AC 2009-243: PC-BASED PHOTO REALISTIC VIRTUAL ENVIRONMENTS TO FACILITATE CONSTRUCTION DESIGN AND NONDESTRUCTIVE TESTING

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PC-based Photo Realistic Virtual Environments to Facilitate Construction Design and Non-Destructive Testing

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ABSTRACT *–Virtual Reality (VR)-based visualization offers a wide range of capabilities whereby several versions for a design can be generated, viewed, and manipulated before narrowing down on the final blueprint that can be chosen for implementation. More importantly, hierarchical modeling of the scene in 3D facilitates facile project management, and is economical, considering the rising costs of materials, equipment, and labor. Besides, VR-based visualization offers a wide range of advantages including testing the positioning of component elements of a scene (construction project), verifying line of sight or other visibility issue, and enhancing the aesthetics of construction. This study demonstrates using appropriate 3D scenarios the various aforementioned advantages of VR-based scene-tree visualization and proposes the use of a OLE (Object Linking and Embedding) Interface for enhanced interaction with clients.*

I. Introduction

Despite the tremendous advancements made in the domain of construction design, due to the increasing number of factors to be considered in designing any construction, the overall process of construction design has become a complex and multifaceted process. Every construction project has specific purposes or objectives to meet; for instance, an office would have certain requirements, such as space for a set number of computers, reception, meeting rooms, and washroom. A restaurant would accommodate a particular number of patrons, should have spaces for spreading buffet, restrooms, etc. Similarly, every construction inherently should be driven by the needs of the consumer and there should be a means to verify if the proposed plan will meet all the demands. It amounts to a tremendous waste of time, effort, and money to build some project and finally realize that it falls short or fails to meet the objectives. Hence, considerable care has to be taken in planning and designing phases. Visualization is a very useful tool that holds immense potential in the domain of planning and designing (Berry et al., 1998, Tufte, 1990, 1992). Visualization enables observing beyond the individual elements or scene components and aids comprehending the scene in its entirety as an interlinked framework. In real world systems, objects do not subsist in absolute isolation, but are interrelated to each other, either directly or indirectly. Visualization enables viewing the constituent elements of a construction framework in whole as well as in parts. This kind of object-based visualization is of significant value to planners, designers, and decision makers (Church et al. 1994, McGaughey, 1998). McCormick et al. (1987) very appropriately points out that

> "*Visualization is a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for*

seeing the unseen. It enriches the process of scientific discovery and fosters profound and unexpected insights. In many fields it is already revolutionizing the way scientists do science" (McCormick et al., 1987).

Visualization models have been built in research disciplines including medicine, education, mining, GIS (Geographical Information Systems), and various other domains to facilitate information comprehension and analysis (http://envision.purdue.edu).

II. VRML and 3D Visualization

Today, a term that is synonymous with web-based multimedia visualization is "Virtual Reality." A great deal of the 3D visualization for a wide range of applications is done in a virtual cyber space that is frequently typified as "virtual worlds." The users can navigate within these virtual worlds, interact with the scene components, rotate, translate, or scale them. These virtual worlds facilitate user interaction with the scene components and provide a sense of immersion whereby the user feels that he/she is actually part of the 3D setting itself.

Modeling using virtual environments makes it possible to envision the finished product (the current construction) beforehand. When the planners and designers view such a model, it facilitates non-destructive testing. If, after construction, the decision-makers feel that the location of facilities is not appropriate or the positions of some architectural elements have to be changed for aesthetic purposes, this would involve a lot of wasted time and resources. However, a 3D immersive virtual environment enables visualizing the final construction even before it is built and the planners and decision-makers can view and navigate through the model at the convenience of an office desktop. Changes can be made without wasting any money (Chandramouli & Huang, 2008). The model can be viewed, discussions held, modifications can be finalized and these can be incorporated before the actual construction can begin. One recent trend is to incorporate public-participation in infrastructure projects. In such cases, the model can be hosted online and members of the public can walk-through the model and suggest possible modifications. Suitable suggestions can be incorporated into the model before actual construction can begin.

III. Designing 3D models in VR using an object-oriented approach

The prominent advantages of such 3D visual representations are that multiple scenarios can be evaluated and infinite viewpoints can be generated. Decision-makers can view the finished product beforehand, and the visibility of scene elements can be tested. The virtual models are extremely time-saving and economical.

The primary objectives in the design and planning must pay utmost care to include the aesthetic look, provisions for emergency management, and the adequate quantity and quality of facilities.

