PERSPECTIVE ON THE USE OF VIRTUAL REALITY IN THE GHANAIAN BUILDING CONSTRUCTION INDUSTRY

By

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DECLARATION

I hereby declare that this project report is the result of my work towards the award of MSc Construction Management, and to the best of my knowledge, this submission has neither in whole nor in part been prescribed by another degree at Kwame Nkrumah University of Science and Technology, Kumasi or any other educational institution, except where due to acknowledgement is made in the thesis.

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Head of Department **Signature** **Date**

ABSTRACT

With the increasing complexity of construction projects, there is the need to find ways to manage these projects and deliver within time, budget and meet quality expectations. Generally, digital technology offers such opportunity in the 21st century.

This study focused on one aspect of the emerging digital technology landscape. That is Virtual Reality and how technology can contribute to the improvement of project delivery in the Ghanaian building industry. The study sought to examine the use of virtual reality in the building construction sector in Ghana. The methodological paradigm used was the pragmatist approach and relied on the use of questionnaires. There were sixty respondents (60) out of eighty- two questionnaire distributed and comprises of individuals from the Building construction industry (D1K1, D2K2, Design consultancies and Real Estate developers). The study found that the Ghanaian building industry has the exposure to virtual reality technology; however, are unaware of the full potential it has to offer. Majority of users considered it a useful marketing tool first before all others. The virtual reality technology is utilised mainly during final visualisations and clients meetings. A significant setback, however, was the lack of awareness of the benefits of the technology and the corresponding budgetary constraints with its adoption.

Keywords: Virtual Reality, Building Industry

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LIST OF ABBREVIATIONS

- AR – Augmented Reality
- D1K1 and D2K2 – Contractors Classification according to the Ministry of Works and Housing
- MR – Mixed Reality
- VCE – Virtual Construction Environment
- VR – Virtual Reality

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DEDICATION

This entire project is dedicated to God Almighty and my parents, Very Rev. and Mrs Quartey

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The process of designing and constructing buildings and other related infrastructure is often a complex one, involving multiple stakeholders and substantial investments of time and financial resources. In a quest to improve the building and construction industry, as a whole, significant processes have been computerised in recent times (Greenwood et al., 2008). These are very different from the first digital tools that comprised the use of computers for necessary line drawings.

Currently, the use of virtual reality (V.R.) and augmented reality (A.R.) technologies, introduced by such software companies as Autodesk, are seen by many observers and industry players as pointing to the future and bringing about a more advanced set of tools to help enhance the entire industry (Designblendz, 2017)

Although sounding new, Virtual Reality has existed since the 1950s. It has evolved from passive VR, which involves simple actions, and activities as watching a TV screen as a spectator, to exploratory VR. Virtual reality includes the interactive use of the computer monitor in exploring three-dimensional environments and now to immersive VR which gives the user a chance to interact with the virtual world and have one's senses stimulated (Spaeth and Khali, 2018).

The current enthusiasm within the industry regarding this form of immersive possibility stems from several options it offers: architects, engineers, and builders could certify design decisions collaboratively in environments where the building will be situated (Designblendz, 2017). It enables them to view models in 3D to scale, which helps to improve field team knowledge; it also helps in creating the awareness of likely construction problems before it begins. VR and AR help in scenario-based training and offers workers the opportunity to explore job safety practices through sample site backgrounds – a useful tool for safety training and evaluation. Finally, VR is a better way to seek client approval, since the technical teams are better able to explain scenarios to clients by showing a walk-through of their designs, leading to faster understanding and decision-making (Designblendz, 2017).

It is not difficult based on the discussions above to envision all how VR and AR can contribute to reducing risk, increasing technological innovation and improving business processes (Spaeth and Khali, 2018). Professional project teams can use technology to visualise and handle increasingly complex designs and engineering data. Other means specific to the built environment industry include coordination and detail design, design review and value engineering, and construction scheduling and mainly as a means of marketing. These are further categorised as system integration, customer interface and new market penetration (Greenwood et al., 2008).

