

INTERACTIVE HOME DESIGN IN A VIRTUAL ENVIRONMENT

Kevin Kitchens
School of Construction
The University of Southern Mississippi
Hattiesburg, MS 39406
USA
kevin.kitchens@usm.edu

Mohd Fairuz Shiratuddin
School of Construction
The University of Southern Mississippi
Hattiesburg, MS 39406
USA
mohd.shiratuddin@usm.edu
<http://www.fairuz.us>

ABSTRACT: In today's residential market, clients are often faced with many challenges when designing and buying their own home. Most clients find it difficult to visualize exactly what they need by simply going through two-dimensional (2D) blueprints or floor plans. Study shows that 2D visualization has a much steeper learning curve because human naturally sees three-dimensionally. Common tools used to create 2D plans such as AutoCAD have certain advantages in home design, but it may be complex for average users to visualize exactly what has been created. 3D modeling addresses the third dimension (i.e. depth) that is not present in 2D CAD drawings. It allows for better visualization and understanding of designs. For architects, this is a leap from traditional method whereby clients are presented with numerous 2D drawings. The use of 3D modeling can improve precision and speed of the design process and eliminates potential costly errors. However, current 3D modeling software provides limited real-time 3D interactions for users. This paper presents an interactive home design application in a virtual environment. We developed a prototype using a next-generation 3D game engine known as the C4Engine. This paper also describes the development process of the prototype application, its components and features.

Keywords: home design, interactive visualization, next-generation 3D game engine, virtual environment

INTRODUCTION

Home design relies heavily on the communication between the architect and the client. It is the responsibility of the architect to ensure clients completely understood every design aspect of their future home. Communication between the architect and client may be in the form of verbal communication, written documentation, architectural drawings (sketches and technical), and architectural renderings and walkthroughs. Oftentimes a "bad design" is not design that was done poorly, but at some point during the design process, the design is misinterpreted by either architect or the client.

An architect often communicates with the client using 2D architectural drawings, and this method of communications oftentimes is a challenge for new home owners to correctly understand the 2D drawings and visualize them mentally (3D mental model). Architects tried to remedy this problem by offering clients to see photorealistic still renderings and walkthrough movies of their future homes. These still images may give clients better understanding of the design but the images are not interactive and making designs seem permanent to clients. In many cases, clients often trust the intuition of the architects without questioning or fully understanding the spatial layout of their new homes. A client may not be aware of the design aspects he/she dislikes until construction is either underway or completed. Some of the aspects that may be inconsistent with the client's expectation can be as basic as the incorrect materials or lighting conditions, and can be as major as changing the layout of rooms. If such occurrences happen, inevitably, more costs are incurred by the client.

This paper presents an approach for a client to walkthrough a design of a three bedroom house in a virtual environment (VE). A prototype application is currently being developed using BuildITC4. BuildITC4 is based on a next-generation 3D game engine known as the C4Engine developed by Terathon Software (Lengyel, 2007). Based on our students' inputs, BuildITC4 is being modified on an on-going basis and our end goal is for it to be a VE-based interactive architectural design software. To date, the prototype application has following features; simulation of depth of textures and materials through the use of bump and parallax mapping, real-time interaction and visualization of the 3D model of a house, clients are able to change certain characteristics of the proposed house design, interact with different lighting conditions, visualize different alternative materials, make layout changes such as adding or remove walls and changing the layout of rooms. This paper also describes the development process of the prototype application.

2D MISCOMMUNICATION, 3D REMEDY AND VIRTUAL ARCHITECTURE

Architect-to-client communication is important and oftentimes being the overlooked aspect of design. According to Chen (2004), an unbalanced number of defects and flaws in architectural design can be traced to the inefficiency of communication between the architect and the client. Poor communication has been the main hindrance to the quality of design and at the same time affected clients' satisfaction. The root of this miscommunication stems from the fact that majority of the clients have difficulties understanding the aspects of 2D architectural drawings. Human beings see objects three-dimensionally and do not think in a two-dimensional perspective. Chen (2004) further states that "The first problem the information receiver experiences when communicating with the architect by architectural drawings is the difficulty to visualize the three-dimensional space by combining various information from the plans and the facades." In fact, architects and designers go to school and study the method 2D interpretation for several years until it is fully mastered (Sweller, 1988; Dobert, 1999).

