PAPER 2

VIRTUAL REALITY AS AN INNOVATIVE INFRASTRUCTURE SOLUTION

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ABSTRACT

As human beings, our interpretation of reality is derived from what we can perceive with our five senses. Our brains combine the sensory information received when we see, hear, taste, touch and smell; and it colours in our reality based on these inputs. Virtual Reality (VR) allows our senses to be presented with constructed and designed stimuli, and in response, our perceptions of reality are re-constructed and re-designed. Through VR, a synthesized world which the user can interact with is created. VR combines hardware and software, and through synchronizing sensory experiences, the user can become immersed in a three-dimensional, computer-generated environment, that appears completely (or rather, virtually) real.

In order to stay relevant in the ever-evolving technological era which we live in; we, as engineers, need to remain on the precipice of developments such as virtual reality, which can aid the delivery of innovative solutions to challenges encountered in the provision of infrastructure.

Design, review, and analysis of design alternatives forms part of any infrastructure project. VR offers an innovative way to perform the aforementioned functions, through 3-dimensional visualization, so as to ensure that the best possible infrastructure solution is ultimately implemented.

Virtual Reality has numerous applications, making it attractive to the various stakeholders involved in an infrastructure delivery project. The acquisition of virtual reality hardware and software will enable the engineer to interrogate and improve designs during early project stages, through analysis of a VR model in which construction appears to have been completed. It becomes possible for an architect to make design amendments while immersed within the virtual realm. It allows clients a look into the future to see 2-dimensional drawings spring to life in 3-dimensional spaces. It presents the opportunity for collaboration by allowing engineers, architects, clients and other stakeholders to work on and provide input on a virtual model. It empowers the user to provide training, and allows trainees to become accustomed with the layout of a development in South Africa, while s/he may be in a different corner of the globe. The possibilities are effectively (or rather, virtually) endless.

Virtual Reality provides an innovative solution to some of the challenges faced in the provision of infrastructure in South Africa; especially as it pertains to design review and analysis. iX engineers' presentation for the 2018 IMESA Conference endeavours to illustrate how VR can be used as a tool to transform engineering processes and challenge the way engineering design has taken place in the past.

1. INTRODUCTION

Virtual reality allows a user to explore and interact with artificially created 3-dimensional spaces in real time. It incorporates tracking of natural head and hand interactions to simulate the feeling of navigation of the virtual space. In order for an experience to qualify as virtual reality it should satisfy the following requirements - it must:
• involve a virtually created world;
• be interactive; and
• be immersive.

Unpacking these three requirements, it is understood that:
• The virtual world refers to a digitally created 3-dimensional environment (let it be noted that VR is different from Augmented Reality (AR), as the latter provides a composite view by superimposing computer generated stimuli onto the user's view of the real world);
• For an experience to be interactive, it means that there must be an action by the user and a reaction by the virtual space, i.e. one is able to affect and interact with the virtual environment to some extent; and
• For the experience to be immersive, one must be surrounded by the virtual environment and be able to interact with the 360 degree space.

As we enter the Fourth Industrial Revolution, we note how the distinction between the real world and technology becomes increasingly unclear. Technology has become entrenched in many aspects of our daily lives, both in a personal and professional sense.

The technological encroachment of the Fourth Industrial Revolution forces us to interrogate our "business as usual" approach to engineering tasks, and think of innovative ways in which technology can be used to assist us in reaching our desired outcomes. The extent to which VR can be used in engineering to merge the real world and the technological world, so as to yield the best possible infrastructure solutions, will be explored.

This paper undertakes to demonstrate how a virtually created world which is interactive and immersive can be used as a powerful visualization tool in the engineering context, and how it can be used to improve workflow and design outcomes in an innovative way. The paper will discuss how VR is perceived by the user, it will introduce the hardware and software required to make virtual reality a success, and will then delve into the workflow involved with the creation of a virtual world in the engineering context. The uses of VR as an innovative engineering solution will be explored, with consideration given to the associated challenges and potential future developments within the industry.

2. HUMAN PERCEPTION OF VIRTUAL REALITY

In order for developers to create successful VR immersions, and hence, provide the best experience to the user, some understanding of the human eye and it's response to visual stimuli is required.

