DESIGNING A VIRTUAL MODEL OF A REAL CITY BASED ON WAYFINDING STRATEGIES AND DIFFICULTIES OF THE USERS

ITZHAK OMER
Senior Researcher
ESLAB - Envionmental Simulation Laboratory
Tel Aviv University
Tel-Aviv - Israel
www.eslab.tau.ac.il

RAN GOLDBLATT / UDI OR
Students at ESLAB - Envionmental Simulation Laboratory
Tel Aviv University
Tel-Aviv - Israel
www.eslab.tau.ac.il

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1. Introduction

The users of every VE experience difficulties of orientation. These difficulties can be related to the characteristics of the VE, such as: the real time nature of the VE, the lack of “presence”, restricted fields of view, and using standard input devices that might affect performance during navigation (Witmer et al., 1996; Waller et al, 1998). However, the type and intensity of the problem depend on the VE type, the wayfinding task, the user's ability and the design of the VE.

In this paper we concentrate on the design of a virtual model of a real city. Such VEs are uncommon and they are also limited in their degree of realness and the size of the simulated area. However, it is reasonable to assume that such models will be more widespread with time, due to their potential as research and practical tools. They can serve as a tool for study of factors that may have a potential influence on wayfinding in familiar and unfamiliar environments. In addition, virtual cities can play an important role in planning support systems, especially those which encourage participation in planning (Laurini et al., 2001; Omer, 2003).

Based on an empiric study, which will be reported in detail in this paper, we found that the characteristics of virtual models, such as real time movement in open terrain, high speed of locomotion, varying perspectives and geographical scales could entail an unfamiliar and non-intuitive behavior, resulting in wayfinding difficulties. We refer here to wayfinding as a process of determining and traveling a path through an environment (Darken & Sibert, 1993).

From our perspective, design of a virtual model of a real city means enhancing wayfinding by enabling the users to move from their current location to another desired one. But, of course, the success of designing such a virtual model depends on knowing how the users fit their spatial representation of a real city to its virtual representation, i.e. how do they transfer spatial knowledge from a real city to a virtual one.

Most of the past VE studies deal with a virtual model of an unfamiliar environment, where the aim is to examine how the users carry and transfer knowledge gained in the virtual environment to the real environment (Darken et al., 1999; Janzen et al., 2001). However, there are no studies that deal with the transfer of knowledge of users who are familiar with the real city to its virtual representation, and there is no clear idea in what sense the virtual representation makes a difference. Namely, we do not have the necessary knowledge to design such virtual environments.

The aim of the paper is to study the behavior of users during wayfinding tasks in virtual Tel Aviv (the virtual model of Tel Aviv city). Based on this study we suggest a methodological principle for designing a virtual model of real cities. More specifically, we intend to answer the following questions:

a) What are the techniques and strategies that the users of virtual models adopt during wayfinding tasks?

b) What are the difficulties of using a spatial representation of a real environment in the virtual model of it?

c) Does the user's' level of knowledge of a real city correlates with the type of wayfinding strategies used and with the efficiency to cope with wayfinding tasks within the virtual model of that city?

d) How should one design a virtual model of a real city?

In the first section we describe the qualitative and quantitative methods we used for documentation and analysis of the empirical study. In the following section we report the findings that arose from the study, with regards to the above questions. On the basis of these findings, in the fourth section we suggest principles for the design of a virtual model of a real city.

2. Methodology for studying the behavior of virtual Tel Aviv users

Virtual Tel Aviv was built in the Skyline 4.5 software. Using the software, we combined an orthophoto of Tel Aviv in resolution of 25cm with DTM data in a resolution of 50 m grid, creating a real time virtual model of Tel Aviv city, an area of about 50 sq km (Fig. 1). The virtual model enables the user to “fly” from one place to another at any height or speed. The main goal of the experiment is to explore the difficulties users face and the wayfinding strategies they adopt during wayfinding tasks in this model. In the following paragraph we describe our experiment and the method of documentation and analysis we have used for achieving this goal.

Fig. 1: a piece of virtual Tel-Aviv in the Skyline software interface.

2.1 Experiment: Subjects, materials and tasks

12 participants (nine males and three females), 26 to 58 years of age, took part in the study. All participants declared they know the city of Tel Aviv “well”. In order to make sure that they are familiar with the city, a list of nine locations in Tel Aviv was read to them, and they were asked whether they know their exact location and how to get there. The experiment was conducted at the Environmental Simulation Laboratory, in front of a 19” desktop monitor.

In the first phase of the experiment, each subject was provided with an A4 sheet of paper, on which the municipal borders of Tel Aviv were marked. In addition, in order to give the respondents reference points, we also marked two very familiar landmarks along the coastline of Tel Aviv – the new Tel Aviv harbor and the old Jaffa harbor; The main national highway (‘Ayalon’ highway) was also marked (Fig. 2).

