RECONSTRUCTION OF VIRTUAL ENVIRONMENT USING CAD-VR APPROACH

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ABSTRACT

Virtual environment should be able to replicate real environment as realistically as possible. This paper proposes a design framework for constructing virtual environments using Computer-Aided Design (CAD) and Virtual Reality (VR) packages, or in short, the CAD-VR approach. This paper discusses the technical issues involved based on the experience in developing two prototype models of the Universiti Utara Malaysia Sports Complex and the Sultanah Bahiyah Library. The benchmark of the development is the compatibility of the three dimensional (3D) CAD models with VR packages. The CAD modelling issues that have been encountered throughout the development stages are also discussed for future guidelines.

Key words: Virtual Reality, Virtual Environment, Computer-Aided Design, Design Framework, Modelling Issues

1.0 INTRODUCTION

The idea of the ultimate virtual environment by Sutherland (1965), states that VR should be indistinguishable from "real" reality. A real environment includes objects both simple and complex and also living things. However, it is almost impossible to include them all in a virtual environment because of the required time and the complexity of the process (Kalawsky, 1997; Beier, 2000). What is to be included in a virtual environment should be minimal but sufficiant to replicate a real environment. Therefore, the importance of real objects and their behaviour that has to appear in a virtual environment need to be identified.

On top of that, it should also be emphasized that the model of such objects should look real. CAD was chosen although that there are other techniques available for doing the same task. These modelling techniques would be discussed in detail in the following sections.

CAD is widely used in various applications including architecture, constructions, design graphics, electronics, and manufacturing. Among the frontiers in CAD are Autodesk that produced AutoCAD and Mechanical Desktop, and Dassault Systems that developed CATIA and SolidWorks. Numerous giant companies use this kind of software to design their products, namely Boeing 777 and Ford Thunderbird (Amato, 1996; Vasilash, 1998). To date, CAD is well known for its high level of speed, accuracy and ease of use (Leach, 2000).

The existence of CAD began in the early 1950's in accordance with the first graphics system used by the US Air Force. It was the initial step to the first CAD program in 1960. At that time, CAD used simple algorithms to display patterns of lines in two dimensions (2D) and later in 3D. The first commercial CAD system was developed by Computervision in 1969. Since then, CAD had experienced tremendous change and advanced in its development with the foundation of Autodesk. AutoCAD, one of the Autodesk's products has sales over $27 million in the year 1985 and in 1994 Autodesk sales reached $465 million. The sales figure is increasing every year (Bozdoc, 2001).

By the year 2005, Machover Associates anticipates that Computer-Aided Design Computer-Aided Manufacturing (CAD/CAM) software will lead the global market as shown in Table 1 (Wahab, 2001). This indicates of the crucial use of CAD in the near future. Hence, the combination of CAD and VR will provide a perfect solution in constructing virtual environments.

Table 1: Forecast market for commercial/industrial 3D computer graphics applications, by type, worldwide. *Includes desktop video

Applications	US$ - billion	
	In 2000	In 2005
CAD/CAM	7.6	15.9

Art/Animation	5.2	11.0
Multimedia*	7.5	16.7
Real Time Simulation	1.2	2.2
Scientific Visualization	1.5	3.9
Graphic Arts	4.3	12.6
Virtual Reality	1.4	3.6
Others	2.6	5.4
Total	31.3	71.3

The CAD-VR approach has been used in the house building industry (Whyte *et al.*, 1999), manufacturing and design applications (Beier, 2000) and civil engineering (Bodamer, 2001). In architectural design, either a crude or optimised model is obtained at the end of this process (Whyte, 2000). In manufacturing, Beier (2000) shows that element such as behaviour, lights, background, and sound can be further added to any crude model using VRML.

Kalawsky (2000) has suggested a comprehensive authoring process in Table 2 for the education context. This process, though, is generalised to creating virtual environments and is not tailored to the CAD-VR approach specifications. It is more towards standalone development in high school laboratories rather than Web-based applications. One positive point is that the steps are more detailed compared to the previous design steps by Whyte (2000) and Beier (2000). Hence, Kalawsky's guideline has been used in developing the prototype in this research.

