

# A Proposed Framework for a Virtual Reality Training Tool for Design and Installation of Electrical Systems

Tulio Sulbaran      Mohd Fairuz Shiratuddin  
University of Southern Mississippi  
Hattiesburg, MS 39406, USA  
{tulio.sulbaran, mohd.shiratuddin}@usm.edu

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## Abstract

*Electrical systems design and installation represent a minimum of 8-10 percent of the total construction cost. As such they must be properly designed and installed to avoid any cost overruns. The design of the system is the responsibility of the engineer, while its installation is the responsibility of the builder. It is not uncommon that there is a 'disconnect' between designers and builders. The former have limited experience in installing the system and the latter is not familiar with the design of the system, thus potentially leading to errors, rework and ultimately project cost increase. This paper proposes a framework of a Virtual Reality (VR) training tool that can be used in tandem by electrical designers and builders. We envision that this tool will allow designers and builders to better understand each other's concerns for the success of design and installation of the system, thus costly mistakes and rework can be minimized, if not eliminated. Additionally, the VR training tool is expected to enhance the level of interactivity, and provide real-time analysis of possible "what-if" scenarios.*

## Keywords

*Construction, design, electrical systems, training, virtual reality*

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## 1. INTRODUCTION

Studies have indicated that Virtual Reality (VR) environments have the potential to assist and enhance user's learning experience. Examples of such studies include: development and visualization of project designs (Schnabel and Kvan, 2002; Shibano et al, 2001; Messner et al, 2002), visualizing construction plans and schedules (Haymaker and Fischer 2001; Whisker et al 2003), designing and analyzing construction equipment (Lipman and Reed, 2000; Opdenbosch and Hastak, 1994), and communicating and training of the project team (Haymaker and Fischer 2001).

Neville (1998) suggests that training is important for rehearsal purposes and to prevent accidents and injuries in construction. Barsoum et al (1996) develop an interactive virtual training model known as the Safety in construction using Virtual Reality (SAVR), to train construction workers to avoid falls from platform-metal scaffolding. Using Head Mounted Displays (HMD), users are able to interact with the VR environment and detect hazardous conditions (e.g. missing guardrails, loose, weak or inadequately spaced planks, inadequate connections between scaffolding components, and defective components) and attempt to eliminate them.

In a VR environment, users have the opportunity to navigate, visualize and have meaningful interaction with computer generated models. This can reduce or eliminate physical trainings in laboratories or construction site

which normally requires prior arrangements, permission, and onsite safety issues to be addressed first. This paper presents a proposed framework for a VR training tool that can be used by both electrical system designers and builders.

## 2. OVERVIEW OF ELECTRICAL DESIGN AND INSTALLATION

Designing a facility requires the collaboration of many disciplines such as Architectural, Civil, Structural, Mechanical, Electrical and Plumbing. Each discipline is represented by its own design experts. Specifically for the Electrical Systems, electrical designers determine and lay out electrical circuits, locations of junction boxes and switches, and most importantly to establish the electrical load requirement for a facility. Without good designs, sufficient amount of electricity required to power up the electrical appliances and lightings for the occupants of a facility cannot be met.

Builders work with 2D blueprints prepared by the designers to install the electrical systems. The blueprints indicate the locations of the circuits, outlets, switches, load centers, panel boards and other electrical equipment. Designers and builders involved in electrical work must follow the National Electrical Code, comply with State and local building codes whenever they design and install these systems. Regulations vary depending on the settings and require various types of installation procedures (BLS 2006). Unfortunately, errors and reworks are com-

monplace, resulting to costly mistakes. These problems originate from the fact that the designers have limited experience in installing the system and the builders are not familiar with the design of the system.

