

Development of VRML Visualization with AutoCAD

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ABSTRACT

A feasible approach for supporting Virtual Reality (VR) visualization within AutoCAD ADT environment is presented. This approach is founded on a standardized representation of the 3D CAD building components; which offers many automation advantages if compared with the existing VR visualization methods. This paper describes the visualization development of a VRML interface built as an add-on to AutoCAD that re-uses the original CAD geometrical design data. The interface is used within the PECASO system for generating effective 4D VR visualization of construction processes in space and time. The core aspect of this integration relies heavily on the appropriate interpretation of the 3D-CAD modeling environment to VRML (i.e. converters library). The overall conceptual scheme, detailed procedures, and selected VR visualization examples are shown. Finally, the paper highlights the added value from using the VRML approach, as there is greater demand for integrating CAD with VR technology.

KEYWORDS

3D modeling, shape translation, visualization, VRML

INTRODUCTION

In recent years, 4D visualization technology has increasingly become an effective communication medium for visualizing construction processes. Users of this technology, such as architects and construction engineers, have realized the great potential from such emerging technology in conveying the design concept and the construction plan amongst their team. Consequently, the technology has highlighted the importance of developing 3D product models of buildings to be used in the AEC sector for the visualization purposes. For example, the team of researchers from CIFE at Stanford University pioneered the first approach for 4D-CAD visualization utilizing annotation of construction activities (McKinney *et al.*, 1998). The work undertaken by Staub *et al.* (1998) reported the benefits of developing 3D multimedia environments to communicate the Computer Aided Design (CAD) architectural design information to the construction team.

Further revolution in VR systems has also introduced tools to assist project planners in visualizing construction processes and detecting possible constructability problems before commencing work on-site. The research work by Waly and Thabet (2002) proposed the Virtual Construction Environment (VCE) system as an integrated virtual planning tool. Similar techniques have been applied to increase the knowledge of

engineering students about construction methods (Clayton, 2002), bringing students attention to the importance of using animation and multimedia to visualize the construction aspects of architectural design. Sulaiman (2001) has made use of a developed software environment to integrate VR with CAD and considered two-way communication channel to transfer the information between CAD and VR.

Although existing research has paved the way for the technological opportunities to integrate CAD and VR, the AEC industry has lagged behind adopting such technology. Gardiner and Ritchie (1999) confirmed clearly this big gap as a result of not using VR technology cost effectively yet in practice. The authors founded that in many situations ‘potential VR users’ were put off from implementing the technology because it looked so expensive. This is particularly the case when construction planners require on-the-fly visualization for rehearsing many what-if scenarios in real time VR. Several UK construction companies are facing a difficult challenge for implementing available commercial VR visualization software and equipment as reported by Whyte (2001). From a technical point of view, the process for converting and transferring the needed CAD information to a virtual world suffers from the following limitations:

- The first problem is the importing/exporting of different file formats (such as DXF, DWG, and 3DS) to a VR toolkit. This problem is time consuming and consequently creates what so called ‘file transfer’ incompatibility. It requires expert VR developers to convert files and it is error prone due to possible loss of the geometrical data (see Figure 1).