Fig. 2: The municipal borders of Tel Aviv and the reference points on which the locations were marked.

All participants were given the same instruction: “Please mark each of the above 9 sites on the map. Please be as accurate as you can”. The obtained sketch maps were anchored to the objective frame of reference system. The relations between each of the nine marked elements were measured (directions and distances) and were compared to their real locations. Such information allows us to define the spatial knowledge quality of the participants, a factor that might influence their behavior.

In the second phase, the participants were introduced to the Skyline software. We explained them how to use the flight simulator: moving forward, backwards, controlling the speed, stopping, moving up scale and down scale and manipulating the viewed screen. In order to prevent the participants from seeing the orthophoto of the examined area (Tel Aviv), they practiced using the simulator on a different area outside of Tel Aviv for 5 minutes or longer if they felt (or we felt) that they needed extra practice.

The third phase included two wayfinding tasks. In the first task, the participants were asked to "fly" to three different locations in Tel Aviv: The starting viewpoint was above the ‘Ha`Shaon’ square in Jaffa. The initial viewing angle was 90º, and the viewing height: 315 meters above sea level (Fig. 4a). It should be noted that the coastline was included in the starting viewpoint – a fact that will be discussed later on as crucial for the participants' spatial orientation.

The first task that was given to the participants was to fly from the ‘Ha`Shaon’ square in Jaffa to ‘Habima’ theater. From the theatre they were asked to get to ‘Yehuda Hamakabi’ street, and from there to ‘Ha`aretz’ museum (see Fig. 3).

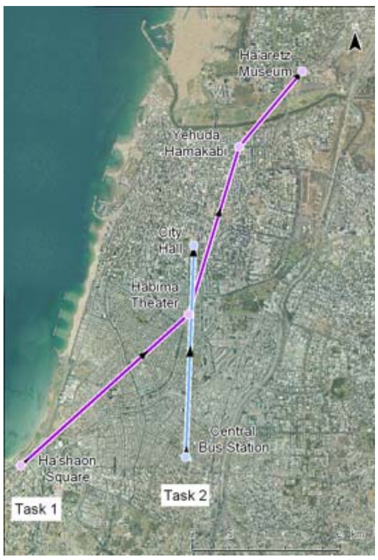

Fig. 3: The two tasks given to the participants and the task locations. Arrows represent the shortest flying path from each location to the next.

In the second task, the participants were asked to fly from the new central bus station to the city hall building. The initial viewing angle of the central bus station was 90º, and the viewing height was 315 meters above sea level (See Fig. 4b). We decided to separate this assignment from the previous one, since we were interested in seeing which techniques and strategies would be used by the participants when no reference object could be observed in the immediate environment. Note that because of the big size of the central bus station building, it took up almost the entire screen area. Since no initial reference objects or other cues were presented on the screen, the participants needed to somehow orient themselves and find north in order to successfully complete the task. In addition, we were curious if the participants would be more confident in this session, in a new area of the city, after having experienced navigating in virtual Tel Aviv and using the flight simulator for some time.

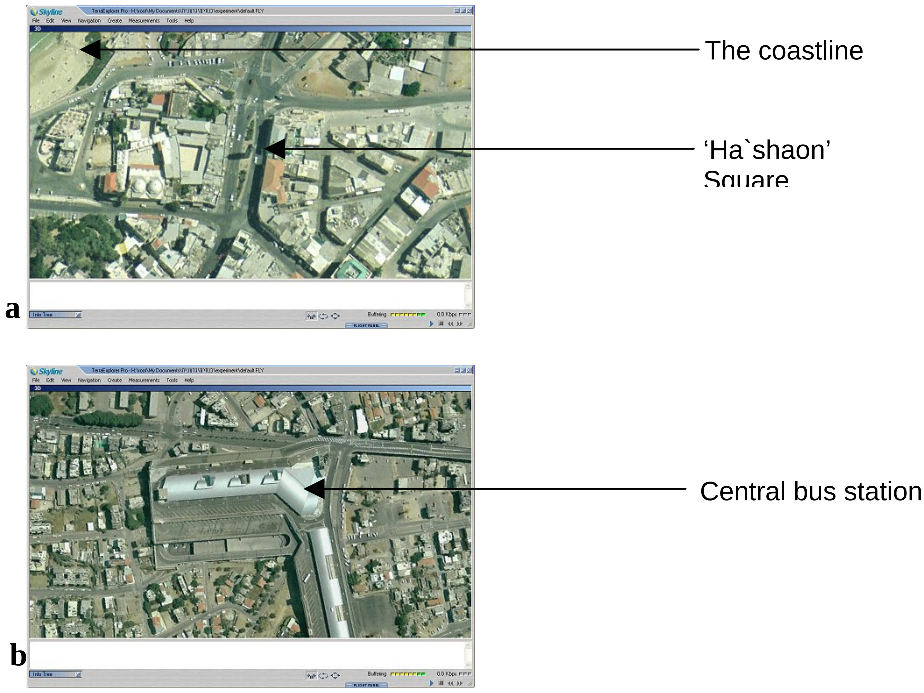

Fig. 4.: The initial viewing point of a. the 'Ha`Shaon' square in Jaffa and b. the central bus station.

