

Virtual Environments in Design and Evaluation: *An Aid for Accessible Design of Home and Work Settings for People with Physical Disabilities*

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Keywords: accessibility, environmental-modifications, 3D simulation, barrier-free design

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, which 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

Analyzing and evaluating the suitability of built environments to human activities is typically performed only after the construction phase has been completed. The major challenges facing professionals originate from the fundamental characteristic of design – one can test the suitability of a designed environment only after it has been completed. The study described in this paper presents a different approach wherein a virtual reality (VR) environment serves as an alternative environment to carry out analysis and evaluation before the final realization of the construction phase. Our study related to the research framework of VR and environmental modification.

1.1 Home Modification Process

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, Isacson and Lanke 1998). Successful environmental modifications to an existing structure can eliminate these barriers by accommodating age and health related disability 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); the goal is to achieve an environment that facilitates the individual's ability to perform every day activities and occupations by providing a compensation for their functional loss. Environmental modifications are an inseparable part of the rehabilitation process in the western world (Gitlin 1998).

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 a number of major challenges, starting from the need of achieving an optimal fit between the individual and the setting in which he or she operates (Gitlin 1998). Other challenges relate to the modifications of a private home that require having sufficient knowledge and funds or, in contrast, to modifications of public areas where successful adaptations have to meet the needs of a broad range of disabilities (Palmon et al. 2004). Limited success of environmental modifications are also related to the lack of reliable and valid assessment tools and the lack of common conceptual definitions between the professional parties involved in the modification process (Gitlin 1998).

1.2 Virtual Reality and Environmental Modification

Only recently, virtual reality has begun to be applied to environmental modification and to designing and testing the accessibility of an environment for people with disability (Eriksson, Ek and Johansson 2000, Maver, Harrison and Grant 2001). Eriksson, Ek and Johansson (2000) have developed an immersive, desktop simulation program for the design of barrier free home and work environments. Users view a typical living environment and are able to manipulate objects (e.g., furniture) within the environment. It was found to be a useful planning tool in encouraging communication and participation of all the people involved in the design process. The users of the system enjoyed the opportunity to make modifications and to implement their own ideas for barrier-free design, but participants with physical disabilities had difficulty in adopting a user-centered viewpoint while using it. Maver, Harrison and Grant (2001) developed a wheelchair motion platform that was designed to allow wheelchair users to navigate and explore a virtual representation of buildings. Their aim was to develop a tool that would enable the evaluation of wheelchair accessibility of a building in the early stages of building design or redevelopment of old buildings.

The overall goal of this study was to address the problem of assessing accessibility 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 test users' abilities to identify and modify accessibility barriers. This interactive model is implemented via an immersive VR 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 HABITEST – DESIGN AND IMPLEMENTATION

We aimed to construct and evaluate a tool, known as HabiTest, which 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 the 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 Figure 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 3D 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 the user's ability to gather relevant data from the simulation process. EON Reality software also records all collision 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. Figure 1 below, illustrates a typical HabiTest environment. The larger central view is the main view and is "first Person" (ego-centric). The other two auxiliary views are "bird's eye" view (upper left corner) and "third person" side view (upper right corner).

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Figure 1 A typical HabiTesT environment from EON Reality

2.2 HabiTesT: Designing the Key-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 so that ‘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.

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; an avatar representing the user within the environment having 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. Since most electric wheelchairs are operated with joysticks we selected a force feedback joystick, specifically Logitech’s Wingman and Microsoft’s SideWinder. Both of these devices provide vibratory collision feedback to the user, enhancing the realism of the environment when the user collides into a wall or furniture while navigating.

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 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, and up while exploring a new environment. This “looking around” option is available to users both while standing in one place and while navigating within the environment. A benefit of large scale projection is the ability of engaging a group of people in the design and testing process (Knight and Brown 1999).

The final design consideration is the provision of a means to perform tasks, and specifically to touch objects within the virtual environments. We have elected to provide a virtual hand which is controlled by the user. The hand may be seen in the environment at any time and it has several levels of control. The first level of control is achieved by putting the hand at a fixed distance in front of the user’s eyes; when users wish to perform any manipulation with the hand, they may move the hand separately from head movements. In order to simplify 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 must press and hold one of the joystick’s buttons in order 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 (Palmon et al. 2004).