Table 2: Key Steps to Creating a Virtual Environment (Kalawsky, 2000, p.80)

Key Step	Sub-Task
Scene Definition	• 3D object definition • Model accuracy/detail – could involve specification of different levels of detail • Material definition • Description of textures to be applied to models • Definition of preferred performance trade-offs (e.g. high polygon versus low polygon and texture mapping) • Scene lighting description • Definition of environmental effects • Definition of interaction between individual

	objects (user initiated behaviour or autonomous behaviour)
Object Modelling	• Geometric modelling – may involve creating models with different levels of detail • Material application • Texture map application
Optional Database Conversion	• Object scaling • Polygon flipping • Polygon reduction
Virtual Environment Authoring	• Scene building (placing of objects in the environment) • Integration of level of detail models • Lighting implementation • Autonomous behaviour implementation • User initiated behaviour implementation • Inverse kinematics linking • Integration with other modalities (e.g. audio properties)
Testing/ Debugging	• Performance testing • Optimisation • User interface testing

2.0 VR MODELLING TECHNIQUES

There are three techniques for building 3D models. The first technique is by using scripting language, e.g., Virtual Reality Modelling Language (VRML). VRML is a standard specification language for 3D graphics over the Internet. It consists of nodes such that the combination of these nodes will perform a collection of objects in VRML files. A node consists of parameters or fields to define the characteristic of the node. For example, the following VRML file performs an interactive door. The shape of the door is performed by the Box node with parameters are 0.1 x 5.8 x 2.0 units. The interactivity is performed by TouchSensor and TimeSensor nodes and the path of the door movement is set by OrientationInterpolator node.

```
#VRML V2.0 utf8
# Copyright (c) 2001
# Left leaf
Group {
 children [
        DEF Door1 Transform {
                translation -1.8 2.9 1.1
                children Shape {
                   appearance DEF White Appearance {}

                   geometry Box {
                        size 0.1 5.8 2.0 }
                }
        },
        DEF Touch TouchSensor {},
        DEF Clock TimeSensor {cycleInterval 4.0},
        DEF Door1Path OrientationInterpolator {
           key [0.0, 0.5, 1.0]
           keyValue [
                0.0 1.0 0.0 0.0,
                0.0 1.0 0.0 1.57,
                0.0 1.0 0.0 1.57 ]
        }
 ]
}

ROUTE Touch.touchTime TO Clock.set_startTime
ROUTE Clock.fraction_changed TO Door1Path.set_fraction
ROUTE Door1Path.value_changed TO Door1.set_rotation
```

By using scripting, behaviour can be assigned to each object. VRML is extensible by integrating Java components in its scripts (Brutzman, 1998; Isdale, 1999). However, it involves tedious and personnel intensive tasks. It is suitable for modelling simple objects but very laborious for complex ones.

The second technique is by using VR authoring tools. VR authoring tools are additional tools that can be used to help in performing such tasks. They usually come with their own modeller and browser and they support VRML. The examples of these tools are Cosmo Worlds from SGI[1] and World Up from Sense8[i].

[1] URL: http://www.sgi.com/

[2] URL: http://www.sense8.com/

However, they work independently and the modellers are not user-friendly in terms of precision and movement though they have graphical user interface.

The third technique is by using conversion programs such as CAD. The use of conversion programs will overrule the pain of having to learn individual VR packages. Theoretically, its output file format is capable of conversion to all VR packages (Whyte, 2000). This method makes a major contribution to the reconstruction of virtual environments where lots of modelling intense will be reduced.

3.0 RECONSTRUCTION PROCESS

The reconstruction of virtual environments follows the proposed design framework in Fig. 1. The four main processes in the framework involve gathering of information, construction of 3D CAD models, file conversion based on VR formats and adding information to the models.

