Navigation aids for multi-floor virtual buildings: A comparative evaluation of two approaches

Luca Chittaro
HCI Lab, Dept. of Math and Computer Science
University of Udine
Via delle Scienze 206, Udine – 33100, Italy
+39 0432 558450
chittaro@dimi.uniud.it

Subramanian Venkataraman
HCI Lab, Dept. of Math and Computer Science
University of Udine
Via delle Scienze 206, Udine – 33100, Italy
venkatar@dimi.uniud.it

ABSTRACT

Virtual environments (VEs) very often contain buildings that have to be navigated by users. In the literature, several navigation aids based on maps have been proposed for VEs, but in virtual buildings they have been typically used for single-floor scenarios. In this paper, we propose and experimentally evaluate two different navigation aids for multi-floor virtual buildings, one based on 3D maps and the other based on 2D maps. We compared subjects' performance with two different types of tasks: search and direction estimation. While the 2D navigation aid outperformed the 3D one for the search task, there were no significant differences between the two aids for the direction estimation task.

Categories and Subject Descriptors

H.5.1 [**Information interfaces and presentation**]: Multimedia Information Systems – *Artificial, augmented, and virtual realities*. H.5.2 [**Information interfaces and presentation**]: User Interfaces – *Interaction styles, evaluation*. I.3.6 [**Computer graphics**]: Methodology and techniques – *Interaction techniques.*

General Terms

Experimentation, Human Factors.

Keywords

Multi-floor virtual buildings, navigation aids, evaluation.

1. INTRODUCTION

Navigation is an important aspect of interaction with a virtual environment (VE). Navigation aids research aims to create solutions to help the user explore and learn the environment around her and prevent her from getting lost, simplifying navigation, which often is only an intermediate task that the user needs to perform inside a VE together with other tasks (e.g., object manipulation, collecting information etc.) [7]. Different kinds of navigation aids have been proposed in the literature, e.g., based on highlighting landmarks [10,17], adopting particular travel techniques [22], submitting queries [3], seeing through surfaces [8], direction indication [6],...

A number of navigation aids are based on maps, but in the context of virtual buildings they are often able to handle only a single floor or they have been tested on tasks that involve navigating only a single floor. Supporting navigation in multi-floor virtual buildings is thus an interesting and largely unexplored area of research. These buildings have floor designs of varying complexity and are characterized by severe occlusion due to the presence of multiple layers of geometry. In virtual buildings, it is important to provide users with navigation support in such a way that they can: i) view the structural details of every floor, and their own immediate surroundings within the context of the entire building; ii) gain both route and survey knowledge of the virtual building. To the best of our knowledge, there are no experimental studies in the literature which have tried to compare different navigation aids for multi-floor virtual buildings. In this paper, we propose and experimentally evaluate two different navigation aids for multi-floor virtual buildings, one based on 3D maps and the other based on 2D maps.

The paper is organized as follows: section 2 discusses related work on navigation aids based on maps, particularly for virtual buildings; section 3 illustrates the two navigation aids we considered in our evaluation; section 4 describes the experimental study and its results. Finally, section 5 presents the conclusions and future work.

2. RELATED WORK

To navigate effectively an environment, users resort to two distinct types of navigational knowledge. Route knowledge is usually developed from a first person (egocentric) perspective, is usually gained by personal exploration of an area and describes paths between locations in the environment. It allows a user to travel to destinations through known routes, but does not allow the user to exploit alternate unfamiliar routes. Survey knowledge is attained by multiple explorations of an environment using multiple routes or also through study of a map/pictures of an area. Survey knowledge is characterized by the ability to take a third person (exocentric) perspective of an area. It describes relationships among locations, provides the mental equivalent of a map and allows one to recognize alternate routes between locations [20].

Navigation support for wayfinding in virtual buildings has been provided in different ways (e.g., [5, 7]) but has typically focused on single-floor buildings. Niederauer et al. [14] recently proposed an interesting building structure visualization that is able to show both the interior and exterior structure of multi-floor buildings simultaneously. They implemented a low level 3D pipeline-based geometry extraction and processing technique that is able to take a building model as input, automatically detect the presence of multiple floors, extract the corresponding geometry at the pipeline level and finally produce an "exploded" view of the entire building. However, they did not apply the proposed technique to support user's navigation in VEs.

Navigation aids based on maps present the user with a third person perspective of the environment, which the user must then relate to what she sees in front of her. This may require a significant cognitive effort to relate the third person perspective to the first person perspective [2]. Electronic maps can however provide features like automatic north-up/forward-up orientation, indicating user position and orientation in real-time, which are not available in paper maps.

Maps can also be used to support map-based travel techniques where the user can drag the icon representing herself to a new position on the map. Once the user drops the icon, the system can animate the user's transition from the current location or instantaneously jump to the target location. However, automated point-to-point navigation can limit the spatial knowledge users gain from the virtual experience. Users may be shown (and thus may learn) little or nothing about the route (and its surroundings) between initial and target locations [4].

The earliest map-based navigation aids employed 2D maps (e.g. [9]). The Worlds In Miniature (WIM) proposed by Stoakley [21] was the first attempt at employing a 3D map. A WIM is a 3D miniature version of the VE, floating in front of the user, as if it were in her virtual hand. The user's position and orientation are indicated in the WIM that also provides the user with object manipulation and navigation capabilities [21]. The WIM has some shortcomings that do not make it directly applicable to virtual buildings. First, the WIM has been used for simple single-floor designs (e.g., [12]) and the problem of visualizing more than one floor of a building while trying to avoid/reduce occlusion is left unsolved. Second, the WIM may be unsuitable for representing large spaces, since it would be too detailed for users to comprehend. A lower level view able to show part of the large VE in sufficient detail, would need to provide some kind of scrolling or pan and zoom techniques. However, details may become unrecognizably small when users zoom out, and larger worlds increase the time required to pan and zoom [17]. Third, it is important that users follow some path through the stairs and corridors to gain navigational knowledge of a virtual building. Following this path is important to give the user knowledge of the relative location of objects in the virtual space [19]. Thus, map-based travel techniques or automated point-to-point navigation techniques (e.g. [16, 21]) may not help users gain knowledge about the routes and internal structure of the virtual building they are navigating.