The mere provision of space required for the infrastructure cannot satisfy the aforementioned goals. More than the amount of space available, it is the ingenious utilization of this space that determines the efficiency and performance of a construction project. In cases such as restaurants, or public amenities the consumers might have diverse observations spaces and such views should be able to elicit the amenities available and hence provide a clear view of the overall project. One important consideration while including various amenities should be that the components should be carefully located so as not to impede movement, and at the same time not be situated in such a place that would deem their utilization impracticable. In today's scenario, design and approval might involve experts and specialists from diverse backgrounds, such as designers, engineers, technicians, architects, economists, and various other stakeholders. In order for the designers and architects to be able to explain their schema to all the members clearly, they need to make use of a tool such as visualization. 3D visual worlds are excellent tools for communication and can be easily understood by a broad spectrum of people.

IV. Design using VRML

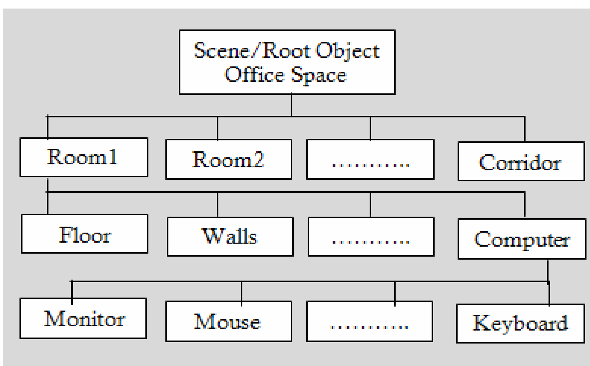

Figure 1. Hierarchical grouping of a scene

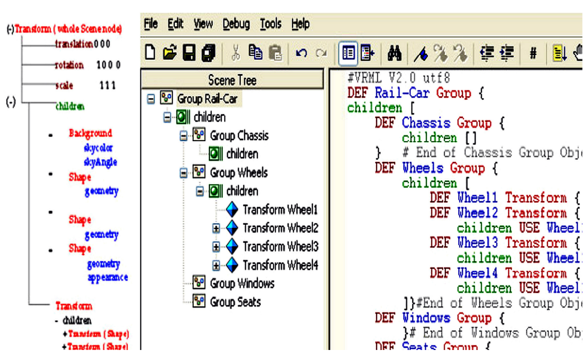

Figure 2. Scene tree structure showing "Parent-child" relationships

VRML (Virtual Reality Modeling Language) adopts a hierarchical structure for describing 3D worlds (Shiode, 2001). Visualizing the world as a group of objects within a structural framework facilitates modeling real-world scenarios better. The overall scene, e.g. restaurant or office space can be considered the root object that is at the top of the hierarchy, under which all other objects fall. There can be further ramifications depending on the object's complexity. For instance, meeting room is a child of 'Office space' and 'PC' is a child of 'Meeting Room' object *(Refer to Figure 1).*

There are several advantages of such grouping of elements composing a scene in the form of objects that have group or parent-child relationships. First and foremost, the overall organization becomes lucid and basically no element, however large or small, is left out. This facilitates quantity estimation greatly and also aids locating system components within a huge framework. Quantity estimation is a very important aspect of construction projects and facilitating this process via a visual means will be of immense value.

Another prominent feature offered by the object-oriented approach is that of "reusable software objects" *(Refer to Figure 2).* Quite frequently, a single element is used more than once within a parent or group object. For instance, wheels of locomotives, sleepers used in the track system, inventory elements such as lamps, sign posts, furniture elements etc. In such a case, the object that occurs repetitively can be defined just once and instances of the object can be used subsequently.

V. User interface for multi-perspective and multi-scenario visualization

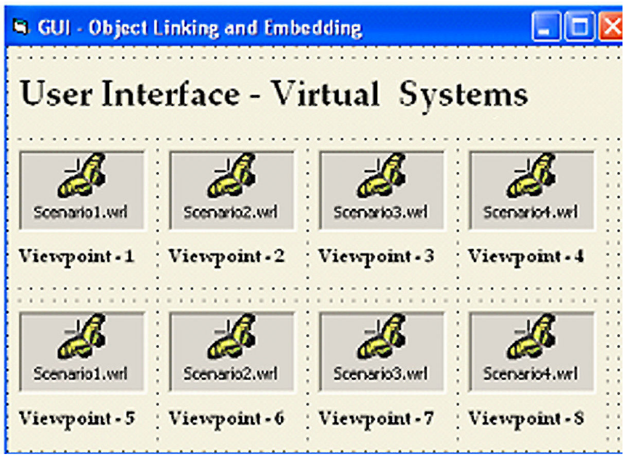

Figure 3. Visual Basic GUI with object linking and embedding (OLE) for multi-scenario visualization.

