INFORMATION-RICH VIRTUAL ENVIRONMENT (VE) FOR DESIGN REVIEW

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ABSTRACT: In the A/E/C industry, design review techniques are used to improve design quality, insure compliance with current codes and standards, improve design constructability, and meet project's goals and owner's objectives. Design review is a multi-tasking approach; information from various independent sources (e.g. building codes and standards, design specifications, design manuals, etc.) needs to be referenced concurrently while reviewing and coordinating plans of various design disciplines.

Current common design review methods rely mainly on paper-based checklists and 2D plans to perform the review. Several disadvantages of these manual methods can be identified, including: 1) checklists are generic and reviewers need to identify the guidelines that apply to a given review; 2) checklists are also linear in nature which may force the review to follow a pre-defined top-to-bottom sequence; 3) current methods do not allow for a structured automated approach to capturing and sharing reviewers' comments and feedback; 4) information may not be retrieved quickly and efficiently within the limited review time frame. This renders the design review process time- and resource-intensive which may force reviewers to sacrifice the thoroughness of their reviews.

This paper describes an information-rich virtual environment (VE) framework for design review. The framework utilizes a real-time intelligent algorithm to access needed data and information to perform a design review while viewing the 3D model. The algorithm provides various search and retrieval modes to assist the user in filtering, querying, sorting and displaying data and information during the 3D model walkthrough. Reviewer's comments and changes are captured and shared by others. A proof of concept prototype is being implemented using the Torque 3D Game Engine.

KEYWORDS: 3D modeling, design review, game engines, rule-based, torque game engine, virtual environments.

1 INTRODUCTION

Design review processes are used by the Architects, Engineers, and Contractors to improve design quality; maintain proper usage of material and assemblies; insure compliance with current codes and standards; improve design constructability; and meet the project's goals and owner's objectives. Design review processes are crucial for detecting and identifying discrepancies, errors and inconsistencies in designs (East et al 1995, East 1998, Spillinger 2000, Soibelman et al 2003, and East et al 2004). Such deficiencies are anticipated because the designs are prepared by various design professionals.

The traditional approach of design review has always aimed to guide reviewers in performing the review on the design produced. Guidelines in the form of checklists and sets of procedures (Shiratuddin and Thabet, 2003a) are oftentimes used to accomplish this task. Without proper guide and due to the complexity of the review process itself, reviewers can easily be bogged down with multitude of information that needs to be accessed, compared and confirmed. In addition to geometric, numeric and textual design information presented in a large number of design drawings, the design review process requires access to other information available through various sources including construction contracts, design specifications, building codes and standards, safety manuals, design check lists, and so on (Figure-1). These sources of information are scattered, either in paper-based or electronic (e.g. on-line) format and are not linked. The design review process becomes multi-tasked which makes it hard for reviewers to quickly and efficiently cross-check and reference information during the review. Reviewers need to seek information within the limited review time frame (usually within a week). This renders the review process a time- and resource-intensive, which may force reviewers to sacrifice the thoroughness of their reviews (East, 1998).

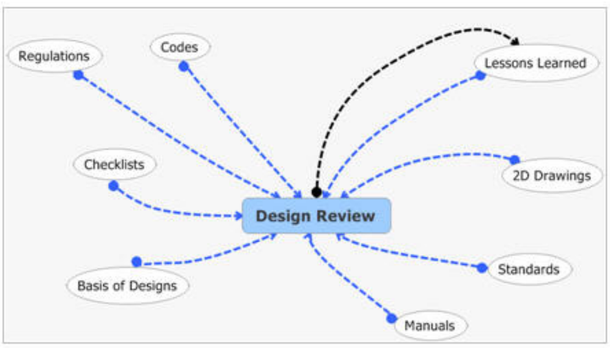

Figure 1. Sources of information used during design review.