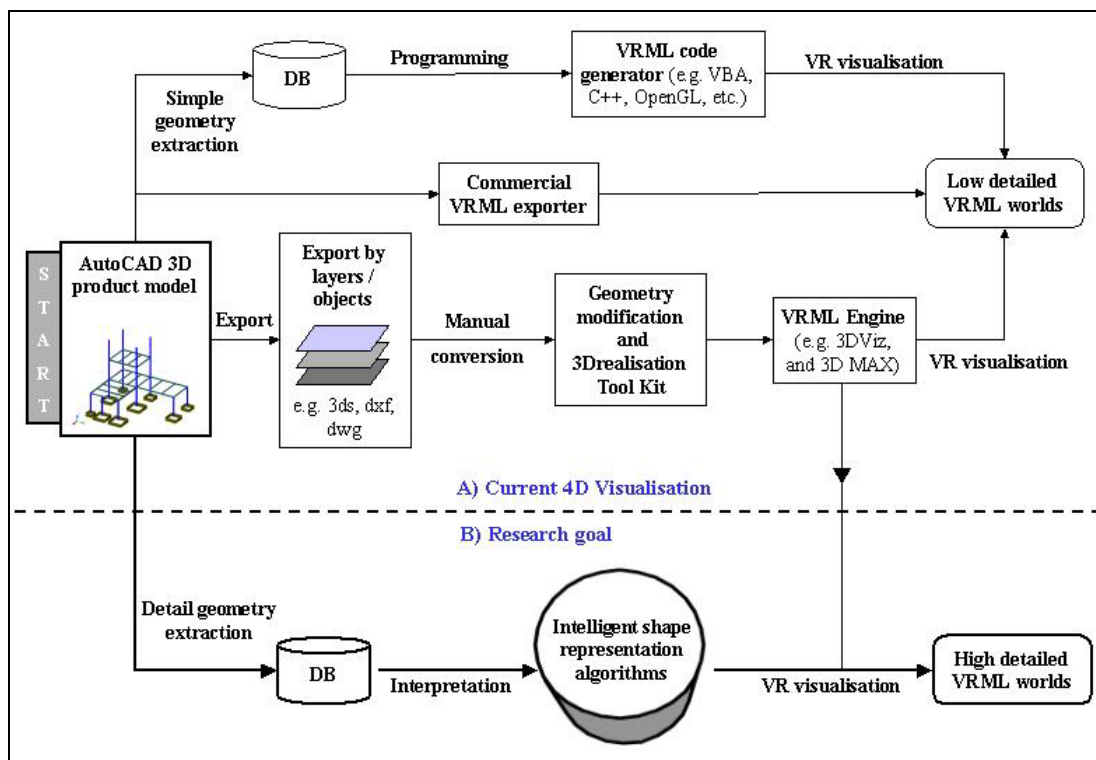


Figure 1: This research development goal compared with existing VR visualization

- Secondly, tools that implement sharing of VR visualization worlds are stand-alone packages from AutoCAD. To speed up the data transfer, there is a great

need to develop VR worlds directly and accurately from a single source of information, i.e. CAD packages that are normally used in the construction industry. The CAD add-ons that support VRML export available in today's market are currently incapable of translating accurate AutoCAD environments (e.g. the VRMLout from Xanadu CAD Studio[©] or the DDDoolz[©] 4.0 from Eindhoven University of Technology)

- ❑ Current conversion techniques limit its users to produce rough models to experiment with and far away from achieving the level of realism that VR technology offers to its users. This is a geometrical information representation and compatibility issues between CAD physical worlds and VR worlds where interpretation process becomes complex.

The Rationale for Product Model Development

Thinking in the direction of putting a standard for the construction products is conceptually a knowledge representation tactic in order to give a meaning to the 3D products of a geometrical model. If computers interpret the geometrical information beyond the limits of shapes, location and dimensions of 3D components, then products models will be able to facilitate design-construction evolution. Eastman and Jeng (1999) observed that utilizing a base information structure in 3D models would facilitate consistency in communication between the design and construction domain. Numerous studies have implemented the Industry Foundation Classes (IFC) as product models standards to enable AEC construction data to be shared and presented between the project partners. As described by Faraj et al. (2000) in the WISPER project, the IFC object-based standard was developed by the International Alliance for Interoperability (IAI) and evolved as an information exchange format between the project team. However, and till now, Santos et al. (2002) justified that the building view associated with product models like IFCs may not satisfy all the requirements of a building standard. Therefore, a proposed product model for structuring construction workspace information is advised. The result is 3D CAD model focusing on geometrical information in terms of products and processes classification.

Based on the above, an initial approach consists of suitable standard is further implemented here to glue together the geometrical products information in one structure. The overall CAD information structure implemented the British Standards layering convention (BS 1992-5, 1998). The BS 1192-5 compliant layering convention is usually useful because it represents the building products as in the construction schedule view. However, it is known that the majority of CAD systems have a static layering interface. In other words, there are no hierarchical relationships (parent/child) between layers. For such reason it was necessary to introduce a concept in this research called *sub-layering*. The *sub-layering* utilizes the Uniclass Civil Engineering construction works classification by the Construction Industry Project Information Committee (CPIC, 1997). This is a central CAD management principle and an open approach to increase the ability for AutoCAD layer manipulation. This standard principally allows various project members to communicate and exchange CAD files in a more unified format. Figure 2 shows a typical implementation of 3D product model information in the AutoCAD layer. For example, it was necessary to provide one layer for each activity. For example, the activity *Foundation* in the project schedule is presented in the *Pad Foundation layer*. Furthermore, Additional physical

components such as supporting activities and project specific activities were modeled in separate layers.