There are many external sources of information known as monocular cues, which are perceived by the human eye as one looks around. Monocular cues include occlusion, height in the visual field, relative size, relative density, accommodation, conversion, motion perspective, and so forth (Cutting, 1997). The aforementioned stimuli relate, amongst others, to how objects hide one another from a line of sight; the height of objects with reference to a datum point or surface; increasing indistinctness of objects with increasing distance; how focusing on an object near, or far, distorts that which is not been focused on; and so forth- all of which is considered when a virtual model is developed (Cutting, 1997). When a VR model is created, the developer takes these monocular cues into account, along with an understanding of how the eye positively perceives increasing amounts of pixels in generated images. Furthermore, the experience of the colour spectrum and light intensity is taken into account when developing the virtual world. This understanding is used to improve realism, as well as enhance and add dimension to a virtual 3-D model.

Considering the above, VR aims to simulate reality by approximating lighting, materials, colour and so forth, and in doing so, deceive the brain into thinking that what it is perceiving is real.

3. HARDWARE AND SOFTWARE REQUIRED FOR VIRTUAL REALITY

In order to optimize the visualization achieved through VR, certain hardware and software is required by the user.

Hardware

A few options for VR hardware exist, inclusive of room-scale, seated and mobile phone based solutions; each with their own advantages and disadvantages. The discussion of the various products and possible configurations available falls beyond the scope of this paper; hence, the hardware required will be discussed in a general sense.

To achieve the best possible immersive experience, a head mounted device must be employed. It should have a high refresh rate, such that movements made with the head are translated to differences in the perceived virtual space smoothly. Additionally, when the user moves their head, their field of vision should be immediately updated without lag. The head mounted device must have a high resolution, so that the rendered image can be perceived as realistic, such that all objects have clearly defined edges.

There are also different options available for the laptop that will power the virtual reality immersion, with factors such as RAM and the strength of the graphics card to be taken into consideration. The specifications of appropriate laptops are however, not the focus of this paper.

Figure 1: Hardware required to explore a virtual model

The success of virtual reality immersion, as opposed to simply observing a 3 dimensional model, is that VR allows for a more natural interaction with the model. Tracking of the user's physical movements within the model can be done using camera-based rigs which detect movement, or specialized depth sensors. However, most successfully and most accessibly for the average user, is interaction through the use of handheld

motion tracking devices (Hilfert & Konig, 2016). The hand held devices allow the user to navigate the virtual world by "walking" through the space, opening doors etc.

Furthermore, the Building Information Modelling or BIM (which will be discussed in the following sections), will be accessed using the hand-held motion tracking devices.

Software

There is an array of software on the market which can be used to model developments and simulate virtual experiences. The intended end use of the virtual model will inform which software is most applicable. Whilst some engineering applications might require "one click solutions" which aim only to visualize the model, others could require more customizable software solutions to incorporate BIM information etc. For the purposes of this paper, the software currently employed by iX engineers (Pty) Ltd will be discussed, so that the workflow for the creation of a successful VR model can be unpacked. The software used includes Autodesk Revit, 3DS Max and Unreal Engine 4 (UE4).

4. VR WORKFLOW

The succeeding section will demonstrate that there are numerous uses for virtual reality in engineering. The true benefit, however, is only realized if the best possible workflow is used to achieve the desired outcomes. The software workflow currently used to create a virtual model is shown in Figure 2.

In Revit, the engineer is able to design a model with all its respective components in three dimensions. Revit is a powerful tool for modelling and dynamic change management. The latter, dynamic change management, refers to the software's ability to correct the model once a change has been effected by the design engineer. For example, if the designer chooses to increase the height of a roof, then the adjacent walls automatically become taller to remain connected to the roof; ensuring that the model remains consistent throughout.

From a visual perspective, standard / default materials can be assigned in Revit, i.e. the user will indicate that a pipeline will be PVC-U material, and the software will apply basic textures, which it recognizes as PVC-U, accordingly.

Furthermore, one of Revit's most commendable features is its ability to store information pertaining to the respective assets in the model. Such information for a pipe system for example, could include but not be limited to the pipe's material, its class, its roughness coefficient, inside and outside diameters etc. This information is known as Building Information Modelling or BIM, and its value in virtual reality will be expanded upon subsequently. Ultimately, Revit allows the designer to create a dynamic 3-dimensional model, comprising of both geometric components (the physical model) and non-geometric components (the BIM information).