### 3. PROPOSED FRAMEWORK FOR THE VR TRAINING TOOL

The proposed framework is extensible and is intended to guide VR application developers in developing the training tool. The framework for the VR training tool focuses on the design and installation of the electrical systems. This tool will allow designers and builders to better understand each other's concerns for the successful design and installation of such a system. With this training tool, mistakes and reworks can be minimized, and eventually eliminated. Users will be able to freely navigate inside a virtual facility, visualize the electrical components from any perspective in real-time, evaluate the design, and make changes if necessary. Users can virtually "disassemble" and "reassemble" electrical components, rehearse installation processes, develop and plan for proper installation sequences.

The proposed framework (Figure 1) is organized into six elements: 1) Knowledge Content/Management, 2) Graphic User Interface, 3) Virtual Reality Devices, 4) Virtual Reality Development Tools, 5) Communication, and 6) Assessment. These elements are inter-related and decisions and outcomes from one element affect the other. In this paper, each of the elements the proposed framework of the VR training tool is presented.

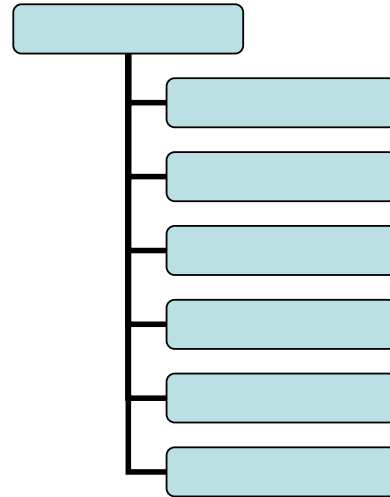
#### 3.1 Knowledge Content/Management

The Knowledge Content/Management refers to the knowledge to be disseminated using the VR training tool. This is the most important element in the development of any teaching or training related materials. It is essential to identify this knowledge so that it can accommodate the visual aspect of the training tool. In other words, the creation of the VR training tool is not simply a blind assimilation of all the content of traditional training materials. Instead it is a selective process to identify the best match between the content, the 3D visual and interactive nature of VR. The first step into the selective process of the content to be included in the VR training tool is to identify all the possible knowledge required to perform a given task.

For example, in the case of the electrical designer some of the tasks involve in designing the electrical systems are:

- 1) Assessing the functionality and lighting requirements of each room and location within the facility
- 2) Determining the accessibility and amount of natural and artificial lightings that can and will be utilized at any given time
- 3) Determining the suitable fixtures to be installed
- 4) Assessing the orientation of the facility (north or south facing walls and windows)
- 5) Laying out the electrical circuits, outlets and switches

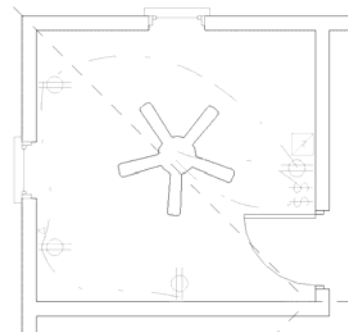
- 6) Calculate the electrical load requirement



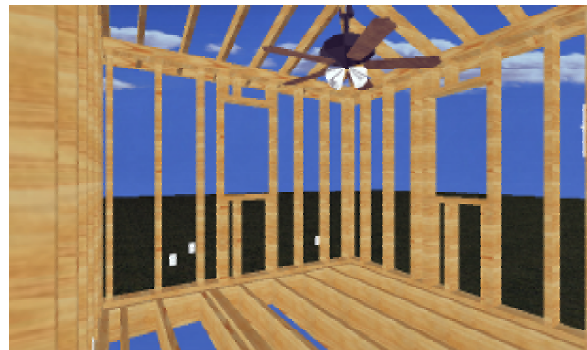
**Figure 1: Proposed Elements of the Virtual Reality Training Tool**

Based on the abovementioned tasks, the content of the VR training tool has to be developed to reflect the knowledge required for designers.

Figure 2 shows a sample segment of a 2D blue print generated by an electrical designer. Figure 3 shows a virtual 3D mock-up developed based on the blueprint.



