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Using Quest3D to develop VES: a tool for enhancing electrical safety and design in the built environment

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Abstract

This paper presents a novel desktop virtual reality model titled Virtual Electrical Services (VES), developed to enhance electrical safety and design in the built environment. The model developed using Quest3D has the potential to be used as an industry design tool or as an educational tool for third level students and represents a significant watershed in how electrical services engineers can potentially design buildings and interpret their design decisions. A description of the software development process of the virtual reality model is presented along with the applications that were developed within the model. Based on the early implementation of this prototype model, it would appear electrical services engineers perceive the prototype to be a useful tool and were receptive to using VES as a learning and design tool.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—Virtual Reality and Virtual Environments

1. Introduction

In recent times enhanced computing power and modelling techniques have aided researchers improve their understanding in many fields of study. Virtual Reality (VR) is one benefactor of these technological enhancements and as a result is one of the most in demand genres for the delivery of innovative solutions for scientific research. In contrast to other simulation and interactive applications, VR allows the user to interact with rich 3D environments and receive instantaneous feedback each time the user interacts with the application.

One of the key advantages of virtual reality is the potential it offers to expose users to simulated hazardous environments in a highly visual, safe and interactive manner. In doing so, users can familiarise themselves with a potential work environment, technology, or a decision making process and immediately evaluate the consequences of tasks undertaken giving the user time to become more competent in a virtual real world setting which can be experienced at the users own pace.

The concept of applying virtual reality simulation systems to the field of electrical services engineering will allow users walk around an electrical installation, view and inspect equipment, simulate designs, have the possibility of operating equipment, view current wiring regulations, receive maintenance assistance and advice and undertake design decisions without causing any damage to the equipment or injury to themselves. This should offer users the ability to expeditiously attain proficiency and knowledge. It should also provide higher education institutes or engineering firms with a potential training tool that will allow trainees quickly and cost effectively up-skill and attain knowledge of fundamental concepts, best practices and emerging technologies.

In this paper, the software development process of developing the prototype application designed to enhance electrical services design and safety in the built environment using a desktop VR system is set out. The aim of VES is to provide a novel tool to improve electrical safety and design in the built environment that can be widely accessed by the end user. By performing a value-engineering design through the implementation of the virtual reality model, users can attain a higher level design while also becoming aware of the current issues surrounding electrical safety in the built environment. Initially, this paper sets out the background to the development of the model. Following this, the system requirements are set down and a solution identified. In section 4, the software development process is documented and subsequently feedback is provided on the early

implementation of the model and the possible future direction for VES. The paper concludes by providing a discussion of the findings.

2. Background and Related Work

In recent decades electricity has become pervasive in modern society to an extent where it has become an intrinsic part of our daily lives. However, the same electrical forces that operate our lighting, motive power and communications systems along with an innumerable number of other devices are also capable of interacting with the human body. The biological effects of which can be beneficial when utilised correctly or alternatively can be destructive as with inadvertent exposures that are commonly referred to as electric shock. The dangers associated with electricity in the built environment have long since been a priority for the electrical services industry and also the general public who live and work in this environment. However, it has been shown statistically that the built environment is one of the leading locations for death due to electric current [BOS10][PH07] and injury and death as a result of electric shock and fires caused by failed electrics and unsafe installations are very often repetitive and preventable. Therefore, for electrical safety to continuously progress, it is incumbent on those within the industry to consistently strive for better regulation, improved engineering systems and enhanced tools/methods to allay these risks.

From the authors own research [BOS10] three predominant factors related to preventing electrical accidents in the built environment are design, maintenance and persons. Virtual Reality (VR) is identified as one potential method of addressing each of these elements. Through the use of a virtual environment electrical services engineers can investigate the impact of their designs, a skilled person can become more informed or virtually instructed before carrying out maintenance while ordinary persons can become more aware of the dangers of electricity. By providing a format to develop and address each of these elements should serve to heighten awareness and encourage people to use safe electrical practices. Utilised in this manner, VR can add value to the electrical services industry and become an integral part of training for third level students, electricians, design engineers and a valuable electrical safety tool for educating the general public.

