Using virtual reality in the adaptation of environments for disabled people

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ABSTRACT

This paper describes work on a computer aided design and visualisation toolkit for the adaptation of homes and workplaces for disabled people. The basis for this work comes from a number of case studies which used a prototype planning tool based on ordinary 3D modelling and drawing packages. These case studies highlighted the need for a 3D object library containing office furniture, mobility aids, building construction elements and so forth. Three further prototype tools have also been developed: a user-friendly design and visualisation tool for non-computists based on a 3D graphics API; a mannequin modeller; and a VR based design and visualisation tool.

Keywords: physical disability, adaptations, visualisation, mannequins, 3D object library, Quickdraw 3D.

1. INTRODUCTION

People who have a disability or who have become disabled often require alterations to existing environments to accommodate their needs, or may wish to design their own work places or homes with their specific needs in mind. Traditionally, the design process is performed by architects - professionals who presumably know best what the disabled person wants.

This situation prompted the question: But what about us, can't we have a say in how the environment shall look? This question was raised, of course, by the people with the disabilities themselves and their occupational therapists. Now consider the following statement:

Pictures can convey graphical information more efficiently than words. By the same reasoning, three dimensional visualisation of a potential environment can, for most people, be preferable than textual descriptions or even architectural plans (Wagner, 1994). The former is not usually enough to build up a proper feeling for the environment and the later can be hard to interpret by laypeople. 3D visualisation also promotes communication and is less open to misinterpretation.

Put these together, and one comes naturally to the idea of using computerised three dimensional visualisation as a tool to help include the people who want the alterations, and others affected, in the design process. This not only allows the disabled people to incorporate their own ideas, but ensures that they feel more at home in the environment they have helped to plan. However, there is a complication: The tools that architects use for visualisation - CAD packages - are designed for computer literate professionals. Simpler tools need to be developed that can be used by the disabled people, occupational therapists and other, not necessarily computer literate, people.

Furthermore, if an alteration is made, or an environment built that requires further adjustment and modification due to unforeseen problems, then money is wasted. With more effective visualisation tools at the start, this inefficiency can be minimised.

These points form the basis for the work described in this paper.

2. BACKGROUND

When alterations to an environment are carried out, architects, perhaps in consultation with occupational therapists, engineers and others, discuss what is needed with the help of two dimensional plans and drawings. These plans and drawings can be hard to understand, are open to misinterpretation and hinder the *'how would it be if we put this, here...'* approach. Furthermore, testing usability factors can be extremely difficult, and relies heavily on the experience of the designers with disability related problems. Mistakes can easily be made, and features required for a particular person's needs may be omitted.

By using a 3D design and visualisation toolkit, many people, not just the design professionals, can work together in a medium that is not so easily misunderstood, using an iterative planning process where ideas can be visualised, tested for suitability and re-thought until all are happy with the final decision.

This planning toolkit could be used in the following ways (Fig. 1). A group can work together around a screen, sharing ideas and viewing interesting configurations. When a viable environment has been decided upon, those who actually will be using the environment can 'walk through' it and see whether it meets their criteria. Finally, the computer can be told to test the environment automatically against ergonomic heuristics using the anthropometric measurements of the people involved.