Figure 3 illustrates a VB powered GUI (Graphical User Interface) that facilitates multiple-scenario visualization with interactive functionalities. By means of OLE (Object linking and Embedding), the various virtual worlds are embedded and linked on a common interface. Each scenario depicts a different configuration of the same scene, which can be a simple re-organization of the elements in the previous scenario or a total rearrangement of the components.

Such virtual environments can also be used to create sophisticated construction models in 3D. A very high level of detail can be built into the design of such 3D models and the dynamic functioning of the locomotive components can be visualized. Under real-world circumstances, it is practically impossible to get to the level of the individual components each and every time when it is required to visualize changes made. Using VRML highly detailed models capable of dynamic behavior can be generated. More importantly, the training can be incorporated even when the model is being designed. Some other key functionalities that can be added into the virtual worlds are described in Figure 4.

VI. Progress Evaluation with built-in PERT/CPM charts

Construction and design processes typically involve a sequence of tasks or activities. These may involve tasks that can be classified as series or parallel, the former referring to tasks that follow one after another, while the latter refer to tasks that can be performed simultaneously. The CPM (Critical Path Method) was an early method for project management that employed fixed time periods for tasks, which did not accommodate the fact that variations in time schedules can occur. The PERT (Program Evaluation and Review Technique) model is a network model that accommodates this possibility of fluctuation in times for completion of tasks. These models involved recognizing specific tasks and targets and establishing an appropriate sequence in which these tasks can be executed. This is portrayed in the form of a network diagram with the time estimates for various tasks. This enables the identification of what is known as the 'critical path' which is the most crucial series of activities. If any of the tasks in the 'critical path' is delayed then it will affect the overall project. Visualization can be used to enhance this process by developing scene renderings for crucial 'milestones' along this critical path. These can be used to double check if the project is on schedule. Figure 4 shows the PERT chart along with the OLE-Enabled GUI that facilitates viewing the visualizations depicting the project activities corresponding to various milestones.

In a construction project, the success of every construction phase can be measured by the physical construction that results from that phase. Clearly defined visualization(s) that depict the expected outcomes from each phase of construction can be generated beforehand and these can be embedded into the framework as shown below. For instance, in Figure 4, the two visualizations show the finished stages of construction at two phases. Any lags or setbacks in construction (in the real-time) can be compared with the pre-planned designs and faults and delays can be easily identified. This facilitates a more concrete evaluation and hence decision-making rather than relying on abstract or vague milestones.