Some navigation aids based on variations of the WIM have been proposed over the years. The original WIM [21] suggested a "pick and place yourself" navigation technique. The first WIM-based navigation aid was implemented in [16]. The user controls an icon representing herself to specify her new position in the map. Once she releases the icon, the system "flies" her into the new location. Navigation based on a "Step WIM" using novel user interaction techniques is proposed in [12] for navigating larger distances. The Step WIM is visualized in a Cave environment. When a user invokes the Step WIM (via a foot-tapping gesture), a miniature version of the VE is placed beneath her feet such that the actual position of the user in the VE coincides with the approximate location of the user's feet in the miniature. The user can either walk around the Step WIM to gain a better understanding of the virtual environment, or he or she can use the Step WIM to navigate to a specific place by simply walking to a desired location in the Step WIM and invoking a scaling command, causing the Step WIM to animate scaling up around the user's feet, thereby seamlessly transporting the user to the specified VE location. Thus, instead of being a hand-held object (as proposed originally in [21]), the Step WIM functions as a map and provides an effect similar to walking through a miniature environment landscape [12]. A WIM applied to virtual buildings was proposed in [5] where user interaction takes place by means of an interface called the "saw". The saw is a planar virtual cutter operated by the user with the hand not holding the WIM. When it is brought into contact with the WIM, all detail on the "cut" side are removed and the internal contents are revealed. In [7], we have proposed the I3BAM, a novel navigation aid based on an extension of the WIM applied to multi-floor virtual buildings. The I3BAM supports user navigation in virtual buildings as a navigation aid, but also provides a means of examining any floor of a virtual building without having to necessarily navigate it. The aid presents multiple views of the virtual building and provides information about both the internal and external structure of the building [7]. Recently, a Scaling and Scrolling WIM (SSWIM) has been proposed [23], which tries to overcome one of the shortcomings of the WIM, i.e. the inability to represent large scale VEs that would be too detailed for users to handle. This WIM implementation allows users to perform two operations (scaling and scrolling) on the WIM by means of two-handed interaction making use of a mouse and a wand.

Map-based navigation aids have been studied also in the field of aviation psychology (e.g [1,15]), but with target users (pilots) and tasks (flying a plane in outdoor environments) that are very different from those considered in our work (more diverse user population, walking inside multi-floor virtual buildings).

Montello et al. have studied human acquisition of navigational knowledge in large-scale spaces, including multi-floor buildings in [11,13,18]. In [13], they study the acquisition and integration of configurational (survey) knowledge in a large multi-floor building complex. Users first learnt two vertically separated routes containing landmarks, one by one. Then, the experimenter provided a verbal description in which he revealed that the two routes were actually located one above the other and also how the two routes were related spatially, asking users to integrate their knowledge of the two routes based on the verbal description. They then had to perform direction estimation tasks. In [18], the authors compare the nature of spatial representations of large-scale real spaces in users in different learning conditions. Users had to learn complex routes containing landmarks in one of three different conditions: i) by studying architectural maps; ii) by navigating within a virtual reconstruction of the building using a computer (without any additional navigation aids); iii) by navigating in the real building itself. In the map condition, the route was drawn on the map and the landmarks were indicated by hand. In the other two conditions, verbal instructions were given regarding the route to be taken by the experimenter who accompanied the user and the landmarks were described as they were encountered. After the users had learnt the routes (and were able to remember the landmarks), they had to perform distance and direction estimation tasks in the real building. These studies respectively pointed out that: i) within-route direction estimates had smaller errors than between-route direction estimates; ii) users of a map or VE reconstruction of a building tend to develop orientation-specific knowledge. In [11], Montello et al. describe an experiment where users are driven along two routes in an unfamiliar neighbourhood over multiple sessions. During various sessions, users had to perform direction and distance estimation tasks and map sketching tasks. The authors concluded that users could quickly acquire some metric knowledge of an environmental layout upon first exposure.

3. THE CONSIDERED NAVIGATION AIDS

The experimental evaluation we carried out compares a 2D and a 3D navigation aid we propose for multi-floor virtual buildings. Both aids are based on maps and aim to provide information about the position of objects in the environment with respect to the user's position. Sections 3.1 and 3.2 provide a more detailed description of the two aids, while section 3.3 outlines the features that are common to the two navigation aids.

3.1 The 3D Map Aid

The 3D Map (3DM) aid we employed for the experiment is a simplified version of the I3BAM navigation and examination aid we proposed in [7]. The 3DM provides the user with a miniature 3D model of the building she is navigating. It displays in detail the floor on which the user is walking (the *user floor,* hereinafter) while the other floors are visually indicated by means of colored rectangular outline boxes of the same height as the corresponding floors (see figures 1 and 3). When the user is walking on staircases, a transparency effect is provided for the two floors between which the user is "transitioning": as long as the user is on a staircase, the higher floor and lower floor are displayed in detail and become semi-transparent to provide the user with a convenient view, irrespective of whether the user is ascending or descending the staircase. As soon as the user reaches one of the two floors (the higher or the lower), the reached floor becomes solid, while the other floor disappears. For example, in figure 5 the user walks on a staircase leading to floor 2 from floor 1, and those two floors become semi-transparent.