**Figure 2: 2D Blue Print of an Electrical System**



**Figure 3: The virtual 3D mock-up**

In the case of the builders, they are responsible for installing, connecting and testing the electrical systems. This responsibility also includes installing systems for climate control, security and communications. Testing of these systems is then conducted using various testing equipment such as multi-meters (ammeters, ohmmeters,

voltmeters) and oscilloscopes. These testing are done to check the circuits for proper connections, ensuring electrical compliances and compatibility.

In the case of the builders, they are responsible for installing, connecting and testing the electrical systems. This also includes installing systems for the climate control, security and communications. When a builder install wiring systems in factories and commercial facilities, they will first place the conduits (pipe or tubing) inside the partitions walls, or other concealed areas as depicted in the 2D blueprints. They then make the connection of all types of wires to the circuit breakers, transformers, outlets, or other components. The builders are also responsible to fasten to the walls small metal or plastic boxes that will house the electrical switches and outlets. Additionally, builders performing the electrical work will pull all insulated wires or cables through the conduit to complete the electrical circuits. In residential construction, builders typically install plastic encased insulated wire. The gauge and sizes of the wires installed in all settings depends upon the electrical load requirement of the facility. Hand tools such as conduit benders, screwdrivers, pliers, knives, hacksaws, and wire strippers, as well as power tools such as drills and saws are used during installation of the electrical system. Once completed, testing is performed to check for proper connections, to ensure electrical compliances and compatibility, and also safety of the supply components and appliances. Various testing equipment is used, such as multi-meters (ammeters, ohmmeters, voltmeters) and oscilloscopes.



**Figure 4: Builder Working on an Electrical System**

The current approach in electrical systems training for new electricians is through attending classes, with additional laboratory practices, and also on-site trainings (Thompson Education Direct, 2006; NECA-MEI 2006). Upon completion of the training, some of the expected outcomes are for the trainees to be able to:

- Recognize the basic electrical symbols used on electrical schematics and wiring plans
- Describe how to bend and install conduit
- Explain the operation and construction of motors, generators, and transformers
- Use the National Electrical Code handbook effectively
- Select the correct type of lamp needed for a given application

- Size and select conductors for a given installation
- Calculate electrical equipment ratings based on electrical loads
- Test for opens, shorts, and grounds circuits

For the proposed VR training tool presented in this paper, it has been identified that the best match for the design and installation of electrical systems are: 1) locations of the outlets 2) locations of the switches 3) cable routing 4) outlet installation 5) switch installation and 6) cable installation. The first three activities are performed by the designer, while the last three activities are performed by the builder. These activities are interdependent. Both designer and builder have to ensure that the items are correctly installed and in working order. The VR training tool will be able to provide a real-time interactive 3D visualization of items 1-6.

### 3.2 Graphical User Interface and Interaction Techniques

A graphical user interface (GUI) is one type of interface for humans to interact with computers. A GUI may consist of windows, icons and menus, which can be manipulated through the use of a mouse and keyboard. A common issue with regards to the GUI design of software applications is that the design is not easily understood and used. The GUI for the VR training tool will be designed to be intuitive, and supported by audio and visual and cues.

In any VR environment, suitable interaction techniques play an important role for user to effectively and efficiently interact with objects in the virtual environment. According to Willans (Patch, 2006), no single interaction technique is suitable for all applications even the one as basic as how a user move in the virtual environment. The proposed VR training tool will only utilize a desktop VR setting, hence allowing the classical Windows, Icons, Mouse, Pointer (WIMP) approach to be used along with 3D interaction techniques for VR environment. The WIMP approach allows user to familiarize with navigating and interacting with the objects in the VR environment with ease.

The GUI design for the proposed VR Training Tool will be divided in two areas. The screen area on the right (approx. 33%) will be reserve for textual information, and area on the left is for the graphical interaction (approx. 66%). Within the graphical interaction area is the navigation bar that allows users to use one of the three navigation metaphor; Walk, Fly or Examine. Additionally, inside the VR environment objects will be linked to additional information stored in databases. Figure 5 shows a sample of the GUI design for the proposed VR Training Tool.