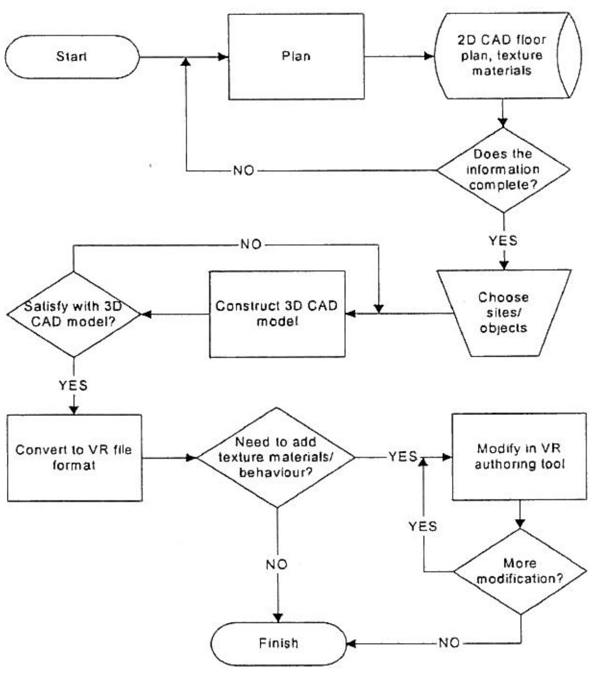

Fig. 1: The Proposed Design Framework for Reconstruction Process of Virtual Environments

3.1 Gathering Information

The reconstruction process begins with the gathering of information on the real physical building to get relevant data. The data includes detailed measurements of the building, which are taken from the blueprint consisting of 2D floor plans and elevations. Snapshots of the actual building are also taken for texture preparation and mapping. These snapshots are also used as 2D images of the real objects appearing in the virtual environment.

The 2D floor plan might be available in hard and soft copies or either of these. For the prototype models, hard and soft copies of the floor plan are available for the Universiti Utara Malaysia (UUM) and the Sultanah Bahiyah Library and only hard copy is available for the UUM Sports Complex. Therefore, two approaches in constructing 3D CAD models have been encountered: one is based on soft copy of the plan that is 2D CAD floor plan and another on hard copy. The following sections discuss in general the construction of the 3D CAD model based on the two approaches.

3.2 Construction of the 3D CAD Model

The construction of the 3D CAD model mainly involves pre-editing process, wall extrusion, roof and floor construction, and texture mapping. Following this section is a description for these tasks.

3.2.1 Pre-editing Process

The pre-editing process involves setting the scales, measurement units and User Coordinate System (UCS) for the workspace. This process is normal practice before creating any workspace. Usually, the scale is already set for the soft copy of the floor plan. The scale once set, can always be changed using a *SCALE* command or by clicking its icon on the *MODIFY* toolbar.

The measurement units for building construction are usually in feet and inches and its precision is up to four decimal points. This feature is not available in VR modellers and is a credit to CAD. Another credit is the UCS where the workspace's origin is set. This UCS can be moved to anywhere in the workspace for convenience. In VR modellers, the UCS is fixed and each object has to be transformed to its position with reference to its fixed UCS.

3.2.2 Wall Extrusion

Extrusion is a modelling method where 3D objects are created from 2D shapes by pushing up the 2D shapes through a path or assigning a specific height to them (Din, 2000). The height of the building was obtained from the blue print of the document or by manual measurements done earlier.

In a 2D CAD floor plan, wall extrusion starts by drawing the *MULTILINE* on the plan. This *MULTILINE* is disconnected using the *EXPLODE* command and then combined to perform a closed polygon using the *PEDIT* command. The polygon is later extruded to its specific height. Fig. 2 shows an example of extrusion where each wall is separately constructed.