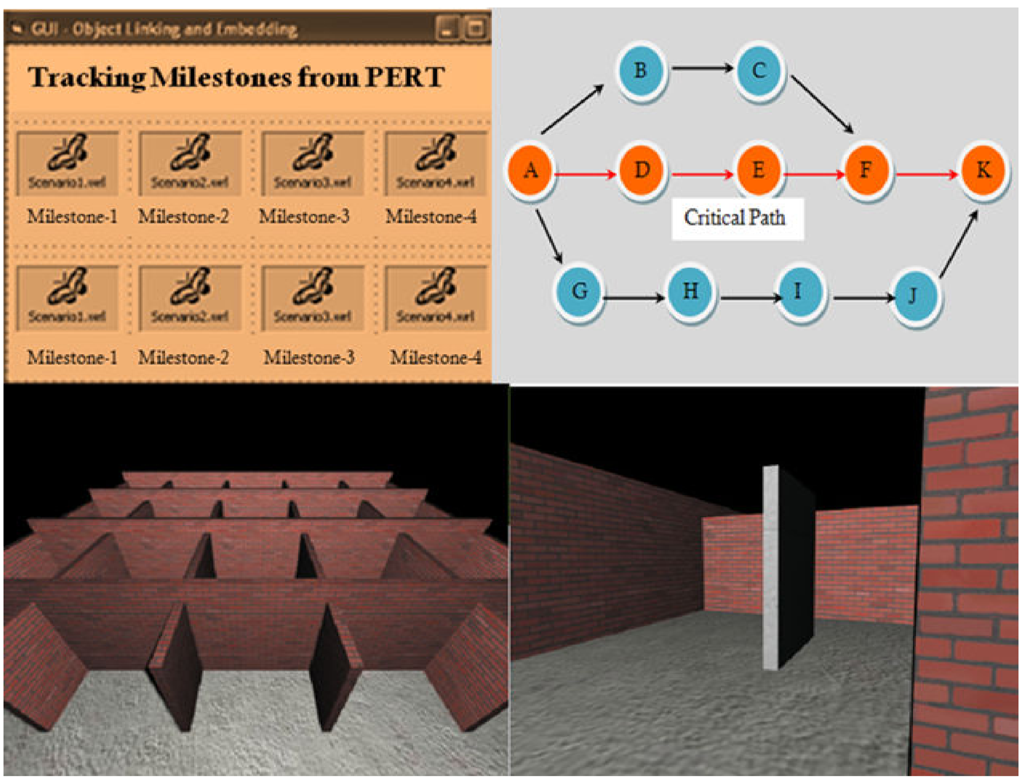

Figure 4: Diagram illustrating the integration of CPM/PERT stages with Visualization and the use of OLE (Object Linking and Embedding) to select and view milestones along the critical path

VII. Alternative Design Scenarios and Quantity Estimation

Once the purpose(s) or objective(s) of the construction project have been identified various design schema can be sketched of which the most appropriate one can be chosen. Construction costs or figures involve different elements including manual labor and materials. From the perspective of this study, we would primarily focus on materials from the 'quantity estimate' point of view. In other words, it is important to evaluate alternative design scenarios that satisfy the objectives of the construction project with due consideration the quantity estimates corresponding to the various designs. The selection of the final design may be based on various factors including: (1) economy of construction, (2) aesthetics, and (3) other practical advantages a design offers.

Also, similar to the process of tracking construction progress and verifying milestone achievement as discussed in the previous section, the material requirements during various construction phases can also be better understood based on corresponding virtual representations. This will serve as a significant boost to enhancing performance and cost-efficiency of the construction.

IIX. Results and Discussion

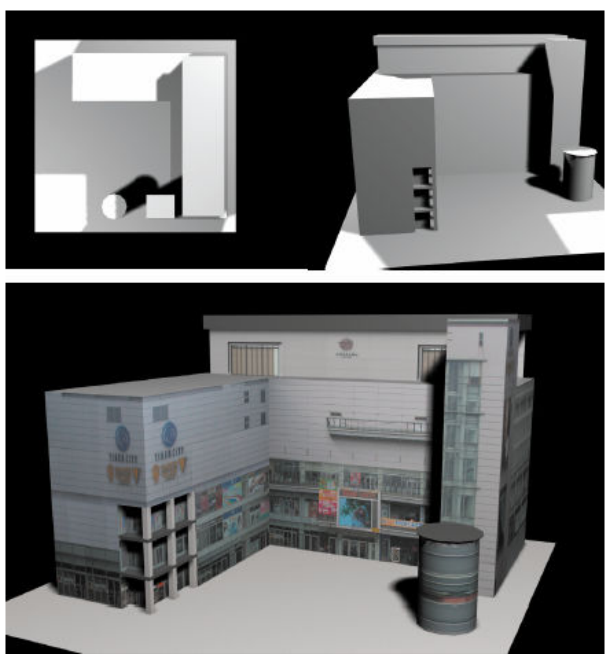

Figure 5. Detailed model of a building. Top, Front, and Texture-mapped Views

This research proposed a prototype 3D design environment in the form of a virtual world and the positional and descriptive details of the scene elements incorporated into it. The intention was to create a 3D design that serves as a model guiding the overall construction process; nevertheless, the 3D design can also serve as visual database that serves various purposes including construction management processes, including schedule tracking and quantity estimation. This aids the construction design in a holistic manner by facilitating cost effectiveness and time-efficiency. The study was carried out only on a small scale since this model was intended to serve only as a prototype. The resulting scene representation is in the form of a three dimensional world containing the pictorial 3D representation of the design in a setting similar to their original environment wherein the users can not only get a 'feel' of the real world setting but also navigate within the world. This also enables the users to view the environment and elements from different angles and perspective and even manipulate the environment.

Besides the conventional views that typical building drawings would provide, the scene depicted in Figure 5 gives a glimpse of the finished product, which facilitates deciding on the final combination of textures and appropriate juxtaposition of component scene elements. In Figure 6 below, the various pitfalls in the proposed design are easily found using the visualization. Improper allocation of space, unused spaces, disproportionate alignments and various other shortcomings, which would otherwise not be noticed, can be easily studied using the virtual representations. A vast majority of the shortcomings can be detected at an early stage and rectified. The proposed model that integrates project planning has various advantages including the following: (1) verifying if the project is on schedule, (2) checking the status of all activities, (3) evaluating the on-site activity with planned activity, (4) making modifications if the design is not satisfactory, and (5) double checking if the construction on the critical path is on the mark.