Once the engineer is satisfied with the model created in Revit, it is imported into software called 3DS Max. In 3DS Max, the polygon count can be addressed and desired animations such as flow through a pipe can be effected; all of which contributes to the realism of the model. As alluded to in preceding sections, the human eye's ability to perceive an increasing number of polygons is considered when creating a virtual model. Up to a certain plateau, the more polygons in the model, the more detail the model and the components within have, and thus, the more realistic the virtual environment becomes.

Increasing the number of polygons is equivalent to increasing the number of edges that a rendered object will have. To illustrate
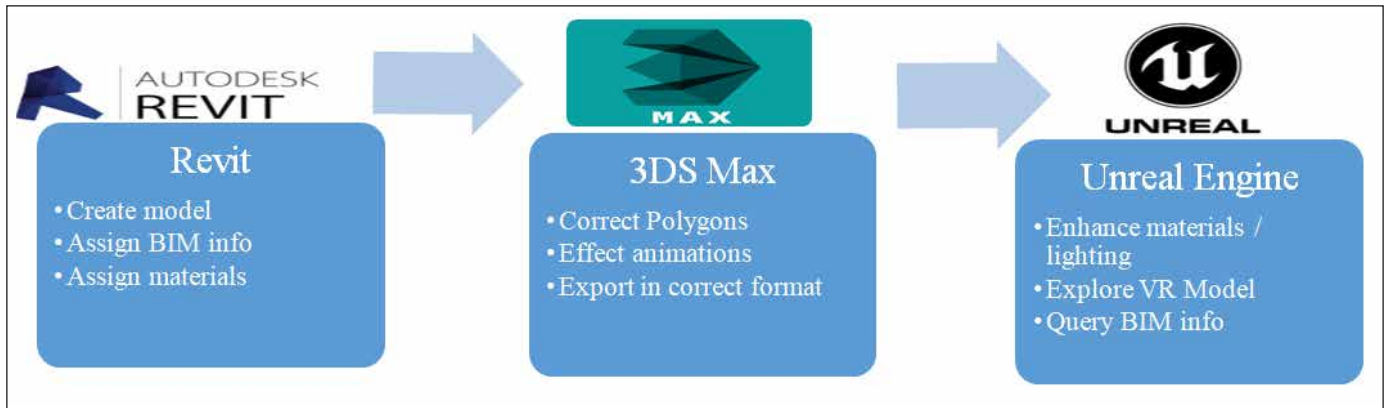
Figure 2: Workflow for the creation of a virtual model

this, consider a pipe as a component of a system, as pictured in Figure 3 below.
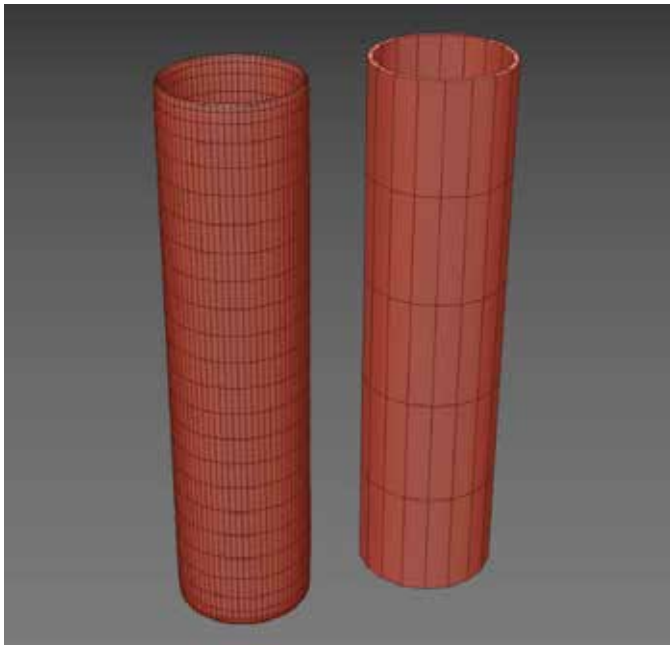

Figure 3: Optimization of polygons in pipelines

Prior to optimization, the model will have a high number of polygons, as illustrated by the rectangles visible in the left pipe in Figure 3. Once the number of polygons is optimized, the number of rectangles that the object has decreases, illustrated by the rectangles on the right pipe in Figure 3. Reducing the polygon count allows the computer to more easily render or create objects within the virtual model, since the amount of data to process is dramatically reduced. From Figure 3, it is evident that the significantly reduced polygon count does not have a negative effect on the level of detail perceived from a human's perspective. Every virtual model created requires that the designer strikes a balance between the Level of Detail (LOD) required and the number of polygons.