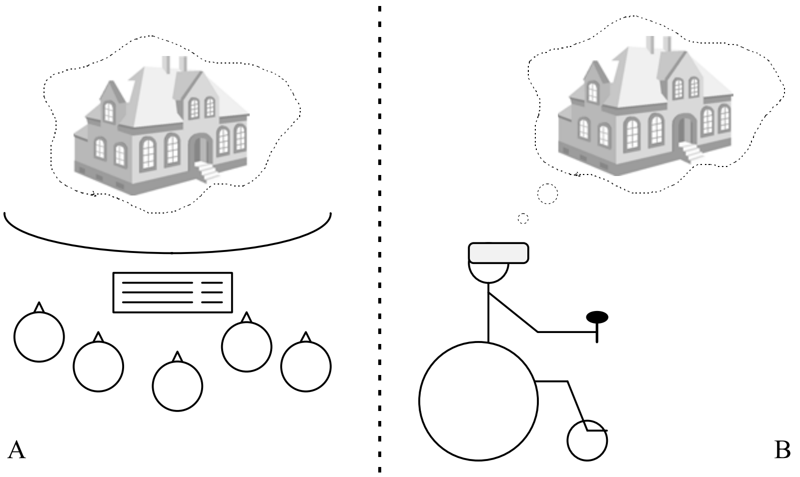

Figure 1. *Alternative Design Strategies, A: Group work, B: Single Person Visualisation*

This idea for a planning tool has been developed into a prototype using conventional modelling tools and has been tested in a series of case studies.

3. THE CASE STUDIES AND PLANNING TOOL PROTOTYPE

Six case studies of real-life planning situations were performed between 1990 and 1993, investigating the usefulness and effectiveness of a computer based planning tool that would enable all people responsible, or affected, to participate on equal terms. The tool was meant to support the planner (who is usually an occupational therapist) in designing and evaluating multiple alternatives at an early stage, and in making improvements throughout the planning process. As well as to be used during planning sessions, in order to visualise suggestions, and in making instant changes, thus enhancing communication and participation among the people involved (Eriksson *et al*, 1995; Eriksson and Johansson, 1996).

The planning tool was prototyped with a set of commercially available software packages in order to conceptualise possible features of a planning tool, and to evaluate the usefulness and efficiency of such features. The prototype involved 3D-modelling and multimedia software based on a Macintosh computer (Apple Inc.). The programs most frequently used were Swivel 3D Professional, Modelshop II, MacroModel, MacroMind Three-D and MacroMind Director (MacroMedia Inc.). Fig. 2 shows schematically the use of the different programs.

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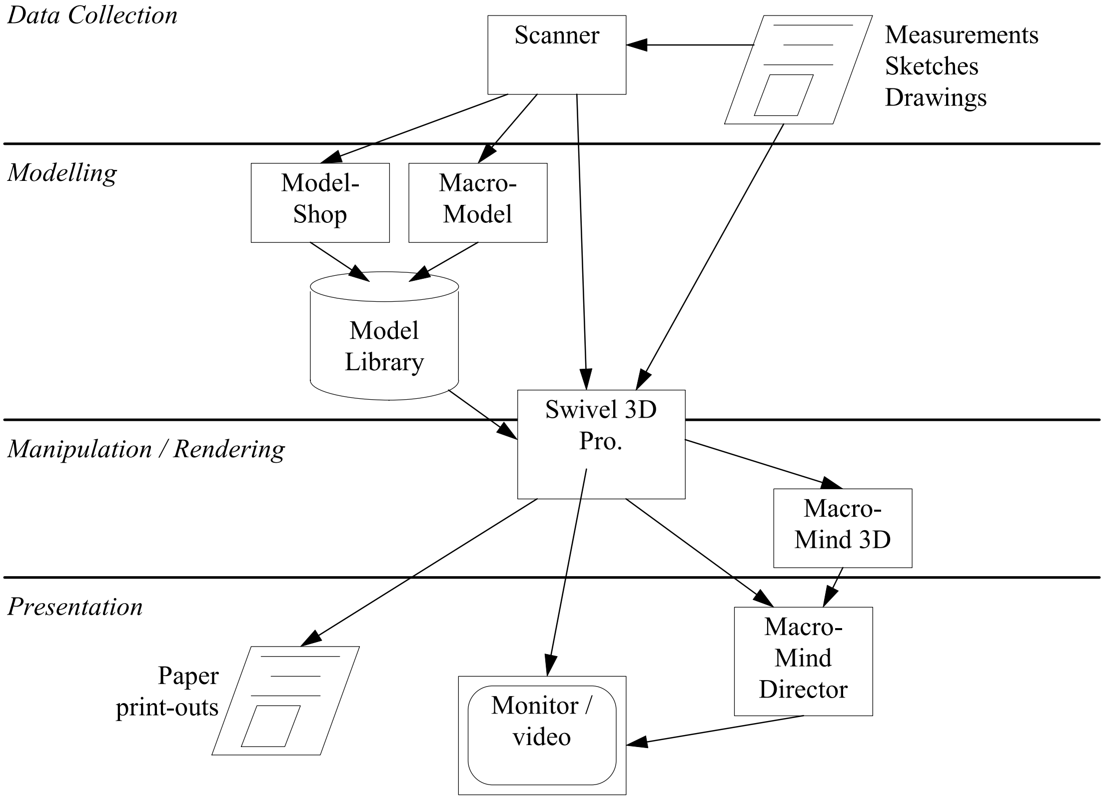