The 3DM visually indicates each floor by displaying a colored rectangular outline box having the same height as that floor and at the same position as the floor itself, with the corresponding floor number being displayed at the lower right corner of the outline. Different colors are used to indicate the user floor (yellow colored highlight), the floor on which a target object is located (red colored highlight) and all the other floors (gray colored highlight). This allows the user to visualize the entire building (and all its floors) volumetrically, while providing her with a detailed view of the floor on which she is navigating, without occlusions. Figure 6 shows the different highlights in a three-floor building.

The 3DM indicates user position and orientation by means of a glyph (a sphere with an inverted triangle in front of it, as in figures 3 and 6) having the same color as the user floor highlight. Users' position and orientation are updated in real-time as the user navigates. The position of a possible target object is indicated by means of another glyph (a sphere) having the same color as the target floor highlight. Figure 6 shows the user's position and orientation while she is entering floor 1 and a target position on floor 3.

3.2 The 2D Map Aid

The 2D map (2DM) aid we employed for the experiment is based on 2D maps of each floor of the building (see figures 2 and 4). As with the 3DM, the user floor is displayed in detail, while only the outlines of the other floors are displayed. The 2DM highlights a specific floor by displaying a rectangular outline around it, with the corresponding floor number being displayed at the lower right corner of the rectangular outline (figure 4 shows how floors are highlighted). The color scheme is the same employed by the 3DM. Figure 7 shows the different highlights in a three-floor building.

The 2DM indicates user position and orientation in the same way as the 3DM. Figure 7 shows the user's position and orientation while she is navigating floor 1 and a target position on floor 2.

3.3 Common Features

We took care to ensure that none of the two navigation aids had any artificial advantage over the other. Both navigation aids: i) visualize the map of the floors of the building, with only the user floor shown in detail (see figures 3 and 4); ii) highlight all the floors of the building including the floor on which the user is navigating and the floor on which a (target) object is located (see figures 6 and 7) using the same highlight scheme; iii) indicate the position and orientation of the user with the same glyph; iv) indicate the position of a target object with the same glyph. Moreover, both navigation aids indicate the user and target positions (as described previously) but do not indicate or display other objects. Both aids are placed into a tiled window of the same size at the bottom of the screen with a gray background. This way, screen space devoted to the user's first-person view and to the navigation aids did not change in the 2D or 3D case. Slider controls for map orientation purposes were provided in a panel at the bottom of the window for both navigation aids. Two slider controls were provided for the 3DM, allowing the user to rotate the 3DM around the horizontal or vertical axes (see figure 3). One slider control was provided for the 2DM, allowing the user to rotate the 2D maps about the axis normal to the gray panel surface (see figure 4).

4. EXPERIMENTAL STUDY

4.1 Tasks, Conditions and Hypotheses

The experiment focused on two tasks. The first one was a wayfinding task where subjects had to find a path to three specific objects starting from a pre-determined position inside a multi-floor virtual building. The second one was a direction estimation task. Travel inside the VE was based on a first-person perspective "walk" mode, controlled by mouse movement. Forward or backward movement of the mouse mapped to a forward or backward motion, whereas left or right movement of the mouse was mapped to a left or right turn within the VE. When the user

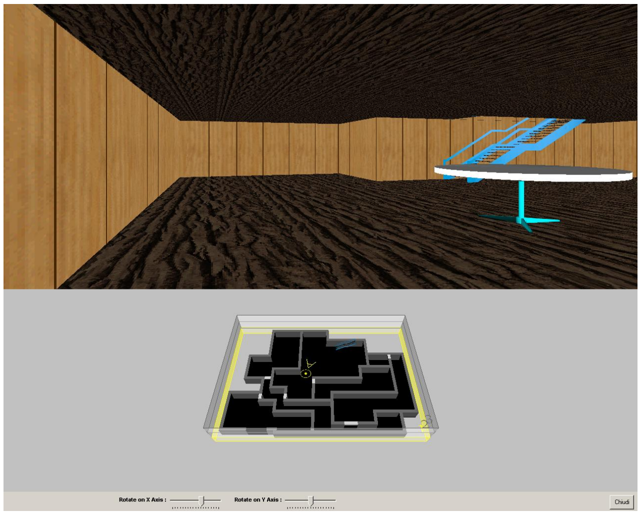


Figure 1. Navigation using the 3DM.

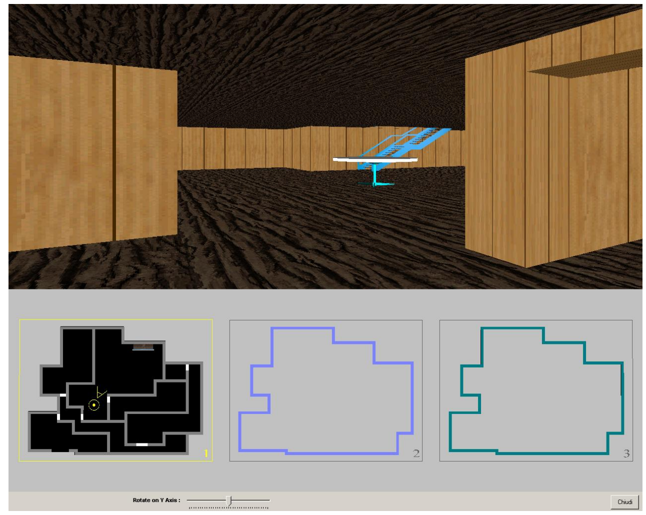


Figure 2. Navigation using the 2DM.