The next step in rendering a VR Model is the importation of the model from 3DS Max into Unreal Engine 4 (UE4). The UE4 software allows the user to enhance the model by introducing real life additives such as lighting, the perception of wind, shadows and realistic textures; all of which significantly increases the realism of the model. The LOD can also be influenced in UE4, such that the user is exposed to a greater level of detail when they are close to an object, and a lesser level of detail when they are further away from it (Hilfert & Konig, 2016). All these methods will assist in improving the user's VR experience.

As previously mentioned, BIM pertains to the physical and functional characteristics of an asset in a model. Relevant BIM information is assigned to the respective assets in a model and is stored within Revit, and hence can be accessed within a VR model in UE4 once the model has been imported. In UE4, a stakeholder could use the handheld controls to identify a component of a model, select that component and then access its associated BIM information. For example, in a model of a wastewater treatment works, the BIM information associated with a pump could be its material, geometry, the supplier information, maintenance requirements et cetera, as illustrated in Figure 4. The designer has complete control over the BIM information which is to be assigned to an asset, i.e. irrelevant information can be filtered out and hence will not be imported into UE4. BIM is a powerful enhancement of the virtual model, because it allows the user to seamlessly access an additional realm of information without breaking immersion (Hilfert & Konig, 2016). This is a very useful tool which can serve value from the design stage, throughout the design life of the component.

Figure 4: Accessing BIM in a virtual model

5. USES OF VR IN THE PROVISION OF INFRASTRUCTURE

The preceding sections have explained what virtual reality is and how a virtual model can be created in the engineering industry. The following section will provide examples of the numerous ways that virtual reality visualizations can be used to improve the design and delivery of infrastructure projects; hence making the use of VR in engineering design an innovative solution.

Interrogation, Analysis and Improvement of Designs

Virtual visualization software allows the user to explore, interrogate and interact with the design in a real world sense, before the final product has been constructed. In this way, improvements can be made during initial project phases and design alternatives can be explored without incurring significant abortive costs.

In typical engineering applications, a structure, process, network or system is designed using appropriate software, often in 2 dimensions. While design checks are performed on the 2-D design in order to ensure that there are no errors, there is a possibility of miscalculation.

If the model is visually interrogated from a virtual perspective in three dimensions prior to commencement of construction, errors can be identified and corrected. Since the virtual model is a 1:1 representation of the design, the engineer will be able to navigate the model and ascertain if there are any components which are inaccessible, identify any obstructions, pinpoint areas where working spaces need to be increased, and so forth.

If an error is identified as a result of VR visualization, and corrected in the model prior to construction; the following will be avoided:
• Time spent by the engineer verifying the error and formulating a design solution;
• Rework required, with associated abortive cost;
• Delays in construction program

As a further benefit, through software development, it is possible to manipulate the VR model to show the user components of the design that are otherwise hidden. This can include pipework and ducting in walls, or services beneath the floor's surface. Furthermore, the software can be programmed so that the hand tracking devices highlight an entire system when selecting a single component from that system. Being able to isolate systems provides the benefit of easy identification and successful analysis of interaction where respective systems cross one another.
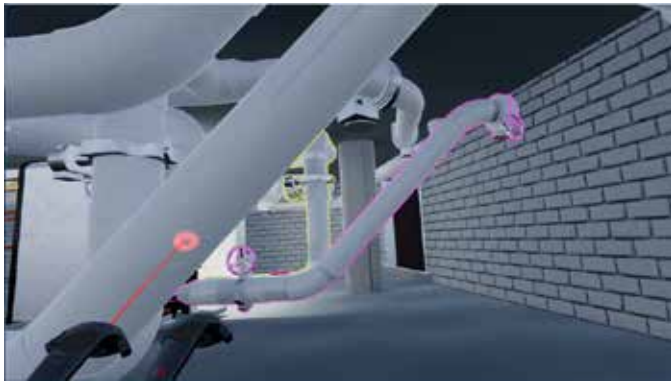

Figure 5: Isolation of systems with different colours in virtual reality

This demonstrates the potential of VR as a tool for the user to see what otherwise would not be seen, and amend designs where applicable. Being able to visualize the completed project, while the project is actually in the design phase ensures that the best possible design is ultimately implemented.

