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Using Virtual Reality to Enhance Electrical Safety and Design in the Built Environment

Martin Barrett, Jonathan Blackledge, Eugene Coyle

***Abstract* — Electricity and the inherent risks associated with its use in the built environment have long since been a priority for the electrical services industry and also the general public who must live and work in this environment. By its nature 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 replicate. This paper presents a prototype desktop virtual reality model, to enhance electrical safety and design in the built environment. The model presented has the potential to be used as an educational tool for third level students, a design tool for industry, or as a virtual electrical safety manual for the general public. A description of the development of the virtual reality model is presented along with the applications that were developed within the model. The potential for virtual reality is highlighted with areas identified for future development. Based on the development of this prototype model, it appears that there is sufficient evidence to suggest that virtual reality could enhance electrical safety and design in the built environment and also advance training methods used to educate electrical services engineers and electricians.**

***Keywords* — virtual reality, touch voltage, electrical safety, training and education**

I. Introduction

Virtual reality (VR) can be described as a technology that allows users to explore and manipulate computer-generated, three dimensional, interactive environments in real time [1]. Since its origins which can be dated back to [2], VR has developed significantly and has gained widespread use across many disciplines e.g. [3,4,5,6]. Seen initially as an expensive tool, that required vast investment, it is now possible to illustrate complex, expensive or dangerous systems economically on a computer screen [7].

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VR systems are generally considered strong in both visual and spatial representation of physical environments. Consequently disciplines that require training in inspection tasks and procedural training [8] should benefit from this type of system. VR also offers the advantage of being safe for both user and equipment, while at the same time offering the user an opportunity to be exposed to a range of scenarios that are hazardous to recreate or occur infrequently. The culmination of these factors suggests that VR should not only be an ideal system to enhance the training and understanding of electrical services engineers and electricians but can also play a significant role in creating awareness of electrical safety issues and reducing accident rates within the general public.

This paper presents the design process of a desktop VR prototype, “Virtual Electrical Services” (VES), which was developed to demonstrate how VR technology can be applied to the electrical services industry and used to enhance electrical safety and design in the built environment. Three interactive scenes using a domestic dwelling as the virtual environment were developed to illustrate this point. The first interactive scene, ‘Touch Voltage Simulator’ allows the user to carry out a touch voltage analysis of a domestic dwelling and is based on previous studies into touch voltage [9]. The second interactive scene ‘Electrical Safety and Accidents’ demonstrates how electrical accidents occur in domestic premises and provides safety guidance to the user based on the findings of [10]. The third scene ‘Electrical Rules and Standards’ outlines the potential of VR for the dissemination of Electrical Regulations and standards to the electrical services industry to allow for greater understanding and rapid transfer of knowledge.

Electricity is one of the most convenient forms of energy that is used in every building today. The added comfort that it brings to our daily lives in addition to the advances in electrical safety have contributed significantly to our well being in the built environment. However, the inherent risks associated with its use will always exist and will continue to be a priority for the electrical services industry. Previous electrical safety studies have identified the home as one of the leading locations for electrical injury and death to occur [10, 11] and in recent times greater attention has been drawn to domestic electrical safety due to an ageing housing stock, lack of maintenance and inspection and the increasing use of electrical appliances [12]. Consequently, the importance of safe design and the ability to recognise how accidents occur are of the upmost importance. VR is a technology that provides an opportunity to enhance our understanding of these issues, train the user how to interact safely with equipment, while also giving the user an opportunity to interactively design an environment and investigate the consequences safely. Desktop VR has the added advantage that it can be utilised universally due to the widespread availability of computers. In short, VR can add value to the electrical services sector and has the potential to become an integral part of training for third level students, electricians, design engineers and a valuable electrical safety tool for educating the general public.

This paper presents an overview of VR development systems and tools concentrating on the software used in this prototype model. It reviews previous VR engineering applications, outlines the development of this prototype model and presents an in depth explanation of each scenario developed. A discussion is then presented of the potential for future development of this VR prototype and concludes by presenting the findings of this paper and outlining the benefits of using VR in this sector.