In each assignment, the participants were asked to identify the target location and get our confirmation that this is indeed the requested place. It is important to mention that at the beginning of all tasks, the participants were told that they were not being examined on how well they use the software or on how quickly they could reach the destination.

2.2 Methods of documentation and analysis

a. *Tracks of movements*: In order to investigate the difficulties and wayfinding strategies of the model's users, we recorded the real-time-log data (e.g. coordinates, speed, height etc.), of all the individuals' tracks during the use of the model (including the track as it was seen by the user). Such documentation of the user's movements enabled us to perform high-standard quantitative analysis. During analysis, the recorded real-time-log data was converted to GIS layers, and then visualized as polylines in GIS layers in ArcGIS 8.3 environment. The statistical analysis was performed using SPSS 12.0.1 environment.

b. *"Think-aloud" method:* In order to reveal and understand the strategies and thoughts of the participants during the assignments, a "think-aloud" or "self-report" method (Golledge, 1976; Darken and Sibert, 1996; Murray et al., 2000) was implemented. The participants were asked to talk to us during navigation and to say everything that passed through their minds (strategies, thoughts, questions, internal conflicts, decisions etc.). When we felt they were not verbal enough, we encouraged them to talk and asked them what they were thinking about. Everything they said was recorded and later analyzed.

Each participant's documentation was analyzed. We characterized the reports according to the following four categories: strategies for wayfinding and spatial orientation; the process of establishing proportions understanding of the viewed VR elements, in comparison to the real-world same elements; the process of getting used to the differences between movement in the virtual environment and the movement in the real environment; the types of urban elements used for orientation and recognition.

3. Wayfinding strategies and difficulties of virtual Tel Aviv users

3.1 What are the techniques and strategies that the users of a virtual model adopt in wayfinding tasks?

Although each participant used different techniques for arriving to the destination object, we can classify these techniques into two basic wayfinding strategies: path-integration and position-based strategies that are usually involved in real world navigation (Loomis et al. 1999).

Path-integration

Navigation by path-integration or (deduced) dead reckoning relies on motion cues that provide a basis for interpreting mobility and relative scale during navigation. Path integration means continued integration of transnational and angular components, allowing estimation of direction and distance. By this strategy for example, one can arrive to a desired location by moving at a constant velocity and direction from a known origin location.

Using such strategy requires configurational knowledge, since the strategy is based on the relative directions and distances between locations. The necessity of this kind of knowledge, which incorporates information concerning directions and the relative positions of places (Golledge, 1992) for adopting the path-integration strategy, is expressed well by participant number 9 in our experiment. When this participant started navigating from the 'Ha`Shaon' square to 'Habima' theatre, he said: "*First of all, I'll raise the camera and look to the northeast… I'll start flying in the general direction of northeast*". He had on mind the general location of the target destination and he chose to fly directly to the theatre. Participant number 1 also used the strategy of flying in a general direction. During the third task he said that: "*I knew the general direction from 'Milano' plaza to the 'Ha`aretz' museum… I wasn't following any specific streets, just flying in a certain general direction*".

Relying on global reference elements of the city was found to be a common strategy used by many participants. Three main linear elements were found to be of use while navigating: the coastline, 'Ayalon' highway and 'Hayarkon' river. During navigation, the coastline was found to be a dominant reference line, a fact that can be verified both by the verbal report and the track patterns of the participants. In the first few minutes of the navigation, participant number 9 said: "*I keep looking in the direction of the sea, to see where I am so I don't get lost... This is my point of reference… I'll continue parallel to the coastline*". Another dominant reference line for this participant, as well as for other participants, was the 'Ayalon' highway. The participant said: "*I can identify the 'Ayalon' highway and I'm going parallel to it… rather than over it… my purpose is to get to the area of 'Azrieli' mall*".

The use of these two reference elements: the coastline and the 'Ayalon' highway was also found as dominant when analyzing the tracks which tend to be close and parallel to these reference lines (Fig. 5).