As part of the VR development process, the cause and effects of electrical accidents in domestic properties were identified [BOS10]. This research highlighted the high-risk activities, which lead to receiving an electric shock in a domestic property and identified the most at-risk groups that could most benefit from electrical safety interventions. The author also examined the theory of transfer touch voltage calculations and developed a touch voltage simulator verified by field measurements which allows designers and installers of low voltage electrical installations to test and evaluate the resulting touch voltage for various design parameters [BOS10]. These data sources provided the major foundation blocks upon which to develop the VR model.

The benefits of VR have increasingly gained recognition from researchers, developers and numerous commercial organisations. Potential applications have been identified and developed in many diverse fields. To date, VR has been employed with varied success across many engineering disciplines, examples of such systems include; a VR safety-training system for construction workers [XTS06], using virtual reality to enhance the manufacturing process [MSH99] and VR technology applied in Civil Engineering education [SHM08]. VR systems specifically related to the electrical industry include; VR systems used to train electrical sub-station operators [RMF*08] [WL10], a VR training tool developed to allow electricians and builders better understand each other's concerns in an attempt to prevent costly mistakes [SS06]. [ZLT09] outlines the development of a prototype simulator to support electrical safety awareness in construction, while a VR system for training electricians in electrical inspection and testing is currently in operation in the UK. [NIC10].

3. Motivation and Aims

It is believed that VR can be successfully applied to enhance electrical safety and hazard awareness issues in the field of electrical services engineering. Virtual reality offers the potential to immerse users into an interactive and well controlled virtual world containing the main components of an electrical installation which may operate as an enhancement to existing training and design methods. The development of 'VES' constitutes a first attempt at addressing a number of the electrical safety concerns highlighted.

The ultimate goal of 'VES' is to provide a prototype interactive VR model that will allow interactive data querying and provide realistic responses with optimal speed and quality and thus it will incorporate the ability to:

- simulate the dynamic operations of the electrical circuits in accordance with ET101 (national rules for electrical installations in Ireland);
- provide maintenance assistance;
- view current wiring regulations;
- provide the ability to view, operate and inspect equipment;
- undertake design decisions without causing any damage to the equipment or injury;
- provide safety advice.

3.1 Identifying the System Requirements

Due to the demand and commercial potential involved in developing VR applications, many companies have developed software products for developing such applications. For VES, it was envisioned the completed application should run on a standard desktop pc, be capable of being
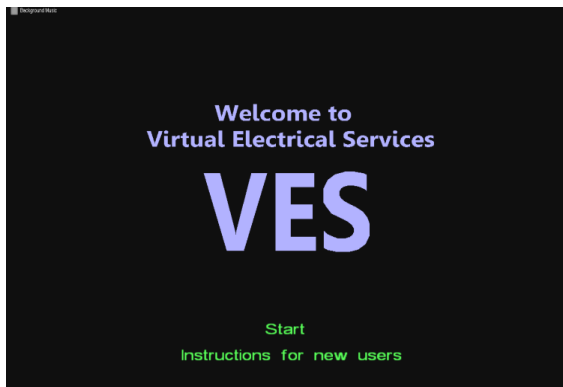
Figure 1: *Screenshot of welcoming menu in VES*

distributed via the web or alternatively downloaded as .exe file, so that it can reach the widest audience possible with relative ease. Therefore, in order to determine a suitable software package objectively, the requirements for the system were compiled and evaluated, these included:

- Scene modelling and development - Is a modeler contained in the application or is an external application like 3D Studio Max or Google SketchUp required;

- File formats supported for importing 3D models;

- 3D libraries, widgets;

- Number of polygons, object scaling, animation, collision detection, extensibility, support for input/output VR devices;

- Hardware supported;

- Methods of publishing a completed application;

- Licensing conditions;

- Price – Are there educational licenses available;

- Developer support and upgrades;

- Soundness of software provider in terms of future existence.

3.2 Solution

Quest3D [QUE12] is a software for creating interactive 3D scenes developed by the Leiden company Act3D since 1998. Quest 3D uses a unique style of visual programming called channelling and in contrast to writing many lines of code, developers can logically combine large set of powerful building blocks to build complex scenes in a timely fashion. This method of programming reduces debugging time and avoids time consuming syntax errors. In addition to this, scene development in Quest3D occurs in real time meaning the developer is constantly working on and viewing the end result. This is a major advantage in that time is not lost compiling code or rendering scenes.