II. Virtual Reality Technologies

Previously, public expectations exceeded the ability of VR to deliver realistic applications within meaningful timescales. The root causes of this can be attributed to inadequate PC hardware, costly investment requirements and over optimistic coverage in the media. User disappointment resulted in the practical benefits of VR being questioned and the consequent drifting of funds to new and emerging fields of interest. However, steady progress by small groups of scientists who continued their VR research [13] lead to the rebirth of VR in the late 1990's [14]. The main contributory factors for this re-emergence can mainly be attributed to the rapid advancements in PC hardware which occurred during this time. Central processing units became much faster along with speeds of PC base graphic accelerators. As such, this meant that VR was much more accessible and the consequent growth inevitable. To emphasise this point VR went from a$50 million dollar industry in 1993 to $1.4 billion dollar industry in 2000 [13] and this is estimated to reach $4.3 billion by 2012 [15].

VR systems are generally classified into four main categories which are determined by their display technology; immersive, semi immersive, projected and desktop. Immersive VR systems aim to completely immerse the user inside a virtual environment ensuring the user has no visual contact with the physical world. This is generally achieved by using a Head Mounted Display (HMD). With this device, the user views the virtual environment through two small screens placed in front of his eyes and motion trackers monitor the user's movements and update the virtual scene via the attached processor accordingly. Immersive VR systems generally offer the greatest sense of immersion in a virtual environment, and allow the user move around in an intuitive manner in comparison to other systems. Nevertheless, there are commonly acknowledged shortcomings related to immersive VR and side effects such as eye strain, nausea and dizziness associated with its use are well documented [16, 17]. Semi immersive VR combines a virtual environment with a physical model. A car driving simulator would be one such example, whereby the drivers use a head mounted display to view the virtual environment and a physical steering wheel, gearstick and pedals etc to control the simulated driving experience. In projected systems such as CAVE (Cave Automatic Virtual Environment) the user is surrounded by stereo images which are projected onto screens. The user can walk freely within the CAVE and view the virtual environment with stereo glasses. In a similar fashion to immersive VR systems, motion tracking devices adjust the projection of the images onto the screens to account for a change in user position. Despite the truly impressive nature of some of the applications developed using the systems outlined above, cognisance must be taken of the significant initial investment in specialist equipment required to develop such applications and also in the ability to make them accessible to a far reaching audience.

Desktop VR systems display their virtual environments on a conventional pc monitor and interaction is generally achieved by using the associated mouse and keypad. However, it can support other visual and interaction devices such as 'shutter glasses' and 'joysticks' to name a few. In contrast to the systems outlined above, desktop VR offers a much more simplistic, versatile and less expensive method to develop a VR system, albeit at the expense of a more immersive experience. As outlined by [18], desktop VR systems have received criticism for not utilising the full potential of the three dimensional and 'presence' qualities of higher end VR systems, as images are essentially still two dimensional. In addition, desktop VR systems uses a screen of limited size in a fixed location, it does not fill the user's complete field-of-view, and hence it is possible to get distracted by objects in the peripheral view which ultimately impacts on the user's feeling of presence. However, since desktop VR systems can be utilised on standard computer systems and also projected onto larger screens for group instructional training, its relatively simple and inexpensive set up costs added to the accessibility offered via the World Wide Web makes it a very appealing system. Undoubtedly, the global accessibility by multiple users to desktop VR is one of its major proponents and for many VR applications, desktop VR will continue to be the way forward.

III. Virtual Reality Development Tools

Selecting the most appropriate VR development tool is an essential component in developing a VR application. The level of flexibility and pre-programmed components can vary substantially between packages. Many features require careful consideration from a developers point of view such as file formats supported for importing 3D models, number of polygons, object scaling, animation, collision detection, extensibility, support for input/output VR devices, 3D libraries, widgets, developer support and methods of publishing a completed application.