However, when clients are presented with three-dimensional images, their mind does not have to generate the mental imagery from the abstracted 2D architectural drawings. This leaves more space to the actual spatial reasoning process (Chen, 2004). Furthermore, the series of 3D images or 3D animation decomposes the information of the architectural concept into small chunks hence avoiding the chance of information overloading during communication. Chen's research shows that a 3D image can greatly simplify the communication process by offering the client a chance to see the architectural concept with the presence of depth, and thus taking away the need to piece together two or more static images in order to get the desired mental image of the architectural design. Referring to another research by Sweller (1988) and Dobert (1999), it can also be concluded that a person without formal architectural training is unable to digest the information presented on typical 2D technical drawings. The information required to visualize a specific design concept is scattered across several different illustrations. This will greatly reduce both the fidelity and speed of communication between the architect and the client.

In order to tackle this communication problem, architects are beginning to utilize 3D computer generated models. 3D modeling opens up the avenues for architects to create photorealistic renderings and walkthrough animated movies that are easier for clients to understand and comprehend. A complete 3D model constitutes of the following elements (Cory and Bozell, 2001): **Form** - Shape and Size, **Attributes** - Materials and Physical Properties, **Relationship/Assembly** - How parts are related, and what moves with what and **Behavior** - Doors opening and closing. The use of 3D modeling gives the architect the upper hand when it comes to showing the client aspects of design. However, there are still flaws in this approach. According to a research conducted by Kheir Al-Kodmany (2002), when a client views a 3D animation walkthrough of ones future home, one may see something that needs to be changed e.g. the material used. Since the animation was not rendered in real time (or pre-rendered) it is not possible for the architect to make instant design changes. This limitation makes the client felt like the design is permanent or stagnant (Kheir Al-Kodmany, 2002). In fact, if the client wishes to change something such as textures, lighting conditions, or remove a partition wall, the architect must take back the model, make the changes, re-render it, and then show it again to the client. What if the client wants to make more design changes? This process becomes a repetitive-loop and this is one of the main problems of non-interactive design. Most clients do not understand the elements that go into developing 3D scenes; therefore, they will not understand the length of time it takes to re-render a 3D scene or model (Kheir Al-Kodmany, 2002).

It is a common practice that the architects and contractors create a sample life-size mockup or physical mock-up (PMU) of a house or a building (Shiratuddin and Thabet, 2001). Mackie et al (2002) discovers that, "Three-

dimensional (3D) visualization is currently used widely in the design process. There is a point, however, at which traditional 3D visualization approaches (viewing 3D models using software on desktop displays) becomes limited. While these visualizations are very helpful, they have no comparison to the experience of viewing a physical, full-scale mockup in real space. A PMU provides a better understanding of the 3D spatial structure and scale of the current design. Thus, some construction companies create actual life-size mockups of model homes so that problems can be discovered before construction begins. While life-size PMUs may have proven useful, they have problems as well. The problem mainly lies in the cost and time to construct these mockups that will add up as cost, space and time for the professionals involved. Mackie et al (2002) concludes: "Unfortunately, finding a problem is not the same thing as finding the solution. Therefore, several iterations may be needed, and there may be several mockups created and destroyed. The obvious costs of parts, labor, and travel costs for domain experts to get to the mockup site outweighed the finished design; and it is a cost that adds up for any company." The abovementioned problem can be resolved through the use of real-time interactive and immersive VE. Creating life-sized digital mockups (DMU) using 3D modeling and immersive VE instead of hands and nails is more economical and faster, resulting in a more efficient design process (Mackie, 2002).

According to Kheir Al-Kodmany (2002), VE takes 3D visualization a step further and is generally defined as a 3D computer-generated synthetic environment that gives the user the sense of being immersed as in the real world. But not all types of VE are immersive, e.g. desktop VE often lacks immersion because user must still use the computer screen as the gateway to the virtual world. Immersive VE will give the user a first person view of the environment that will in turn, offer a more realistic sensation of the explored space. The immersive VE can be used as a design tool and is a step above the PMUs. Mackie et al (2002) proves that, "Architecture has been one of the major application areas for VEs. Immersive walkthroughs have been used extensively for design verification in which architects, clients, and other stakeholders can immerse themselves within the design to obtain realistic first-person views and a sense of 'being there' that is not possible with the desktop VE. More recently, researchers have studied immersive design and the idea of VE can be used not only for visualization purposes but also for design and modification of it. Immersive design tools are highly interactive hence requiring close attention to 3D user interface design. In a VE, a prototype can be designed more quickly without any overhead costs for parts, and a smaller amount for the labor."