Figure 2. *A summary of the prototype compilation used in the case studies.*

The case studies were evaluated with observations, interviews and questionnaires. In the last three cases, all participating people received a uniform set of questionnaire and interview questions. Table 1 summarises the results of the questionnaire from case studies four to Six (Eriksson and Johansson, 1996). If the subject answered "yes" to the first question, then the options were A="It was possible to visualise a suggestion"; B="It was possible to test clearance for objects/people"; C="It was possible to test reach"; D="Others".

Table 1. *Summary of results for case studies 4 to 6.*

		Useful in the case	Supported understanding	Supported discussions	Encouraged participation	Useful tool in the future
Case 4	Subject	yes; B,C	yes	yes	yes	yes
	Employer	yes; A,B,C,D[1]	yes	yes	yes	yes
	Therapist	yes; C,D[2]	yes	yes	yes	yes
Case 5	Relative	yes; A,B	yes	yes	yes	yes
	Therapist, clin.	yes; B	yes	yes	no	yes
	Therapist, distr.	yes; B,C	uncertain	yes	uncertain	yes
	Engineer	yes; B	uncertain	yes	uncertain	yes
	Home help	yes; A,B,C,D[3]	yes	uncertain	yes	yes
Case 6	Subject	no	no	uncertain	no	yes
	Relative	no	uncertain	no	no	uncertain
	Therapist, clin.	yes; B	uncertain	yes	yes	yes
	Therapist, distr.	uncertain	uncertain	uncertain	yes	yes
	Engineer	no	no	no	no	yes

[1] "Print-outs supported my presentation for the other employees."
[2] "One could see the workplace from an arbitrary viewpoint"
[3] "Provided several alternatives."

4. SUMMARY OF THE CASE STUDIES, THE WAY FORWARD

The questionnaire answers indicated that laypeople seemed to appreciate the tool mainly as a visualisation aid, while the therapists and engineers emphasised the ability to evaluate a solution's functionality. However, the opportunity to interact with the model and to evaluate clearance and accessibility, seemed equally appreciated.

A frequently mentioned advantage was that mistakes could be more easily avoided. All therapists agreed that it is worth spending extra time, if it pays off in better communication and if flaws can be discovered at the planning stage. Some participants remarked that suggestions can be over-elaborated, and that details that are not possible to display graphically risk being forgotten. Concern was also expressed that the tool itself could become too much in focus, thus diverting attention away from the actual planning issues. The level of detail and realism was generally considered sufficient, and one therapist thought that it was better with a coarse animation rather than a video recording for instance, since it may then be easier to focus on the issue of concern, that is, accessibility. In general, the answers indicated that people who were professionally experienced about these kinds of adaptations, required fewer details and less realism than those with no previous experience.

The case studies also indicated that a planning tool, such as the one prototyped, can be useful to a planning group in supporting understanding and active participation amongst all kinds of participants. It also makes it possible for a professional planner to make designs of future environments and evaluate the functionality with high accuracy. Dealing with various kinds of physical impairments, it is important that the human models can be adapted to an individual's size and physical abilities.