As outlined by [19] VR development tools can be categorized into three main groups, Application Program Interfaces (API's), Software Development Kits (SDK's), and

Authoring tools, the latter being the tool utilised in the development of the ‘Virtual Electrical Services’ application outlined in this paper. Generally, an authoring tool is an icon-based application coupled with a graphical user interface (GUI) that enables the author to develop a unique style of programming. The tool is designed for users with nominal programming knowledge. Instead of having to write lines of code, developers make use of a set of building blocks. This approach significantly widens the market for VR applications development. Developers in various fields suitable for VR applications can enhance understanding, transfer of knowledge and learning potential for employees, clients, students or the general public in their areas of interest. Typically, to develop a fully operational inviting VR application, a user links together objects such as 3D objects, lights and cameras etc. in a graphical interface and defines their relationship in a sequential and logical structure. Many authoring tools also support some form of a scripting language that will allow for more elaborate interactivity and icon development. Examples of authoring tools currently available in the market are: Virtools, Eon Studio and Wirefusion.

The VR application presented in this paper utilises the authoring tool Quest3D developed by ACT-3D B.V. which allows for a relatively short development time and low development cost when using an educational license. This was a significant factor in choosing this particular application for the development of VES. In addition, Quest3D does not generate pictures or 3D models; instead the developer creates a repository of pictures, 3D meshes and sounds in a separate program and imports them into Quest3D. The basic building blocks in Quest3D are the so-called ‘channels’. In brief, a channel is a reusable component that contains a piece of application logic. This component is able to interact with the Quest3D interface engine and other channels.

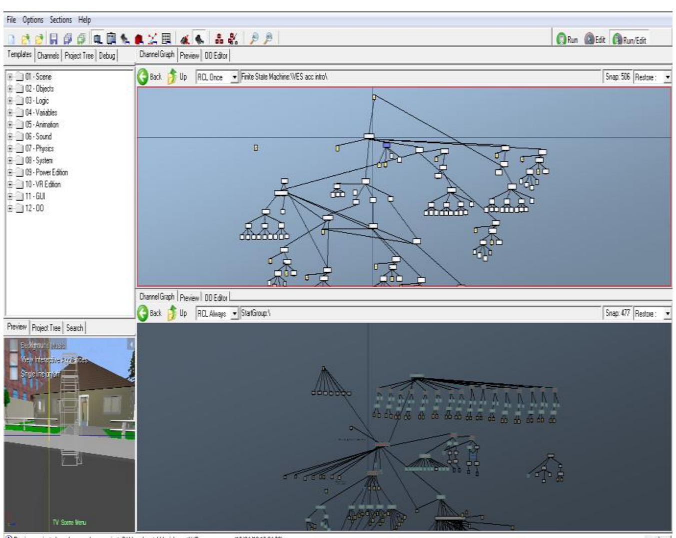

Figure 1 Overview of the Quest3D user interface

By creating a hierarchical logical framework of linked channels (see figure 1) an interactive application can be developed. Quest3D contains many default channels, allowing for the development of a wide range of applications. If more functionality or interactivity is required, the C-based Lua scripting language can be used to create new channels. In general, by employing this graphical form of scripting, experimentation with program flow is easier and there is also no concern regarding syntax errors. Quest3D also affords realtime feedback with no need to compile code. The ability to create successive iterations of your application with instant visual feedback is a beneficial feature and it shortens debugging time. Quest3D use a DirectX 9 game engine and hence is supported by all DirectX 9 compliant graphic cards and operating systems. The hardware requirements to run the VES application are Intel Pentium III or Higher or AMD Athlon processor, 512MBytes RAM, Hardware accelerated DirectX compatible graphics card and 1024x768 display resolution [20].