Mackie (2002) has basically concluded that these VE are very useful in conducting design changes and are cheaper in cost but they require a lot of study into the user interface. People can often be intimidated by a complicated user interface; therefore, keeping the interface simple is the way to approach any immersive design tool. However, one can also stand the chance of taking away the virtual experience by making the interface too simplistic. This would ultimately make the virtual experience obsolete. In fact, this is often the criticism of immersive VE used in architecture. Most critics' state that VEs lack a satisfactory level of detail with perhaps the lighting effects is not realistic enough or the materials used are not satisfactory which take away from the realism of the virtual experience. Kheir Al-Kodmany (2002) states that, "In a Virtual House Project created by a Division in Japan, the user, wearing a headset and holding a three-directional mouse, can explore every room in a house. A hand appears on the screen and using this hand, the user can reach out and open drawers, push door handles, turn lights on and off, run the water in the bathroom (with realistic sound effects), open and close curtains, and move furniture. However, architects criticized this program for not providing a satisfactory level of detail to the client." Kheir Al-Kodmany (2002) is stressing the fact that a VE must maintain a certain level of detail for the client so they will feel like they are actually exploring their new home. Based on these facts; realism, non-complicated user interface, cheap and fast construction, we move on to the development tool we are currently using.

DEVELOPMENT TOOL USED

The video and computer game industry is growing at a phenomenal rate. "Contemporary computer games offer a level of detail and realism that leaves little to the imagination. Photorealistic environments along with increasingly sophisticated characterization can give the player the impression that they are actually taking part in the onscreen events," (Doughty and O'Coil, 2005). Computer games have become more interactive and they can engage the user into a whole new world of virtual existence. Doughty and O'Coil (2005) explain that, "Computer games have the ability to engage the player as active participants in the narrative rather than as passive observers. A growing opinion is the notion that computer games can make an important contribution to other processes outside the gaming

field by using these powerful interaction mechanisms.” In fact, using these interactive mechanisms is beneficial when creating a VE for home design and visualization.

However, there are still questions to be answered. What system to use and why? Most next generation game engines can cost as much as \$300,000 to license and this would be a big investment and risky for small and medium-sized architectural or design firms. Utilizing low-cost, highly efficient and high performance engine such as the C4Engine would be the answer to this dilemma. The C4Engine license comes with the engine’s source, meaning that the user has the ability to customize the features and code to his or her liking. If an architectural company were to purchase the C4Engine, then the engine could be modified to fit the specific needs of that company making it a very powerful tool indeed.

We named our tool as BuildITC4 and currently is being developed on top of the C4Engine. Our goal is to make BuildITC4 a 3D real-time and interactive design tool for architecture and construction visualization purposes. The learning curve of the engine is relatively small in comparison to other engines. The online support and resources are great allowing end-users access to numerous documentations, tutorials and discussion threads. Table 1 compares the features of the C4Engine (the C4Engine is the 4th most reviewed engine) to four other most reviewed commercial gaming engines on the market (DevMaster.net, 2007). The reviews are taken from opinions of professional game designers and developers who use the products for commercial purposes.

Game Engine	Developer	Program Language	Operating System	Engine Features	Stability	Ease of Use	Support
Torque Game Engine	Garage Games	C/C++/ Torque Script	Windows Linux MacOS	3.5/5	3.5/5	3/5	3.5/5
TV3D SDK 6	Truevision3D, LLC	C/C++ C# Delphi Visual Basic VB.NET	Windows	4/5	4/5	3.5/5	3.5/5
3DGameStudio	Conitec Datasystems	C/C++ Delphi	Windows	3/5	3.5/5	4/5	4/5
C4 Engine	Terathon Software	C / C++	Windows MacOS	4.5/5	4.5/5	4/5	4.5/5
Unity	Over the Edge	C# Python	Windows MacOS	4.5/5	4.5/5	4.5/5	4.5/5

Table 1: Comparison between different 3D Game Engines

THE PROTOTYPE SYSTEM

The interactive home design application comprises of two main components; software (developed using BuildITC4) and hardware (immersive VE system). The software component consists of the necessary features to support the interactive home design prototype application. The hardware include the Head-Mounted Display (HMD) to allow for immersive display in the VE hence giving users a realistic sense of scale, a 3D-mouse for navigation and interaction in the VE, and a desktop computer (Figure 1).