The planning tool can support an iterative planning process: Initially, rough models of several alternatives can be presented in order to start discussions. When a certain solution has been agreed upon, the design can continuously, and in finer detail, be improved based on discussions in subsequent sessions. However, to take advantage of such an iterative process, it is important that all the people concerned can attend throughout the whole process to a greater extent than they do today. For homes, it may be important to include construction engineers, nursing and home-service personnel. For workplaces, colleagues, employers and assistants should be represented.

During the sessions, it was apparent that the planning tool was used not only to show pre-manufactured images or animations, but also to interactively view and manipulate the 3-D models. We believe that this is essential in order to support active participation.

With the prototype used, operations such as manipulating viewpoints, rearranging furniture, adjusting postures, etc., were carried out quite easily and directly, but several improvements needed to be made to simplify operations and increase the level of interactivity. Future development should also include frequently requested tools such as measurement control and collision detection.

At the conclusion of the case studies, it was apparent that a toolkit for the design and visualisation of home and work environments should be composed of a number of facets:

1. A library of 3D objects to be used as a basis for environment design.
2. A user-friendly design and visualisation programme.
3. Kinematic and dynamic mannequins based on anthropometric data for added realism and testing of new environments.

Furthermore, a new and exciting tool was becoming available that could be used as a complement to the above: Virtual Reality. All these tools are essential and interwoven (Fig 3), together combining to form a complete product.

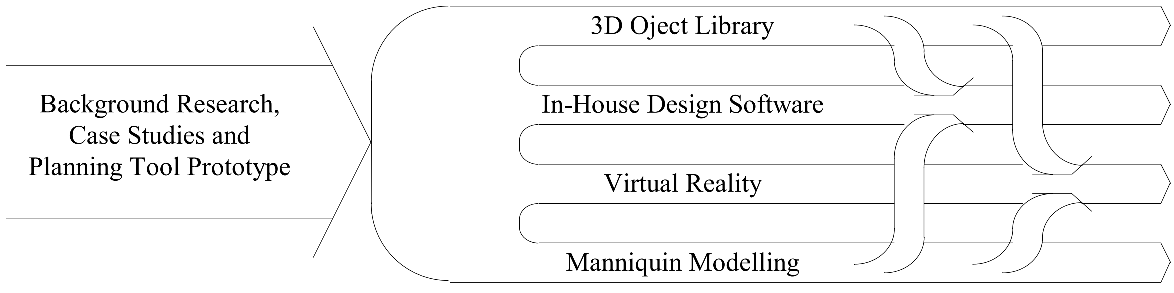

Figure 3. *The interplay between the different aspects of the design and visualisation system.*

These four aspects and their roles in the design and visualisation tool are discussed in the following pages.

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5. THE NEED FOR AN OBJECT LIBRARY

The first aspect to be considered is the 3D object library. Such a library must be based on a standard file format, consisting of objects such as construction elements, furniture, office equipment, transportation aids, etc. This may concern thousands of articles, and yet one can never expect that the library will cover more than a fraction of all such items available on the market. In the immediate future, it will probably be necessary to concentrate on a limited set of environments such as office-sites, kitchens and bathrooms. To efficiently build a large model library, therefore, it must also be possible to exchange files between different 3-D modelling and CAD programs, but unfortunately, there are presently no generally accepted 3-D graphics formats (beside traditional CAD standards, such as DXF). In the future, one may hope for the breakthrough of modern standards, such as VRML and 3DMF. Maintaining and distributing an extensive object library will probably require a support organisation, which could also be responsible for technical support and in training the occupational therapists.

6. A PLANNING TOOL USING QUICKDRAW 3D

The object library, however, is of no use alone. It needs to be complemented by a design and visualisation tool that is both easy to use and sufficiently powerful to help in the task of environment design and visualisation. CAD packages that are available are too complex for ordinary people, whilst most PC based 3D modelling programmes are either too slow or not adequate for visualisation.