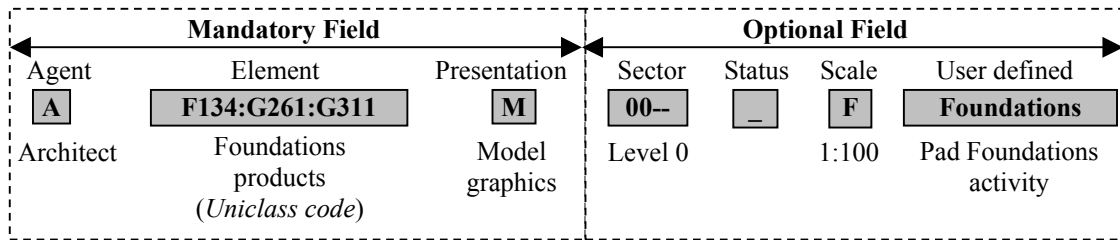


Figure 2: AutoCAD products representation using BS 1192-5 and the Uniclass

The focus of this paper is, firstly, to bridge the gap between CAD and VR visualization development by exploring the principles for auto-generating VR worlds of a building project from within AutoCAD environment. Thereby designing a methodology to reduce the tedious efforts for producing such VR worlds, as shown earlier in Figure 1.

Secondly, to associate shape representation algorithm necessary for complete geometrical data transfer between the 3D-CAD product model and the VRML worlds. The applied algorithms interpret the AutoCAD World Coordination System (WCS) environment and then export a realistic VRML world. Thirdly, we developed a 4D visualization system using Visual Basic for Applications (VBA) with AutoCAD ADT that automatically extracts 3D data of a building model and generates VR visualization of construction progress according to the project schedule.

The paper does not attempt to go into detail about the production of CAD product models. It does however focus on the required geometrical representation and approach for translating CAD to VRML. The readers are expected to have some background knowledge in 3D computer visualization.

TECHNOLOGICAL BACKGROUND

Computer Aided Design in Construction

The rapid progress in computerization and CAD systems seems to offer great opportunities for retrieving building construction information. For example, AutoCAD ADT utilizes a 'drawing integration automated' technique through the Open Database Connectivity (ODBC) and stores the CAD graphical information in the project database. This successful automation in CAD is widely applied in many research, and lead into the development of next generations CAD systems. Kunigahalli *et al.* (1995) generated the concrete placement process by extracting the topological relationships of floor slabs from CAD models. Complete building geographical information can be retrieved from the CAD model like the components coordinate values, 3D components dimensions, geometrical adjacency relationships, volumes, and location data. Other models used Geographic Information Systems (GIS) for dynamic site layout planning (Tommelein *et al.*, 1992).

A UK research initiative VIRCON to develop a 4D-CAD decision support system for construction project planning have reported the feasibility from using AutoCAD with a project relational database (Dawood et al., 2001). Several construction case studies highlighted key benefits of using the VIRCON tool as a visualization tool for project participants; the technical survey about 4D-CAD research by Heesom et al. (2003) have benchmarked the construction knowledge and resources necessary to develop 4D models.

Data Representation from AutoCAD to VRML

In order to successfully generate VR visualization, one must realize the differences between two different visualization environments, i.e. the AutoCAD and VRML environments. The most important feature in the VR visualization is that users can immerse themselves and navigate interactively in the virtual world using the Virtual Reality Modelling Language (VRML) browser. AutoCAD is a simple 3D modeling and drafting package and does not contain the powerful features that VRML environment has like immersion and interaction. VRML is an international standard for three-dimensional programming language (ISO/IEC 14772) used to model 3D virtual worlds for the Internet. As mentioned earlier, VR applications are seen in the current research that explored the use of Virtual Environments (VE) and multimedia to improve site processes and management. Therefore, data representation issue becomes crucial to address whenever the CAD models are to be used for strategic VR construction visualization for site related operations (Retik and Shapira, 1998).