3 INITIAL EVALUATION OF “HABITEST” BY USERS

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 Initial Usability Testing

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 Figure 1) was modified to be used as a HabiTest environment for demonstration and

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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 trial 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 center 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 opening made the navigation task demanding one. Similarly, given the small size of the bathroom, the need to turn around within it in order to exit was also difficult. Although this navigation task is difficult, it is possible to complete. Note that the collision detection feature was activated during the test, so that the participants were made aware of any "impossible" routes.

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 without help. All participants were then 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 accessible for a wheelchair user but only with great difficulty. 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 showcase of VR equipment navigated within it using the joystick. As a result of the FOV difficulties observed during these 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 programming of several of the joystick buttons to enable users to look around in a way similar to how people turn their heads to the right, left, up and down while exploring a new environment (Palmon et al. 2004).

3.2 Ongoing Usability Testing of the HabiTest

The objective of following pilot study was to further test users' abilities to navigate within the new virtual environment when using a joystick. Ten healthy volunteers participated in this study. Three were high school students, two were university students, and five were people with academic positions. Their age ranged from 13 to 46 years (mean = 26.6, standard deviation (SD) = 10.7). Three of the participants were females, five had experience in navigating in virtual reality through computer gaming and six had experience using a joystick in the past. The participants' general experience in using a computer ranged from five hours to 40 plus hours per week.

3.2.1 Procedure

A new setting was created for the purpose of this testing, a rendered model representing the inner area of the main section of the University's Dean of Students office. This setting was selected since the physical premises have been made available to us for testing purposes. As shown in Figure 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 Figure 2 (left: a "first person" view of the central area / right: a blueprint of the entire area used for testing). Participants were shown how to use the joystick to navigate within HabiTest and given a trial period of 20 minutes (including explanation time) to practice its various functions. During the trial period participants used the model of a one bedroom apartment and an open kitchen area described above (see Figure 1). Following the trial period participants were asked whether they needed any extra time to practice the use of the joystick and none of them did. The Dean of Student's office virtual model was used during the test period. One clearly visible virtual object (plant, plate with fruit, toy train and a red phone) was placed in each of the four rooms. Participants were requested to navigate within the virtual world to each object and "touch" it with a blue "hand" that appears on the screen. The moment the hand touched the required object, the hand turned red and the object reacted in a distinctive manner -- the plant grew bigger, the train started moving, the phone rang and one of the pieces of fruit jumped up and down. A chair located along the navigation pathway was also a selectable virtual object and the participants had to "touch" it with the virtual hand in order to make it move closer to the table enabling access to that room. In order to be able to touch the objects with the virtual hand, participants had to get within a preset distance from the objects. Thus, they were forced to travel to regions that were difficult to navigate. During this test, participants were represented within the virtual environment as if they were sitting in a wheel chair (first person viewpoint). All actions were performed using the joystick's programmed buttons. All tests were timed, all collisions incurred by the participants were counted and the path length in virtual meters of each participant was recorded. The x-y coordinates of each subject's pathway was stored for subsequent analysis by Matlab, a tool for performing numerical computations with matrices and vectors. Following testing, participants completed a usability questionnaire that included 27 statements that they ranked on a 7-point scale from 1 = "totally disagree" to 7 = "totally agree". The statements queried participants' views on various aspects of HabiTest including the clarity of the pre-test explanation and practice session, operating the joystick, navigating within the virtual environment, and performing the tasks. There was also a general feedback statement on the whole system.



Figure 2 View of the Dean of Students area: HabiTest Environment

Figure 2 illustrates a view of the Dean of the Students area. The figure on the left illustrates a “first person” view of one of the rooms showing its furniture. The figure on the right illustrates the blue print of the entire area used for testing (marked by dots).

3.2.2 Results of the Navigation within HabiTest

The pathway traversed by the participants was divided into six sections (S0-S5). For example, S0 was measured from the moment the participant started navigating in the virtual environment until the moment that the first object was touched. S5 was measured from the moment the participant finished touching the last object until exit from the Students' Dean Office.