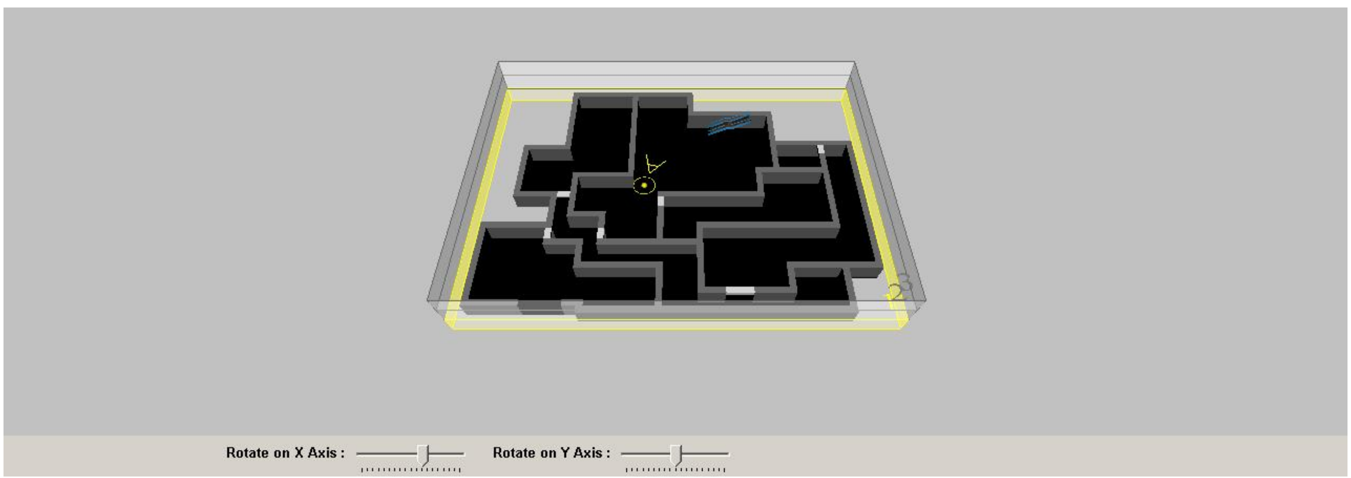


Figure 3. A closer view of the 3DM and the related controls.

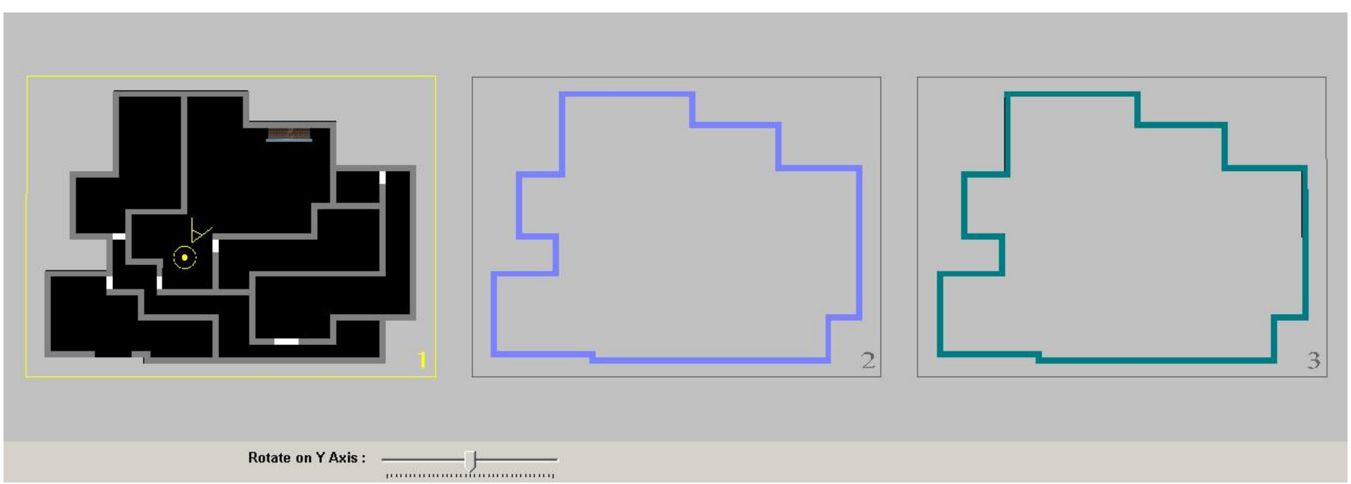


Figure 4. A closer view of the 2DM and the related controls.

moved, the travel speed was constant. Collision detection was enabled thus preventing the user from traveling through walls.

The employed virtual building had three floors, each one with a complex structure. Each floor consisted of rooms of different sizes and each room had one landmark inside it (e.g. tables, lamps, couches, shelves, a television set, beds). No object was repeated on the same floor (e.g. there could be only one table on a floor). However, some objects were repeated on different floors (e.g. lamps in corridors, couches, tables) but they were made visually distinct among themselves by changing their colors and/or shapes.

All the objects were easily memorable (see figure 9 for an example). One distinct object on each floor (visually different from the other objects on that floor) was designated as a target object (a rocking chair on the ground floor, a plant on the first floor and a bunk bed on the top floor). The positions of the objects on the floors were fixed and did not change during the entire duration of the experiment.

Each subject used only one of the two navigation aids in a standard between-subjects design. Figure 1 shows a screenshot of the 3DM condition, while figure 2 shows a screenshot of the 2DM condition.

For the wayfinding task, the user was placed at a start position outside the building on the ground floor. The user would then be verbally instructed to search for a target object. The floor on which the target object was located and its position on that floor were indicated by the navigation aid (figure 6 and 7 illustrate the 3DM and the 2DM indicating a target object). The user would then find her way to the target object. Upon reaching it, she would be taken back to the same start position as before to start searching for the next assigned object.

