Virtual environments as an aid to the design and evaluation of home and work settings for people with physical disabilities

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ABSTRACT

One of the major challenges facing the professionals involved in the home modification process is to succeed in adapting the environments in a way that enables an optimal fit between the individual and the setting in which he or she operates. The challenge originates primarily from the fundamental characteristic of design - one can see and test the final result of home modifications only after they have been completed. The goal of this study was to address this problem by developing and evaluating an interactive living environments model, HabiTest, that will facilitate the planning, design and assessment of optimal home and work settings for people with physical disabilities. This paper describes the Habitest tool, an interactive model that has been implemented via an immersive virtual reality system which displays three-dimensional renderings of specific environments, and which responds to user-driven manipulations such as navigation within the environment and alteration of its design. Initial results of a usability evaluation of this interactive environment by users are described.

1. INTRODUCTION

People with disabilities are often severely limited in their ability to function independently in their homes or at work as a result of physical, cognitive or sensory environmental barriers (Iwarsson et al, 1998). Environmental modifications to an existing structure can eliminate these barriers thereby turning an environment from one that is disabling into one that is enabling. Such modifications aim to achieve an accessible environment that can be fully utilized by the user for its intended purposes (Nielsen and Ambrose, 1999) and are an inseparable part of the rehabilitation process in the western world (Gitlin, 1998; Iwarsson and Stahl, 2003). Yet, despite 30 years of experience and research, the gap between client needs and successful environmental modification remains large since adaptations to home or public settings present major challenges (Gitlin, 1998; Sundin and Medbo, 2003). In the home, the challenge relates to having sufficient knowledge and funds to make the necessary modifications. In public environments, the challenge is to succeed in making adaptations that will meet the needs of broad range of disabilities.

One of the central issues in environmental accessibility is the adaptation of environments to achieve an optimal fit between the individual and the setting in which he or she operates. Modifications to the physical environments in the home and at work to accommodate age and health related disability make these settings less challenging thereby facilitating the individual's ability to perform every day activities and occupations (Gitlin, 1998; Iwarsson et al, 1998).

One of the major challenges facing the professionals involved in the home modification process is to succeed in adapting the environments in a way that enables an optimal fit between the individual and the setting in which he or she operates. This challenge originates primarily from the fundamental characteristic of design - one can see and test the final result of home modifications only after they have been completed. Additional reasons for the limited success of environmental modifications include lack of suitable reliable and valid assessment tools and lack of common conceptual definitions between the professional parties involved in the environmental modification process (Gitlin, 1998; Iwarsson and Stahl, 2003; Steinfeld and Danford, 1999).

Virtual Reality (VR) has only recently begun to be applied to environmental modification. Eriksson et al, (2000) immersive, desktop simulation program was first tested through case studies (Eriksson and Johansson, 1996) and found to be a useful planning tool in encouraging communication and participation of all the people involved in the design process. This software was tested again more recently with a group of occupational therapy students and a group of people with physical disabilities (Eriksson, et al., 2000). Users view a typical living environment and are able to manipulate objects (e.g., furniture) within the environment. Although both groups enjoyed the opportunity to make modifications and to implement their own ideas for barrier-free design, the group with physical disabilities had difficulty in adopting a user-centred viewpoint.

More recent developments in software permit the creation of virtual environments that allow a designer to simulate three-dimensional (3-D) space and motion with a high degree of accuracy and detail (Moas, 2001; Kalisperis et al. 2002). Such programs enable the testing of architectural designs by the future tenants before the building has been constructed with the aim of minimizing the gap between a theoretical design and the actual end product (Moas, 2001). These tools enable the construction of and interaction within environments that are immersive, are ecologically valid, and can be graded with respect to their level of difficulty.

The overall goal of this study was to address this problem by developing and evaluating an interactive living environments model that will facilitate the planning, design and assessment of optimal home and work settings for people with physical disabilities. The first objective of this paper is to describe a tool that we have used to develop interactive environments that can be used to tests users' abilities to identify and modify accessibility barriers. This interactive model is implemented via an immersive virtual reality system which displays three-dimensional renderings of specific environments, and which responds to user-driven manipulations such as navigation within the environment and alteration of its design. A second objective is to present the initial results of a usability evaluation of this interactive environment by users.

2. THE DESIGN AND PROGRAMING OF HABITEST

We aimed to construct and evaluate a tool, known as HabiTest, that overcomes the inherent limitation of a posteriori design by providing a priori opportunities to verify the suitability of a proposed design for a particular user, using the option of virtual reality platform. This tool has been designed to address the needs of the environmental modification intervention process as well as the needs of a newly designed rendering.