The AutoCAD 3D components are constructed and stored in vertex-to-face relationships. In contrast, information in VRML objects is constructed in face-to-vertex relationship. Figure 3 illustrates this comparison, where an eight-sided 3D CAD object is modeled by extruding the six connected points of 2D *Polyline*. The same 3D object is also represented in VRML as eight-connected faces. The AutoCAD conventional space -modeling environment is founded on a World Coordinates System (WCS) and User Coordinates System (UCS) where the user models entities in horizontal, vertical, and inclined planes (VB Design Espresso Forum, 2003). However, the case is different in VRML where faces of objects are defined either Clockwise (CW) or Counter Clockwise (CCW) in an *IndexedFaceset* geometry object. The *IndexedFaceset* is a VRML polygon geometry constructor used to represent a single 3D CAD component. Finally, the issue of storing the topological information from CAD is complex. This is because the AutoCAD environment does not record the face-adjacency information within wire-frame CAD components.

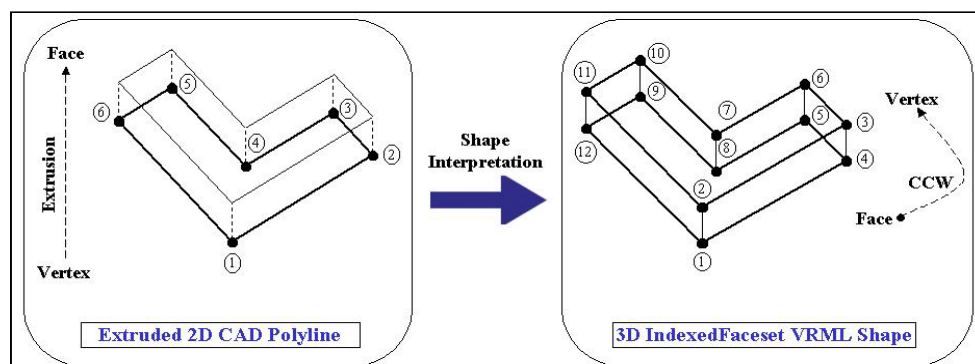


Figure 3: 3D shape representation in AutoCAD and VRML

The Objectives

Therefore, the ideal solution for translating AutoCAD data into a realistic VRML visualization requires computational converting algorithms (Figure 4) to overcome the differences mentioned earlier. The algorithms accomplish the following:

- 1) **Topology:** a detailed topological extraction of the AutoCAD product model is essential; to include the coordinates of points required for constructing VRML objects (i.e. *IndexedFaceset*).
- 2) **Shape reasoning:** stores the faces-adjacency relationships, which are taken into account in the algorithm. Face-adjacency relationships are provided here to define the sides of VRML polygon shape.
- 3) **Construction progress visualization:** using the rich capabilities of the VRML environment by deploying transparency, textures, and color mapping technique to indicate the construction progress in space and time. The advantage of such deployment will provide qualitative information to help communicating the construction schedules.
- 4) **VR exploration:** using alternatives to free navigation within VRML worlds are needed. This can be easily provided through a hierarchical viewing structure showing the construction site view, sides view, top view of the constructed building, and predefined views to allow users switching the view to specific areas (e.g. *internal views*).