Quest 3D contains a comprehensive set of default channels or building blocks which are all self-contained within the application allowing for the development of a varied range of programs and scenes. In the event of the application under development requiring more specific needs, a C-based Lua scripting language can be used to
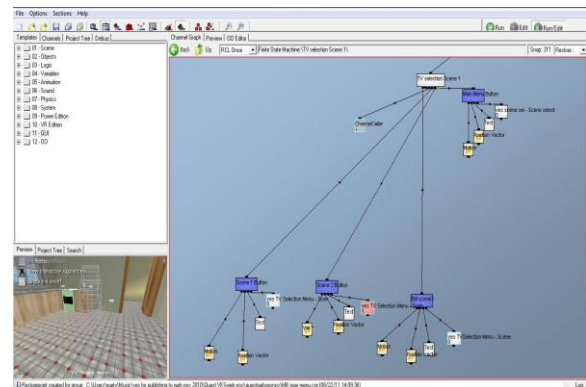

Figure 2: *View of the editor and sample channel structure in Quest3D*

create new channels. Also, in addition to the default channels, Quest 3D boasts a suite of graphic features including a number of animated characters, smoke and fire effects and vegetation all of which can be added to a scene with relative ease.

Channels within Quest3D have a parent child relationship whereby each child provides input to its parent channel. To realise the real time rendering, the software scans the channels from left to right in a single frame.

While Quest3D allows the programmer significant flexibility in managing the logic of the application, building blocks can be logically grouped in multiple channel groups and stored in folders to ensure the editor remains uncluttered and is suitable for team development. Also, if programmers use dynamic loading whereby only the portion of the application that is required is called, the potential of the graphic card can be utilised and software such as Quest3D can run smoothly on standard PC's. Programmers can achieve this at the developmental stage by planning their scene and dividing an application into its logical parts.

Overall it would be fair to comment that there is a steep learning curve associated with Quest 3D. However in making that comment, from an engineer's perspective, developing an application from scratch is certainly viable. In fact within a relatively short period of time Quest3D becomes quite intuitive. One of the driving forces behind this assertion is the editor which is one of Quest3D's main strengths. The editor in Quest3D is a 'wysiwyg' what you see is what you get making all changes instantaneously visible in the scene making testing very straight forward, it also allows control of almost every detail of an application and has customizable task interfaces. Indeed almost all elements of what is required when developing a project is visible on the one pane limiting the need to navigate between numerous panes.

In terms of modelling in Quest3D, it is possible to create a basic scene by adding standard primitives where lighting, texture shading etc can be added however what is achievable is not very sophisticated. To achieve more complex objects, programs such as 3DS Max or Maya should be used. 3D models developed within these applications can then be subsequently imported into Quest 3D using a '.X' exporter.

In summary, the justification for the selection of this software is ultimately based on it's ability to afford the author an opportunity to build a prototype model to demonstrate the potential of using desktop VR for enhancing electrical safety and design. In addition, Quest 3D can be purchased relatively cost effectively (educational license) and obtained in a relatively short period. Its user interface is workable and the 'wyiwyg' editor speeds up development time. The number of default channels available makes it possible to find a solution for almost any complex scene required and the ability to publish to the web or as .exe file makes any developed prototype widely available and easily accessed. Therefore in terms of developing a prototype model to achieve the objectives outlined, the software selected offers a viable option.

4. Development of VES

There are three scenes developed within 'VES' 'Touch Voltage Simulator', Electrical Safety' and 'Electrical Rules and Standards'.

In terms of the overall design heuristics of 'VES', the ambition was to create an intuitive user friendly tool that required minimal instruction for the user. By aiming to do this, it was hoped that the user will experience a unique method of enhancing their knowledge of electrical safety and design that is widely accessible on personal computers via the web. It was thought that a sense of immersion and intuitive interaction was necessary to invigorate the user. Many studies have highlighted the usability problems associated with virtual environments [GH97]. Hence, cognisance is required when developing 'VES' of the art of human computer interface and the methods required to achieve a positive user experience. Sutcliffe and Gault [SG04] provide a good overview of the heuristics required to engage the user effectively.

4.1 Scene Modelling

As already highlighted what is achievable in terms of modelling using Quest3D is primitive in contrast to more sophisticated programs such as 3DS Max and Maya. Hence Quest 3D is not used to develop complex models. Models are developed in a 3D modelling package and exported to Quest3D for simulation, logic and interactivity.