2.1 Selection of simulation platform

The construction and simulation of these environments was carried out using EON Reality's (www.eonreality.com) tools, considered to be among the leading tools in the field of VR simulation. An environment used for our initial feasibility testing is shown in Fig. 1. In the figure are shown the three alternate points of view that are available to the user. These include a first person view, a third person view, and a bird's eye view. EON Reality's tools enable a rapid development of interactive 3-D environments that are easy to navigate in real time while performing accurate collision detection. Accurate collision detection (which was until recently available primarily in mechanical, non-interactive simulations) enhances our ability to gather relevant data from the simulation process. In previous generations of VR tools, the collision detection was limited to a bounding box. This bounding box was a rough approximation of the user's body contours and left out many of the fine details (such as curves, gaps and protrusions) which are needed to accurately represent the body.

EON Reality software not only enables identification of each collision, it also records their occurrences into a database. Moreover, auditory, visual and haptic feedback to the user prevents the attainment of positions that are physically invalid. That is, a user cannot navigate to a position where any part of his body nor an item associated with him (e.g., a wheelchair) is allowed to overlap with another object (e.g., wall, door, stair, table leg). The ecological validity of this simulation allows the user to identify corners or narrow passages that, although passable, would be difficult and inconvenient to navigate on a daily basis due to the number of moves and collisions they would necessitate.

2.2 *HabiTest Design Features*

The team that designed and programmed the Habitest consisted of two occupational therapists with expertise in environmental modification, assistive technology and virtual reality applications, two architects with expertise in spatial design and in three dimensional (3D) modelling and a programmer with expertise in virtual reality platform programming.

HabiTest must enable users to navigate independently within realistic virtual environments while allowing them to identify any barrier that blocks their ability to navigate or to perform tasks in these environments. HabiTest supports layered presentation. Since each object is associated with a particular layer, the display and elimination of any object is simple. Thus, an environment can be rapidly de-cluttered and 'what-if' testing is supported. For example, it is easy to query how navigation and obstacle identification are affected if any given object is added or removed. Removing layers of objects allows a user to perceive the effect this has on accessibility. It also allows users with cognitive or visual limitation to study the environment in an easier manner prior to testing it.

Figure 1. *Screen shots of a typical HabiTest environment. The larger central view is the main view and is "first person" (ego-centric). Two additional auxiliary views are available – "bird's eye" view (upper left corner) and "third person" side view (upper right corner). These views can be turned on and off as well as switched (i.e. the main view can be show bird's eye point of view while the top right auxiliary view can show the ego-centric view).*

A number of key features were considered to be essential for this tool. These include:

- real time rendering
- accurate collision detection of objects and walls
- low cost portable tool that could be readily implemented in clinical and home settings
- navigation that is easy and intuitive
- The avatar representing the user within the environment must have realistic characteristics (i.e., seated in a wheelchair with anthropometric measurement similar to an actual user.

In addition to the design requirements of ease of use and intuitiveness, the selection of a navigation tool was based on considerations of what would be the most appropriate hardware for use by people who drive an electric wheelchair since they are the initial targeted population for HabiTest. (Most electric wheelchairs are operated with joysticks.) We selected a force feedback joystick, specifically Logitech's Wingman and Microsoft's SideWinder. These both provide vibratory collision feedback to the user, enhancing the realism of the environment. Habitest can also be operated with other interface devices, most notably a standard mouse or even a head movement based mouse such as the TrakIR head mouse.

The size of the field of view (FOV) people need to navigate comfortably in an environment has certainly presented a challenge since healthy users who pilot tested HabiTest on a 17 inch monitor found the FOV presented to them to be too narrow for realistic and effective navigation. More recently we have improved the FOV in two different ways. The HabiTest environments may be projected onto a large surface using a video projector and/or several of the joystick buttons have been programmed to enable users to look around in a similar way people would turn their head to the right, left, up and down while exploring a new environment. The "looking around" option is available to users while standing in one place and while navigating in the environment.

The final design consideration is the provision of a means to perform tasks, and specifically to manipulate objects within the virtual environments. We have elected to provide a virtual hand which is controlled by the user. The first level of control is achieved by putting the hand at a fixed distance in front of the user's eyes; this means that when the user looks around, the hand will follow the look and will keep its position in the middle of the main view. Further control of the hand relates to its offset from the centre of the view. To simplify the interaction with the system, and reduce the different number of devices required (keyboard, joystick, mouse etc.), this offset is also controlled by the joystick. The user has to press and hold one of the joystick's buttons to activate this specific manipulation. After pressing the button, moving the joystick will affect this offset. To reset this offset, another button has to be pressed. The hand may be seen in the environment at any time.