An in-house planning tool prototype is therefore being developed (Eriksson *et al*, 1996), dubbed 'Magrathea' (Fig. 4), which exclusively supports the tasks a common user, for example an occupational therapist, would work with most frequently:

1. fetching construction elements from an object library, such as wall-, door-, and window-modules, and assembling them into one or many rooms;
2. fetching furniture, or other equipment of interest, and creating different interior arrangements;
3. testing ergonomic aspects such as reach, clearance, accessibility, etc., with help of mannequins and, if applicable, transportation aids; and
4. showing and interacting with different suggestions during planning sessions.

In order to provide a cheap and simple program, Magrathea operates in an open environment, where features that are more peripheral to a common users' usual work are supported by separate programs or software modules. For instance, a therapist would rarely have the time and skills to custom-design models, or prepare sophisticated presentations, such as animated sequences and photo-realistic renderings. Hence, the program is backed-up by the 3D object library.

Magrathea utilises QuickDraw 3D (Apple Computer Inc.), which is a 3D graphics technology that provides an open, cross-platform file-format and API (Application Programming Interface) (Apple Computer Inc, 1995). The file format, 3DMF (3D MetaFile), can retain data that constitutes a complete 3D-scene with various kinds of objects and attributes, such as cameras, lights, transformations, geometries, textures, shaders, etc. It also possible to handle custom defined objects and attributes. The API calls an extension module of the Macintosh Operating System (Apple Computer Inc.), which supports file handling, object manipulation, rendering, hardware acceleration, and so forth. (it is reported to also be supported under Windows in the future).

Magrathea features the following:

- interactive rendering with optional hardware acceleration;
- key-controlled camera navigation (walkthrough), and support for multiple views;
- direct exportation and importation of 3D-objects in a standard format (3DMF);
- manipulation tools for moving, rotating, and linking objects;
- browser window for object searching, and assessing a world's hierarchical structure;
- object info window for alpha-numerical control of various parameters and attributes; and
- a tool for measuring distances in a world.