Finally, accessibility and ability to communicate with the published VR application is often a major concern for developers. Quest3D supports a large number of delivery formats including web, executable, installer and windows screensaver but it requires the user to download and install a plug-in in order to view the content. However, the size of the plug-in is relatively small and its installation does not require technical competence.

IV. Virtual Reality in Engineering Training

The application of VR technologies for engineering design, training and education has generated much interest across many sectors of the engineering community. This is not surprising as using VR technology to build virtual training systems has the advantages of being safe, economical, controllable and repeatable [21]. Virtual Reality also offers the ability to expeditiously attain proficiency and knowledge which is a critical factor for the profitability and sustainability of companies, governments and training organisations. In an era where regulatory practices are amended on an ongoing basis there is a requirement on the part of industry and higher education institutes to provide training methods that will allow trainees to quickly and cost effectively up-skill and attain knowledge to adapt to the new and rapidly emerging practices and associated technologies.

Both educational theory and cognitive science support the role of VR as a training tool [8]. According to [22], the main pedagogical driver that motivates the educational use of VR is constructivism. Constructivists assert that individuals learn through their experience of the world, through a process of knowledge construction that takes place when learners invest intellectually in meaningful tasks [23]. From this it can be concluded that interaction with an environment or process is key to the learning process and perhaps outside of actual reality, VR offers one of the most appropriate methods to create a contextualized trainee activity. It is also recognised by [24] that using VR can enhance cognitive learning through active participation in tasks, increased motivation and flexibility in terms of time and location. Through active participation, trainees in VR can make decisions without real world consequences and they can effectively learn by doing and hence become active in their own learning. This in many respects is in contrast to traditional educational methods which rely on the trainee attaining knowledge from teachers and literature and then subsequently attempting to apply this knowledge to the real world. Situated learning theory also suggests that VR maybe an advantageous tool as it asserts that knowledge should be learnt through contextualised activities in authentic situations that reflect the way in which the knowledge will be used [25]. In any case, research in human learning processes to date outline that humans acquire more information if more senses are involved in the acquisition process and as such VR can be a beneficial tool.

VR has been employed with varied success across many engineering disciplines, examples of such systems include; a VR safety-training system for construction workers [26], application of VR for the teaching of semiconductor device physics [27], using virtual reality to enhance the manufacturing process [28] and VR technology applied in Civil Engineering education [29]. VR systems specifically related to the electrical industry include; VR systems used to train electrical sub-station operators [30, 31, 32, 33], a VR training tool developed to allow electricians and builders better understand each other's concerns in an attempt to prevent costly mistakes [19]. [24] 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. [34]. No known VR systems, considers the applications developed in this paper.

V. Virtual Electrical Services

The fundamental objective of VES (Virtual Electrical Services) is to develop a prototype VR simulator to demonstrate the potential benefits of employing virtual reality to enhance electrical services design and safety in the built environment. The potential market for which the VR system could add value includes undergraduate engineering students, practicing electrical services engineers and the general public, who perhaps could benefit from the electrical safety advice and instruction contained in a potential virtual electrical safety manual. From an educational viewpoint, VES is not seen as a replacement for traditional teaching methods, but merely as a complementary teaching resource that could significantly enhance student understanding and motivation. VES has the potential to engage students and present problems which they can investigate and solve in their own time. This offers encouragement to students to become more active in their own learning in an environment which relates to the problem. Practicing engineers could use the application to grasp emerging technologies or recent changes in regulations that could influence their designs. VES could also be utilised as a continual professional development application for industry.

In order to provide the user with the highest degree of realism the following were set as the benchmarks for the VES application; 1) visual representation of an electrical installation in the built environment, 2) simulation and representation of the functionality of the installation, 3) strict adherence to the appropriate electrical rules governing the installation under investigation. In addition the VES application had to ensure the provision of interactivity in an intuitive manner and provide accessibility to the application across the widest range of platforms and interested parties.

The following sections describe the creation of the virtual environment and the applications developed within VES.