In terms of developing 'VES', 3DS Max was chosen as the program of choice to model the 3D scene. 'VES' required the development of a domestic building which contained the component parts of an electrical installation such as the main distribution board, cables, sockets, isolator switches and also the most commonly found electrical appliances in a home such as an electric cooker, shower etc. The practicalities of developing and modelling scenes in 3ds Max is well documented in many text books and on the web, therefore in terms of this paper it is unnecessary and of little benefit to the reader to re-trace these steps. However, what may be of interest to the research community is to outline any knowledge gleaned from preparing and importing models into Quest3D which may benefit a fellow researcher.
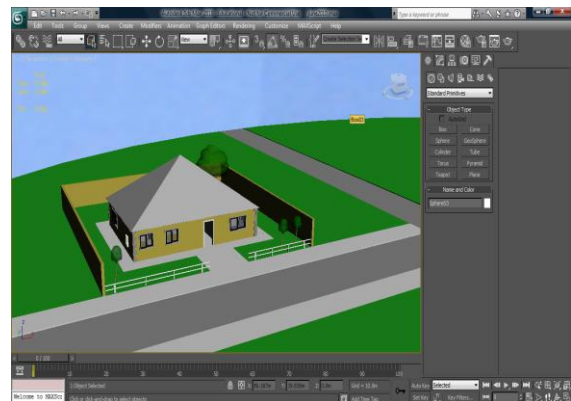

Figure 3: *Model developed in 3DS Max*

Even though Quest3D does not have a preset limit on how many polygons and objects a scene should contain or how large a 3D scene should be, it is advisable to simplify the scene as much as possible when modelling in a 3D drawing package. A reduction in the number of objects and polygons improves the rendering performance and reduces the file size. However, as a result the visual quality may suffer and in turn decrease the user experience. Hence a balance needs to be struck so that the user experience is not reduced by either the performance or poor visual quality. In terms of optimising a scene it is worth bearing in mind that Quest3D possesses a real time 3D engine which in effect means that each image is rendered in real time. Therefore in order to maximise the frame rate it is essential that the 3D scene is optimised to its full potential. In order to achieve this, two key areas to focus on include, geometry (as already highlighted should be as simple as possible) and texture size. This can be achieved using the principles of low polygon modelling which combines geometry optimisation with the use of textures to create fake geometry. For the creation of shapes and objects in 3DS Max, parametric surfaces or polygons can be used. However if parametric geometry is utilised, models should be converted to mesh before exporting as Quest3D like most similar products only works with polygon surfaces. Indeed, it is worth bearing in mind that only faces and polygons are visible in Quest3D, lines cannot be exported.

Finally, one of the early problems encountered when using Quest3D was flickering, this is caused when two planar surfaces overlap with very little height distance. Being aware of this issue when modelling in 3DS Max can overcome this problem.

4.2 Scene Management and Scene Development

In an attempt to give the entire application a professional appearance and to give the user clear entry and exit points, a menu style format was developed to provide a seamless transition for the user between scenes in 'VES'. This was achieved using the 'Finite State Machine' channel, which provides a method to manage complex menu structures. It is possible to create similar transitions using logic channels, however as a project becomes more complex, this can become quite elaborate and cumbersome if future expansion is required.

4.2.1 Touch Voltage Simulator

To carry out a touch voltage study within this scene, the user can mouse over any of the interactive appliances and left click the mouse to bring up the GUI associated with whichever appliance is chosen. From here the user can select to simulate an earth fault from this point in the installation and receive feedback on the value of touch voltage that could possibly develop. The option of carrying out a touch voltage sensitivity analysis and viewing the impact of varying any of the design parameters is also possible. This is achieved using dropdown menus for the various parameters which include, the external fault loop impedance, the open circuit terminal voltage of the supply transformer, the size of the phase and protective conductor and the distance the appliance is from the distribution board. An option also exists to calculate the transfer touch voltages which may develop on healthy appliances which share the same protective conductor.

The 'Expression Value' is the channel utilised to formulate the mathematical expressions required to develop the simulator in this scene. The actual value of the expression value channel is determined by the result of the entered expression.

4.2.2 Electrical Safety'

This scene allows users to navigate through a domestic home and receive electrical maintenance and safety advice, and also information on electrical accident case histories associated with various rooms within the home.