For the direction estimation task, the user was moved along a predetermined path from the same start position as in the wayfinding task, to three different end positions by means of an animated walkthrough. Each of the end positions was on a different floor of the building. We chose these end positions in such a way that there was a notable difference among the elevations from that position to the three target objects. None of the target objects was directly visible from any of the end positions. At the end of each walkthrough, an arrow would appear in front of the user (as shown in figure 8). By making use of the arrow keys, the user could rotate the arrow along the vertical or horizontal axis (azimuth and elevation, respectively) to orient the arrow in the direction in which she believed the target objects previously searched were located with respect to her current position. User movement was disabled as soon as the walkthrough animation stopped. No navigation aid was provided while the direction estimation task was carried out by the subjects.

We had two hypotheses for the experiment. First, for the wayfinding task, we expected users to perform better in the 2DM condition compared to the 3DM condition. Our assumption was based on the reason that people are more familiar with using 2D maps as often seen in computer applications varying from video games to navigators and in real life (e.g. building plans and city maps). Second, for the direction estimation task, we expected that the elevation error in the direction estimates to be smaller in the 3DM condition than in the 2DM condition. Our assumption was that the 3DM (which presents a buildings' structure volumetrically) would help the user to understand the floors of a building particularly in the height dimension in a better way compared to the 2DM, which instead presented top down maps (which did not give any idea of the height of the floors).

4.2 Experimental Design and Procedure

Subjects who participated in the experiment were graduate, undergraduate, doctorate and post doctorate students of different disciplines at our university. There were 26 male and 6 female participants in total. Their age ranged from 20 to 35, with an average of 27 years. All subjects worked at least one hour with a computer daily (the average was six hours daily). Four subjects had neither any gaming experience nor any experience in navigating virtual environments. The rest of the subjects had either 3D gaming experience and/or previously navigated in virtual environments. Data related to two subjects concerning one of the three target searches had to be discarded as a result of a software malfunction.

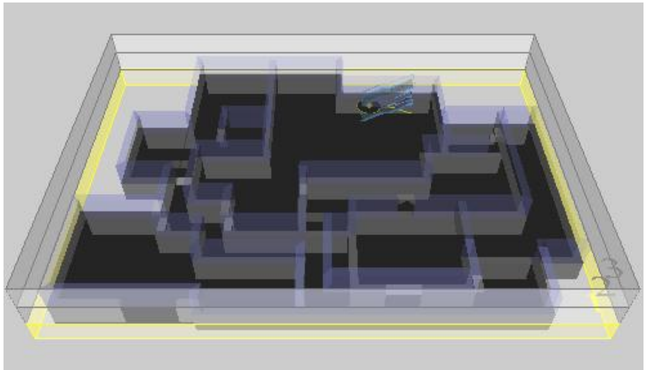
Before beginning the experiment, subjects filled out a brief questionnaire regarding their experience with computer usage and 3D games or navigation in virtual environments. Then they started the experiment, which was organized into five phases.

In the first phase, the subject was familiarized with navigation in a simple "practice" virtual building while making use of the navigation aid assigned to her. When subjects felt at ease with the navigation aid, they were instructed verbally to search for a target object (a blue cube). The floor on which it was located and its position on that floor were indicated by the navigation aid. The subjects would then find their way towards the target object.

In the second phase, users were familiarized with the arrow tool for direction estimation. An animated walkthrough transported the user from the entrance of the building (from which the user began navigating in the previous phase) to a pre-determined position in the same building (from the first phase). When the animation stopped, the user was asked to indicate the direction in which the target previously searched for was located, as precisely as possible. This concluded the familiarization phases of the experiment.

In the third phase, subjects were given 10 minutes to freely explore the three-floor virtual building described in the previous subsection. They were asked to gain structural knowledge of the virtual building (i.e. understand the structure of the building). The objects placed in each room of each floor of the building acted as landmarks to facilitate understanding. For this phase, neither of the navigation aids indicated any target position for the user to reach.

The fourth phase consisted in the wayfinding task where the user had to find her way from a starting position to three different objects. The starting position of the user was always the same for all the three objects. The target object was verbally specified by name and the floor on which it was located and its position on that floor were indicated by the navigation aid (as shown in figures 6 and 7). The user then moved from the starting position and the system started measuring the time taken to reach the target object. The user had to collide with the target object. Then, a window appeared telling the user that the target had been reached (and the system stopped measuring time). After this, the user would find herself at the starting position. The user was asked to remember the absolute location of the target object just reached with respect to the entire building (since it would serve her for the direction estimation task, which she had to perform in the next phase). This sequence was repeated for each of the three objects. The order in



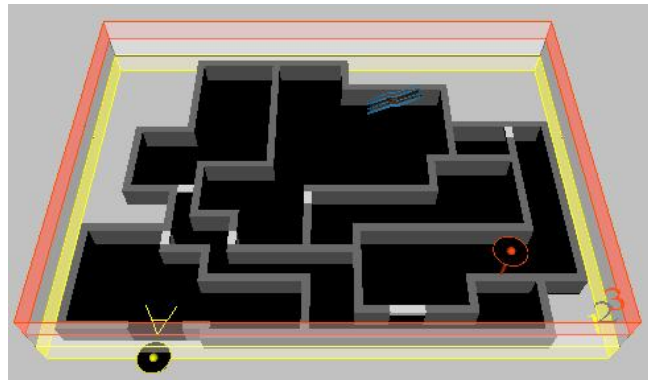


Figure 5. The 3DM with user walking on a staircase.

Figure 6. The 3DM indicating user and target positions.