### 3.3 VR Devices

Since the inception of VR in the early 60s, many VR devices were invented, developed and improved. In a typical VR system, there exist 3 major components (Figure 6); the real-time engine/VR application that resides on the computer, the input devices that relays user's in-

interaction with the VR application, and the output devices that displays and sends feedback to the user. All three components work together in a continuous loop along with the user. In recent years, most development focuses on improving the input and output devices such as the CAVE™, the head-mounted-display (HMD), the immersive workbench, the data glove etc. Coupled with such devices, VR applications are being developed by both educational/research and commercial sectors.

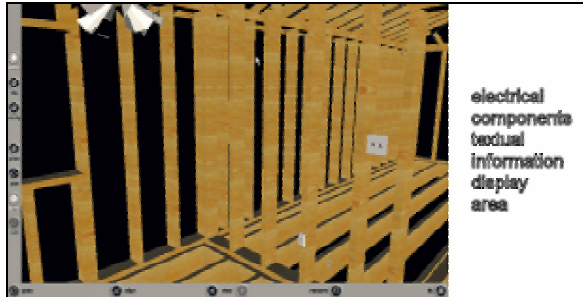


Figure 5: Sample GUI for the VR Training Tool

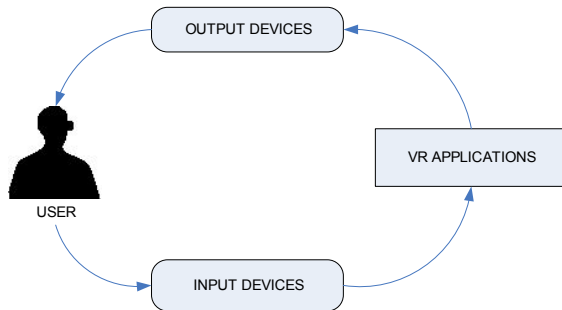


Figure 6: A typical VR system (adapted from Pimental and Teixeira 1994)

In the proposed VR training tool, a desktop VR setting will be used. The VR Application will be developed using X3D. Keyboard and mouse will be used as input devices, and the computer monitor will display the VR environment. It is the intention for the VR training tool to be accessible to everyone at anytime, anywhere, can be set up, maintained, and used with minimal effort.

### 3.4 Virtual Reality Development Tools

VR development tools support a wide range of VR applications. These tools are used for development of 3D objects, navigation and interaction within the VR environment. There are other features that need to be considered when selecting a VR development tool, such as support for importing varieties of 3D model file formats, 3D libraries (core programs, modules or plugins), optimization of level of detail (LOD) and number of polygons, object scaling, rotation and translation, stereo viewing, animation, collision detection, and multi-user environment, extensibility, and support for input and output VR devices.

Throughout the years, VR applications have been developed utilizing various VR development tools available in the market. However, given the diversity in features of the development tools, many of these tools are still proprietary and do not support standard widgets and

proprietary and do not support standard widgets and interaction techniques (Patch, 2006). These tools range from great flexibility with minimum pre-programmed components to minimum flexibility with most of the components pre-built. Therefore, it is important for developers to select tools that best fit the intended applications to be developed and presented.

VR development tools can be categorized into 3 main groups: 3D Application Program Interface (API), Software Development Kit (SDK), and Authoring tools. Figure 7 shows the three groups and some examples for each group.