As the user navigates into the different rooms within the home a GUI with data that is unique to that location is presented. Triggering of each GUI in the various rooms in this scene is initiated by the 'Collision Ray Check' channel. A separate primitive object was inserted under each floor area in the various rooms for the collision ray channel to detect. This ray is determined by the movement vector children and the original position vector [QUE12]. Once detection is achieved the value of the channel is set to one and the GUI appears on the screen. Contained in the GUI are three options for the user to utilise; accident scenarios, room safety tips and appliance tips. For accident scenarios an 'array channel' was used to compile a database of accidents associated with that location, once selected the user can select from a range of narrative reports for various accidents within that location. If room safety tips are highlighted the user receives general safety advice specific to that location and finally if appliance tips are selected the user receives electrical safety advice for the interactive appliances that are flashing within the scene.

4.2.3 Electrical Rules and Standards

Using a selection of regulations which were recently updated in ET101 (the national rules for electrical installations in Ireland), this scene illustrates a unique way of disseminating this information. This form of information transfer can benefit installers of installations or aid designers when carrying out electrical designs to inform them of

regulations in place at that time. Initially a sidebar menu was developed in this scene to allow users transfer between the various regulations highlighted. This was created using the command channel in Quest3D. This channel sends a command to DirectX to set DirectX to a different state and is the first channel called by the 'channel caller' channel in this scene. Subsequent to this the, 3D scene is rendered followed by the logic created within the scene to display the relevant regulations. As an example, a screen shot from the wiring system regulations is illustrated in Figure 4. Upon selecting this option the user is confronted with two further options to select from, which include 'protection against impact' and 'protection against corrosive substances'. In the figure shown the user can clearly identify the areas of reduced risk for wiring systems highlighted by the dotted lines where mechanical protection is not required. The dotted lines are achieved using Quest3D's primitive objects. Using the radio buttons the user can obtain the regulations associated with solid or hollow walls. The 'textout' channel is used to display the text of the regulation on the screen, while the 'slider' channel from the GUI template list is utilised to control the physical properties of the wall and make it transparent so the user can visualise the cables which would not be visible under normal conditions.
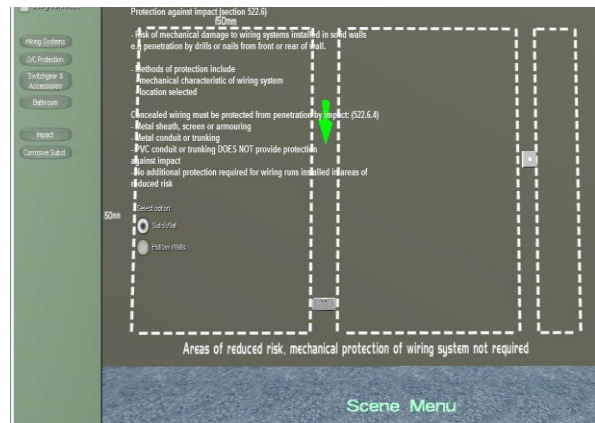

Figure 4: *Screenshot of virtual environment in VES*

4.3 User Control

Once inside the virtual world the user can navigate through the scene using a mouse and arrow keys. It is acknowledged that this method of navigation can at times be cumbersome and will require a brief adjustment period from the user. However, early in the development stage, accessibility was deemed one of the most important design characteristics. Therefore it was decided on balance that this method was the most appropriate for user navigation as it meant no additional hardware requirements and hence the user audience would not be limited by such a design decision.

4.4 GUI Elements

In all the scenes, the use of a 'Head Up Display' or Graphical User Interface (GUI) is integral to the

development of the project as it allows for user interaction and the ability to provide feedback. In Quest3D the GUI is rendered on top of the original scene. In essence, it is a second 3D scene which is rendered with its own unique camera. Therefore for each frame, the 3D scene is rendered followed by the rendering of the GUI layer which is overlaid on the original 3D scene. To prevent interference between these two separate entities the Z buffer is cleared. For the user to achieve mouse interaction with any of the GUI elements, developers can utilise the 'mouse over' and 'user input channels'. The 'text out' channel can be used to promptly produce 2D text on the screen while 2D images can be rendered using the 'copy image' channel [QUE12]. A variety of GUI tools are available from the template list in the channel graph section.

A typical example is the single line diagram of the electrical installation which can be selected from the check box in the top left hand corner of the scene and is included to give the user a visual representation of the electrical installation. It was developed using a separate 3D render channel with its own basic camera and is called by the program after the main scene and only if the check box is selected. The detail of the diagram is developed using Quest3D's primitive 3D objects.