3. INITIAL EVALUATION OF THE HABITEST BY USERS

3.1 Initial Usability Testing of HabiTest

The purpose of the initial usability testing was to verify the ease with which users are able to navigate within HabiTest. A group of eight female occupational therapists, all graduate students at the University of Haifa participated in the initial usability testing. All participants had worked clinically for a minimum of two years in different therapeutic settings dealing with developmental and learning disabilities of children. None of the participants had had any experience with environmental modifications, nor were they experienced in the playing of computer games that required navigation.

3.1.1 Procedure. The participants navigated within Habitest for 30 minutes while sitting in a computer lab, each at her own personal computer. The simulation environment was first presented to the participants by enslaving their monitors to the researcher's monitor. Each of the tool's features was demonstrated. A model of a one bedroom apartment with an open kitchen area, supplied by the EON interactive software (see Fig. 1) was modified to be used as a HabiTest environment for demonstration and testing. Following this short demonstration, each participant was given a trial period of ten minutes, to navigate within the environment freely using a mouse. During the trial period, participants were encouraged to request assistance when any operation was unclear or difficult. Upon completion of the trail period, the participants were asked to locate the bathroom, to drive into it and to exit it. They were given up to 20 minutes to perform this task from a starting point at the centre of the living room. This task was purposely selected as typical of a difficult navigation task since the location of the bathroom door together with its narrow doorway made the test a demanding one. Similarly, given the small size of the bathroom, the need to turn around within it in order to exit was also difficult. It has to be noted that the entrance of the bathroom was very difficult for a wheelchair but possible. Note that the collision detection feature was activated during the test, so that the participants were made aware of any "impossible" routes.

3.1.2 Results. Despite the fact that the participants had used the same environment during the practice trial, none of them were able to locate the bathroom within the first five minutes of the test. They appeared to be stymied by the narrow FOV and they expressed great frustration. The researcher then simplified the task by giving them instructions how to locate the bathroom but they were still required to enter and exit it. All participants were able to enter the bathroom but only five out of the eight were able to exit it within the 20 minute time limit. All participants experienced difficulty when trying to navigate within the narrow space of the bathroom. This was not surprising since the room was not accessible for a wheelchair user. The greatest concern expressed by the participants throughout the trial was their lack of awareness of their current location with respect to the apartment.

Similar difficulties were reported when a group of participants viewing the same HabiTest environment at a exhibition navigated within it using the joystick. As a result of the FOV difficulties observed during the two initial pilot tests we decided to expand the FOV via the two options described above, projection onto a large surface using a video projector and/or several of the joystick buttons have been programmed to enable users to look around in a similar way people would turn their head to the right, left, up and down while exploring a new environment.

3.2 Ongoing Usability Testing of the HabiTest

We are now testing the features of a new HabiTest environment navigated with a force feedback joystick. The participants include 15 volunteers, students at the University of Haifa, who are experienced users of a joystick for computer gaming; the extent of their familiarity with a joystick is recorded on a questionnaire that was designed for that purpose. The objective is to further test users' abilities to navigate within virtual environments when using a joystick.

3.2.1 Procedure. A new setting was created for the purpose of this testing. It is a rendered model representing the inner area of the main office section of the University's Dean of Students. This setting was selected since the physical premises have been made available to us for testing purposes. As shown in Fig. 2, this area contains a large central office and three additional small offices, all of which have doors leading to the central office. The area contains a lot of furniture making it difficult to navigate. Some locations are not accessible for a person who uses a wheelchair. Indeed, some of the furniture must be removed when students who use a wheelchair enter the premises. The rendered model of the Dean of Students central area is shown in Fig. 3. The figure on the left shows a "birds eye" view of the entire area and the figure on the right shows a “first person” view of one of the rooms showing its furniture.

Participants are shown how to use the joystick to navigate within HabiTest and given a trial period to practice the various operations. A 15 minute test period follows during which time participants explore the environment. Four noticeable (virtual) objects (e.g., red phone, plate with fruits, vase with red flowers) are placed in each of the four rooms. Once this period is over, the participants are given a map of the environment (printed on a paper) and asked to identify the location of each object. Participants are then requested to navigate to each object (within the virtual world) and to perform some activity with it (e.g., picking up an orange from the plate, picking up the phone). In order to be able to do so, they have to get within a reach range from the objects. During this test, participants are represented in the virtual environment as if they are sitting in a wheel chair. All actions are performed using one of the joystick’s programmed buttons thereby manipulating a “hand” that appears on the screen. All tests are timed and success or failure in performing all required activities is recorded. At the end of the testing periods the participants complete a usability questionnaire and a Presence questionnaire. The results of this testing will be reported.