Figure2 Virtual environment created for VES application

The initial development stage required the construction of 3D models of the residential building, surrounds and the different components of the electrical installation using a conventional 3D modelling software, 3D *Studio Max* (See Figure 2). Detail in the geometrical modelling was sacrificed to ensure optimisation of the real time rendering capabilities of the software which can be adversely affected by complex geometry and excessive texture sizes [35]. Many real-time 3D applications use the principles of Low Polygon Modelling. This is the amalgamation of geometry optimisation and the use of textures to create bumps [35]. Using 3D Studio Max, it is possible to develop a model with polygons or with parametric surfaces. If parametric geometry is used, all objects should be converted to 'editable mesh' before exporting because Quest3D like many similar applications work with polygon surfaces. Once complete, the 3D models are exported from the animation software to .X format and imported into the development environment.

The VES prototype application consists of three interactive scenes. A user interface allows the user to enter and exit each scene in an intuitive manner. Each of the applications developed are now discussed.

A. *Touch Voltage Simulator*

Protection against electric shock by earthed equipotential bonding and automatic disconnection of supply which gives rise to touch voltages is a universally agreed protective measure used by electrical designers for general applications and implemented in approximately 95% of all electrical installations. As protection against electric shock is one the most important design criteria for electrical services engineers, the ability to understand how touch voltages develop and how they are calculated is imperative.

For the purpose of this paper, we shall define 'touch voltage' as a difference in voltage potential experienced by a person who makes contact simultaneously with more than one conductive part, which is not normally energised. The touch voltage U_t can be calculated using a simple voltage divider circuit:

$$U_t = U_{oc}\left(\frac{R_2}{Z_e + R_1 + R_2}\right)\text{..................}(1)$$

Where,

U_t = touch voltage,

U_{oc} = Open circuit voltage of the mains supply

R_2 = circuit-protective-conductor resistance

R_1 = phase-conductor resistance

Z_e = Earth-fault-loop impedance external to the faulty circuit

From IEC 60479 part 1 [36] (Effects of current on human beings and livestock), when the touch voltage is 50V a.c. or less under normal dry conditions, the body impedance of a person is high enough to prevent a touch current of high enough magnitude to cause any injury.

One of the principle objectives of VES is to allow users enter a virtual electrical installation and investigate the touch voltage that could develop under different design parameters for various earthing conditions. It has been developed primarily as an educational training tool for third level students in Dublin Institute of Technology (DIT) who wish to enhance their understanding of touch voltage design. However, designers and installers of electrical installations may also find this simulator beneficial. In any case, users who familiarise themselves with the simulator can quickly immerse themselves in touch voltage design, identify the potential touch voltage under fault conditions and investigate the necessary design criteria to achieve a safe touch voltage design.

The touch voltage simulator application itself is broken up into three separate components. Initially the user is presented with an introductory scene which informs the user what touch voltages are and how they develop. This section and also gives instructions how to maneuver in the virtual environment. The second section is the touch voltage simulator itself. Here the user is situated in the virtual environment. By moving through the environment using a mouse/keyboard interface the user can enter the virtual home and interact with the electrical installation. The third component presents the user with a multiple choice assessment exercise to examine some of the fundamental design questions related to touch voltage design.

To make the touch voltage simulator as intuitive as possible the user is presented with two check boxes which can be activated and de-activated on the graphical user interface (GUI). One of the check boxes allows the user to view a single line diagram of the electrical installation on screen via a head up display (HUD). The second check box allows all interactive appliances to flash on screen. Previous usability studies of virtual environments have demonstrated that users have a tendency not to recognise or be oblivious to what is or is nor interactive [37]. Making the interactive appliances clearly visible can potentially improve usability and help prevent user frustration which could ultimately reduce its effectiveness as a training tool.

