Applications of virtual reality to computer-aided building design
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1. Introduction

In this paper, the problems associated with building design and generation within a virtual world environment will be discussed. In this paper the term 'Virtual Reality' has been reduced to 'VR' for the sake of brevity. The field of VR is relatively new in nature and proposes some unique opportunities in building design. The object of this paper is to discuss the problems and the potential solutions to them. Specific reference to the authors' own VR and building design systems will be made.

1.1 General Discussion

The field of Virtual Reality has recently developed out of experience gained in the fields of computer graphics and human/computer interaction. The basic concept is the "immersion" of an operator in a synthetic world, such that sensory information conveyed to the operator enforce the impression that this synthetic world is "real". The model is generated by specialised computing platforms, and suitable displays are used such that the required impressions are conveyed to the user. Wherever possible extraneous impressions from the real world are excluded.

A typical VR system is comprised of a headset system, using liquid crystal displays and suitable optics, so that the wearer can see the images from these displays. A set of headphones supplies auditory information to the wearer (whilst also muffling out unwanted extraneous environmental noise). Finally, a tracking system is also included in the helmet, such that the wearer's head position and attitude may be found. For a typical system, please refer to figure 1, where a picture of the authors' system is presented.
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On many of the advanced systems, a "dataglove" system is also often utilised. This is a special pair of gloves that the operator wears. They contain similar tracking systems to the helmet, as well as some form of flexion sensor. From these elements the hand and finger attitude and position may be found. Tactile feedback is very often included in these gloves, either by using piezo electrical "buzzers" in the finger tips, or miniature inflatable air pockets. Thus a user may be given the capacity to pick up and touch objects within a virtual reality.

2. The Building Design Problem

The problem of designing a building is a complex and involved process. In recent years, the development of prefabricated sections, and CAD design suites have enabled more up to date construction methodologies to be utilised. In essence, a building is designed in a similar manner to that of any modern manufactured item. Firstly, the building requirements are decided, i.e. the number of people it has to contain, the volume of space required to fulfil its task, the necessary floor loadings expected. After these have been specified, then the number of work and ancillary areas and their spacial arrangement may be defined.

From these data, the number and positioning of the structural members may be determined. The positioning of the foundations can then be defined and cladding and cosmetic items may be specified and their precise placement determined.

The above approach works best if the complete structure can be specified as a set of prefabricated, manufactured parts which may be slotted together. The construction order can be determined in the design process, such that a complete construction schedule may be created. This, along with a parts list, and placement specification, is sufficient to completely describe the building process.

All the operations above may be generated by a sufficiently complex design tool. Such a tool has been created at Reading, and examples of its output is given in figures 2 to 9 inclusive.

3. The Visualisation Problem

With implementing such a tool, it was noticed that a number of problems enschewed. Firstly, the building requirements have to be tested such that the volumes specified are indeed adequate to the tasks set. Secondly, that the
ergonomic layout of these volumes and the necessary ancillary space (toilets and staircases etc), were satisfactory. Thirdly that the safety requirements with respect to fire escape access be satisfactory. Fourthly, that the construction schedule was possible to implement, taking into account the actual site environment. Finally, that the aesthetic qualities of the building be sufficient to satisfy the client’s requirements. It can be seen that these problems can be tackled using a sufficiently comprehensive visualisation tool. It was decided to examine the use of VR systems to what potential benefits these could bring.

4. Implementing a Virtual Reality System

In testing the applicability of VR systems on these problems, the Reading University "LOKI" VR system was used. This is a platform based around a 68030 computing system, a headset system and a magnetic based tracking system. A common file format was devised between the two systems, and building geometrical data downloaded into its "Virtual World Modeller". The VR system was then able to generate a realtime graphical representation of the building (in various stages in design) and permit "walkarounds" to be performed.

These walkarounds are effectively realtime investigation of the building structure, giving the observer three dimensional spacial information at any viewpoint within this. Unfortunately, due to limitations on the VR systems software, animation of the construction process was not possible. From these walkarounds, some of the design aspects discussed above could be investigated.

5. Investigating Potential Designs

With respect to determining whether the work volumes defined were adequate to the building’s perceived function, there was insufficient information present in the simulation to make accurate assessments. This was judged to be the case because the placement of furniture and people within the scene was not performed. If this had been generated along with the building design, then a reasonable estimate could probably be made.

The ergonomic layout of the volumes could be tested, because there was sufficient information present to come to a judgement. This is again qualified by the fact that no furniture was added to check certain clearance aspects, however, access to staircases and ancilliary areas could be checked.
With respect to safety aspects and access routes, sufficient information could be gained when considering fire escape and stairway access. The visibility of exits and the theoretical placement of exit signs as well as other warning information could be tested and the placement of firefighting equipment. Again, the accuracy of these results is qualified by the lack of furniture detail within the environment.

Due to limitations in the animation system, the construction phase of the operation could not be tested satisfactorily. It was possible, however, to view the building at different stages of construction and make judgements as to where material payloads could be placed without unduly restricting work around them.

Finally, with respect to viewing the final design and presenting this as a proposed solution to the client, this aspect was judged to be excellent. It gave an unparalleled opportunity to examine most of the visual aspects of both the interior and exterior, interactively, such that a clear and unambiguous representation of the building could be brought over to the client.

6. Improvements to the System

From the above experimentation, it was decided that the addition of virtual reality "walkaround" capabilities to the automatic building design system was of considerable benefit. Unfortunately, due to inadequacies in the software and hardware elements of this system, the level of detail needed to test out certain aspects adequately was not present. The next generation of virtual reality hardware and software being developed is targeted at removing these inadequacies.

It is now viewed, however, that part of the building design process should be the specification (to a limited extent) of furniture and person deployment within the proposed structure. This will require a much more detailed brief from the client and possibly an increased, active role in the design stages of the building whilst in this CAD stage. With this information, a much more coherent picture of the buildings' deficiencies may be gained and these corrected.

It was originally envisaged, that the construction phase of the building would be animated, such that the scheduling and materials deployment over the site could be studied in detail. Due to inadequacies in the animator, this could not be achieved. In the next generation VR system, comprehensive animation routines are being generated to address this fault.
Finally, the use of simple file transfer between the CAD system and the VR system is judged to be crude, in that it does not allow for quick design and validation sessions to take place very easily. It is hoped to integrate both systems, such that the building design system is an application which runs on the VR workstation.

7. Conclusions

The use of Virtual Reality in building design to assist in the design and validation of aspects of that design, has been noted. With the relatively crude level of modelling achieved, only a limited number of aspects could be evaluated. This could be increased in number by further refinement of the Virtual Reality system. The use of Virtual Reality suggests a more interactive approach in building design, especially with the capability to visualise the end product more completely. This implies that contact with the client during the design period may have to be increased to take account of this new facility. It is suggested that defining the furniture, or the equipment to be present in the building as well as their placement, should be part of the basic building design.

8. References

Figure 2 - Defining Initial Volumes

Figure 3 - Laying Pads For Foundations

Figure 4 - Placing Columns

Figure 5 - Placing Stairs and Supports

Figure 6 - Placing Floor Panels

Figure 7 - Placing Wall Cladding

Figure 8 - Completed Building

Figure 9 - A More Complex Building