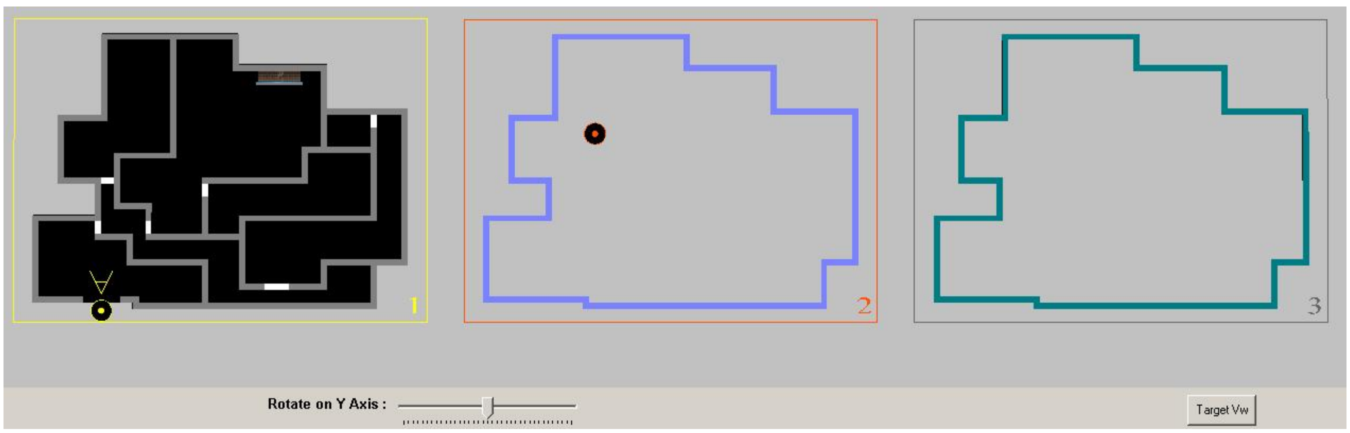
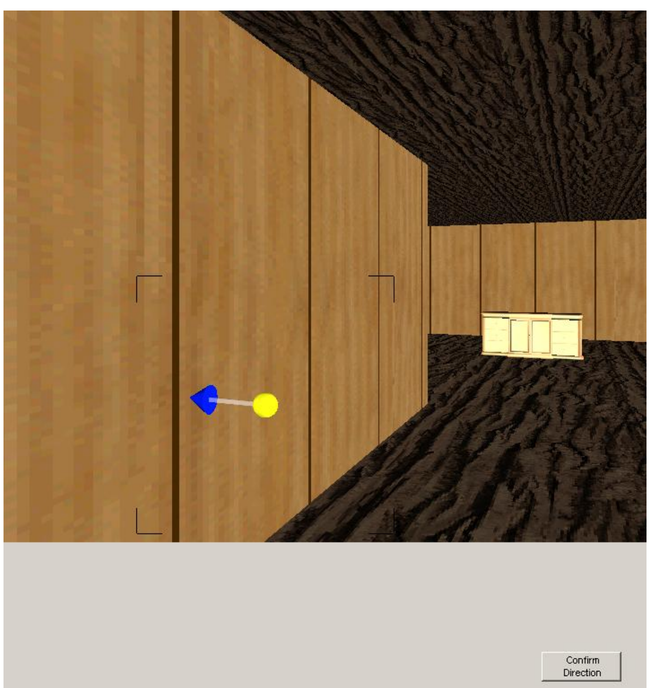


Figure 7. The 2DM indicating user and target positions.



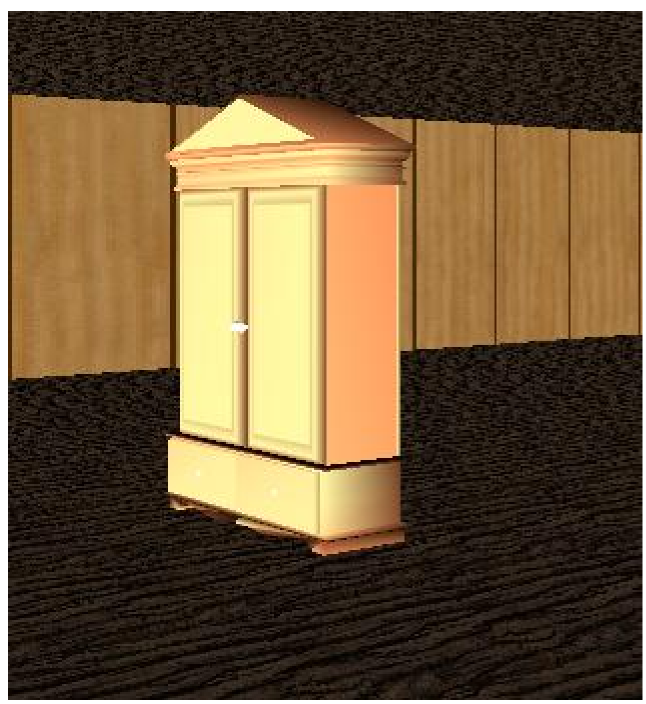


Figure 8. The arrow tool for direction estimation.

Figure 9. An object in the virtual building.

which the user had to find her way to the target objects was the same for all users (first target on floor 1, second target on floor 2 and third target on floor 3).

In the final phase, subjects had to perform the direction estimation task. There were three pre-defined animations, each of which transported the user from the same starting position as the one in the wayfinding task, to a predetermined end position on one of the floors of the same building used in the previous two phases (described in section 4.1). Once the animation stopped, the arrow (i.e. the direction estimation tool shown in figure 8) would appear and the user was asked to indicate in some random order (as instructed by the experimenter) each of the three target objects that she reached during the wayfinding task. Overall, the system recorded 9 different direction estimates (the user had indeed to indicate the 3 target objects from 3 different positions). The animation could be seen only three times at a maximum. Once the user indicated the direction of the target object and confirmed it (by clicking a button), the system would record the azimuth and elevation of the arrow. No time limit was specified to the user for the direction estimation task.

No breaks were allowed between phases. On average, completion of all five phases took about an hour.