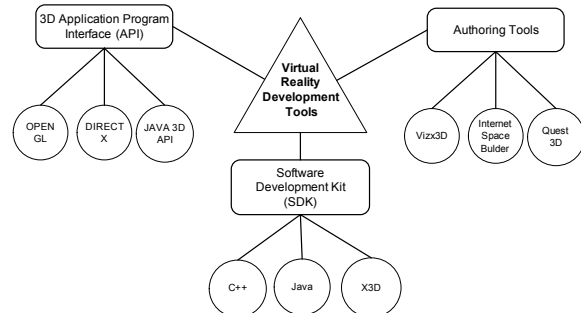


Figure 7: Examples of VR development tools

The Application Program Interface (API) defines how programmers utilize a particular computer feature. In other words, API is a set of routines that an application uses to request and carry out lower-level services performed by a computer's operating system. APIs exist for windowing systems, file systems, database systems and networking systems (AEI, 2006). APIs require high level of programming skills but provide great flexibility to developers because there is direct access to the computer hardware, memory and processor. Some examples of 3D APIs are: OpenGL, DirectX and Java3D. The Software Development Kits (SDKs) are programming libraries (generally written in a programming language such as Basic, C, C++, Fortran etc.) that provide a set of common functions with which a skilled programmer can quickly create a basic structure of a VR application. SDKs are usually application or technology specific and some examples include X3D, OGRE3D, WorldToolKit, Torque Game Engine etc. 3D APIs and SDKs usually work hand-in-hand and for the competent developers, utilizing both can significantly speedup the application development.

Another form of VR development tool is known as the "Authoring Tool". In many cases, an authoring tool is icon-based with very distinct graphical user interfaces (GUIs). An authoring tool is designed for users without or with minimal programming knowledge, to create VR application. An authoring tool allows a user to create a VR application by merely linking together or drag-and-drop objects (3D objects, textures, lightings, sounds etc.). Next by defining the objects' relationships to each other, and by sequencing them in a logical order, a user can produce attractive and useful VR applications. Most authoring tools support some form of a scripting language

that will allow for more sophisticated mutation of behaviors and interactions in the VR application. Some examples of authoring tools available in the market are: VizX3d, Internet Space Builder, Eon Studio and Quest3D.

The VR training tool presented in this paper will use X3D and utilizes an authoring tool called VizX3D developed by Virtock Technologies. VizX3D can speed up the development process as it is a 3D visual authoring tool with a CAD-like interface. It uses the familiar Windows GUI framework. VizX3D allows user to develop 3D objects and environment, import any existing VRML code and provides a unique trigger system. VizX3D also allows users to create interaction logic by selecting nodes, selecting the desired behavior and produce interactive 3D scenes either in VRML or X3D (Figure 8). There are no recommended hardware requirements for VizX3D, but to achieve an acceptable rendering quality of at least 30 frames per second (fps), it is suggested to use a desktop home computer equipped with a good 3D graphic accelerator card. The X3D-based VR environment can be displayed in any internet browser such as Microsoft Internet Explorer, Netscape Communicator or any X3D compliant browsers.

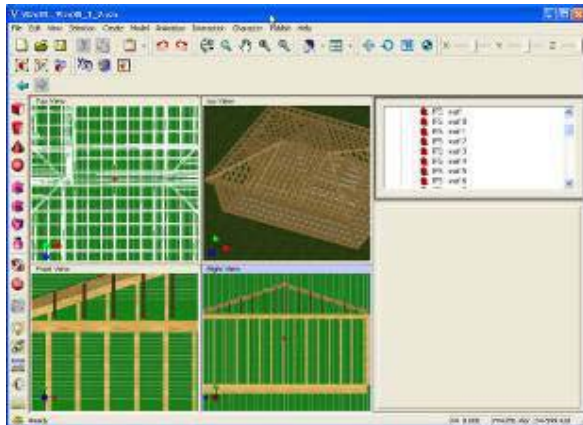


Figure 8: A sample screenshot of VizX3D UI

### 3.5 Communication

The proposed VR training tool will support self-paced learning whereby learners can learn at anytime, and from anywhere. This tool will use the internet as the medium to deliver the training materials. A client-server network architecture and communication protocols will be utilized to achieve this. Streaming media such animations, audios and videos will be used whenever is necessary to enhance and support the training process. References and live links to materials that are already available on the internet will also be provided. Although the VR training tool can be used by a single user, a multi-user environment will also be provided to encourage discussion and instigate a community training environment.