Various tools are used in performing design review such as inter-disciplinary checklists, light-table, online review system, and physical mock-ups (Staub-French and Fischer 2001, Shiratuddin and Thabet 2003a). These methods are mostly manual, inefficient (East 1998, East *et al* 2004), and do not utilize potential technologies such as centralized information databases, information visualization, and intelligent retrieval of information.

The classifications of information shown in Figure-1 were arrived at through a series of interviews that the authors have conducted with local AEC companies in Blacksburg and Roanoke, VA, USA. The interviews were conducted to identify the general trends of design review, participants' view on design review in a virtual environment (VE) and their wish-list/suggestion/recommendations on areas of design review that needs improvement etc. The authors also acquired and reviewed design review information from selected Virginia Tech's past construction projects' design review documents, and expert interviews transcripts. Content Analysis method was used to extract this information. Content analysis is a systematic, replicable technique for compressing many words of text into fewer content categories based on explicit rules of coding (Berelson, 1952; U.S General Accounting Office, 1996); Krippendorff, 1980; and Weber, 1990). The Content Analysis method identifies patterns of design review activities and classifies design review information into themes such as design review entities, trends of design review errors/inconsistency, design review comments, and attributes of design review information (e.g. material type, part number, cost, dimensions, building system type, building codes, project description, etc.).

Previous work has been done by the authors in the area of construction design review and VE (Shiratuddin and Thabet 2002, 2003a, 2003b, and 2003c). The authors found that there is a huge potential for the improvement of design review in construction with the incorporation of VE. The concept of VE if incorporated in design review will improve the design review process because pertinent design review information, from the various sources, can be embedded in the VE, allowing an integrated and effective design review process. The information is more visually presented, complete and would provide a common language for all design review team members.

This paper describes an information-rich virtual environment (VE) framework for design review. A real-time intelligent algorithm is proposed to assist the user in filtering, querying, sorting and displaying data and information while viewing the 3D model. The algorithm comprises four search and retrieval modes:

1. a discipline centric mode: utilizes criteria based on the type/role of reviewer,
2. a task centric mode: utilizes criteria based on the objectives of the design review session being performed,
3. an object centric mode: utilizes criteria based on the graphical component/assembly selected by the user for review,
4. a location centric mode: utilizes criteria based on the relative spatial position of the reviewer within the 3D model.

Using a rule-based approach, the logical links between the needed information, the 3D objects, the reviewers and their location in the environment, are established. Reviewer's comments and changes are captured and shared by others. A proof of concept prototype is under development using the Torque 3D Game Engine (TGE).

2 DESIGN REVIEW IN A VIRTUAL ENVIRONMENT

The current methods of design review could be improved by leveraging the capabilities of VEs. Presently designs are represented two-dimensionally and the drawings function as a communication tool for design and construction. This communication function can be more effective for stakeholders if the designs are represented in 3D, displayed in a real-time VE, and linked to information needed to perform design review. Architectural design has been the main driving force for developments in 3D modeling and VE. By allowing architects to visualize and immerse themselves in the designs, a much clearer understanding is gained of both the qualitative and quantitative nature of the space they are designing.

Visualization and VE enable designers to evaluate proportion and scale using intuitive interactive modeling environments (Kurmann, 1995) and simulate the effects of lighting, ventilation and acoustics in internal environments (Nimeroff *et al*, 1994). The use of visualization in this area also includes the simulation of egress from buildings for the design of fire escape routes (Spearpoint, 1997). As a visualization tool, VE is also used to communicate design ideas from designers to clients by generating walkthrough models to test the design with the clients in a more direct manner (Ormerod and Aouad, 1997). VE allows for developing applications that are more advantageous than standard 2D format or 3D models. This includes capabilities for dynamic walkthroughs, and real-time interaction with the 3D objects (e.g. selection, manipulation and modification). According to van Dam *et al* (2000), visualization offers substantial difference from 2D and 3D because of its medium. 2D and 3D viewing is restricted on screen, gives one the sensation of looking through a window into a miniature world on the other side of the screen, with all the separation that sensation implies, whereas VE makes it possible for one to become immersed in, and to interact with life-sized scenes.