The hardware setup used for the experiment consisted of a Pentium 4 (2.4 GHz) PC with 1 GB RAM, equipped with a NVIDIA GeForce FX 5950 graphics card and a 19 inch monitor.

4.3 Analysis and Results

We analyzed the collected data using t-tests for independent samples. The between-subjects variable was the type of navigation aid with two levels: 3DM and 2DM. The dependent variables were the time taken (in seconds) to reach each of the three targets, and the elevation error and azimuth error (in degrees) for the direction estimates. The mean time taken to reach the first (2DM=85.64, 3DM=117.80, $p<0.05$), second (2DM=69.32, 3DM=95.27, $p<0.05$) and third target (2DM=107.5, 3DM=130.73, $p<0.05$) are graphically compared in figure 10. For each target, user's performance is better in the 2DM condition and the difference with the 3DM condition is statistically significant.

It is interesting to note that only one subject used the map orientation feature provided by the navigation aids, despite the fact that each user was clearly told during the first phase of the experiment that they could make use of the sliders to change the map orientation at any point to gain a better view.

To obtain error values in the direction estimation task, we first determined the precise elevation and azimuth values for each of the three target objects with respect to each of the three final user positions (i.e. where the user found herself after the animated walkthrough stopped). Next, the difference between each of the user estimates for the elevation and azimuth and the correct values was calculated. This gave us the elevation error and azimuth error corresponding to each of the 9 direction estimates made by each user. Finally, we calculated the mean elevation error and azimuth error for every target object the user pointed to, from each final user position. The corresponding means are shown in figures 11 and 12.

Figure 11 shows the mean elevation errors for the 2DM and the 3DM conditions. The values are organized based on each of the three final user positions. For each of the three target objects indicated from that position, the elevation error values for the 2DM and the 3DM condition are shown. It can be clearly observed that sometimes 2DM has a smaller elevation error

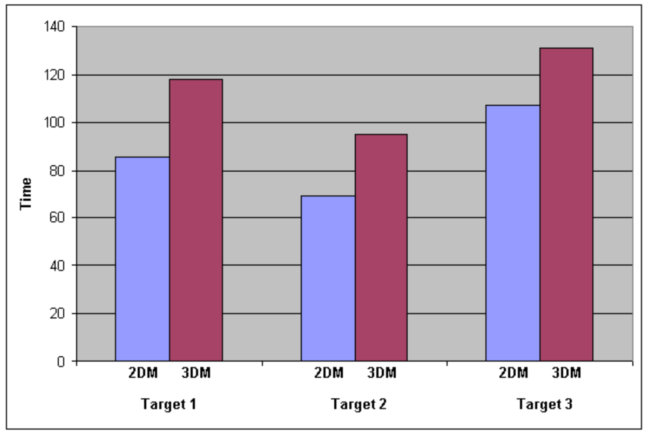


Figure 10. Mean search times (in seconds) for the wayfinding tasks.

		2DM	3DM
first user position	target 1	8.78	7.13
	target 2	34.19	38.85
	target 3	32.99	33.46
second user position	target 1	11.00	13.13
	target 2	7.78	8.13
	target 3	33.51	35.24
third user position	target 1	24.16	22.73
	target 2	20.10	20.72
	target 3	7.50	5.03

Figure 11. Mean elevation error (in degrees) for the direction estimation tasks.

		2DM	3DM
first user position	target 1	16.06	21.73
	target 2	18.31	25.51
	target 3	24.59	27.03
second user position	target 1	24.70	33.85
	target 2	25.74	23.02
	target 3	44.06	37.56
third user position	target 1	24.64	27.10
	target 2	36.36	38.59
	target 3	20.71	21.35

Figure 12. Mean azimuth error (in degrees) for the direction estimation tasks.

compared to 3DM and sometimes it is the opposite. Moreover, none of the differences between means turned out to be statistically significant in the t-test analysis.

Figure 12 shows the mean azimuth errors for the 2DM and the 3DM conditions. The values are organized on the same lines as the elevation error values in figure 11. Again, it can be observed that there is no clear trend among the values across the two conditions. Moreover, there were no statistically significant differences in means also in this case.

5. CONCLUSIONS

We compared two different navigation aids for multi-floor virtual buildings, one based on 3D maps and the other based on 2D maps. The results of the experiment show that the 2DM navigation aid produced better performance than the 3DM one for the wayfinding task (see figure 10), while none of the two aids was better than the other for the direction estimation tasks.

The difference in performance between the 2DM and 3DM aids in search tasks might be partly explained by the fact that subjects were more familiar with 2D maps in different computer applications (e.g. videogames, navigators,…) as well as in the real world. This suggests to consider a possible longitudinal study where subjects could use the navigation aids over an extended period of time.

We plan to use the navigation aids presented in this paper as part of an Emergency Evacuation Training System, aimed at helping users to learn evacuation procedures for multi-floor buildings. Users will use the emergency evacuation training system to gain route and survey knowledge by practicing evacuation procedures in virtual models of the buildings.

We also plan to add more features to the navigation aids like indication of multiple objects (e.g. all the emergency exits on a floor) and path indication over multiple floors (e.g. routes to be taken in case of a fire). Further experiments could be carried out to compare the navigation aids proposed in this paper in the context of evacuation training to assess the users' possibility of gaining route knowledge and survey knowledge of the building (e.g. being able to recall the route to the nearest emergency exit from a given position, recall the positions of the emergency exits on a floor) and transfer that knowledge to the real building. To this purpose, we built a virtual model of our university building, that will be used to experiment with the system.

6. ACKNOWLEDGEMENTS

This research has been partially supported by the Italian Ministry of Education, University and Research (MIUR) under the PRIN 2005 projects "VIA - Virtual Interactive Architecture" and "Adaptive, Context-Aware, Multimedia Guides on Mobile Devices".