1.2 Problem Statement

As a relatively recent phenomenon, few studies have explored the use of (immersive) VR and AR in the construction industry. Previous reviews include “the application of virtual reality in architecture and construction” by Whyte, J., 2007, “the place of VR technology in UK architectural practice” by Spaeth, A.B. and Khali, R., 2018, and “the perspective on the use of virtual reality in the building industries in China, Sweden, The UK and US” by Greenwood et al 2008. In the Ghanaian context, no documentation interrogates the use of VR and AR in the construction industry. This study intends to fill that gap. No research and survey has been carried out to inform the state of this technological phenomenon in the Ghanaian building construction industry and how it could contribute to improved project outcomes.

1.3 Research Questions

1. Who are the users of virtual reality technology and systems in the Ghanaian Building Construction Industry?

2. What are the uses of virtual reality and to what extent is it incorporated within the Ghanaian Building Construction Industry?

3. What are the barriers to the Ghanaian Building Construction Industry in their attempt to adopt the latest VR technology?

4. What are the strategies to overcome the barriers to the adoption of virtual reality?

1.4 Research Aim and Objectives

This paper examines the use of virtual reality in the building construction sector in Ghana. The objectives are, therefore:

1. To identify the users and the extent of VR usage within the Ghanaian Building Construction Industry.

2. To identify the opportunities associated with the use of VR in the Building Construction Industry.

3. To identify the barriers to the adoption of VR technology within the Ghanaian Building Construction Industry.

4. To identify strategies to overcome the barriers to the adoption of VR technology.

1.5 Significance/Justification of the Study

Virtual Reality has over the years gained importance not only in terms of advances in technology, but increase productivity, improvement in team communication and cost reduction through the increasing adoption of its techniques (Brooks, 1999)

Uses of virtual reality in the construction industry are as follows:

- In the improvement of construction education
- Construction safety training and safety evaluation
- Automated project planning approaches
- To check design constructability through virtual construction environments
- Construction scheduling
- Improving the existing processes
- Resource optimisation
- Site layout and planning
- Planning and monitoring of construction processes
- Evaluation of construction scenarios

The Ghanaian construction industry has a lot to benefit from this technology. It is, therefore, of the essence, to know how widespread this technology is in the Ghanaian context and the way forward to help improve the building industry.

1.6 Scope of the Study

The study, due to the resources available, will be limited geographically to the Ghanaian Building Construction industry, which comprises construction companies, design and consultancy firms and real estate companies. These were selected based on the assumption that they were in a better position to be able to afford and utilise advanced technology such as those needed for Virtual Reality in their corporate tasks.

1.7 Research Methodology

The study utilised a pragmatist approach as the methodological framework. With a multi-stage method, a survey was conducted on building construction professionals, explicitly building contractors (D1K1, D2K2), design consultants and real estate developers in Ghana to ascertain the extent of VR usage using questionnaires. Purposive sampling was used; snowball sampling was encouraged. The sampling enabled a form of triangulation to occur across the data sets and allow more in-depth insights to emerge.

1.8 Structure of the Report

The report will comprise five (5) chapters. The first chapter will be the general introduction of the study. The second and third chapters will constitute a critical review of existing literature and a detailed account of methodological approaches, respectively. In the fourth chapter, there will be a discussion of findings and results obtained, that contribute to the understanding of the study. The final section will draw conclusions, make recommendations and point to future research possibilities based on the outcomes of this study.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Virtual reality technology has existed for a very long time; however, due to recent technological advancements, it is gradually becoming a common phenomenon (Kenwright, 2019).

Virtual reality has, with time evolved from what it previously started as, and is currently perceived to be, into a technology broadening the scope of how a man can interact with his imagination manifested physically (Sherman and Craig, 2018).

Gradually, the technology is expanding to multiple disciplines such as education, health, military, industrial uses, and entertainment. The technology is still, however, very young and undergoing tremendous growth from time to time (Brooks, 1999).

This chapter seeks to inform and help in the understanding of existing research relevant to the study.