Bowman *et al* (2003) realized that information-rich VEs, comprising three-dimensional graphics (or 3D model), spatial data, and information of an abstract (or symbolic) nature that is related to the space, can stimulate learning and comprehension A study by Messner *et al* (2003) found that VE when used in construction educational context provides students with enhanced understanding of a subject. This is because students have the opportunity for trial and error, and solve the problems creatively, without the fear of making costly mistakes or unsafe decisions as they would have in real situation.

3 EARCH AND RETRIEVAL ALGORITHM

In overcoming the problem of manually processing the multitude of design review related information, we developed an algorithm to facilitate data and information search and retrieval. The algorithm that we developed comprises rules that binds and guides the processing of design review information. The algorithm is based on the questions that occurred in real-world during design review. In practice, a reviewer will have two questions in mind: (1) who am I? and (2) what do I want to review? When these two questions have been answered, the algorithm will sort out and also anticipate the information required by the reviewer. Sub-questions following question (2) that a reviewer may ask oneself can be (not in any specific order); (2a) where am I? (2b) what construction component do I want to review? (2c) what do I want to do?

The algorithm comprises four search and retrieval modes to assist the user in filtering, querying, sorting, and displaying data and information within the VE. The four modes are; discipline-centric (D), task-centric (T), object-centric (O), and location-centric (L). Designations are assigned to each mode; T represents the task that will be performed, O being the object of interest, L corresponds to the location of the reviewer within the 3D model, and D represents the different construction disciplines which includes architectural, structural, civil, mechanical, electrical and plumbing. Each entity within a mode is given a designation for the purpose of creating the relationships between the disciplines D, the objects O, the locations L, the tasks T and the information stored in the database. New designations can be created and assigned to any of the modes should there arise any needs for them. The designation to the different entities in each mode is denoted by alphanumeric subscripts. Table 1 shows some examples of the designation.

Table 1. Examples of designations given to the entities in each mode.

Designation	*Modes*	*Designation*	*Modes*
D…	Discipline	T…	…Task
Di	Architectural	Ti	Verify that pump size is adequate
Dj	Structural	Tj	Kitchen hoods and ducts are regulated by code
O…	Object	L…	…Location
Oi	Beam-1	Li	Living room
Oj		Lj	

Figure-2 shows an example of interactions between the search and retrieval modes. Subsequent interactions are fission and finite in nature until the required information is found. In this example, the search starts with the discipline of interest to be reviewed. Di, Dj, Dk, D… simply denote the different disciplines designations (refer to Table-1). Once a discipline is selected for review, information search and retrieval will commence. The next level of interaction will either be between Di and Ti, Li or Oi. The interaction between Di and Ti is closely related and almost interchangeable. The T centric is based on the tasks that will be performed by a reviewer, and the discipline selected. In Figure-2, Ti can either interact with Li or Oi. Another form interaction is between Di and Li. The L centric is based on the location where the reviewer is. Once a location is detected and identified, information processing will again commence. The L centric can only interact with O since a location contains objects that can be reviewed. Oi can also interact with Oj whereby Oj is a neighboring object. The interaction between Li and Ti is not permitted since T centric is discipline-dependant and not based on location.