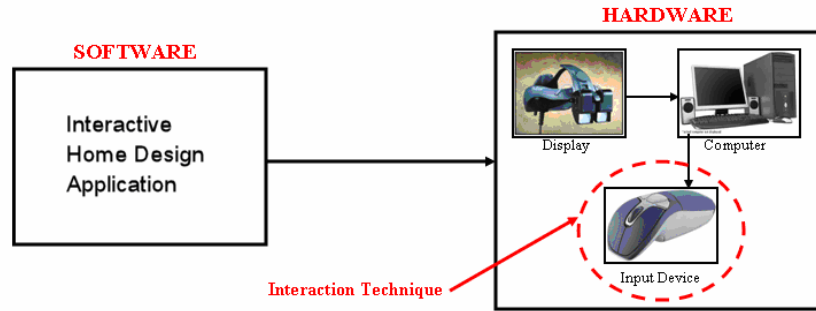


FIG. 1: The components for the interactive home design application

The interactive home design prototype application includes: high resolution material display, various dynamic lighting settings, and interactive panel that gives the user the ability to change materials in real-time. The panels also allow the user to change the different lighting conditions and to take and add certain geometry to the virtual space. These interactive panels are placed in each primary space of the user's virtual home. For instance, most clients are mainly concerned with 3 spaces in their new home: master suite, living room and kitchen. The panel shown in Figure 2 is an example of a living room for a new virtual house. Using this panel, a user will be able to interact with the design and change certain aspects of the room to his/her preferences.



FIG. 2: Interactive Panel Design

The interactive home design prototype application utilizes high resolution textures. The high resolution textures are equipped with bump mapping as well as parallax mapping which give the materials the illusion of depth. A library of these materials is available at the user's disposal for each designated area of the house according to his/her preference of materials. A user is able to change the material on-the-fly of the walls, floors, ceiling, and other geometries such as countertops, furniture materials, and any other geometry found in the space (Figure 3). Figure 3 shows the different material settings applied for the living room space. Each setting shows a different material combination for the walls, floors, and ceiling. Figure 3 also shows the panel controls of the materials for the walls, floors, and ceilings (depicted by the blue arrow switches). Each time the user click on one of the arrows the texture will change for that object.

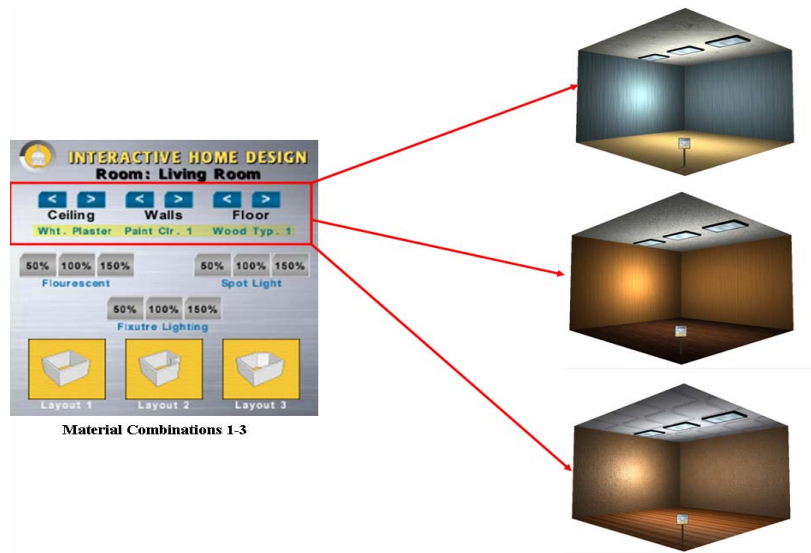


FIG. 3: Real-time Material Change

A user also has the ability to change the lighting conditions for each space. The available lightings are point lighting (Fluorescent), spot lighting (recessed or hanging lights), and also cube light (lighting conditions given off by fixtures such as lamps). A user is able to control the quality of light for each space by selecting different lighting combinations which include the glow intensity of the light (50%, 100% and 150%) and also the number of lights for each room (Figure 4). This will give user the chance to view the different combinations of materials and lighting conditions, the overall atmosphere, and the look and feel of his/her future home.