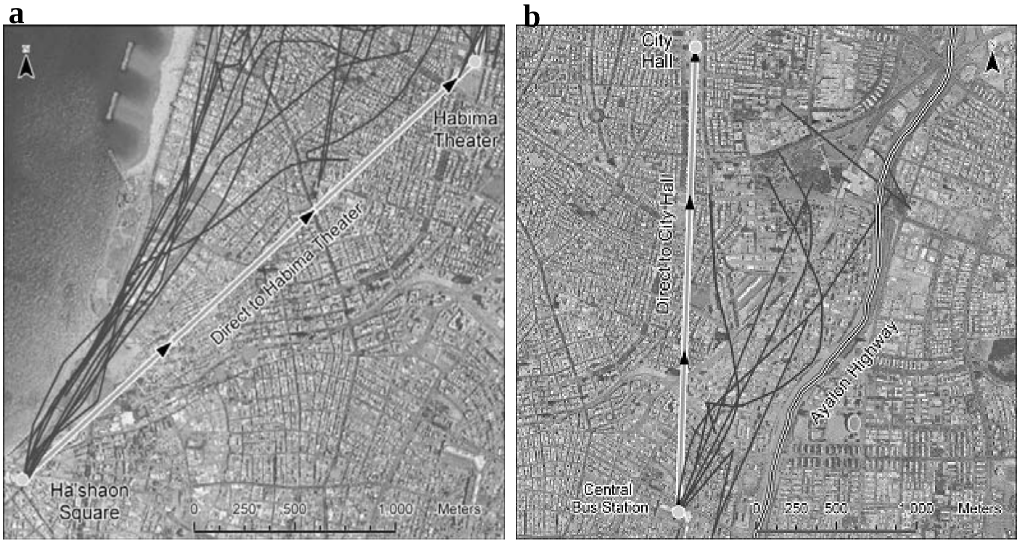

Fig.5: The participants` paths (the dark lines), which tend to be close and parallel to **a.** the coastline and **b.** ‘Ayalon’ highway. The light lines represent the shortest path between the tasks’ locations.

Relying on these global reference objects is critical for those participants who use the path integration strategy (although all of the participants used them). Whenever the participants got lost, they tried to find one of these references in order to “relax”: "*I don't want to get too far away from the beach, because otherwise I wouldn't know where the west is!"; "The coastline is a constant reference point that helps me orient myself… I still want to see the coastline, because I have no clue where I'm headed*" (Participant number 10); "*I'm trying to think where the west is here… I'm trying to find the coastline"; "I don't know which way is north and which is south!... I'll try to find the ‘Ayalon’ highway to find out*" (Participant number 11); “*Once I know where the ‘Ayalon’ highway is, I'll know which way is north*” (Participant number 5); "*If that's the beach, then that's west and this is north*" (Participant number 10).

Many of the participants mentioned that they do not want to lose these elements as anchors till they found another “strong” element upon which to rely. While navigating, they “fly” in a specific direction and rely on major objects. Participant number 8 described this in the best way: “*I'm now moving north over ‘Hayarkon’ street, and I'm trying to find some landmark that I know for sure…like a street that will get me fully oriented… Once I find such a point of reference, I'll be able to get off ‘Hayarkon’ street and into the city*”.
It should be noted that the reference objects used by this kind of navigators can also be local reference object (e.g. squares, famous buildings etc.). For example, ‘David Intercontinental’ hotel is a tall building located next to the coastline. Participant number 3 used this hotel (which she was familiar with in the real world) as a point for changing her route direction: “*I need to take a right at some point… Here's the ‘David Intercontinental’ hotel – I'll take a right there*”. during piloting to locations that are beyond the current sensory field, these navigators may coincidently see a single reference object and then compute their position using bearing differences to the target location.

Position-based strategy
Navigation by position-based or piloting strategy relies on recognizable landscape elements. Such positional location information, or a network of locations, provides the relative distance and information among them, i.e. during movement, the navigator uses cues for knowing where he is and for deciding his next step. As such, this strategy can be more appropriate for those participants whose knowledge is mainly procedural. Adopting a position-based wayfinding strategy leads to using different wayfinding techniques. Instead of freely navigating and looking for dominant spatial features, the navigators continuously update their position using elements or cues, usually elements that the navigator is familiar with from his everyday movement in the real world.

The differences between this strategy and the path-integration strategy described above can be verified with the verbal descriptions and with the visualized paths. The terminology used in each strategy is completely different. While in the latter strategy the terminology used was mainly based on descriptions of the reference points/lines, the participants who used the position-based strategy mainly relied on their experiential procedural knowledge. They even felt as if they were driving a car. Instead of talking about "flying the airplane" they used the verb "driving"; participant number 2 described his wayfinding strategy as follows: "*I wanted to drive north to the opera building and then veer to the east… this is what I do when I drive there*"; Participants number 10 also mentioned the same strategy: "*I know this is 'Ben Gurion' avenue, and so I can take this road like I do with my car…*".

Since the strategy used by these navigators is based on representation built during their everyday life from ground level, these navigators reported they were looking for elements they could have seen had they walked or driven in the real environment. when the participants adopt the position-based strategy (mainly the more "procedural-oriented" ones), they usually rely on each visited cue for decision making for further movement towards the next cue. That is, they perform a "continuous tuning" during navigation, when each identified location functions as decision-making point. For example, participant number 4 said: "*I'll stop here for a second… I'm near the Opera building now … So I can start moving left* [not north] *here until I reach the area of 'Hamedina' square…*".