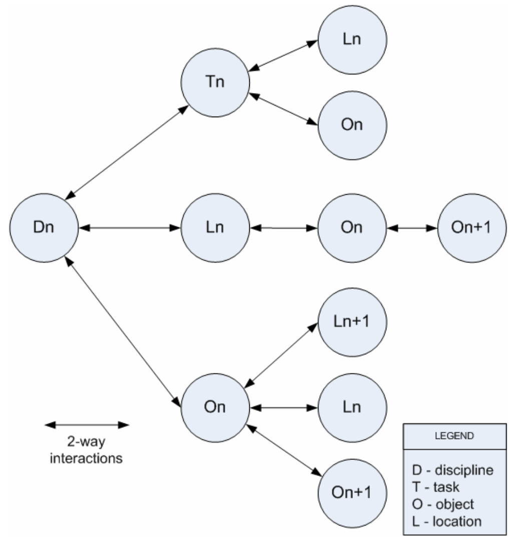

Figure 2. An example of interactions between different modes.

Another example of interaction can occur directly between Di and Oi. Once an object is selected, information processing with regards to the object will be set in motion. The Oi centric can either interact with Li, Lj or Oj. This is due to the fact object Oi (with present location Li) may be connected with another object Oj in location Lj. An example would be a duct system that spans across multiple locations.

Based on the interactions between the modes, the algorithm will accommodate a more methodical approach in performing design review. The algorithm is also used for information processing. The algorithm uses the *If, Then, And, Next* and *Else* statements. Referring to Figure-2, an example algorithm is shown below:

```
If centric D = Di (Architectural)
        Then process information related to Architectural discipline

Next check centric for T, L And O
        If centric = T
        And T = Ti
        Then load Architectural checklist
        And process information related Architectural checklist
        And process information on Li
        And process information on Oi

Else check for L And O
        If centric = L
        And L = Li
        Then process information on Li
        And process information on Oi
        And process information on Oj (neighboring object)

Else check for O
        If centric = O
        And O = Oi
        Then process information on Oi
        And process information on Oj (neighboring object)
        And process information on Li
        And process information on Lj (Oi may also exist in Lj)

End
```

A rule-based approach is used to define the search and retrieval processes. Based on these rules, the relationships and links among information, the 3D objects, locations and reviewers are generated. The design review system's rule-base is made up of many of smaller rules. These rules provide a systematic way of visualizing information and performing design review activities in the VE. This rule-based approach will also provide rules for the processing of design review related information. From the rules produced, complex relationships and links among information will be generated. These rules will: a) generate information relevant to a specific reviewer, related design review tasks, and assist in making decisions, b) help direct/navigate design review activities, c) recommend possible solutions based on the decisions reviewer have made in previous steps, and d) inform reviewer if changes made will affect other adjacent or related components. Figure-3 and Figure-4 show possible information that can be accessed by a reviewer, i.e. in this case a Structural Reviewer. The information that is related to the Structural Reviewer is categorized into three levels; Levels-1, -2 and -3. Higher levels indicate more detailed information.

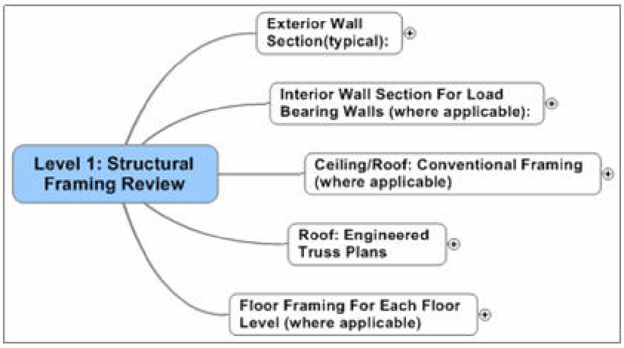

Figure 3. Level-1 information.