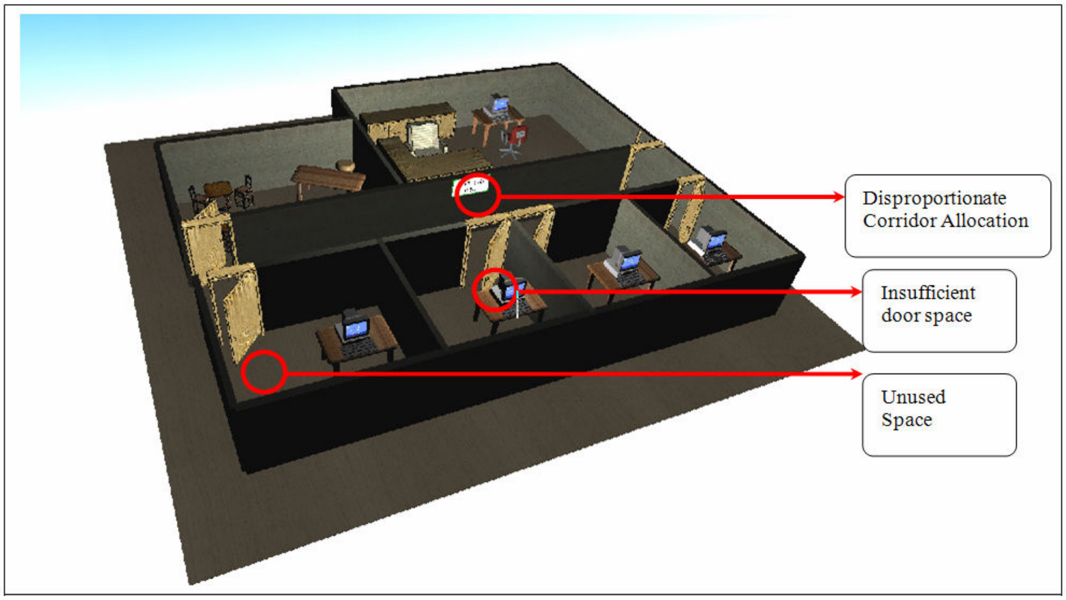

Figure 6. Shortcomings in proposed design illustrated using 3D Visualization Model

The advantages of using virtual environments for construction design are numerous, including (1) that multiple scenarios can be evaluated, (2) infinite viewpoints can be generated, (3) a guided tour of buildings can be generated by linking using scripts, (4) decision-makers can view the finished product before hand, (5) the virtual models are extremely time-saving and economical, (6) aesthetic view quality can be evaluated and modified if needed, (7) all plans/modifications can be done at the convenience of desktop, (8) facilitates proactive interference as future scenarios can be built, and (9) facilitates non-destructive testing as product is available beforehand.

IX. Conclusion

The goal of this study was to design an innovative framework integrating visualization with the various aspects of construction design to aid the overall construction management process and to generate pragmatics designs. With modern construction activities becoming increasingly complex by the day, the process of planning and design is getting increasingly multifaceted. The effective resolution of such multifaceted problems will require the synchronization among various disciplines and exploiting the advances in various related disciplines. This study illustrated with various examples the advantages of using a VR based visualization in the construction design process and the various benefits such a framework would offer to the planners and designers.

References

Berry, J.K., Buckley, D.J. & Ulbricht, C. (1998). Visualize Realistic Landscapes. *GIS WORLD*, Vol. 11, No. 8, 42-47.

Chandramouli, M. & Huang B. (2008). Virtual Environments for Geospatial Applications. Applications, Methods and Issues: *Encyclopedia of Geoinformatics*, Karimi, H. A., (Ed.), Idea Group.

Church, R.L., Murray, A.T., Figueroa, M.A., Ager, A.A., McGaughey, R.J. & Merzenich, J.(1994). *Artificial Landscape Visualization of Ecosystem Management Plans*.

McCormick, B.H., T.A. DeFanti & M.D. Brown (1987). Visualization in Scientific Computing, *Computer Graphics*, Vol. 21, No. 6, November 1987.

McGaughey, R.J. (1998). Techniques for Visualizing the Appearance of Forestry Operations. *J. Forestry*, Vol. 96, No. 6, 9-14.

Shiode, N. (2001). 3D urban models: recent developments in the digital modeling of urban environments in three-dimensions, *GeoJournal*, Vol. 52, No. 3, 263-269.

Tufte, E. R. (1990). *Envisioning information*. Cheshire, Connecticut: Graphics Press.

_________ (1992). *The Visual Display of Quantitative Information.* Graphics Press.