It is clearly seen, that these navigators apply an "if-then" strategy along the path. This strategy characterized for instance participant number 2 who said: "*This is the city hall? Great, then I can continue… 'Hamedina' square is the east, now I can continue onto 'Weizmann' street… This is 'Namir' road? Well then this must be 'Yehuda Hamakabi' street…*". Participant number 6 also used the "if-then" terminology when she tried locating 'Yehuda Hamakabi' street: *"Judging by these towers, this must be 'Pinkas' street… If this is 'Pinkas' street, then that's 'Yehuda Hamakabi' Street…*". Sometimes the navigators rely on paths and main roads for identifying the objects. In order to identify the 'Ha`aretz' museum, participant number 8 used the highway and the street parallel to the museum as a cue: "*It's a piece of cake! Once I've crossed 'Ayalon' highway and 'Rokach' boulevard, I can tell where the museum is located*".

Dominant Elements

The elements that were found to dominate during navigation were those with a unique morphology, such as the city squares or street networks. The two city squares of Tel Aviv ('Hamedina' square and 'Dizingoff' square) were found to be dominant objects for orientation during navigation. When a few participants saw these elements, they knew their exact location and which area they were flying over. Participant number 3 mentioned that: "*Before I identified 'Hamedina' square, it was hard for me to know from above which turn to take for 'Yehuda Hamakabi' street*". Participant number 7 also became spatial oriented when he identified 'Dizingoff' square: "*Here's 'Dizingoff' Square! So that must be the mall, and that's 'King George' street…*". Regarding streets or roads that have a specific and unique morphology (e.g. wide, long, curved streets..), Participant 10 said: "*I'm looking for intersections, for unusual road junctions…*". Participant 8 said he used the curve of a street in order to identify it "*But wait a second, there's a bend in the road… then it can't be 'Ahad Ha`am' street*".

3.2 What are the difficulties in using spatial representation of a real environment in its virtual model?

The data analysis reveals three main difficulties that the participants experienced during the wayfinding task: orientation, recognizing familiar objects and spatial proportions.

a. *__Lack of orientation__*: The first problem the participants experienced was the lack of knowing which way was north. Remarks such as, “You don`t give me a north arrow!” were very common. When Participant number 1 first experienced the interface, he immediately said: “*Which way is north? If I can find north, it'll be much easier*”. Due to this problem, whenever a navigator needed to orient himself and understand where was north (at the beginning of a task and during movement), he relied on cues and reference urban elements, such as ‘Ayalon’ highway: “*Once I know where the ‘Ayalon’ highway is, I'll know which way is north*”… "*If that's the beach, then that's west and this is north*” (participant number 5); “*I don't know which way is north and which is south... I'll try to find the ‘Ayalon’ highway to find out*” (participant number 11).

A few participants oriented themselves by paying attention to the morphology of main streets and junctions between identified streets. Participant number 10 gave a very good explanation for that strategy: “*I need to go back to an area I know – the center of Tel Aviv – and take a route I know, like ‘Eben Gabirol’ street, and then I'll be able to tell which way is north and which is south*”.
Other participants used the relation between several landmarks for inferring the north direction. For example, participant number 1 used his knowledge about the relations between ‘Meir’ Park and ‘Dizingoff’ center for knowing where is north, as he said: “*Once I saw ‘Meir’ Park and ‘Dizingoff’* [center]*, I was sure about which way was north*”.

Sometimes, one can even rely on a shape of a specific landmark or building to know which way is north. This is a useful strategy only when the user has prior knowledge about the form of the object. For instance, participant number 7 had prior knowledge about the central bus station, and so he said that: “*Now that I recognized the central bus station, I can tell which way is north*”.

b. *__Lack of familiar cues__*: The differences between the real environment and the virtual one stem from the fact that the city elements appear differently from ground level than from a birds-eye view, and then the navigators have difficulties recognizing elements during navigation. While they know what landmarks look like from ground, they have no clue what to expect when they have a view on it from the “plane” e.g.: “*This is what the central bus station looks like from above*?” (Participant number 8); “*I know what I see when I drive [there], and what I see now just doesn't make sense*” (Participant number 10). This problem is especially dominant when the searched cue is a 3D one. Participant number 1 looked for the ‘Migdalor’ building. When he discovered that it is too difficult to locate the building, he decided to look for another cue: "*My plan was to follow ‘Namir’ road, reach ‘Migdalor’ building and take a right. I couldn't find ‘Migdalor’ building, so I went for another node”* (Participant number 1); “*I'm heading south from ‘Hayarkon’ street until I see something that sticks out and looks like ‘Habima’* [theater]” (Participant number 6).