2.1 Historical Development of VR

VR in the 1960s

The computer scientist, Ivan Sutherland often referred to as 'the father of computer graphics'' is known to have written about the ultimate display in 1965. The Ultimate display included interactive graphics, force-feedback devices, as well as mentioning audio, smell and even taste. In 1968, he made the first virtual and augmented reality head-mounted display system that traced and corrected the change in viewing positions of the viewer through several updated graphics display. The system he invented utilised two displays visible from a pair of 'half-silvered mirrors' and superimposed images onto the real world with stereoscopic computer graphics for the viewer (Gigante, 1993).

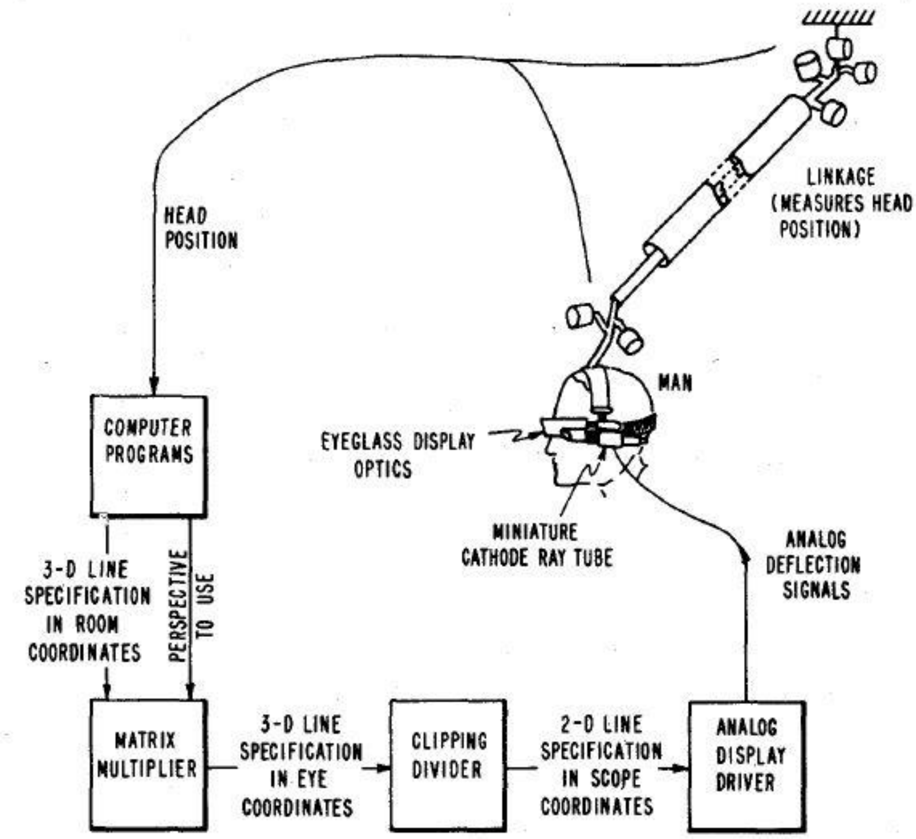

Figure 1: The parts of the three-dimensional display system by Ivan. Sutherland in 1968

The US military service was a contributor to the development process of virtual reality technology. In the 1960s, military flight simulators were a significant push in the technology, and a great deal was developed at the US Air Force's Armstrong Medical Research laboratories by Tom Furness. These simulators fostered a greater understanding of the technical requirements for the effectiveness of VR. Fighter pilots had head-mounted displays with graphics, which helped serve as an identification system. This identification system graphics included friend-or-foe identification, targeting information, threat information (e.g. ground-based missile sites) as well as optimal flight path information (Gigante, 1993).

The experiences of participant viewers from the flight simulators provided an in-depth understanding of the technical requirements of virtual reality and served as a contributor to the improvement of technological development. These experiences of the viewers were precise, captured and served as indicators to address and provide other needs, which include:

- rapid update rates (i.e. high-speed tracking and redisplay, preferably at least 30 frames per second);
- short lag times (so there is no noticeable delay between movement and the production of the correct (new) visuals);
- secondary visual cues like shadows and textures;
- motion feedback and force feedback;
- Techniques for the management and an efficient display of complex worlds (Gigante, 1993).