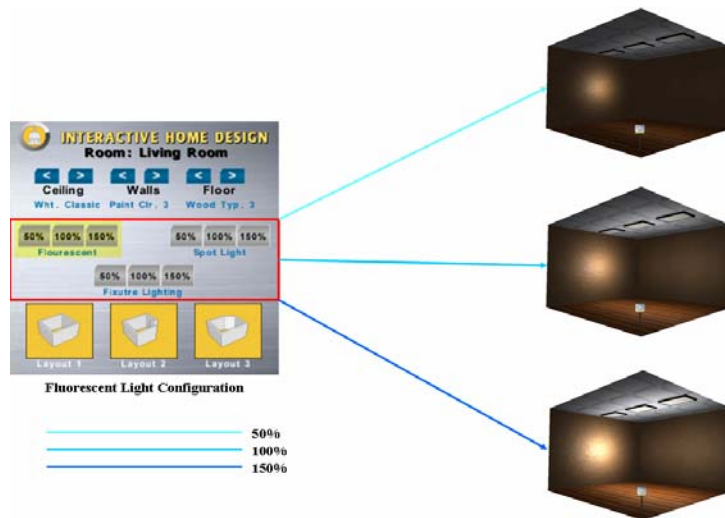


FIG. 4: Interactive Lighting Conditions

The interactive panels also give a user the chance to make minor layout changes to each space, including the furniture layout and even the subtraction of certain walls from each space. Figure 5 shows an example of three different space layouts that have been created including a basic square layout, chamfered layout, and the third layout has an added closet space. The layout schemes are notified by the switches located on the interactive panels.

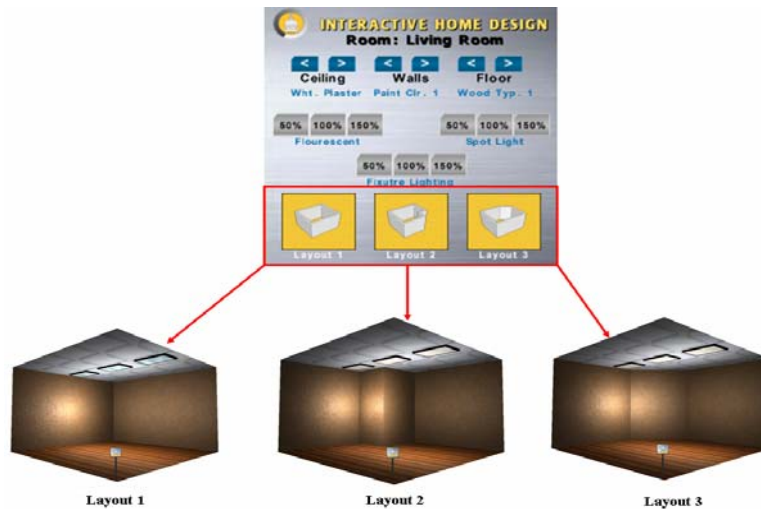


FIG. 5: Interactive Layout

The interactive home design application is deployed in an immersive VE system. A user has the ability to navigate from a first-person viewpoint in real-time of his/her future home in the VE. The immersive VE system will give user the feeling of immersion within the virtual home hence improving the overall sense of the spatial layout and scale as well as the design scheme used for his/her home. In this immersive VE setup, the eMagin's Z800 HMD is used as the immersive VE display and user navigates in the VE using a 3D mouse. Each mouse button is set to perform a different function; such as, movement in all directions as well as the ability to execute different commands on the interactive panels. By using this setup, the user's VE experience is no longer hindered by a desktop computer, keyboard and mouse; allowing for better and natural navigation in the VE.

DEVELOPMENT OF THE PROTOTYPE APPLICATION

The development process began with 3D CAD modeling. The 3D CAD model of the house was developed in 3D Max since it supports exporting to the Collada file format. Once 3D modeling is completed, the 3D CAD model is imported into BuildITC4 in pieces to allow for proper geometry organization, zoning and texturing. In the interest of real-time rendering optimization, each room is placed in a separate zone (Figure 6 and Figure 7). Each room consists of its own walls, ceiling, and floor hence resulting in double-hulled walls. This method of double-hulled wall is similar to real-world conditions where each wall has thickness (or depth). Doors and windows (openings) are placed in the transition zones because they allow user to transit (enter or exit) from one zone to another.