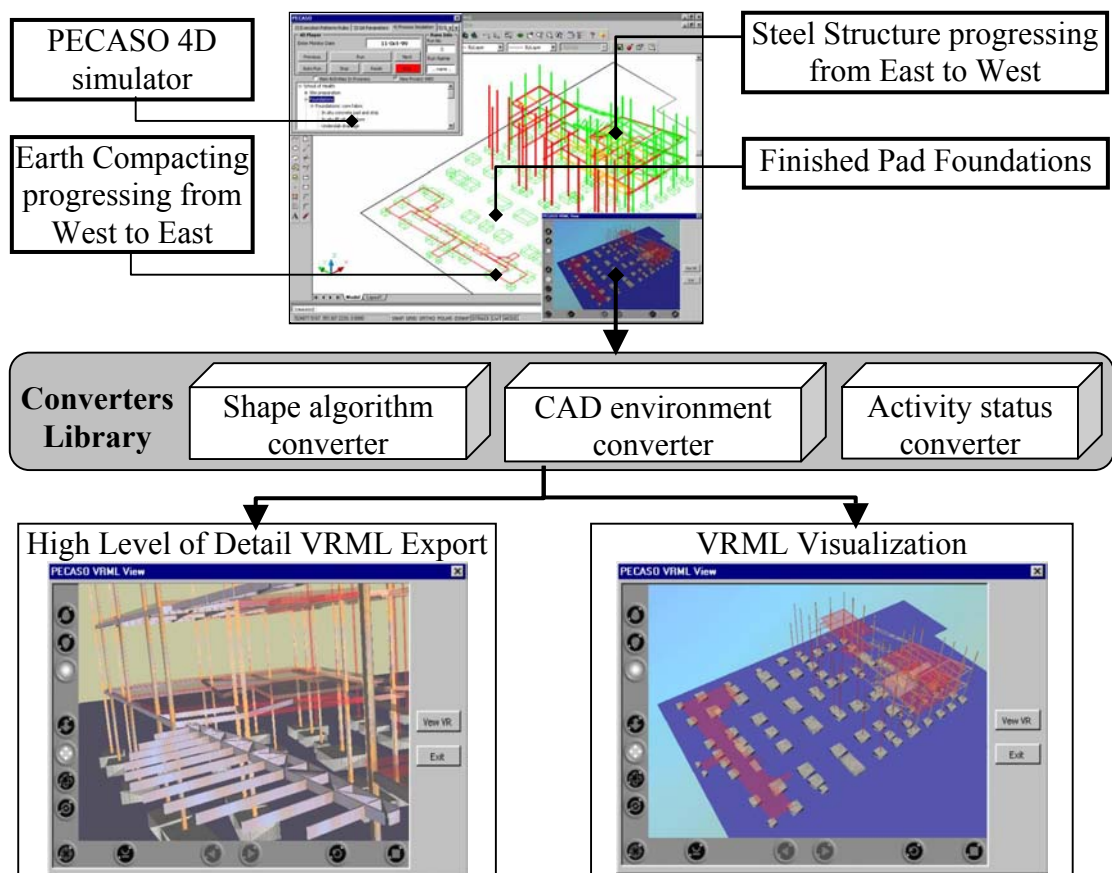


Figure 4: Converters library used to produce on-the-fly VRML visualization

COMBINING VRML VISUALIZATION WITH 4D-CAD

System Description and Implementation

Derived from the above objectives, we considered that the construction progress visualization for the PECASO system (Mallasi and Dawood, 2003) must be based on single-source of information combining the CAD and the schedule details via a central database. The developed 4D-CAD system brings together the project schedule information using planning software like MS Project and 3D-CAD components of a construction project using AutoCAD ADT. Then the implemented VRML viewer uses VBA to embed a CORTONA[®] VRML browser. In this way, users can utilize the VRML interface to export and visualize ‘on-the-fly’ the weekly 4D simulation of a particular construction stages. This enhances the users level of realization, as they find more freedom for exploring the 4D in VRML.

We have on the one hand the 4D simulation of construction stages in AutoCAD using the PECASO system. On the other hand there are the converter library acting as the VRML exporting engine. The scheme illustrated in Figure 4 previously has shown the library of converters and they are divided into three:

- ❑ **Shape algorithm converter:** this converts the CAD geometrical information into the VRML geometry. For instance, the CAD WCS and UCS are obtained from AutoCAD environment to produce the *IndexedFaceset* point coordinates. Then the correct order of face-adjacency is interpreted to construct each VRML 3D shape.