Stakeholder Engagement

There are often multiple stakeholders involved in a project, all of whom can benefit from exploring the VR model to provide input on their respective areas of expertise. For example, through exploration of a virtual model, an architect may want to assess the illumination in a certain room, while a structural engineer might be interested in a beam in that room, and a

non-technical client would have the goal of assessing the overall feel, flow and utility of the room. Being able to visualize the end product prior to commencement of construction is a tool which can challenge and change the way inspections are done by the various stakeholders in this industry. However, it must be noted that the function of VR is not to replace the specialist mathematical and scientific design performed by engineers, but can be a useful tool to visualize the outcome of the aforementioned engineering designs.

From an architect's perspective, a major benefit of experiencing a design in a 3-dimensional virtual environment, opposed to a 2-dimensional drawing, is that a greater appreciation for space and scale can be achieved in 3-D. In addition, sight lines can be assessed more successfully in a VR model. Furthermore, avatars can be created to occupy the virtual space along with the user, so that the areas available for interaction can be evaluated within the model in real time. This makes VR a useful tool for architects and engineers alike, as the aesthetics and ease of movement around the model can be visualized and tested, in conjunction with interrogating the success of the engineering design (Hilfert & Konig, 2016).

Figure 6: Image generated from a VR model, which can be used for a visual impact assessment

For any project to be a success, it requires acceptance and endorsement from the surrounding community. Virtual reality can be used as a tool during community participation programs to foster dialogue and create a point from which discussions can commence. For example, if the community is concerned that a new building will be an eyesore, the building footprint can be created using virtual reality as in Figure 6 above, and community members will be able to provide comment on the aesthetics of the finished product before construction even commences. This provides community members with a platform from which they can provide meaningful feedback, as well as gain a greater appreciation for the ways in which the project will affect their community. For such applications, still images generated from the VR model can also be beneficial for the purposes of discussion.

In the aforementioned applications, VR is used as a visualization tool which allows the various stakeholders to provide input on / improve their component of the works before the project is constructed. In order to do so seamlessly, the user requires the ability to annotate the virtual model, without breaking immersion. This is required so that records can be made of Revit components which need to be revisited once the immersion is over, points for later discussion are noted, clashing services are recorded, etc. With successful programming in UE4, the user can take a screenshot of their field of view, which will be stored automatically for easy access at a later stage- thus providing the user with a graphic reminder of what needs to be revisited in the model post immersion. Alternatively, an audio recording can be made as the stakeholder takes a VR "walk" through the model.

This audio recording can be used as a verbal to-do list of the changes to be effected post immersion. Finally, the option exists for the user to make notes on a virtual keyboard while immersed. This is the most time consuming form of annotation, because the input method allows selection of only one key at a time on the virtual keyboard using the handheld devices.

VR as an Asset Management Tool

An engineering design created in Revit will consist of many components or assets. As a result of the varied assets, there will be differences in the frequency, nature, and requirements for maintenance across the system. Virtual reality software can be developed to represent the maintenance requirements visually, by incorporating this information as BIM in Revit, and hence, making the data accessible in UE4. Using VR to visually represent maintenance requirements, for example, using red to indicate assets which require urgent maintenance and green to indicate assets which do not require immediate attention; operations officers will be able to manage and allocate their resources according to the components of the system which most require it. It will also ensure that no asset is overlooked with regards to maintenance. Without breaking the immersion, the user can identify a "red" asset using the handheld devices, and can access further BIM information relating to the component's maintenance, e.g. supplier details, specialized requirements and so forth.

Consider an example where a specialized part has been imported from overseas for incorporation into a plant in South Africa. When this part requires maintenance, a specialist overseas can access the VR model, identify which components of the asset require attention and schedule maintenance accordingly. Owing to the fact that the VR model is a scale representation of the design, through VR visualization, planning of the actual maintenance process (e.g. scaffolding required, assessment of adequacy of working space etc.) can be concluded by remote exploration of the VR model too. Furthermore, the specialist can access the model as many times as is required without having to incur the travel costs. Thus, virtual reality presents an innovative way for asset management and maintenance to take place within the engineering context.