NASA Ames

More contemporary setup for VR was developed in 1984 at NASA Ames. Dr Mike McGreevy and Jim Humphries were the inventors. The VR setup was called VIVED (Virtual Visual Environment Display) (Fig. 2). This system was for future astronauts, and in later years, the VIEW (Virtual Interactive Environment Workstation) (Fig 3) project developed a general-purpose, multi-sensory, personal simulator and telepresence device.

The head-mounted system included head and hand tracking, monochrome full field-of-view stereo head-mounted displays, speech recognition, 3D audio output, and a tracked and instrumented glove (Gigante, 1993).

Figure 2- Virtual Visual Environment Display (Gigante, 1993)

Figure 3 - Virtual Interactive Environment Workstation by (Gigante, 1993)

VR in the 1990s

As early as the 1990s, many considered a job in virtual reality research a prestigious position — the technology, it seemed even then was going to be the next stage in the gradual march of technological advancement (Gigante, 1993).

As could be expected, science and science fiction enthusiasts in the film and media industries, inundated researchers with requests for interviews and information about this emerging area and soon, the technology started to appear in "popular culture". Science Fiction films such as The Matrix 1999 became representations of Hollywood's embrace of the future. Novels, sitcoms, comic books, cartoons, among others started to show one version or the other of head-mounted technology that gave one access into another reality – a virtual universe (Whyte, 2003).

Much of the excitement centred on immersive VR— sophisticated technologies that replaced real-world sensory information with synthetic stimuli such as 3D visual imagery, spatialized sound, and force or tactile feedback. The goal of immersive virtual environments (VEs) was to let the user experience a computer-generated world as if it were real—producing a sense of presence, or "being there," in the users' mind.

Though generally intriguing, an immersive VR lay at the heart of the cultural buzz about the emerging technology. The idea that this technology could take the place of and reproduce "real-world sensory information with synthetic stimuli such as 3D visual imagery spatialized sound, and force or tactile feedback" (Bowman and McMahan, 2007) was exciting. Since then, a virtual reality both as a field of research and as a consumer product has grown in leaps and bounds.

2.2 Definition of VR

The task of defining what constitutes virtual reality is essential for the operationalisation of the term as far as the study is concerned.

According to Webster et al. (1996), Virtual Reality (VR) involves simulation of an artificially created environment using digital tools such as computers and electronic mouse. These digital tools use other forms of technology or in plain terms computer-aided design software in creating the virtual world.

Within the created interface, the user rather than engaging with the artificial environment via a two-dimensional screen immerse into the virtual world. It is this additional feature of immersion and the ability of the user to manipulate and make changes within the artificial world that sets virtual reality apart from traditional computer technological interfaces (Zheng et al., 1998; Webster et al., 1996).

In other words, the senses of the user such as vision, hearing, touch, and even smell are involved in the experience. The actions of the user are virtually limitless in the artificial world and the participant has control, enabling them to move around in the virtual world as well as see it from different angles, reach it, grab it and reshape it just as it could have been manipulated if it were real life (Zheng et al., 1998).

Virtual reality can involve more than just the use of computer technology in representations of the real world; it is a technology that can combine “computerised clothing” (the use of hand gloves and the head-mounts in the communication) with the real world OED, 1989 as cited by (Whyte, 2007). The virtual world from this time is a responsive environment (Brooks, 1999) and sensitive to the motions of the user.

2.3 Types of VR

According to Spaeth and Khali (2018), an understanding of the technology is enhanced by viewing it as a continuum rather than as a single or fixed entity. In one extreme of this continuum, we have the empirical world which is the world as is known and lived, and on the other, a virtual world which is artificially created or designed and entirely simulated. In between these, there is a mixed reality, which can be divided into augmented reality and augmented virtuality.