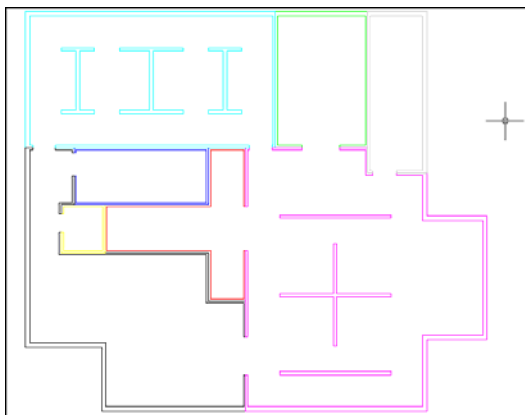


FIG. 6: Different zones for each room)

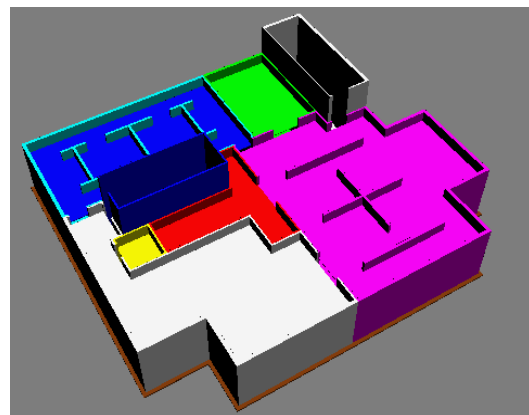


FIG. 7: 3D Wall Layout

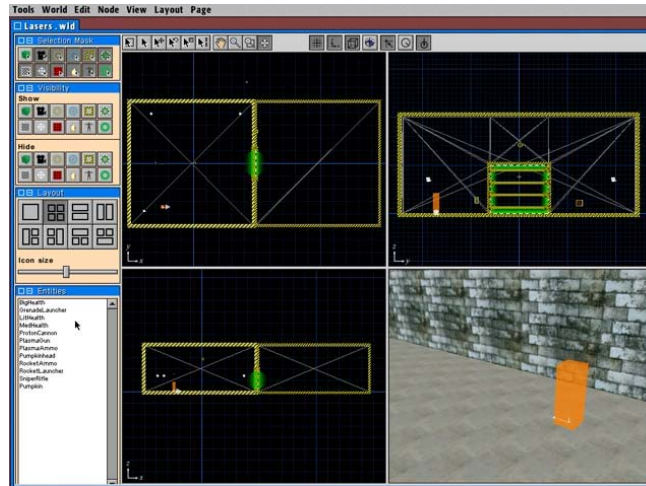


FIG. 8: Zoned Structure

Figure 8 shows a structure that is zoned for maximum rendering speed and quality. Once zoning is completed, the next step is to texture the geometry using the material manager. If the textures needed for the model are not available in the material browser, they must be imported using similar methods that are used for the geometries. The textures must be to the powers of 2 (128x128, 256x256, 512x256 etc.) and in the Targa (TGA) file format. The texture files can be imported individually or collectively into the material browser. The C4Engine has the ability to import and create several different types of textures including normal maps, transparent textures, and parallax map to name a few. Figure 9 and Figure 10 are examples of a normal color (diffuse) texture and its normal map respectively.

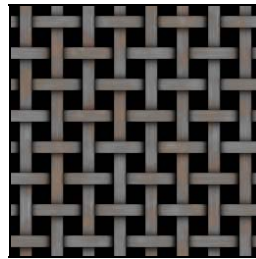


FIG. 9: Diffuse Map 256x256

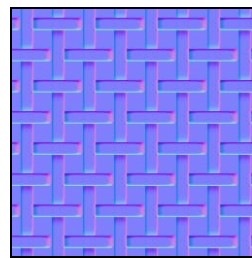


FIG. 10: Normal Map 256x256

Once modeling and texturing are completed, lightings are given to each zone for dynamic lighting and shadow effects. There are five different light sources: Point Lighting, Spot Lighting, Cube Lighting, Depth Lighting, and Infinite Lighting. Each serve a specific purpose: Point lights are basically light bulbs while Spot lights are mainly used to represent flash lights or hanging lights. Cube lights are used to emit light from fixtures such as lamps or lanterns using baked lighting techniques or shadow maps, and Depth or Infinite Lighting can be used to simulate sunlight. The only difference between a Depth Light and Infinite light is that a Depth light can use a shadow map to essentially fake dynamic lightings.