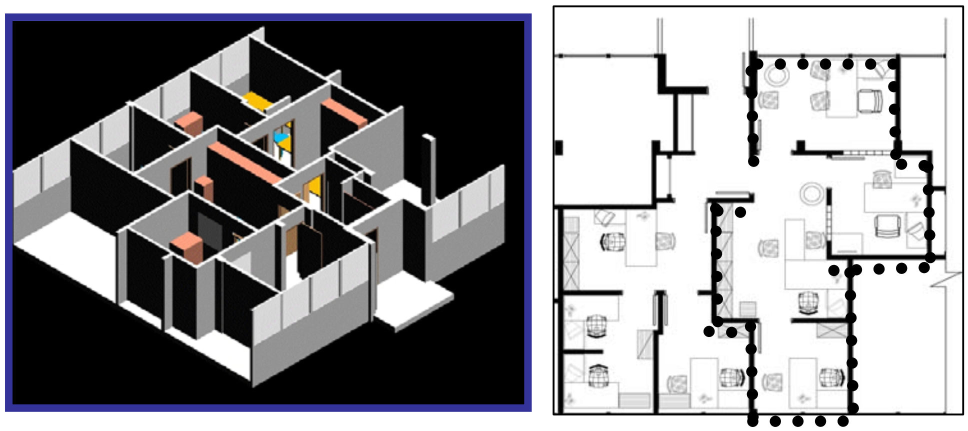


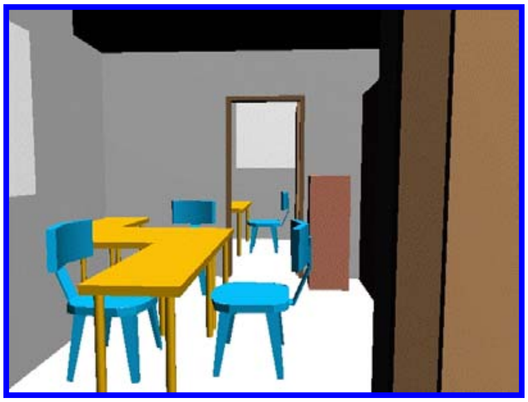
Figure 3. *Two views of the Dean of Students area as rendered by the EON Reality model. The figure on the left shows a “birds eye” view of the entire area. The figure on the right shows a blueprint of the same area (the heavy dotted line indicated the rendered area).*

3.3 *Future testing*

Our future plans include comparing performance within the HabiTest to that within an identical real environment in terms of: (1) ability to perform tasks and to navigate from one point to another (2) ability to identify accessibility barriers. Fifty male and female adults, aged 20 to 50 years, who use a powered wheelchair as a result of neurological (e.g., paraplegic spinal cord injury) or orthopaedic (e.g., amputation, arthritis) disability will participate in the study. They will all have had the disability for at least one year. The disability will be primarily of the trunk or lower extremity with sparing of the upper extremity. Prior to testing all participants will go through baseline measures that will test their functional level of personal independence and their ability to navigate a wheelchair in the real environment. Participants will use a joystick to navigate within the virtual environment. While navigating, participants will be confronted with different types of accessibility barriers (e.g. door is too narrow to pass through, table top is too low for a wheelchair to fit underneath). The participants will know that accessibility barriers exist in the environment; their task will be to identify what they are. A tester will observe the participants throughout the testing process. The EON interactive software will be used to render an interactive, 3D virtual environment, depicting real areas at the University of Haifa. The environments will have barriers that will make them inaccessible to people who use a wheelchair and will be programmed to enable the performance of specified tasks. Prior to testing, each participant will be instructed in the use of the HabiTest, software and hardware and given a trial period that will not be limited in time.

4. CONCLUSIONS

One of the major challenges facing the professionals involved in the home modification process is to succeed in adapting the environments in a way that enables an optimal fit between the individual and the setting in which he or she operates. We have begun to address this problem by developing and carrying out an initial evaluation of an interactive living environments model, HabiTest, that will facilitate the planning, design and assessment of optimal home and work settings for people with physical disabilities. This paper has described the design considerations taken into account while developing the Habitest tool. Several examples of interactive models have been pilot tested with users who are not disabled and their feedback has been used to improve the tool. We will soon commence testing HabiTest with a group of users who navigate with a wheelchair due to neurological or orthopaedic disability.



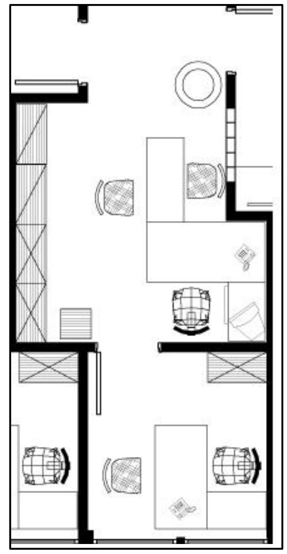


Figure 2. *Two images showing a part of the Dean of Students area used to test the HabiTest environment. The figure on the left displays a "first person" view of one of the rooms showing its furniture. The figure on the right shows the blueprint of the same area.*

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