significant p = 0.480
Dynamic – static	4.00	1.257	2.28	1.179	4.344	Significant p < 0.001
Pleasant – unpleasant	2.75	1.070	3.00	1.029	-0.732	Not significant p = 0.469
Attractive – unattractive	2.80	1.005	2.61	1.195	0.529	Not significant p = 0.600
Ordered – chaotic	2.15	0.988	3.11	1.323	-2.553	Significant p < 0.05
Secure – insecure	2.40	0.940	3.78	1.263	-3.840	Significant p < 0.001

These three dimensions in particular are related to the perception of motion in the environment. As described above, ST2 is actually characterized by a heavy traffic of speeding motorcycles and tuk-tuks which share the pavement with large numbers of pedestrians. It appears that, as a tool, Google Street View did not allow participants who explored ST2 virtually to perceive the actual dynamic and chaotic nature of the street. In fact, for ST1, participants who explored the street physically also rated it as more dynamic, more chaotic, and more insecure than those who explored it virtually (see Table 5). Differences are not significant probably because ST1 is much less dynamic and chaotic in nature compared to ST2. However, these results seem to confirm what the results for ST2 suggest. Virtual exploration through Google Street View may not allow to accurately perceive motion related characteristics of the urban environment.

4.4. Analysis of Paragraph Writing

The paragraphs written by participants presented their views about the differences between the physical and virtual explorations of the environment. The qualitative analysis of these paragraphs revealed three main themes: (1) physical and virtual explorations as different experiences, (2) differences in relation to "knowing" the environment, and (3) differences in relation to "feeling" the environment.

4.4.1. Physical and Virtual Explorations as Different Experiences

Paragraphs written by participants often contrasted the physical and virtual explorations of the environment as very different experiences. According to the participants, physical exploration allows for a more authentic and genuine contact with the environment. By being physically present, they felt they were able to be truly in touch with the surroundings. The multi-sensory nature of physical exploration permitted a more holistic experience of urban space. For participants, physical exploration was a much more dynamic and exciting experience.

"For a full experience of an urban environment, the physical exploration wins as you can use all senses."
"In the physical exploration, I interacted with everything varying from the dog sleeping under the shaded tree to the time people spend waiting to cross the street."

On the other hand, participants expressed that, in virtual exploration, they lacked real contact with the environment. They felt too conscious that they were dealing with screens rather than the real world. Participants also expressed some dissatisfaction with the mono-sensory nature of virtual exploration and that it did not permit to experience the life of the two streets. As a result, participants described virtual exploration as a static and monotonous experience.

"In the virtual experience, I kept looking at the 2D map each time I went forward with the mouse and go back to see how much I moved."
"The sensual experience of the spaces is missing in the virtual exploration."
"I could not feel the overall experience in the virtual exploration."
"Virtual exploration was boring because you couldn't live the experience."

According to participants, in physical exploration, they felt free to acquire information from the environment. In contrast, in virtual exploration, they felt confused and restricted in their exploration.

"In the virtual exploration, I felt caged and limited."

On the other hand, participants suggested that, during virtual exploration, they felt calmer, more comfortable, and more secure which allowed them to focus better.

"I felt more secured and relaxed in the virtual exploration than the physical exploration."
"Virtual exploration is quiet; you can focus while analyzing."

4.4.2. Differences in Relation to "Knowing" the Environment

Paragraphs written by participants generally expressed the idea that physical exploration permits to form a more complete and more accurate reading and understanding of the environment than virtual exploration.

"The virtual exploration allowed overall observations about the environment although it may be not accurate enough."

According to participants, physical exploration permitted to capture and acquire a greater amount of information and details about the environment. In physical exploration they felt freer to capture the information and details that one may be seeking to understand the environment.

"In the physical exploration, I can describe every detail along the street."
"During the virtual exploration, I could not see all the details clearly, and I could not recognize all the elements of the street."

Participants also felt that physical exploration permitted a more accurate sense of scale. In virtual exploration they felt they had difficulty in judging distances and estimating the size, the height, and the importance of various elements of the built environment (building heights, street width, etc…).

"Physical exploration allowed to look around more and have a sense of scale of the surroundings."
"Virtual exploration lacked sense of scale and height."

In addition, participants emphasized that the multi-sensory nature of physical exploration permitted to capture auditory and olfactory information that they saw as important for a more complete understanding of the environment.

"In the physical exploration, hearing, seeing, and smelling made me see hidden things that cannot be seen from the first glance."

Furthermore, participants stressed the idea that, in contrast with virtual exploration, physical exploration allowed them to experience the environment in motion and to more accurately acquire information about people and their activities. Consequently, physical exploration permitted a better understanding of the human and social component of the environment.

"The physical exploration provided answers to how people actually live and how they interact in the site."
"The virtual exploration lacked the soul of people which bring out weight, although it imaged frozen actions of people."

Participants agreed then that physical exploration permitted to capture a greater amount of information about the environment. However, as also suggested by the perceptual sketches, a number of participants indicated that the reduced amount of stimuli in virtual exploration helped them notice some specific types of details such as signage, litter, and graffiti.

"The virtual exploration, made me notice some small things more as the graffiti on the walls or shops front or signs, specific unique fences, and colors."

4.4.3. Differences in Relation to "Feeling" the Environment

Paragraphs written by participants also expressed the idea that virtual exploration did not permit them to really feel the environment. According to them, the static and mono-sensory experience of virtual exploration and the associated lack of environmental information and stimuli did not allow them to appropriately capture the ambience of the place and form clear emotions about it.