With all the basic viewing elements put in place, the interactive elements for the home design prototype application are then added. Panels are constructed from scratch using the panel editor. The panel is constructed (Figure 11) with the appropriate graphical user interface (GUI) design. Each panel is a controller of interaction and is attached to a “Connector” (light, geometry, etc.) using the “Select Connect” tool in the world editor interface which results in a certain action or method being executed upon request. In this prototype, the Panel (Controller) is equipped with several connectors for the lights, materials and layout and upon selecting certain switches on the Panel a method is performed in real time (Figure 12). The methods are assigned to each switch on the panel using the visual script editor (Figure 13). The script editor contains several functions that can be assigned to each switch of the panel, such as calling a function for execution or stopping a function.



FIG. 11: C4 Interactive Panel Editor

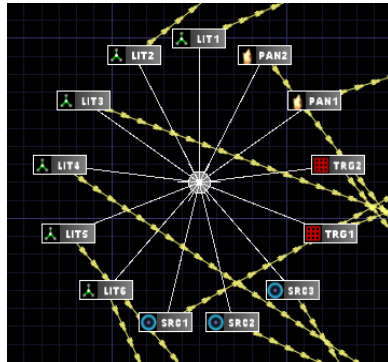


FIG. 12: The Connectors

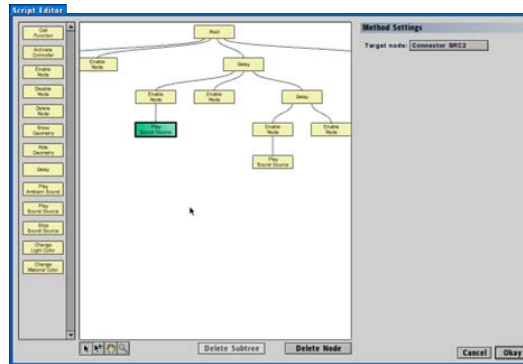


FIG. 13: Script Editor

Once all interactions have been defined the prototype application is complete. Figure 14 the features and components of the interactive home design prototype system.

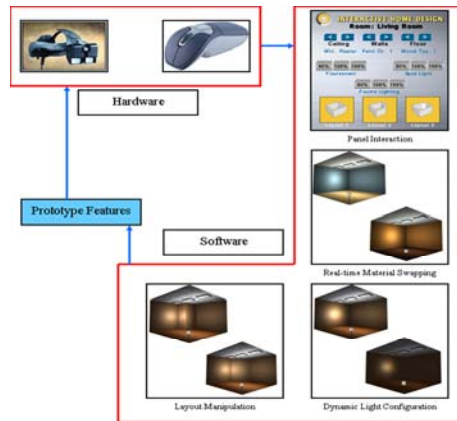


FIG. 14: Prototype Features and Components

CONCLUSION

In conclusion, the current state of home design relies heavily on the communication between the architect and the client. It is the responsibility of the architect to ensure that clients completely understand the design aspect of ones future home. It is often the case that a bad design is not bad but rather it was misinterpretation by either the client or the architect. An architect often communicates with the client through the use of 2D architectural drawings. This can be a challenge for new home owners because the correct understanding and visualization of the drawings can take years to master. Architects have tried to remedy this by offering clients to view photorealistic still renderings and walkthrough movies of their future home. These rendered images may give clients more understanding of the design but they do not allow clients to interact with them, making them seem permanent to clients. It is often the case that

future home-owners will trust the intuition of the architect without questioning or fully understanding the spatial layout of their new home. As a result, the client is not aware of what aspect of the design he/she may dislike until construction is either underway or completed.

This paper presents an approach for a client to walkthrough and interact in real-time with his/her future home design in a VE. A prototype system is developed using the C4Engine; a next-generation 3D game engine. The use of the C4Engine allows for simulation of depth of textures/materials hence enhancing the realism of the VE. Utilizing this prototype clients are able to change certain characteristics of the proposed house design, interact with different lighting conditions, visualize different alternative materials and make minor layout changes such as adding or remove wall, or changing the layout of rooms. This concept of interactive home design in an immersive VE can offer architects a new way to communicate with clients and it is hopeful that it can diminish the current communication barriers.

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