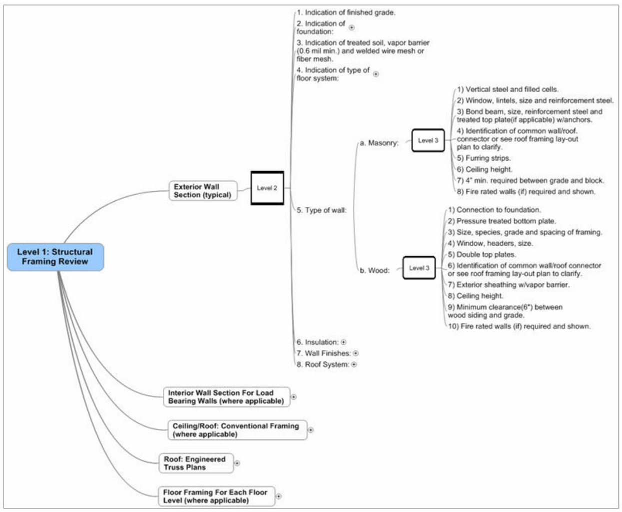

Figure 4. Example of Level-1, Level-2 and Level-3 information.

4 DEVELOPMENT OF THE PROTOTYPE SYSTEM

The widespread usage of 3D game technology beyond the traditional video games and the entertainment applications to include education and research applications is very promising (Shiratuddin and Thabet, 2002).

In this research, we use the Torque 3D Game Engine (TGE), to develop a prototype VE design review system for real-time 3D and information visualization. The TGE is a commercial grade game engine which has been successful in bridging the gap among multiple industry sectors (Shiratuddin and Fletcher, 2006). The TGE was originally developed by Dynamix; a computer game development company called. Dynamix created computer games titles such as Earthsiege, Starsiege, Tribe and Tribes 2 (Maurina III 2006, Finney 2005). The founders of Dynamix then created GarageGames and currently distribute TGE as one of the products for independent game developers. Although there are other game engines available, without access to the entire source code (or SDK) it is difficult to further expand beyond what the stock engine is, to include features and requirements that can be used by design and construction industry (Shiratuddin and Thabet, 2003a). Current licensing of the TGE only costs $150 and this includes the entire source code that can be modified.

The prototype design review system is a heavily modified version of the TGE. Utilizing C++ and C-like syntax scripting language, additional codes were written to provide the added functionalities for design review purposes. Microsoft Visual Studio is used as the programming IDE (integrated development environment) developed using an IBM-PC compatible desktop computer. The prototype has been tested and supports VE devices such as the head-mounted-display (HMD), tracking devices, data glove, 3D navigation input devices, game input devices and stereoscopic display (through the use of nVidia consumer stereo driver).

A new component which is a database utilizing SQLite is currently being integrated into the design review system for the purpose of storing and retrieving design review related information. Current approach of querying design review information only includes a one keyword search. When queried information is found, a list of search results will be displayed. The results are classified into their own category to allow easy identification of the required information. Besides querying, reviewers are able to delete and add new information into the database hence allowing for future expansion of the information database. Future implementation will include Boolean search and multiple keywords. A rule-based engine is also being developed to complement the intelligent information filtering and processing (refer to section 3).

Figure-5 shows the structure of the design review system engines and how they work with one another. In the design review system, the TGE provides the real-time visualization in the VE, the graphical user interface (GUI) and the capability for 3D object manipulations. As abovementioned, a SQLite database engine is currently being integrated with the Torque engine to provide support for storing all the design review information. Whenever a reviewer interacts with the 3D objects and information in the VE, interactions between the three main engines will occur in the background. The interaction between the database engine and rule-based engine is almost cyclical, and when the requested information has been retrieved (based on the flagged *True* statement provided by the rule-based engine), the information is then passed to TGE so that the information can be visually presented to the reviewer in the VE.

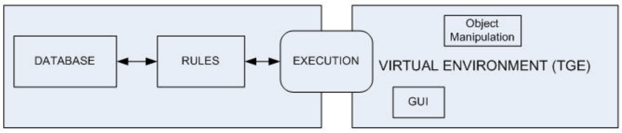

Figure 5. The structure of the engines that drive the design review system.