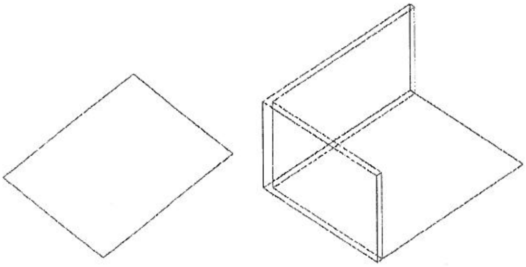

Fig. 2: Wall Extrusion

With the information from a hard copy of the 2D floor plan, the walls of the building are constructed using primitive objects. These objects include box, sphere, cone, cylinder, wedge and torus (Matthews, 1999). In this case, box is the most likely primitive object to be used. For a room that shares the same wall, solid editing is used. A room is built by extruding a rectangular shape from its 2D components, i.e., x and y axis to its z direction. A smaller box, which is an offset of the last box, is also extruded. Using Boolean operations, i.e., *UNION* and *SUBTRACT*, the smaller one is then withdrawn from the box to perform a hollow area as shown in Fig. 3.

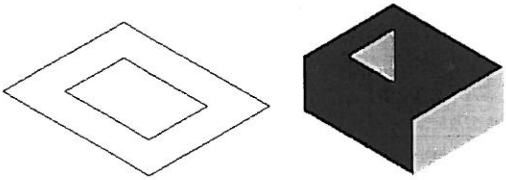

Fig. 3: Wall Extrusion using Solid Editing

3.2.3 Roof and Floor Construction

A floor is constructed simply by drawing a box. The roof, however, is quite fancy. For example, the roof of the UUM Sports Complex, as shown in Fig. 4, is cylinder-like in shape. Thus, a cylinder is drawn according to its size. A hollow area is performed using solid editing and Boolean operations. This cylinder shape is then sliced into half and the unnecessary section is finally removed.

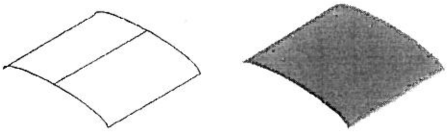

Fig. 4: Roof Construction

3.2.4 Texture Mapping

Texture mapping is a process of projecting onto an object such as floor and water with an image such as a tile pattern, color or shade to create the appearance of that object (Leach, 2000). Two methods of choosing texture materials have been encountered. The first is by capturing the image using a digital camera where the image is stored as a texture file in the CAD materials library. The second is by using existing materials available from the CAD materials library itself.

This texture mapping process should take into account the supported image file formats for VR packages. Cosmo Worlds supports JPEG[3] and PNG[4] file formats whereas World Up supports JPEG and TGA[5]. Texture mapping can also be done in the VR authoring tools or other 3D modelling software that supports all file formats mentioned earlier.

3.3 Conversion of 3D CAD Model to VR Authoring Tools

One of the advantages of using CAD is the capability of exporting its files to other 3D file format such as 3DS[6] file format and saving its file as DXF[7] file format. DXF file format is supported by most 3D modelling software namely 3D Studio Max and Maya where geometry models, color and data layer can be exported.

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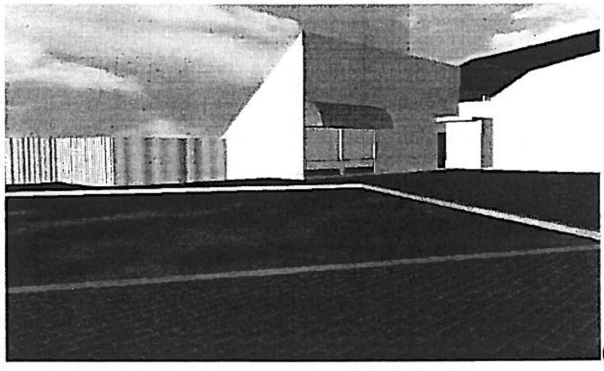
[3] Joint Photographic Experts Group
[4] Portable Network Graphics
[5] Targa
[6] 3D Studio
[7] Drawing Exchange Format

CAD file formats can be converted to VRML with minor misrepresentation such as the difference on World Coordinate System directions (Beier, 2000; Bakar *et al.*, 2001). However, this is not of a great concern because the model is still in upright position. World Up can also import CAD models (Othman *et al.*, 2001).