"I could not sense the place during virtual exploration."
"I was not able to feel the ambience of the street during the virtual exploration. I could not have clear impressions about, for example, welcoming or not, sense of security, etc..."

In contrast, participants indicated that experiencing the environment in person during physical exploration allowed them to fully feel the urban space and form clear and strong impressions about the area.

"Physical exploration is necessary to really feel the place and have emotions."

5. Discussion and Conclusion

The objective of the study was to compare physical and virtual exploration of urban spaces in terms of the different aspects of environmental perceptions including (1) cognitive aspects and (2) affective, interpretive, and evaluative aspects. As a whole results showed differences in environmental perception between physical and virtual exploration.

5.1. Differences in Cognitive Aspects of Perception

In relation to cognitive aspects of environmental perception, it was found that the same "type" of information about the built environment was acquired in both physical and virtual exploration except for types of information related to motion in the environment and information related to auditory and olfactory stimuli. In virtual exploration, information related to motion and to auditory and olfactory stimuli was not captured and most of the participants resorted to suppositions and inferences about these types of information in their perceptual sketches. Of course, this reliance on suppositions and inferences led to discrepancies between physical and virtual exploration. This appears to be in line with findings of previous research which suggest that levels of agreement between physical and virtual exploration tend to be relatively low for transient characteristics of the environment [5].

It was also found that the "amount" of information and details acquired about the built environment was clearly greater in physical exploration than in virtual exploration. In contrast with the conclusions of Nesse and Airt [5], this suggests that, even for large, permanent characteristics of the urban environment, levels of agreement between physical and virtual exploration may not be that high. According to participants, physical exploration allowed to capture more information and details than virtual exploration because of physical presence in the environment and the multi-sensory experience associated with it.

On the other hand, results of the study show that, in virtual exploration, probably, because of reduced amount of stimuli, participants were able to notice some specific details such as signage, litter, and graffiti that were much less noticed during physical exploration. This is in contradiction with the findings of studies that suggest that small characteristics such as litter are often not noticed through virtual street view imagery exploration [9], [49], [50].

Results of this study also revealed that physical exploration was associated with a better sense of scale and a greater ability to estimate distances and heights than virtual exploration. In addition, the analysis of cognitive maps revealed that cognitive maps drawn after physical exploration tended to be higher in accuracy and complexity than those drawn after virtual exploration (for similar results see [2]).

Accordingly, in relation to cognitive aspects of perception, physical exploration seems to allow to form a more complete and accurate reading and understanding of the urban environment than virtual exploration.

5.2. Differences in Affective, Interpretive, and Evaluative Aspects of Perception

In relation to affective, interpretive, and evaluative aspects of environmental perception, results show differences between physical and virtual exploration primarily due to reduced information and stimuli, and not experiencing the environment in motion in virtual exploration.

For affective aspects, it was found that perceptual sketches drawn during physical exploration featured a much greater amount of references to expressions of feelings and emotions than those drawn during virtual exploration. Furthermore, for the same street section, feelings and emotions expressed in perceptual sketches drawn during virtual exploration tended to be in contradiction with those expressed during physical exploration. The analysis of answers to semantic differential questions, conducted to assess differences in subjective perception between physical and virtual exploration, revealed similar contradictions for dimensions more related to the perception of motion in the environment (dynamic – static, ordered – chaotic, and secure – insecure).

For interpretive aspects, perceptual sketches associated with virtual exploration generally featured a greater amount of suppositions and inferences than those

associated with physical exploration. As confirmed by the analysis of the paragraphs written by the participants, this is because, during virtual exploration, participants tended to resort to suppositions and inferences to compensate for what they felt was missing information.

And, for evaluative aspects, perceptual sketches clearly indicated a greater tendency to formulate evaluations about the different components of the urban environment in physical exploration than in virtual exploration.

Findings of the study appear then to be in line with the previous research literature which suggests that levels of agreement between physical and virtual exploration tended to be relatively low for the assessment of subjective dimensions of the environment [9]. It should be noted, however, that, in this study, the analysis of answers to semantic differential questions reveals that virtual street view imagery may permit an appropriate subjective perception of the urban environment for components not related to motion and to auditory and olfactory stimuli. But, overall, in relation to affective, interpretive, and evaluative aspects of environmental perception, the study suggests that experiencing the environment in person during physical exploration allows to fully feel the urban space, capture the ambience of the place, and form clear and strong impressions about the setting much more effectively than experiencing it virtually.

5.3. Practical Implications

According to the findings of this study, virtual street view imagery exploration of the urban environment cannot replace actual physical exploration for fully comprehending and reaching a holistic understanding of an urban space. However, as suggested by participants, virtual exploration could be used as a more relaxed and comfortable preliminary exploration of an environment to acquire a general initial understanding or as a more focused follow-up exploration to check or complete information about physical characteristics captured during physical exploration. Combining both physical and virtual exploration could help benefit from the advantages of each of the two methods and reach a better understanding of an urban space.

5.4. Limitations and Suggestions for Future Research

The limitations of the study need to be pointed out to bring forth suggestions for future research. First the selection of settings for the study was affected by the limited Google Street View options in Cairo. Although the two settings selected are two street sections with very different characters, future studies could replicate this study in other types of urban spaces and environments.

Also, for participants, this study relied exclusively on architects and architectural students who are trained to audit urban spaces. Research might be needed to investigate if findings will differ for lay people. Finally, the virtual environment technology on which the study relied is virtual street view imagery. The realism of the environment that this technology recreates is somewhat limited as it depends on the combination of still photographs. Future studies could replicate the current study with other virtual environment technologies that could offer better immersion, interactivity, and sensory experience.

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