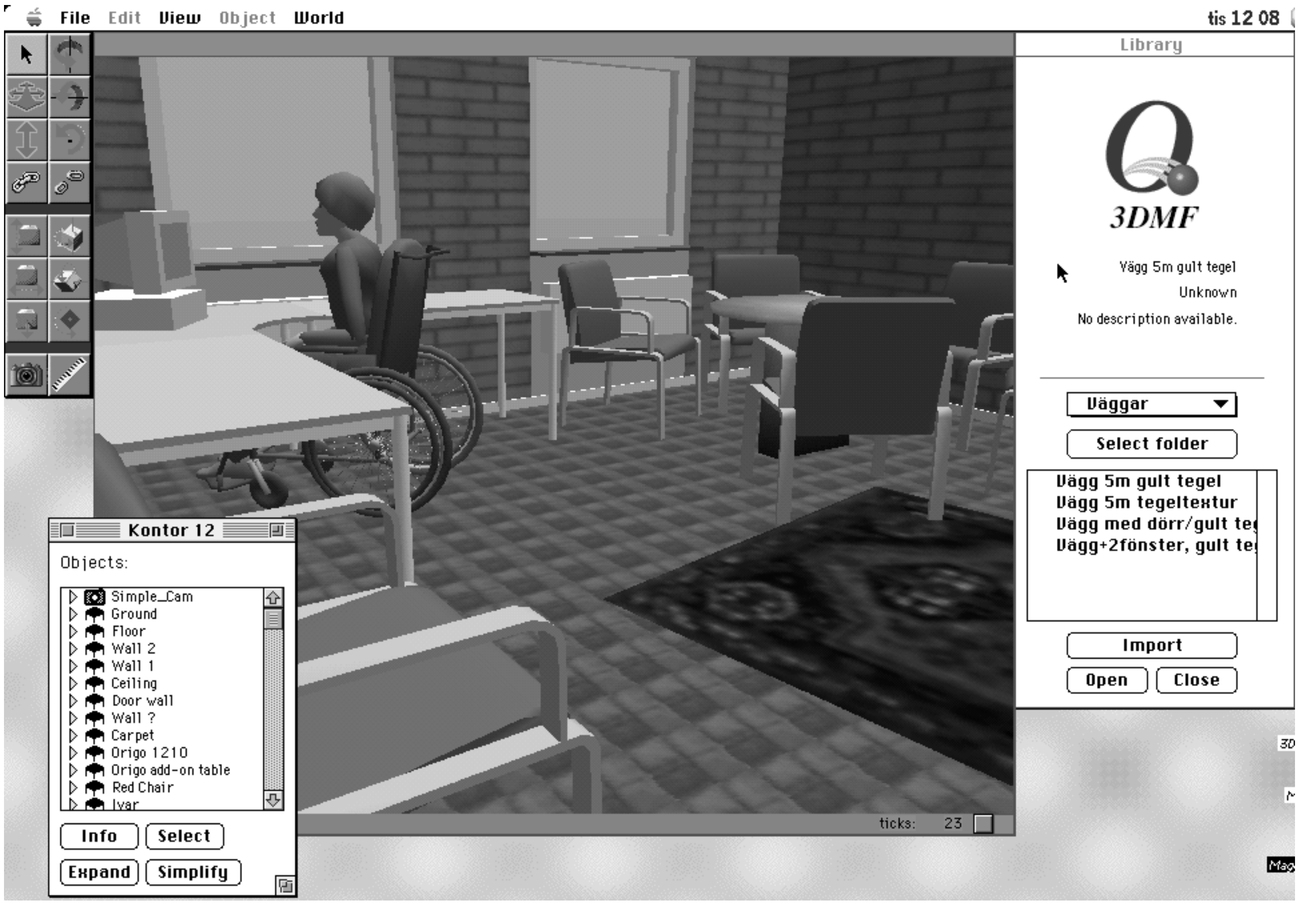

Figure 4. *A screen-dump of the Magrathea interface.*

7. MANNEQUINS

Mannequins (models of humans) are a common aid in ergonomic evaluation which provide designers and architects, for example, with an opportunity to assess factors such as postural comfort, accessibility, clearance, reach and vision early in the design process. Mannequins can also form the basis for automated motion and biomechanical calculation or simulation. Unfortunately, mannequins have traditionally been available only in expensive, expert-oriented CAD-systems, in incompatible formats, making it impossible to compare results and exchange models between different systems.

The inclusion of mannequins, therefore, in the environment design and visualisation toolkit, is vital to improve realism and help in the assessment of suitability for the disabled person. An open mannequin-design should support:

- simplicity in creating, modifying and interacting with mannequins;
- comparability of results between different applications;
- portability of mannequins between different file-formats and applications; and
- flexibility for both developers and end-users in modifying the mannequins' characteristics, complexity and behaviour.

In order to build both static and dynamic mannequins, parameters of interest are:

- stature and body mass;
- anthropometric body dimensions and their proportions to stature;
- dimensions of body segments;
- joint offsets/link lengths;
- body segments' mass and centre of mass locations;
- range of joint motion; and
- moment of inertia.

Unfortunately, there does not exist a unified or complete set of data of a sufficiently large population upon which to base such a mannequin modeller. This means that assumptions, estimations and extrapolations need to be made, all of which compromise the accuracy.

In this project, a mannequin tool has been designed (Eriksson, 1994) that allows static mannequins to be constructed, based on anthropometric data from a North-European population (Jürgens *et al.*, 1990). Plans have also been made to allow mannequins to be constructed in an object-oriented way using detail levels ranging from overall body dimensions to individual segment sizes. One begins, for example, by choosing the sex, height and weight of the mannequin. This then gives a mannequin which can be progressively, and in ever-finer detail, modified to suit the individual to which the environment is being tested.