Within the simulator the user can walk around the virtual electrical installation and interact with or simulate an earth fault on any of the interactive appliances, such as the main distribution board, cooker circuit, shower circuit, socket circuit etc. For example in the case of a socket circuit when the user points and clicks at one of the interactive sockets in the virtual installation s/he is presented with the circuit details and a menu of options via the GUI. Assuming that the chosen option is to simulate an earth fault then the potential touch voltage under these circuit conditions is presented. If the user wishes, it is possible to vary the four major design parameters U_{oc}, Z_e, R_1 and R_2 that govern the value of the touch voltage. By varying any of these parameters the touch voltage automatically updates and the user can immediately view the impact of any design decisions. It is also possible to view the transfer touch voltage that could develop on the other socket outlets related to that circuit under fault conditions and any variance in the design parameters will also update the transfer touch voltages in realtime. A visual example of the GUI and the interactive cooker appliance can be seen in Figure 3.

Figure 3 View of kitchen and GUI in VES

Familiarity with the virtual environment can allow users to quickly become absorbed in touch voltage design. In this way the user can easily identify if a potentially dangerous touch voltage will develop and the possibility of designing a circuit to have a transfer touch voltage not exceeding 12V to provide protection against electric shock for a person with very low body resistance in a special location (e.g. bathroom) and 50V for all other dry locations. Adopting the use of the 'touch voltage simulator' as an educational tool is a more student centered approach and shifts away from conventional learning techniques to one where students can self learn by investigating the touch voltage outcomes for their own inputted data in their own time.

B. *Electrical Safety and Accidents*

Electricity is one of the most clean, convenient, easily distributed and reliable sources of energy that is used in every building today and the comfort that it brings to our daily lives has greatly improved our standard of living. In addition to this, advances in protective devices and wiring practices in conformance with modern standards have all contributed to higher levels of electrical safety since the introduction of electricity into buildings more than a century ago. Nonetheless, the implicit risks associated with the use of electricity will always exist and will therefore continue to be of major concern to the electrical services industry.

Statistically it has been shown that domestic properties are one of the leading locations for electrical injury and death [10]. A further investigation into electrical accidents by the author [11] also singled out domestic properties as one of the prime locations for electrical accidents to occur. This investigation highlighted over the years investigated that approximately 46% of all fatalities due to electric current in England and Wales occur in domestic premises and identified 25–34 year olds as the main at risk group to electrical injury. Worryingly 0–4 year olds were also highlighted to be a vulnerable group. The investigation concluded that accident rates can be reduced if electrical installations are designed correctly, adhere to current wiring standards, maintenance is performed correctly and periodically and occupants are aware of the dangers of electricity and how accidents occur. In addition, a report produced by five international organisations details the growing concerns for electrical safety across Europe [12] and it suggests that more can be done to make premises safer. Therefore the ability to raise awareness, recognise how accidents occur and enhance electrical safety knowledge among residents, landlords, building managers and owners is vital.

VR provides an opportunity to deepen society's understanding of these issues, raise awareness of potential dangers, train the user how to interact safely with equipment and instruct owners how to carry out maintenance safely. The prototype VES application addresses these concerns and emphasizes the potential benefits of using VR for this purpose.

When the user enters the virtual environment s/he is presented, via the GUI, with an array of general electrical safety statistics derived from [11]. The purpose of this information is to give the user a general overview of how electrical accidents occur in residential dwellings and to outline statistically who are the most likely victims. Subsequently, if the user chooses to navigate through the virtual home, electrical safety guidance associated with the user location can be obtained via the GUI. The unique information provided for the user in each location is broken into three sections. The first presents a database of accident scenarios associated with that location based on information obtained from a HASS/LASS report that was compiled by interviewing patients who attended Accident and Emergency units in hospitals across the UK. [38]. The ability to select from a range of electrical accidents in the database enables the user to see how accidents occur and the measures required to prevent such accidents. The second section provides general safety advice related to the users' location and the third section provides safety guidance and maintenance advice for the electrical appliances installed in that location