Once inside the virtual world interactive appliances can also be viewed by clicking a check box. By doing this the appliances gently flash green and become clearly identifiable to the user. To create the flashing green appearance a value operator channel is selected which can perform operations on vectors and matrices. By selecting 'loop relative value' the value operator loops between two values. To perform this operation the channel requires three input values. The first value is used as the start point of the looping value. The second is the end of the loop while the third is the value by which the loop is increased or decreased.

Figure 5: *Screenshot of virtual environment in VES with a number of GUI elements highlighted.*

Mathematical operators such as the one outlined above are used throughout the development of the 'VES' project and are generally used to allow the scaling, movement and rotation of 3D objects in VR scenes. These very useful 'Operator channels' allow developers affect each of these elements dynamically in real-time. Many of the functions

of the Value Operator base channel are used to access information from other channels. Examples include use of a Value Operator to obtain a distance (vector, vector) or alternatively a 'Vector Operator' base channel may also be used to retrieve information from other channels such as 'Get Translation position from Matrix'. Transformation of vectors is achieved using 'Vector Operators'. This may range from basic addition and subtraction to multiplication and division of two vectors. 'Matrix Operators' can be used to turn vectors into matrices, such as 'Create Translation Matrix'. Information can also be retrieved using 'Matrix Operators' such as 'Get Current Camera Matrix'. 'Damping' is a unique type of operator which can be used for values, vectors and matrices. Over a period of time it dampens a variable, providing a smooth transition from the current state to the new. The speed can be adjusting using the second child link position and the effect is logarithmic in nature [QUE12].

Figure 6: *Screenshot of virtual environment in VES*

4.5 Visualisation

An important aspect when developing a VR application is camera selection as this defines the point of view in which a scene is presented and as such directly influences the user experience. Quest3D offers a selection of camera templates to select from including animation camera, animation camera with target, object inspection camera and 1st and 3rd person walkthrough camera. For 'VES' a 1st person walkthrough camera was selected as this allows the user walk freely through the scene at standard eye level. As this offers a view as close to real life as possible it provides the user with the highest level of immersion.

5. Future Direction

The development of the prototype model and the subsequent evaluation [BB12] highlighted that the users perceive the prototype to be a useful tool and are receptive to using VR as a learning and design tool. However, it would be remiss not to acknowledge that the prototype, albeit fully functional, is not optimised in its current format and could benefit from further research and development. Even within the most comprehensive and large scale studies, there are limitations by virtue of the practical realities. In the context of this development stage, the VR model served its purpose, in that it demonstrated the concept of utilising VR in the electrical services industry and highlighted the

potential to heighten safety as a result. However, for a package of this nature to be commercially realised in an expedient manner, a team consisting of 3D artists, software developers and electrical services consultants would potentially achieve the optimum result. On a micro level the VR prototype could be enhanced by utilising an alternative method of navigation, enhancing the graphical display and by employing more content for the user to investigate including additional scenes, staged in industrial and commercial installations. However, it is worth acknowledging that if the prototype in its current format suggests that VR can be successfully employed in the industry, enhanced content, display, user navigation and so forth will only serve to reinforce this point.

6. Discussion and Conclusion

The 'VES' prototype application designed to enhance electrical services design and safety in the built environment using a desktop VR system has been set out in this paper. Justification for the selection of the software chosen was detailed along with an insight into software process involved in the development of 'VES'. Evidently, developing a VR application still requires significant enterprise particularly if developed on an individual basis, however with properly selected tools such as those set out in this paper, it is possible to produce convincing results in a relatively short time frame.

The system developed allows full navigation of a virtual electrical installation environment and interaction with many of the electrical elements. This constitutes a first attempt at attaching a new dimension to the training of electrical services engineers and addressing many of the safety concerns raised. Unlike traditional design or training methods virtual reality has the advantage of being safe for both the user and equipment. In addition, it offers the user an opportunity to be exposed to a range of scenarios and conditions that either occur infrequently or are hazardous to mimic.

The potential of using virtual reality for enhancing the field of electrical services should be embraced and by affording users the ability to visualise; the three-dimensional representation of a problem, abstract concepts, dynamic relationships in a system and interact with scenarios that are unfeasible due to distance, time, or safety factors should only serve to improve electrical safety in the built environment.

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