c. *__Lack of familiarity of spatial proportions__*: Not only do the users are not used to seeing the city from the bird`s-eye view, they also have difficulty getting used to their proportions. Due to this, when an object or an area have a familiar shape, lets say a city square, it is extremely difficult to define which city square it is without seeing its surroundings. Many participants experienced problems distinguishing between ‘Hamedina’ square and ‘Dizingoff’ square; although the ratio between these two areas is about 1:2 (approximately 850 sq m and 450 sq m respectively) the participants couldn’t distinguish between these two until they saw each of the areas and were able to apply a spatial understanding of the proportions. It should be mentioned that the confusion in understanding the element's proportions characterized the entire virtual environment, and not only city squares. One participant (number 6) saw the city market of Tel Aviv and was sure she was looking at the airport (which is far away in another city), and another participant who saw ‘Rabin’ square was sure he was looking at the sport center.

In addition to the problem of the elements proportions, the participants had also problems estimating how far they moved with every click on the keyboard. This fact caused them to wrongly estimate locations as they thought they have moved too far away and vise versa.

3.3 How does the quality of spatial knowledge influence wayfinding efficiency?

The accuracy of the sketch maps serves as an indicator for estimating the quality of knowledge. For this purpose, the distances between the locations drawn on the anchored sketch maps and the real locations were measured. A significant positive correlation was found between the distortions in the sketch map and the length of the flying path (0.615, p=0.03). This means that the participants with a more accurate representation of the city can navigate more efficiently in its virtual model.

Moreover, when the participants were classified according the knowledge they mainly expressed during wayfinding tasks (participants whose knowledge is mainly procedural versus participants whose knowledge is mainly configural), a significant correlation was found between these categories and the distortions in the sketch maps (0.681, p=0.015). A significant correlation was also found between the type of knowledge mainly expressed and the length of the flying path (0.897, p<0.001). This finding can be explained by the fact that the participants whose knowledge is mainly procedural do not “fly” straight forward to the destination point, rather they “fly” (or “drive” as they always mentioned) along known streets as if they where driving or walking in the real environment. In addition, there are many “breaks” along the paths, mainly above junctions, landmarks, or the local cues used as decision-making points.

Thus, efficient navigation in a large-scale virtual city requires not only procedural knowledge that allows one to get from one place to another, but a configurational or survey knowledge that enables the users to grasp the overall structure of the space (Darken, 1995). These findings are not surprising since it is well know that such spatial knowledge allows people to navigate efficiently in a real geographical environment (Montello, 1998; Kitchin, 1996) as well as in virtual one (Janzen et al. 2001).

4. How should one design a virtual model of a real city?

The possibilities and limitations of navigation within a virtual environment make some elements more usable. Such objects should be highlighted in the virtual environment on all scales in which navigation takes place in order to help the users fit their spatial representation of a real city to its virtual one. As suggested in previous studies (Charitos and Rutherford, 1996; Vinson, 1999; Jansen-Osmann, 2002), such design is essential for enabling the users’ temporary spatial representation. It permits the local perceptual cues to be of use in tracking or maintaining a sense of orientation (Cutmore et al. 2000).

However, the main question is how to design the simulated environment, that is, which elements are necessary for navigation on different scales and in different observed areas of the city, i.e. deciding which urban elements should be highlighted in the virtual environment. The uniqueness of designing virtual models of real cities lies in the possibility of knowing how their residents perceive them and to use this knowledge in order to design a more legible simulated environment. Accordingly, we used the “think-aloud” documentation for locating the elements that are needed to be highlighted in the virtual model with respect to scale and perspective. The objects mentioned by the participants during the wayfinding tasks in the virtual Tel Aviv environment include global objects for general orientation as well as local objects that were mentioned with respect to the specific location of the relevant task destinations (see Fig. 6).