Example VBA Pseudo Code:

A) WCS/UCS Coordinates Translation:

```
For each ACADLWpolyline_Obj
  GetObjBasePlane_Points.Coordinates 'obtains the X, Y and Z values for BasePlane
  Get ACADLWpolyline_Obj.Thickness 'obtains the Thickness for Object
  ObjTopPlane_Points.Coordinates = (ObjBasePlane_Points.Coordinates + Thickness)

  For each Coordinate_Value
    ACADLWpolyline_Obj.Translate.Coordinates 'obtains the Normal direction for WCS
  Next Coordinate_Value
Next ACADLWpolyline_Obj
```

B) VRML *IndexedFaceset* Face Adjacency Relationships:

```
For each ACADLWpolyline_Obj
  ConstructVRMLObjBasePlanePoints 'constructs the BasePlane for VRML IndexedFaceset
  ConstructVRMLObjTopPlanePoints 'constructs the TopPlane for VRML IndexedFaceset
  ConstructVRMLObjSidePlanesPoints 'constructs the SidePlane for VRML IndexedFaceset

  Assign CCW=TRUE
  Assign CreaseAngle = 1
Next ACADLWpolyline_Obj
```

- ❑ **CAD environment converter:** this is used to add hierarchal relationship between the 3D geometry (*similarly to CAD layering system*). This is an approach implemented to organize the geometrical information in VRML world and uses the *Group* and *Child* VRML nodes, for further development and interaction with the objects.

Example VBA Pseudo Code:

A) Finished Activities in VRML:

```
If CAD_Layer is Pad_Foundation THEN
  Group_1 = Pad_Foundation  'defines VRML Group_1 Node for each CAD layer
  IndexedFaceset_Obj Transparency = FALSE  'defines solid object for the VRML object
  IndexedFaceset_Obj Texture = "concrete.gif"  'defines texture material from library
  Child_1 = AllIndexedFaceset_Objs_Finished  'defines Child_1 for all finished activities
                                           'IndexedFaceset objects
End IF
```

B) Progressing Activities in VRML:

```
If CAD_Layer is Pad_Foundation THEN
  Group_1 = Pad_Foundation  'relates to same VRML Group_1 Node for each CAD layer
  IndexedFaceset_Obj Transparency = TRUE  'defines transparent object for the object
  IndexedFaceset_Obj Colour = RED  'defines red colour for progressing work
  Child_2 = AllIndexedFaceset_Objs_Progressing  'defines Child_2 for all progressing
                                           ' activities IndexedFaceset objects
End IF
```

- ❑ **Activity status converter:** this gives realism to the VRML visualization by adding the textures, transparency, and defines camera views - and is achieved through combining the logic of activity progression status and activity type.

Processing the Construction Progress in VRML

The original 4D simulation occurs in the AutoCAD environment. Users can instantly generate a view of the virtual world for the construction progress complementing the original CAD view through the 3D VRML interface. They can simply associate the logic of construction of activities in relation to space and time. The idea for processing such CAD information allows the planners to recognize the construction situation at anytime. This means that the planner can easily identify areas including progressing activities and finished activities intuitively. In order to allow proper process of such CAD/Scheduling information, we have implemented the following construction information visualization techniques:

- a. **Participation:** in the visualization can be shared where project members can discuss the construction sequence, method and the activities logic in a VR way. The visualized construction stage can be studied from different predefined camera views (Figure 5, a).
- b. **Finished construction work:** is assigned a transparency value and texture material to show the finish status. For example, part of the second floor concreting is shown as solid with applied texture retrieved from a library of materials stored in the database (Figure 5, b).
- c. **Activities in progress:** are displayed in the VRML viewer as transparent and with red color mapping to indicate the progression status (Figure 5, b).
- d. **The spatial conflicts:** arising between any construction operation are shown in yellow and displayed as a transparent 3D virtual object surrounding the location of conflict (Figure 5, c).