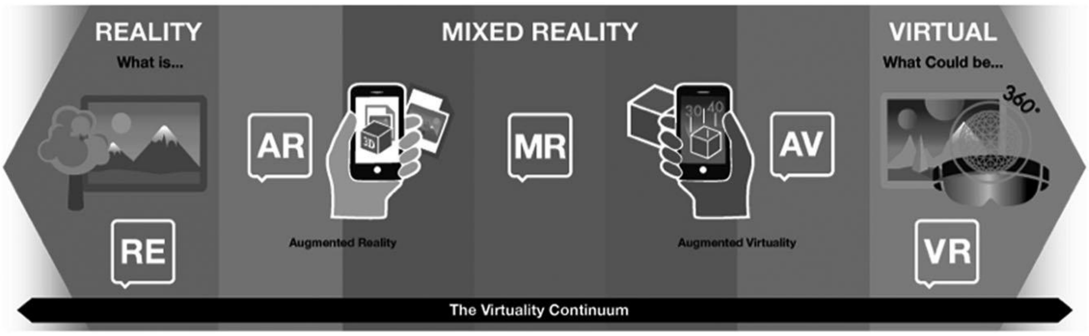

Figure 4 Reality–Virtuality Continuum by (Spaeth and Khali, 2018)

2.3.1 Mixed Reality

The conceptual space between the virtual world and the real world is occupied by mixed reality. Mixed reality is a general term that refers to systems involving a merger between the real world and the virtual or simulated world and is classified into two broad categories: Augmented Reality and Augmented Virtuality (Spaeth and Khali, 2018)

Figure 5: Mixed reality is a powerful tool for collaborative planning by Microsoft HoloLens,2018.

2.3.2 Augmented Reality

Augmented reality refers to the extension, layering or mapping of the virtual or artificially created world onto the real existing world (Safety, 2019). Augmented reality systems overlay virtual and real-world imagery, allowing the user to interact with the virtual and real-world simultaneously. This then creates a hybrid of the artificial and the real, and that is what constitutes augmented reality (Spaeth and Khali, 2018).

Figure 6: Augmented Reality in Construction by Jeff Yoders, 2018

Figure 7: mixed reality display by Micke Tong, 2016

2.4 Stages of Virtual Reality

As already indicated above, virtual reality is using computer technology to create a simulated three-dimensional world that a user can manipulate and explore while feeling as if he were in that world (Strickland, 2007).

Simple forms of virtual reality systems include video games in three-dimensional graphical displays and stereo sound controlled by an operator using a joystick or computer keyboard (Whyte, 2007).

According to Lingard (1995), VR technology is classified into three stages: passive, exploratory, and immersive. Passive forms of VR are everyday life scenarios and very familiar experiences to people. These include watching TV and seeing movies and are termed passive because the participant cannot interact with it but can only observe.

Explorative VR gives the user a chance to interact with the 3D environment. This interaction is, however, on a monitor or screen through actions as rotations of the object, zooming in and out and orbiting amongst others as a means of exploring.

However, passive and explorative VR constitute what is known as non-immersive VR. Non-immersive systems typically use generic hardware, do not involve advanced software techniques and do not immerse the viewer. This is sometimes described as window-on-a-world systems; they allow the user to see virtual reality through a screen or display that does not take up their entire field of view (Spaeth and Khali, 2018).

Immersive VR is the ultimate stage of advanced technology, which enables the user to interact with the artificial world. It provides a simulation for all the senses and all actions made directly impact the virtual world. Advanced systems of virtual reality such as those used in pilot training and immersive entertainment experiences incorporate head-mounted displays or large projection screens for displaying images and 3D sounds (Whyte, 2007). These require powerful high-end computers with particular specifications to achieve a level of realism. Immersive VR provides an unmediated experience (Spaeth and Khali, 2018).

In general, immersive and non-immersive VR are further broken down into three different viewing systems.

Viewer-Centred or egocentric – this allows the user to experience or view the virtual world, as he would have the real word. That is, his views are subject to himself. The user could also incorporate the use of an avatar as a representation of himself, which in this instance makes it possible for others to see his position in the immersed world.

Centred on another object within the model or Exocentric – The viewpoint can be disembodied and directed at an object within the world. This is most often a mobile object such as the user’s avatar.

Outside the model and centred on the model itself or exocentric – the user can become an external observer manipulating the world in front of a static viewpoint (Whyte, 2007)

2.5 How VR works

VR technology systems enhance the experience using interactive, spatial and real-time media. These comprise computer hardware and software, the input and output devices, and the data being visualized. (Whyte, 2007).

Virtual Reality functions with specific data formats and this constitute a vital aspect of the technology. The form of data serves as the core element for the creation of the simulated environment.