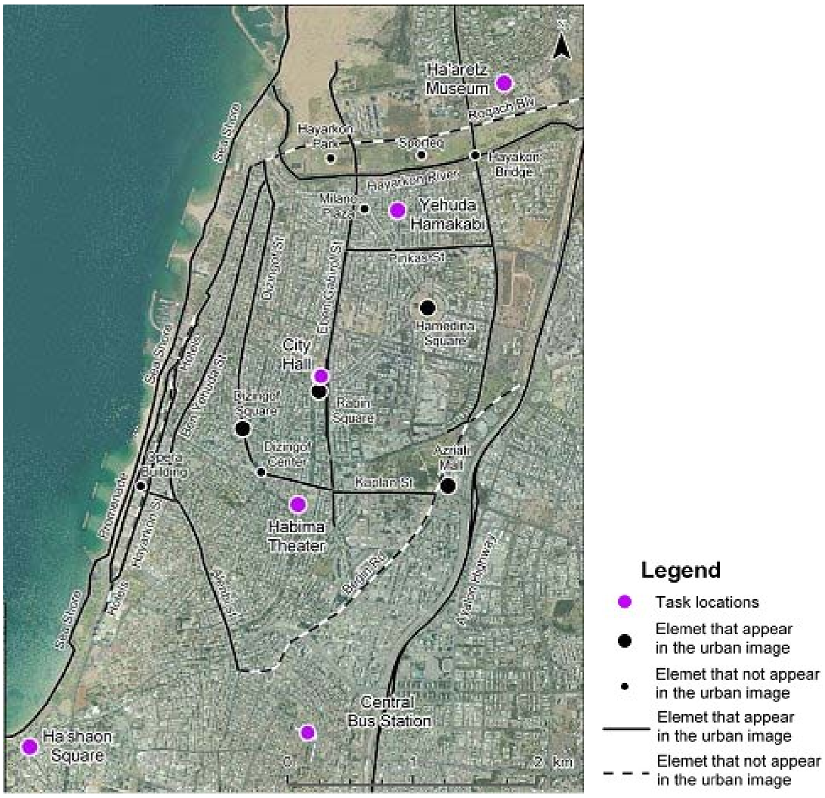

Fig. 6: The objects mentioned during wayfinding tasks and the urban image of Tel Aviv's residents

In order to identify the uniqueness of the elements that comprised in the temporary spatial representation created during navigation in the VE to the spatial representation of the real city, we apply the method of ‘Urban image’, as suggested by Lynch (1960). For that purpose, we conducted another experiment in which 32 Tel Aviv residents were asked “to draw a map of Tel Aviv and to sign/draw the dominant elements in it (no more than 15 elements)”. Then, the data from the individual sketch maps was gathered into one aggregate map representing the urban image or the aggregative cognitive representation of Tel Aviv city (Omer et al., Forthcoming) (Fig. 6).

Three main findings emerge from the comparison between the representation of the city during navigation and the urban image. First, when the users of virtual Tel Aviv employ a “flying-based" navigation mode, the useful elements are usually large physical elements and elements with unique morphology, like squares, junctions and street network, which can be seen from bird’s-eye view. As can be seen in figure 6, these properties characterize the elements that were mentioned by the virtual Tel Aviv users but were not included in the Tel Aviv residents’ urban image. The second finding is the relative similarity between these representations. Analysis of the objects included in the representations, shows that approximately 94% of the objects mentioned during the wayfinding tasks in the virtual model appear in the aggregative urban image. The third finding, and maybe the most interesting one, concerns the structure and quality of the connections between these elements, which Lynch termed as the "structure quality" of the urban image (Lynch, 1960). Since navigation in a virtual model means changing scale and perspective, the VE designer needs to know which elements should be displayed to the user, according to the reference object and its geographical context. A detailed analysis of the individual sketch maps shows that 72% of the elements mentioned in the context of the wayfinding tasks' locations (80% of the first task and 63% of the second task) are mentioned in the context of those locations when they appear in the individual sketch maps. Based on the last two findings, we can conclude that in general, the method of the urban image can be an appropriate tool for locating the useful elements for navigation within virtual model of a real city.

In addition to the design of the simulated environment, a map and compass were found to be necessary for displaying the user's position and orientation. A compass contributes to spatial orientation by adjusting the simulated geographical environment to a frame of reference, while a map assists in spatial orientation and in collecting spatial information from the surrounding environment.

4. Conclusions and further study

Virtual Tel Aviv is relatively more real, recognizable and tangible than other applications of real cities, mainly due its high-resolution orthophoto and real time property. Even though, as a result of its virtual characters, the users have difficulties to use spatial representation and transfer knowledge that they have regarding the real Tel Aviv city. The study of virtual Tel Aviv shows three main difficulties experienced by the participants during the wayfinding tasks: disorientation, difficulty to recognize familiar objects and difficulty to evaluate the right spatial proportions (size and distance). However, these difficulties do not prevent the users from applying the same basic wayfinding strategies of path-integration and position-based knowledge from the real environment. It is clear that the efficiency in wayfinding tasks can be predicted by the type and quality of the subject’s spatial knowledge; subjects who have more accurate configurational or survey knowledge are likely to have more success in wayfinding tasks than those whose knowledge is mainly procedural. In this sense, the virtual environment does not differ from other external representation such as map and orthophoto.

I order to apply the wayfinding strategies and to transfer spatial knowledge of a real city to a virtual city, the users adopt more useful wayfinding techniques appropriate to the “flying-based” navigation mode in open terrain, such as referring to and looking for large physical elements. These elements are mainly those that have unique morphology such as squares, junctions and street networks which can be seen easily from bird’s-eye view. Orientation in the virtual city is usually obtained by using familiar urban elements.