7. REFERENCES

[1] Andre, A. D., Wickens, C. D., and Moorman L. Display Formatting Techniques for Improving Situation Awareness in the Aircraft Cockpit. *International Journal of Aviation Psychology*, 1(3), 1991, pp. 205-218.

[2] Aretz, A. J., and Wickens, C. D. The Mental Rotation of Map Displays. *Human Performance*, 5(4), 1992, pp. 303-328.

[3] Ballegooij, A. van, and Eliens, A. Navigation by query in virtual worlds. *Proceedings of Web3D '01: 6th international conference on 3D Web technology*, ACM Press, New York, 2001, pp. 77–83.

[4] Bowman, D., Koller, D., and Hodges, L. Travel in Immersive Virtual Environments: an Evaluation of Viewpoint Motion Control Techniques. *Proceedings of VRAIS'97: The 1997 Virtual Reality Annual International Symposium*, ACM Press, New York, 1997, pp. 45-52.

[5] Brooks, A. Aids for training real-world spatial knowledge using virtual environments. In *Thompson B.J. (ed.) Research Papers of the Link Foundation Fellows (3)*, University of Rochester Press, 2003.

[6] Chittaro, L., and Burigat, S. 3D Location-pointing as a Navigation Aid for Virtual Environments. *Proceedings of AVI 2004: 7th International Conference on Advanced Visual Interfaces*, ACM Press, New York, 2004, pp. 267–274.

[7] Chittaro L., Gatla V. K., and Venkataraman S. The Interactive 3D Breakaway Map: a Navigation and Examination Aid for Multi-Floor 3D Worlds. *Proceedings of CW 2005: 4th International Conference on Cyberworlds*, IEEE Press, Los Alamitos, CA, November 2005, pp.59-66.

[8] Chittaro, L., and Scagnetto, I. Is Semitransparency Useful for Navigating Virtual Environments?. *Proceedings of VRST-2001: 8th ACM Symposium on Virtual Reality Software & Technology*, ACM Press, New York, 2001, pp. 159–166.

[9] Darken, R. P., and Sibert, J. L. A Toolset for Navigation in Virtual Environments. *Proceedings of UIST'93: 6th annual ACM symposium on User interface software and technology*, ACM Press, New York, 1993, pp. 157-165.

[10] Elvins, T. T., Nadeau, D. R., and Kirsh D. Worldlets: 3D thumbnails for wayfinding in virtual environments. *Proceedings of UIST '97: 10th annual ACM symposium on User interface software and technology*, ACM Press, New York, 1997, pp. 21–30.

[11] Ishikawa, T., and Montello, D. R. Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. *Cognitive Psychology*, 52, pp. 93-129.

[12] LaViola Jr., J., Feliz, D., Keefe, D., and Zeleznik, R. Hands-free multi-scale navigation in virtual environments. *Proceedings of the 2001 symposium on Interactive 3D Graphics*, ACM Press, New York, 2001, pp. 9-15.

[13] Montello, D. R., and Pick, H. L. Integrating knowledge of vertically-aligned large-scale spaces. *Environment and Behavior*, 25, pp. 457-484.

[14] Niederauer, C., Houston, M., Agrawala, M., and Humphreys, G. Non-invasive interactive visualization of dynamic architectural environments. *Proceedings of the 2003 Symposium on Interactive 3D Graphics*, ACM Press, New York, 2003 pp. 55-58.

[15] Olmos, O., Liang, C. C., and Wickens, C. D. Electronic Map Evaluation in Simulated Visual Meteorological Conditions. *International Journal of Aviation Psychology*, 7(1), 1997, pp. 37-66.

[16] Pausch, R., Burnette, T., Brockway, D., and Weiblen, M.E. Navigation and Locomotion in virtual worlds via flight into hand held miniatures. *Proceedings of SIGGRAPH'95: 22nd annual conference on Computer graphics and interactive techniques*, ACM Press, New York, 1995, pp. 399-400.

[17] Pierce, J. S., and Pausch R. Navigation with Place Representations and Visible Landmarks. *Proceedings of*

VR'04: The IEEE Virtual Reality 2004, IEEE Press, 2004, pp. 173-180.

[18] Richardson, A. E., Montello, D. R., and Hegarty, M. Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & Cognition*, 27(4), pp. 741-750.

[19] Russo Dos Santos, C., Gros, P., Abel, P., Loisel, D.,Trichaud, N., and Paris, J.P. Metaphor-aware 3D Navigation. *Proceedings of InfoVis'00: IEEE Symposium on Information Visualization 2000*, IEEE Press, 2000.

[20] Satalich, G. A. *Navigation and Wayfinding in Virtual Reality: Finding the Proper Tools and Cues to Enhance Navigational Awareness.* MS Thesis, www.hitl.washington.edu/publications/satalich, 1995.

[21] Stoakley, R., Conway, M., and Pausch, R. Virtual reality on a WIM: Interactive worlds in miniature. *Proceedings of CHI'95: the SIGCHI conference on Human factors in computing systems*, ACM Press, New York, 1995, pp. 265-272.

[22] Tan, D. S., Robertson, G. G., and Czerwinski, M. Exploring 3D navigation: combining speed-coupled flying with orbiting. *Proceedings of CHI '01: 19th SIGCHI conference on Human factors in computing systems*, ACM Press, New York, 2001, pp. 418–425.

[23] Wingrave, C. A., Haciahmetoglu, Y., and Bowman, D. A. Overcoming World in Miniature Limitations by a Scaled and Scrolling WIM. *Proceedings of 3DUI 2006: 1st IEEE Symposium on 3D User Interfaces*, IEEE Press, Los Alamitos, CA, March 2006, pp. 11-16.