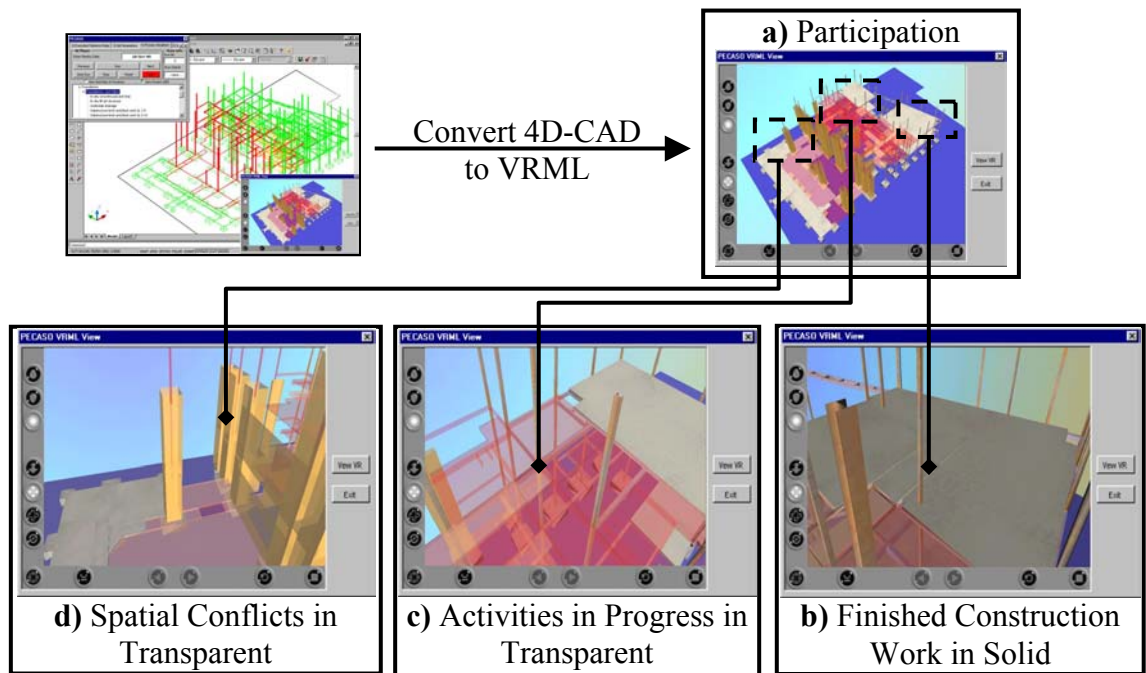


Figure 5: Snapshots of a detail VRML visualization with construction stages

APPROACH EVALUATION AND BENEFITS

The main obstacles faced in this approach were the immense amount of geometrical information and their representation for allowing on-the-fly VRML translation. Nevertheless, the converters libraries achieve fast translation for the 4D-CAD environment with an exact geometrical accuracy. After performing some evaluation of the conversion process, the created VRML files were low in size (maximum of 1.2 MB) and were easy to navigate. The exported VRML files required about 2 seconds of processing time for the total of 5000 to 6000 3D objects. The system was running on Windows with screen resolution 1024 x 768 pixels, and with smooth DirectX 7.0 rendering engine. The final graphic quality of the VRML worlds was fairly real-time. As the main challenge was to enhance the original 4D-CAD simulation, the development of high level of detail VRML allows efficient visualization. In particular, the ability to review the construction progress from different views and interactively. Moreover, the virtual world in conjunction with the 4D-CAD simulation allows the user to explore the proposed construction method in a VR way and have a sense of presence in a dynamic virtual environment. If the VRML files (FileName.wrl) are stored in a web server, then the approach achieves portability and distribution over the web for collaborative visualization for the project team. The shared files can be stored in the server database as sequence of VR visualization.

The approach will benefit those users in the AEC who intend to visualize their complex building projects in 4D virtual world. It is well established that the manual techniques for converting CAD to realistic VR using VRML editors are non-feasible. The reason is obviously because there are no proper VRML modeling packages compared to AutoCAD ultimate environment for designing with engineering precision. The suggested approach here, however, has proven the feasibility to construct VRML worlds with similar accuracy of detail as the AutoCAD environment.

SUMMARY AND CONCLUSION

This paper has described a methodology and approach for extending the capabilities of virtual reality visualization within an AutoCAD environment. The output visualization serves the original real-time 4D-CAD simulation. The usability evaluation showed numerous advantages to the AEC industry in adapting this feasible VR exporting technique. It is believed that the concept is useful and will be important in the future to enhance CAD development. The approach is flexible and extendable to include further complex VRML visualization techniques like including animation and interaction with objects in the virtual world. The unique development described here was the use of single-source of engineering information from the AutoCAD and database including geometry information, in real-time. The developed approach, technique, and the conversion libraries can be used not only for the 4D visualization development but also for improving the standardization of next generation VR-CAD tools.

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