Enhancement of learning and teaching

The rapid development of hardware and software and the migration towards the Fourth Industrial Revolution suggests that virtual reality can be an effective tool in the teaching of engineering at tertiary institutions. Nowadays, many students enter university with a baseline understanding of technology and computing, and thus hold an expectation for being exposed to appropriate technological tools that will enhance and further extend this knowledge (Abulrub, Atrridge & Williams, 2011). Teaching engineering through virtual reality has the advantage of being safe and controllable, in addition to providing the learner with realism and interactivity (Abulrub, Atrridge & Williams, 2011). VR can be used to simulate engineering experiences that are sometimes inaccessible to large groups of students, for example, various applications in the mining industry. Using VR models in education will allow students the opportunity to apply their theoretical knowledge, by visually assessing design errors and considering alternatives whilst under immersion. Because learning through virtual reality is different from learning through reading or listening to lectures that students are accustomed to, VR creates interest and thus encourages learner engagement; as well as enhancing productivity by developing students' creativity, problem solving skills and communication (Horne & Thompson, 2008). Many employers note that while graduates possess the theoretical knowledge to address certain engineering challenges, they sometimes lack the practicality that is required in the industry. VR can assist

in bridging this gap in a manner that can revolutionize the way teaching and learning takes place in the engineering context at tertiary institutions.

Facilitation of training

Complementary to enhancing learning and teaching, is the facilitation of training through VR. Virtual reality can be used to facilitate learning of skills or transfer of knowledge, where the real life applications may prove to be very expensive, inconvenient, time consuming or dangerous. Consider the example where Health and Safety inductions are conducted using virtual reality. Another success of providing training, such as induction, through VR, is that a VR model of a site in Cape Town can be explored by a stakeholder on a different corner of the globe - hence abolishing the barriers of geography. Using virtual reality as a training mechanism allows time and money to be saved and the trainee to remains out of harm's way; without compromising the experience or the value of what has been taught.

Figure 7: Image generated from a VR model, in which the user is undergoing induction training and familiarizing themselves with the layout of a plant remotely

Consider an instance where construction is to take place, and the client has expressed that there should be a transfer of skills from the contractor to members of the local community. It can be both costly and risky to train someone with little or no experience in the operation of cranes, for example. This is where a virtual simulation can be used as a training tool. The trainee will have the first-person experience of sitting in the crane's cockpit, and can experience the actual visibility and movement range of the machine. The model can even be programmed to react if the trainee's controlled load hits another object on the site (Hilfert & Konig, 2016). It is evident that virtual reality has the power to redefine how training is done in the engineering industry.

Exploration of Different Scenarios

Contemplate a scenario in which a new structure is designed, and certain emergency evacuation procedures have been identified by the fire engineer. Using virtual reality, a fire emergency can be simulated, and a user who is unfamiliar with the model can test the success of the various escape routes which have been identified, without being in any real danger. Because the virtual model of a fire breakout can be rendered in a very realistic way- inclusive of sound effects, appropriate lighting changes, etc. the simulation will be a good indication of how a subjective person will react to such an emergency in the real world (Hilfert & Konig, 2016). A simulation of this nature can also be used to test the efficacy of signage relating to entry and exit points under emergency conditions and the value of the positioning of evacuation information et cetera. This demonstrates that virtual reality can be a vital, life- saving tool in engineering design; providing an innovative way to test design success.

Another invaluable application, is testing of different access options for disabled persons. A VR immersion can be generated, in which the user is virtually placed into a wheel chair and thus will visualize and evaluate the accessibility of a new development from the perspective of a physically disabled person. Performing this VR tour through the eyes of a wheel-chair-bound person, can inform the designer of unreachable components, inadequately sized spaces and so forth. This illustrates once more that VR can be used to view the world from a new perspective, and hence, VR offers a new, innovative approach to engineering design in the provision of infrastructure.

6. CHALLENGES ASSOCIATED WITH USING VR

The preceding section provides evidence of the numerous ways that virtual visualization can be used to enhance the design and design review processes in infrastructure projects. The following section will detail some of the disincentives for using VR.

Once a model has been successfully imported and explored in a virtual space, the engineer may want to make some design alterations, e.g. if a clashing pipe has been detected, or there is insufficient working space around a certain component. The designer will then have to revert back to the Revit model in which the initial design was done to effect those changes, and then re-import into Unreal Engine through 3DS Max. Unreal Engine does allow modification of the model to an extent i.e. one will be able to scale a component of the design, but the program is largely a closed form and does not allow changes within the visualization structure to be made without programming tools and detailed knowledge of the software. This is undesirable from a workflow perspective.