A common practice is to import the model from a computer-aided drawing (CAD) software; however, it is possible to generate it inside the virtual environment as well. It is also possible with current advanced technologies such as 3D laser scanning, photogrammetry and geometry capture to obtain the needed data directly from the real world (Whyte, 2007).

CAD software such as Revit live, Enscape 3D, Unreal Engine and Unity 3D amongst others rely on powerful computer hardware specially designed to handle the advanced requirements of complex models and the linkages to the VR environment. Examples of these include personal computers with specifications such as i5-6500 CPU or higher, NVIDIA GTX 980 or AMD R9 390 GPU or higher, 16GB+ RAM and SSD.

Figure 8: VIVE VR system for Fully immersive first-person experience and SteamVR Tracking by HTC, 2019

Figure 9: Vive Virtual Reality System by HTC

The VR system has the capacity to be fully immersive - True-to-life movements with realistic graphics, directional audio, besides, HD haptic feedback.

It can perform precision movement tracking - 360-degree controller and headset monitoring cover movements to the millimetre, floor-to-ceiling.

For a flexible play area, it requires Room-Scale VR with just two base stations. The VIVE system is used seated, standing or in a space up to 15 feet x 15 feet.

Vive Virtual Reality System by HTC Specification

High-End VR Headset: Dual AMOLED 3.6’’ diagonal screens. 1080 x 1200 pixels per eye (2160 x 1200 pixels combined), 90Hz refresh rate, 110° FOV, Front-facing camera, and VIVE Chaperone monitors.

Flexible and Comfortable Design: It has Adjustable straps, Interchangeable inserts, and Eye relief adjustments. The flexibility allows accommodation of most vision types and even glasses and works with VIVE Deluxe Audio Strap and VIVE Wireless Adapter.

VR-Perfected Controllers: Steam VR™ Tracked for accuracy and precision, multiple intuitive inputs, and Realistic HD haptic feedback. Use per charge approximation of 6 hours, Steam VR™ Base Stations 1.0: Enables 360° and room-scale play. It also synchronises it wirelessly — no minute space required for standing/seated play. Min. 6’6” x 4’11” space for room-scale, max. 11’5” x 11’5”. 1/4" threaded mounting points (Vive, 2019).

A simulation system is required to have three key characteristics to perform adequately. These include the ability to provide a digitally realistic environment that is three dimensional, able to respond to the movement and actions of the user and finally should be able to provide the experience of immersion (Whyte, 2007). These features of the system are what come into play and can enhance the immersion experience to provide real-time feedback without “noticeable pause” (Zheng et al., 1998). They aid in the provision of a deeper understanding of the built environment and in the case of building construction, an understanding of the operational processes, than what would have been possible with the more traditional digital technological tools.

In order to interact in the virtual world, a close to precise representation of the virtual environment and tasks are required to ease the process of problem-solving (Whyte, 2007). This enables the user to freely associate him/herself with the virtual world, appropriately interact with the model and make any changes he/she desires whiles still maintaining the abstract form. A good representation will enhance the effectiveness as well as reduce the amount of cognitive time and effort required if it were a traditional digital system (Whyte, 2003).

2.6 Applications of Virtual Reality

Virtual reality has become an essential tool in almost every field of endeavour, especially those in which there is a need to reproduce a real-world scenario for a specific purpose. Areas such as military simulations, scientific explorations, education, health, transportation, manufacturing, and the built environment (Whyte, 2007).

In the built environment and the building industry, the application of virtual reality by various professionals such as the planners, design consultants, architects, civil engineers, mechanical and electrical engineers as well as the building manufacturing professionals or contractors (Whyte, 2003).

2.6.1 Virtual Reality in the Building Construction Industry

In the construction industry, the project teams rely on virtual reality to visualise and manage increasingly complex projects. The lead users in the field include consultant engineers, construction contractors, property owners, and facilities managers. This group of users does not see virtual reality as a subject of interest in itself. Instead, they are concerned with reducing risk, increasing technological innovation and improving business processes, making savings and by extension, increasing profits (Whyte, 2007).