In our implementation of design review, 2D drawings are replaced by 3D models in a VE. The 3D models and the various needed sources of information are centrally located and stored in databases, which can be accessed by the reviewer at a click of a button in the VE. Access to design review information is benefited from a defined intelligent search and retrieval processes that filters, query and sort the needed design review information based on four modes: D, T, O, L. Which ever mode selected by the reviewer, once the 3D model in the VE has been reviewed, and if any errors or inconsistencies are encountered, the reviewer can quickly access any related information to validate that the error or inconsistency has occurred. To further confirm this error, a reviewer will be able to access design review related information (such as manuals, standards etc.) stored in the centralized database. After verifying the related issues, the reviewer can then input any comments or recommendations back into the design review system. The comment or recommendation is then stored and can later be accessible to other reviewers, and more importantly by the designer who will revise the design.

The entire development process of the system involves many aspects such as object manipulation, collaboration, networking, GUI, information processing and visualization etc. In this paper we only described the implementations of the four modes; D, T, O, L. The following sections discuss an example for a design review of a 3-bedroom single story house.

4.1 *Implementation of the discipline-centric (D) mode*

Figure 6 shows the implementation of the login screen to allow a reviewer to define a role and discipline of review interest. Once logged in, the system will present the required view of the 3D model in the VE. For example, a mechanical engineer is interested in reviewing the mechanical systems of the house, hence the system will initially present only the mechanical system related 3D objects. However, should the mechanical engineer need to review other connected building systems, the system will allow for other 3D objects from different building systems to be displayed along with the mechanical system.

4.2 *Implementation of the location-centric (L) mode*

This mode is used when a reviewer wants to get a general overview of the facility. The information filtered and presented will not be too detailed. For example, a structural system reviewer enters the VE with the intention to review the external façade of the house. The pertinent information he needs to visualize graphically and textually is the Level-2 information (Figure-4) i.e. the general indication of: 1) the finished grade, 2) the foundation, 3) any treated soil, vapor barrier (0.6 mil min.) and welded wire mesh or fiber mesh, 4) the type of floor system, 5) the type of wall, 6) the type of insulation, 7) the wall finishes, and 8) the roof system (since roof system is connected to the wall system).

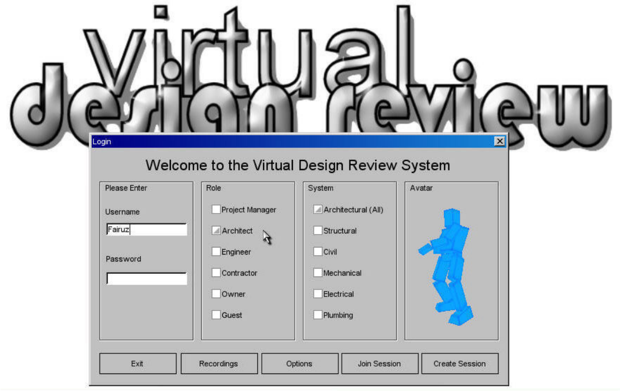

Figure 6. Login screen to cater for discipline-centric information processing.

In this mode, the design review system is designed in such a way that when a reviewer leaves a location and enter another, the system will present a cue alert. The location triggering mechanism (or markers) is placed at specific locations within an area of space, usually at the entrance such as a door entrance. The triggering mechanism is important as it provides the data for the system to start filtering all the possible information required for a specific location in which the reviewer is currently located and wishes to review. Figure-7 shows an example of the placement of the location triggering markers.

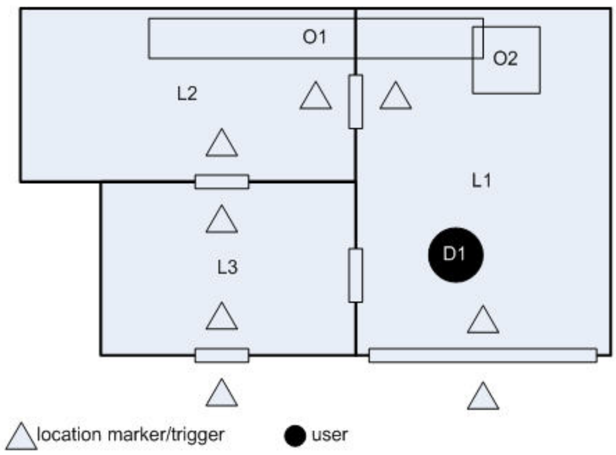

Figure 7. The location marker/trigger placement in different locations.