Ultimately, enhanced communication via VR can highlight the main risk activities associated with the use of electricity in the built environment. It can also provide education on good maintenance practices and enhance the prevention of injury. Owners and occupiers who can identify key safety issues, which allow them to monitor the condition of their installation and carry out minor repair work safely, can significantly improve safety levels [11]. Also, heightened levels of awareness among the public of the potential dangers may improve the renovation rate of electrical installations and hence electrical safety in the built environment

C. *Electrical Rules and Standards*

Electrical rules and standards are the fundamental guidelines for all electrical installations to ensure a safe environment in which to live and work. The use of a virtual reality training tool to educate students, contractors and engineers on these regulations is an exciting and novel prospect. In Ireland, ET 101 [39] is the national rules for electrical installations. On occasion these rules are updated to enhance electrical safety and to ensure harmonisation with CENELEC and IEC standards. Dissemination of the rules via VR can perhaps assist the electrical services industry in the transition between standards and also provide for a clearer interpretation and deeper understanding of the rules amongst practising engineers and students.

Electrical rules and standards such as ET 101[39], BS 7671[40] and IEC 60364 [41] in their current format are well documented and each section is clearly defined. However, the language used in these documents is technical and often complex and the precise interpretation of the rules on the part of the reader requires experience and a strong technical knowledge. The use of visual aids to assist in understanding and interpretation must be viewed in a positive light. It is this author's opinion that a virtual representation of the rules and standards will enhance the method by which knowledge is currently transferred and help students and practising engineers develop a greater appreciation of the rules and standards

Furthermore, as standards evolve from one version to the next it is incumbent on governing authorities to disseminate information pertaining to the updates often in the form of multi-location seminars. The time and cost involved in this process could perhaps be reduced if Web based VR applications such as 'VES' are utilised as a companion training tool by the relevant governing bodies. . The fact that desktop VR applications are reusable, convenient to update, can potentially reduce training budgets and can be distributed via the web presents a very attractive option for the industry.

To demonstrate the potential of this novel approach a number of the current rules in ET 101 are demonstrated in the VES prototype. Examples of these include: protection against impact required for wiring systems installed in solid and hollow walls; in the area of switchgear and accessories, the mounting heights of light switches, control devices, socket outlets and distribution boards are demonstrated; in relation to bathrooms in residential dwellings, the zones and the equipment permissible in each zone for these *special installations* are clearly identified (see Figure 4).

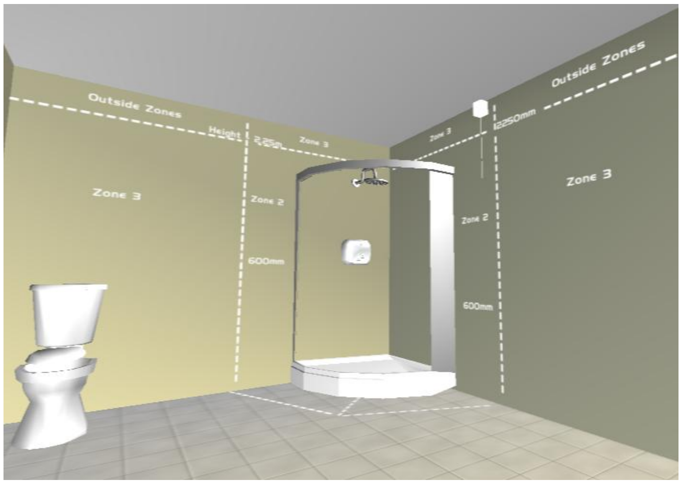

Figure 4 View of Zones in bathroom in VES

Currently there are no known electrical governing bodies or training colleges utilising VR in this fashion. One of the objectives of this paper is to highlight the potential VR offers the industry with regard to enhanced understanding of the regulations. If the view is taken that VR can enhance the learning effect, one could perceivably argue that through enhanced understanding, VR could lead to increased adherence to standards and hence an overall improvement in safety.