Means and standard deviations of the three variables (time, path length and number of collisions) were calculated for each of the six sections. These results showed that there is a large variability in performance between different sections reflecting differences in difficulty in the navigational path (e.g., corners) or in accessibility (e.g., narrow doorway) between sections. For example, in section S2 that was relatively easy from a navigational point of view, the mean number of collisions incurred by participants was 13.3 (SD = 10.5). In contrast, in section S4, the most difficult section to navigate, the mean number of collisions was 96 (SD = 54.5).

Time to navigate and path length could not be compared directly across sections due to differences in their actual path length. Rather, the data from the three variables from each section were compared between subjects. The results show a large within subject variability pointing to typical differences in ability. For example, one of the participants navigated section S3 in 4.6 virtual meters while another navigated the same section in 31.3 virtual meters (see Figure 3). This difference was due to the numerous "back and forth" movements that the latter participant made. Perusal of the trajectory maps of all participants demonstrated that the participants with poorer navigational ability tended to make excessive "back and forth" movements to correct themselves and to place themselves at the correct angle or the correct distance from the doorway or the furniture in order to progress. Even those participants who were

good navigators made at least one or two "back and forth" movements in the more difficult navigational areas as shown in the right panel in Figure 3.

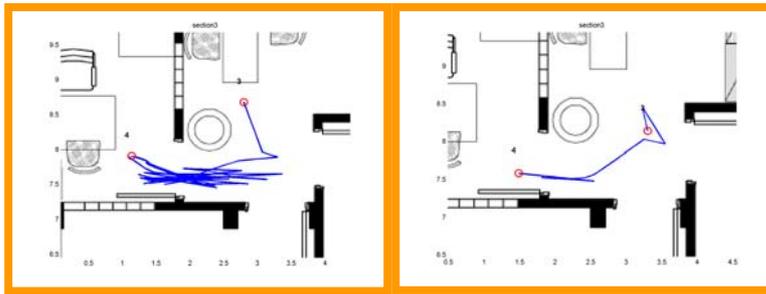


Figure 3 “Back and forth” movements

The left panel of Figure 3, illustrates that the participant has performed many "back and forth" movements to enter the room while the participant shown in the right panel entered the room easily, yet still performed a few back and forth movements.

3.2.3 Results of the Feedback Questionnaire

The means and SDs were calculated for each of the 27 questions completed by the 10 participants, providing information about their subjective responses to the usability characteristics of the virtual environment. For example, participants had high agreement on the sufficiency of time to practice before the actual study (mean = 6.6; SD = 0.5) and the important role that the bird's eye view window played in facilitating navigation (mean=7.0; SD=0). In contrast, participants were not satisfied with the third person view point window (mean = 2.5; SD=2.12). The questionnaire responses also revealed that the participants found the haptic feedback from the joystick even more helpful than the visual feedback (Haptic feedback: mean = 6.0, SD=0.8; Visual feedback: mean = 5.5, SD= 1.2).

4 CONCLUSIONS

We have developed a system that overcomes the possibility of evaluating an environment only after completion of its final construction. By doing so, we have followed the change in the VR paradigm suggested by Maver, Harrison and Grant (2001) to move from simulating mainly VR environments that are distant, dangerous or imaginary into simulating ordinary real environments in order to evaluate their accessibility for people with disabilities. This entailed the implementation of several unique features into HabiTest and the testing of whether a virtual environment is valid as an evaluation tool of an accessibility of a real environment. To date, after the initial testing phase, we suggest that HabiTest, with its unique features (FOV,

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Hand, Joystick, Avatar in wheelchair) is a system that is likely able to distinguish between areas of living environment that vary in their accessibility and in their navigational difficulty. It thus appears to provide users with an opportunity to test accessibility and navigation of a wheelchair in a virtual environment. Future plans include comparing performance within the HabITest to that within an identical real environment in terms of navigation from one point to another and identifying accessibility barriers. Results of this testing will demonstrate the validity of making wider use of virtual accessibility evaluation.

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