4.3 *Implementation of the task-centric (T) mode*

This mode is used when a reviewer chooses to refer to a pre-defined design review checklist to perform the review. The checklist option is made available as a means to systematically guide the reviewers throughout the entire review process. The reviewer does not have to follow what is indicated in the checklist but rather use it as a reference. Table-2 shows an example of a checklist for *Exterior Wall Section → Type of wall → Masonry Wall.*

Checklists categorized by discipline, assembly, location, and so on will be stored in the system. Items in the checklist can be either added or removed at anytime depending on the project's needs. Results from our interviews show that design companies have their own customized checklist/s to review designs. To date, there is no known standardized checklist being produced and used by all reviewers.

Table 2. Example checklist for Exterior Wall Section Level 1.

		OK	n/a	Comments
1	whether vertical steel is used, if yes, the type of steel and the filling used in cells			
2	the type of window and lintels, the sizes and the reinforcement steel			
3	bond beam, size, reinforcement steel and treated top plate(if applicable) w/anchors			
4	identification of common wall/roof connector or see roof framing lay-out to clarify			
5	furring strips			
6	ceiling height			
7	4" min. required between grade and block			
8	fire rated walls (if) required and shown			

The system is designed to allow the reviewer to turn on and off any objects in the VE (Figure-8). This feature allows the reviewer to see what is usually not visible due the nature of the construction assembly, e.g. items 1 to 8 in Table 2. In this example, by turning off the external wall layer (or the interior drywall layer), the reviewer will be able to perform a review on the specific items on the checklist.

Figure 8. A reviewer is able to turn on and off any object selected in the VE.

4.4 *Implementation of the object-centric (O) mode*

This mode is used when a reviewer decides to review a specific object in the VE. For example, a structural reviewer wants to know the details of the rafter used for the house. The reviewer can directly click on the ceiling/roof object. The system will return the information on locations of the rafters, ceiling joist, ridge beam, and collar tie, size, species, grade and spacing in the form of pop-up window (Figure-9).

5 CONCLUSIONS

Our proposed approach of design review has a great potential in improving current design review methods that are highly dependent on paper-based checklists. The new and enhanced features introduced in the process allow reviewers to have access to the various needed information from one source. Reviewers can seek information quickly and efficiently within the limited review time frame, thus need not sacrifice the thoroughness of their reviews. Although many new improvements have been made to the Torque engine to transform it into a design review system, there are still issues that need to be resolved. Future work can research on issues such as improving GUI design, applying better HCI (Human Computer Interaction) techniques, enhancing the networking protocols, design review working protocols, design interaction between users in a collaborative virtual environment, and so on.

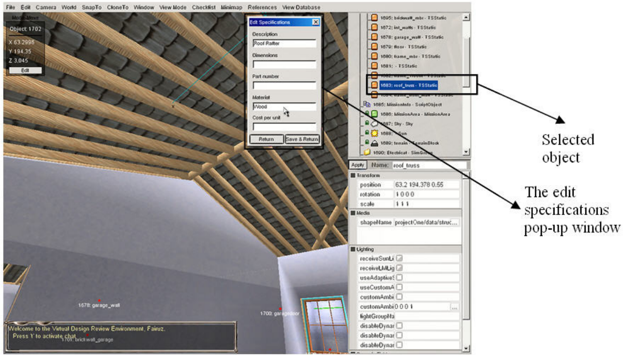

Figure 9. Reviewer is able to select individual object in the VE and review its specifications.

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