VI. Discussion

'VES' constitutes a first attempt at attaching a new dimension to the training of electricians and electrical services engineers. Although in its infancy, the successful development and early implementation of this prototype desktop VR application suggests that 'VES' could be a valuable tool for the industry and could also enhance electrical safety awareness and knowledge of the general public. Based on the initial developments outlined in this paper, it is worth highlighting the potential for future growth to progress VR in this sector.

It must be acknowledged that desktop VR does not utilise the full 3D potential recognised in other more immersive virtual environments. However, it does offer a very useful tool for training that can be widely distributed and easily accessed via a personal computer. Desktop VR also offers a proficient substitute for situations that are either impossible or too expensive to set up in a commercial company or training facility. Modern computers have added impetus as VR scenarios that previously required large and expensive equipment are now possible and graphical programming environments provide for an efficient method to develop an application. Hence the ingredients required, to make desktop VR commercially viable such as swift scene creation, platform reliability and flexibility are arguably here.

'VES' demonstrates the potential for a virtual electrical services design training application. An enhanced application could be used to educate students over a wider variety of design areas. Currently one of the most significant drawbacks for engineering students who attend university immediately after second level is a lack of experience of real world engineering situations. VR offers an opportunity to bridge this gap and provide a safe environment that is less critical should an incorrect decision be made. A virtual design environment such as this allows the user to investigate different scenarios and become more active in a learning environment. The facility also exists to set tasks for the user and let the training simulator carry out an evaluation of the user's performance in real time.

A comprehensive virtual guide to electrical rules and standards could be developed. This could prove to be a very useful tool for governing bodies and electrical contractors associations as a way of communicating with installers and designers of electrical installation. The clear instruction that can be obtained from a virtual demonstration could lead to greater understanding and adherence to the regulations.

Although every dwelling contains an electrical installation none are equipped with a safety manual. A virtual electrical safety manual for the general public could be developed based on existing manuals such as an operating manual for an intruder alarm. This virtual manual could outline how to operate, maintain, test and isolate electrical systems and appliances and could easily be adapted to give feedback on electricity consumption within the home. It could also be used to demonstrate where cable runs are in walls and hold a general safety record of the installation. Bearing in mind the fact there is no requirement for periodic inspection of domestic properties unless perhaps they are tenanted or communal properties, a virtual electrical safety manual could reduce accident rates, increase renovation rates and improve overall electrical safety. A similar virtual safety manual could also be brought to a commercial level whereby facility managers could have a virtual operating manual for the building under their control.

VII. Conclusion

An 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. The system allows full navigation of a virtual environment and interaction with many of the electrical elements. 'VES' can be used as a training tool to improve electrical services design, enhance electrical safety and provide a unique method to disseminate electrical rules and standards. The 'VES' prototype is in its early stages and an in depth evaluation of the system is currently underway with a large cohort of students from Dublin Institute of Technology.

The establishment of VR training systems similar to the prototype discussed in this paper can add value to the electrical services industry. Some of the key advantages are:

- VR offers the user an opportunity to be exposed to a range of scenarios and conditions that either occur infrequently or are hazardous to replicate.
- VR offers a low-cost alternative to creating full-scale real life training mock ups.

- VR is reusable, convenient to update, readily customised and can potentially reduce training budgets.
- Using VR as an educational tool shifts away from conventional learning techniques to one where users can self learn.
- VR can motivate and encourage students to become more active in their own learning
- Use of VR as an educational electrical design tool can enhance designers understanding and improve electrical safety
- VR can play a significant role in creating awareness of electrical safety issues and reducing accident rates within the general public
- VR can increase awareness and understanding of electrical rules and standards among practicing engineers and students.

Undoubtedly the capacity to replicate electrical installations in a virtual environment which affords the same functionality is a very interesting option and it is hoped that the prototype outlined in this paper can provide impetus to the electrical industry to use VR technology to further enhance electrical safety and design in the built environment.

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