### 3.6 Assessment

In the development of any training tool it is important to know that the words ‘Goals’ and ‘Objectives’ have different practical meanings (BSU, 1999) . ‘Goals’ and ‘Ob-

jectives’ are similar in that they serve as guides to teaching and learning. ‘Goals’ and ‘Objectives’ both describe the intended purposes, the expected results of the teaching activities, and establish the foundation for assessment. However, ‘Goals’ express the intended outcomes in general terms, written in broad, global, and sometimes vague language. Whereas ‘Objectives’ express the intended outcomes in specific terms, and are statements that describe the intended results of instruction in terms of specific student behaviors (BSU 1999, Ritchie 2006). Table 1 shows a brief comparison between ‘Goals’ and ‘Objectives’.

Goals	Objectives
Broad	Narrow
General Intentions	Precise Intentions
Intangible	Tangible
Abstract	Concrete
Can't be validated as is	Can be validated

Table 1: Goals vs. Objectives

In this paper, the goal of the proposed VR training tool is to allow designers and builders to better understand each other’s working environment and concerns of the design and installation of electrical systems. It can be observed, although this goal provides the intended purpose and expected results, it is broad, general, intangible, abstract, and cannot be validated. Therefore, the learning objectives must be developed to identify the precise intentions, making them tangible and able to be validated in the context of the goal. The characteristics of the learning objectives are presented in Table 2. Based on these characteristics, a sample of the learning objectives for the proposed VR training tool are shown in Table 3.

The learning objectives will be measured using appropriate assessment tools. The assessment tools measure the progress towards the objectives. Furthermore, the scoring method must agree with the level of competency demonstrated by the designers and builders during the assessment process. All of these assessment tools characteristics are not easy to achieve and in many cases, the results are affected by factors not controllable by the instructors or the learners.

Characteristic	Brief Description
Clear	Both instructor and student can understand it.
Challenging	Requires effort from both instructor and student to achieve it.
Realistic	Does not require time or resources that are not available to the instructor and student.
Specific	States who does what by when.
Observable	Accomplishment of the objective can be observed; there is no doubt

	that the objective has been met.
Measurable	Accomplishment of the objective can be measured (it can be stated that it was 100% accomplished, 50% accomplished, etc.)
Simple	Complexity is no virtue in writing objectives.
Not too confining	There is some flexibility to allow for changes in the overall situation. If the objective can only be achieved under optimum conditions, then it is too confining.

**Table 2: Characteristics of Learning Objectives**

Objectives
Place electrical outlets in the proper location
Place electrical switches in the proper locations
Route the cables according to the blueprints
Install electrical outlets according to the blueprints and national standards
Install electrical switches according to the blueprints and national standards
Connect the cables to complete the system according to the blueprints

**Table 3: Sample Learning Objectives**

#### 4. CONCLUSION

We present a proposed framework for a VR training tool, specifically for the electrical systems. This proposed framework can be used as a guide for VR application developers in developing the training tool. The proposed framework is organized into six elements: 1) Knowledge Content/Management, 2) Graphic User Interface, 3) Virtual Reality Devices, 4) Virtual Reality Development Tools, 5) Communication, and 6) Assessment. The VR training tool for the electrical systems is proposed to overcome the problem of ‘disconnectivity’ between electrical designers and builders. The former have limited experience in installing the system and the latter is not familiar with the design of the system, leading to errors, rework and ultimately resulting to increase in overall project costs. With the VR feature of this training tool, users (trainees) can freely navigate inside a 3D virtual model, and visualize in real-time the electrical components from any perspective, and evaluate the design and make changes if necessary. Users can virtually “disassemble” and “reassemble” components, rehearse installation processes, develop and plan for proper installation sequences.

We believe that this VR training tool can provide the same level of knowledge to the conventional ways of training, and can instigate a better learning environment for the trainees/students, and a better teaching environment for the instructors. An X3D web-based training

application is planned to be developed in the coming Fall 2006 semester.

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