Another disincentive for the implementation of VR is the complexity of hardware and software selection. As previously alluded to, the work flow discussed in preceding sections can be modified through the use of various other software programs. Similarly, there a few options for head mounted devices and hand held controls on the market. Whilst having many alternatives may seem beneficial, without thorough understanding of the intended end use of the model and the desired workflow, one could invest in hardware and software which is not fit for purpose. Because this field is evolving, users may be apprehensive to invest in hardware and software which might leave them outdated soon, since there is so much potential for future development.

A major challenge with the implementation of virtual reality is the high cost of the hardware and software. However, as this technology advances and becomes more accessible, a drop in price is expected, making it more financially viable to implement.

Some users may be deterred from using virtual reality because of the programming skills required. Let it be noted that programming is only required when the user endeavours to add additional functionality (other than just visualization) to the VR model, which is not inherently present in the software used to generate the model. Thus, programming knowledge is an added benefit, but not necessarily a prerequisite for becoming involved in VR.

Finally, it has been reported that the virtual stimuli experienced during immersion can sometimes evoke unpleasant sensations in the user, known as cyber sickness. The extent to which this visually-induced motion-sickness presents itself varies amongst different users, but has been noted by some as a deterrent to the use of VR; as found by Kiryu & So (2007).

7. THE FUTURE OF VIRTUAL REALITY

Virtual reality can no longer be considered technology of the future. It is the technology of now. While the development of VR infrastructure has come a long way to being the portable, lightweight, workflow-appropriate hardware and software available today, the following developments are anticipated for the future of virtual reality:

• Improved workflow from Revit to UE4. As previously discussed, the extent to which design changes can be effected in the UE4 is limited. When the model requires modification, it becomes time consuming to revert back to Revit and re-import into UE4, hence it is expected that this workflow will be improved in the future;

• Higher pixel counts in head mounted displays, leading to higher quality virtual images being produced;

• It is expected that future VR devices will have improved frequency of detection of head and hand movements, leading to an instantaneous response from the model when the users moves;

• Headsets will become wireless with inside-out tracking; and

• Better hand tracking devices to enable multi-finger tracking.

The following outcomes are being pursued by iX engineers, in order to create a more robust system that responds to numerous design challenges:

• Programming of software, such that the functionality developed can be integrated into future projects;

• Development of more comprehensive and accurate Revit models from the design onset, so that the models imported into UE4 do not require much rework; thus adding value and not cost;

• Widespread BIM integration;

• Further simulation and interactivity;

• Easily accessible mark-up and review tools;

• Measurement tools such as virtual range finders, area and volume calculators; and

• Further integration with asset management systems.

8. CONCLUSION

By incorporating virtual reality visualization into a workflow, the engineer can produce more efficient and well- thought out developments and spaces, with reduced design and construction costs. Work will be executed as though all of the stakeholders had foresight into how their designs and visions will be translated into reality, and with VR, that foresight is possible.

Through visualizing and truly experiencing the VR model, engineers are able to better understand engineering design problems and can thus provide robust and practical answers to the challenges encountered.

Virtual reality allows the user to unlock a new dimension of engineering problem solving and thus, allows the engineer to provide truly innovative infrastructure solutions.

REFERENCES

Abulrub, AG; Attridge, A & Williams, MA. 2001. Virtual Reality in Engineering Education: The Future of Creative Learning. Modified version of a paper presented at International Conference IEEE EDUCON 2011

Cutting, J. 1997. How the eye measures reality and virtual reality. Behavior Research Methods, Instruments & Computers 1997: 29 (1), 27 – 36

Hilfert, T & Konig, M. 2016. Low-cost virtual reality environment for engineering and construction. Visualization in Engineering 4:2

Horne, M & Thompson, EM. 2008. The Role of Virtual Reality in Built Environment Education. Journal for Education in the Built Environment. 3:1; 5-24

Kiryu, T & So, R HY 2007.Sensation of presence and cybersickness in applications of virtual reality for advanced rehabilitation. Journal of Neuro Engineering and Rehabilitation 2007, 4:34

Steeds, A. 2017. How virtual reality is changing engineering. Ingenia, 70.