Based on this understanding, we can decide which structure or network of objects should be highlighted in the virtual environment with respect to scale and perspective. The behavior of virtual Tel Aviv users shows, that such a structure should include a global reference object for general orientation and local objects that are important for orientation in a local geographic context. Such design is essential for enabling the user to create spatial representation, which permits the local perceptual cues to be of use in tracking or maintaining a sense of location.

Since the advantage of designing virtual models of real cities lies in the possibility of knowing which city elements are more important, empirical study regarding the way the residents perceive the city, could be the basic principle for the design of a more legible simulated environment. Our study clearly shows that applying the method of "urban image" is an appropriate tool for locating the useful elements for wayfinding within a virtual model of a real city.

References

Cutmore, T. R. H., Hine, T. J., Maberly, K. J., Langford, N. M. and Hawgood, G. (2000). Cognitive and Gender Factors Influencing Navigation in a Virtual Environment. *International Journal of Human-Computer Studies*, 53, pp. 223-249.

Charitos, D. and Rutherford, P. (1996). Guidelines for the Design of Virtual Environments. *3 rd Virtual Reality Special Interest Group Conference, Leicester, Proceedings*. Virtual Reality Special Interest Group and Contributors, UK, pp. 93–111.

Darken, R. P. (1995). Wayfinding in Large-Scale Virtual Environments. *Proceedings of CHI '95*.

Darken, R. P., Alleard, T. and Achille, L. B. (1999). Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces II. *Presence*, 8(6), pp. 3-6.

Darken, R. P. and Sibert, J. (1993). A Toolset for Navigation in Virtual Environments. *Proceedings of the ACM Symposium on User Interface Software and Technology*, *Atlanta, GA.*

Darken, R. P. and Sibert, J. (1996). Wayfinding and Behaviors in Large Virtual Worlds. *Proceedings of CHI '96 Human Factors in Computing Systems*, *Vancouver, BC Canada*.
Golledge, R. (1976). Methods and Methodological Issues in Environmental Cognition Research. In: G. T. Moore and R. G. Golledge (Eds.), *Environmental Knowing*. Stroudsburg, PA: Dowden, Hutchinson and Ross. pp. 300-313

Golledge, R. (1992). Place Recognition and Wayfinding: Making Sense of Space. *Geoforum*, 23(2), pp. 199-214.

Jansen-Osmann, P. (2002). Using Desktop Virtual Environments to Investigate the Role of Landmarks. *Computers in Human Behavior*, 18**,** pp. 301-311.

Janzen, G., Schade, M., Katz, S. and Herrmann, T**.** (2001). Strategies for Detour Finding in a Virtual Maze: The Role of the Visual Perspective, *Journal of Environmental Psychology*, 21(2), pp. 149-163.

Kitchin, R. M. (1996). Increasing the Integrity of Cognitive Mapping Research: Appraising Conceptual Schemata of Environment-Behavior Interaction. *Progress in Human Geography*, 20, pp. 56-84.

Laurini, R. (2001). *Information Systems for Urban Planning: A Hypermedia Cooperative Approach*. London: Taylor and Francis.

Loomis, J. M., Klatzky, R. L., Gollledge, R. G. and Philbeck, J. W. (1999). Human Navigation by Path Integration. In: R. G. Golledge (Ed.), *Wayfinding Behavior*. Baltimore: Johns Hopkins University Press, pp.125-151.

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

Montello, D. (1998). A New Framework for Understanding Axquisitin of Spatial Knowledge in Large-Scale Environments. In: M. J. Egenhofer and C.G. Volledge (Eds.), *Spatial and Temporal Reasoning in Geographic Information Systems*. New York: Oxford University Press. pp. 143-154.

Murray, C. D., Bowers, J. M., West, A. J., Pettifer, S. and Gibson, S. (2000). Navigation, Wayfinding and Place Experience within a Virtual City. *Presence*, 9(5), pp. 435-447.

Omer, I. (2003). Web-Based Planning Support System for Public Participation: An Individual's Perspective, *AGILE 2003, Geographic Information Science.*

Omer, I., Goldblatt, R., Talmor, K. and Roz, A. (Forthcoming). Enhancing the Legibility of Virtual Cities by Means of Residents` Urban Image: a Wayfinding Support System. In: J. Portugali (Ed.), *Complex Artificial Environments*, Berling: Springer.

Vinson, N. G. (1999). Design Guidelines for Landmarks to Support Navigation in Virtual Environments. *Proceedings of CHI '99, Pittsburgh, PA.*

Waller, D., Hunt, E. and Knapp, D. (1998). The Transfer of Spatial Knowledge in Virtual Environment Training. *Presence*, 7(2), pp. 129-143.

Witmer, B. G., Balley, J. H. and Knerr B. W. (1996). Virtual Space and Real World Places: Transfer of Route Knowledge, *International Journal of Human-Computer Studies*, 45**,** pp. 416-428.