The study has proven that CAD file formats can be converted to VR packages. The prototype 3D CAD models can be exported to two VR authoring tools, Cosmo Worlds and World Up. These tools are used to add in texture and behaviour to the prototype models. The prototype models are as shown in Fig. 5 incorporating avatar, terrain and real-time analogue clock.

(a)



(b)

Fig. 5: The Prototype Models using CAD-VR Approach;
a) A Snapshot of the Sultanah Bahiyah Library
b) A Snapshot of the UUM Sports Complex

After the CAD to VR conversion, the prototype models can be further modified in VR authoring tools. This modification can be in terms of adding texture materials or object behaviour to these models.

4.0 CAD Modelling Issues

There are two crucial criteria discovered throughout the whole reconstruction process using CAD. First, the object should be assigned to a layer. Secondly, some models in the workspace should not overlap each other. These criteria should be fulfilled in order to have low polygon count and a perfect model for virtual environments.

4.1 Multiple Layers

CAD allows models to be grouped by layers. In constructing the CAD models, objects that share the same function or texture should be assigned to a single layer.

Fig. 6 shows how an object 'rak' has multiple layers to fulfill its unique entities. This is done for ease in adding scripts and artificial intelligence elements as well as mapping textures to the object. Besides that, this practice can be very helpful in the VR authoring tools environment where the layers will be arranged automatically.

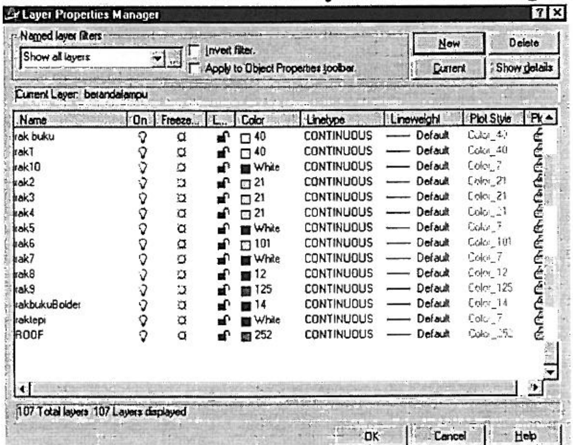


Fig. 6: Multiple layers for an object with different entities

4.2 Overlapping and Adjacent Models

Overlapping models will result in higher polygon count and jagged surfaces as shown in Fig. 7. To avoid this, Boolean operations, i.e., *UNION* command is used to combine these overlapping models into a single model.

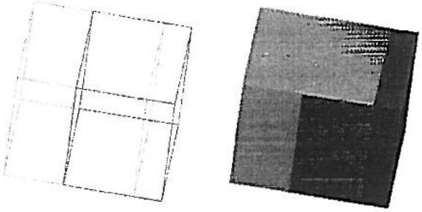


Fig. 7: Jagged Surfaces Caused by Overlapping Models

Two different adjacent models are kept close enough to reduce the gap as shown in Fig. 8. The gap that exists between the models will distract one's view while navigating in the virtual environment.

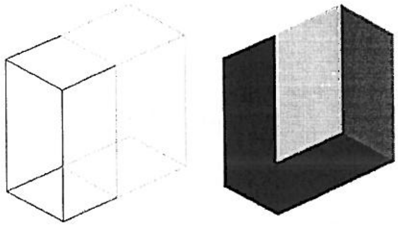


Fig. 8: Gap-Free Adjacent Models

5.0 CONCLUSION

CAD and VR are two powerful technologies that can be integrated to perform realistic virtual environments. Based on the prototype models, VR packages can support CAD file formats directly or via other 3D graphics software. CAD can be used in constructing complex models, is easy to use and provides accurate measurements. Two modelling issues in CAD have been pointed out to alert future developers whose interests are in virtual environments as well as 3D graphics. The ultimate benefit of using CAD that should be remarked is CAD has been established and continuing to lead 3D graphics software in global market for the near future.

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