8. WHAT DOES VIRTUAL REALITY HAVE TO OFFER?

Virtual Reality is fast becoming another tool that can be added to the PC programmer's arsenal. In the area of visualisation, it offers the ability to actually climb into environments, listen to them, perhaps even touch objects, thus providing a better sense of space than other options (Kalawsky, 1993). However, in the past, VR has been exclusive to those with large powerful computers, and bank accounts to match. Nowadays, with the increase in personal computer power and diminishing costs, VR has finally reached the point where ordinary PCs can be used (such as those currently used for word processing and other tasks) and the software can be distributed to and used by ordinary people, not just computer gurus.

But what are the benefits of VR in the area of environment design and visualisation? Obviously, VR offers the opportunity to use full immersion hardware. From the case studies, it was seen that this would help in evaluating a potential environment, although desktop VR would be more suitable in the development phase when several people must work together.

Realism is another crucial feature. With collision detection, patterns, textures, object behaviours and immediate feedback from movements, an environment can be made to seem more realistic. Furthermore, collision detection and behaviours can be utilised in environment evaluation - testing for suitability, tightness of fit for a wheelchair, reach capabilities, mannequin movement and so forth. When it comes to displaying the results of a design, a VR system can offer the ability for automatic walkthroughs, animation and still picture display. These are all important, particularly if some of the design members are remotely located and do not have the correct software or hardware - design alternatives can be pre-packaged in a stand-alone application, sent on video, or photographed and printed out. For those design members that are computerised, an environment can be constructed on a central computer, made available via network, (using perhaps VRML), then viewed, modified and commented on without requiring all the members to be in one place at one time. Even if there is no network, a model can be sent on a disk.

Nevertheless, due to the decision to use only PC based systems, there will be limitations placed on how realistic the environment can be designed to look and still operate at an acceptable speed. This, however, is considered to be only a temporary problem due to the current trend in increasing personal computer speed.

9. A PLANNING TOOL USING VIRTUAL REALITY

In order to explore the use of VR in the planning tool, a PC based system has been purchased (Superscape™) which allows the creation of 3D worlds, selection of objects from an object library, behaviours, interface design and many other features of interest to this project that are not currently planned for the Quickdraw 3D-based planning tool.

At the time of writing this paper, work on the VR part of the planning tool had not yet begun, nevertheless, a number of design directives have been formulated. The VR tool must:

- be compatible with the object library and mannequins;
- allow construction of environments, decorating, placement of furniture etc;
- allow free visualisation from any direction, including walkthroughs;
- allow users to use special VR input and output devices (6 dof mice, joystick, datagloves, HMD, 3D shutterglasses etc);
- allow for pre-recorded walkthroughs; and
- allow models to be published via VRML over the internet.

Furthermore, in designing the interface, it is important to ensure user-friendliness and that the features desired by the users are in fact included (Preece *et al*, 1994). As much as can be gleaned from the case studies will be incorporated into the design, and once the prototype is sufficiently ready, user evaluation will take place.

Development will also continue on the Quickdraw 3D-based planning tool, the aim being to learn what might be possible using the VR system as a prototyping tool, with desirable features ported to the in-house programme if the users deem them suitable. The VR system will also provide possibilities for full immersion and behaviours. One can, therefore, imagine both systems developing side-by-side, twisting together to eventually form a single planning and visualisation tool.

10. CONCLUSION

This work is still in its prototype phase, nevertheless, early indications are good. The case studies have allowed a plan for the future to be formulated based on real user's needs and ideas. A cross-platform 3D object library is planned with arrangements being made to set up a development and support company. In addition, an in-house developed design and visualisation tool has been built which allows placement of objects from the library and 3D interactive visualisation. The work on realistic mannequins has produced exciting results, allowing ergonomic considerations to be taken into account in the evaluation of an environment.

Finally, the plans for the use of a Virtual Reality based software development package are made and a prototype is being constructed.

Once the prototypes of these four tools are complete, the next wave of evaluations can commence involving more real users and providing a new spring-board from which to leap.

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