A study carried out by Whyte (2007) identified the primary business drivers for the use of virtual reality identified by the professionals. These include:

Simulating dynamic operation: The simulation of varied conditions and likely scenarios during operations is a significant driver for the use of VR technology in the construction industry (Whyte, 2003). This is aimed at helping to improve product quality and safety of operation it gives room for the exploration of dynamic processes during the various stages of design and project execution. By using VR, alternative options can be experimented and tested in three-dimensional form. This step helps in time savings, cost reduction, and mainly improves the understanding and learning process of designers and builders because it enables them to produce several iterations electronically and with as much precision as they would have on the actual project (Jacobson and Dray, 2018).

Beyond this, Virtual Reality gives professionals the opportunity to carry out simulations and testing of various aspects of the performance of products or components to verify if it will meet the specified requirements. For instance, the project management and engineering company Bechtel tests the environmental performance of airports – based on specific acoustic components that are yet to be delivered to site – using virtual reality for sound simulation. In that instance, the model of the project is used in the visualisation of noise contours generated from engineering data (Whyte, 2007). Other forms of simulation include people and vehicular movement tracking to give a better understanding of their flow and impact on whatever development is at stake. This is useful both during the construction of entirely new projects and especially helpful when parts of a larger project are to be completed for use, while other parts are still under construction.

Co-ordinating detail design: Another driver for the use of VR on the part of contractors is during the design stage, where there is a Contractors Designed Portion (for example in J.C.T construction contracts) or where the contract is Design and Build. The use of VR enables the consultants involved, to properly coordinate all design work in 3-dimensional virtual space, allowing stakeholders the opportunity to take 360 degree walks around designs and adequately view proposals from all angles. This enhances the ability to detect errors that would have been omitted using 2D CAD or 3D images. This process enhances design coordination through improved communication and helps to minimise construction conflicts. (Jacobson and Dray, 2018).

This buttresses studies that have shown that makers, when given tasks in 3D compared to 2D, are able to understand and eliminate errors significantly. This is because much of the errors (especially those of incompatibility) are corrected during the 3D detailing and design. This means the amount of time and material, which would have been spent if there were the need to first produce a prototype before making corrections, is dramatically reduced on-site. One such study, Barbieri and Marino (2019) concluded that there is a possibility that AR tools can serve as an alternative to technical drawing and CAD systems to help users identify design inconsistencies that occur between the 3D models and the correspondent physical prototypes. The savings in cost could be significant enough to merit a full shift in the construction industry as studies have found that the current use of 2D approaches to work costs more than their 3D VR alternatives (Woksepp and Olofsson, 2008).

With such improved robustness and safety of the overall design, reduced risk of design faults, it is easy to see reduced instances of litigation due to operational failures. It is considering that monies lost by contractors in such legal battles could run into millions. If looked at this way, the investment in VR is worth every penny.

Design review: Closely related to the above, in traditional contract approach Virtual reality fosters a participatory design approach, in which the project trio (involving the client, consultant, and contractor) is able to understand and make the changes they desire to make. It gives the client a fair opportunity to participate in decision-making due to better understanding and appreciation perspectives of the designer and the builder. As is often the case during construction, when the client requests variations, he/she understands better, what is being asked for and the implications of such requests.

In housing interiors, standardisation and customisation are possible: VR in design reviews limits choices made from the pre-determined options in the library of optimised models built up in virtual reality environments. Customers have the first-hand experience in the representations and guided in decision-making.

Planning and Scheduling Construction: For example, to reduce lead times, incompatibilities on site and waste. The success of a construction project is mostly dependent on the planning process, which plays a critical role in effective execution. Virtual reality allows the effective 3D planning process and grants the provision for multiple planning scenario trials, using a Virtual Construction Environment (Waly and Thabet, 2003). Virtual Construction Environment makes it possible to place the project team on-site and track their operations, as it would have occurred in real life. The step helps streamline the processes involved, minimises time spent, as well as the decision-making processes in planning the project at the macro-level (Waly and Thabet, 2003).

In elaboration, the system supports the builders with the means to construct and reassemble building elements graphically in 3D, as they will on the actual site, tracking their actions and movements as they do so. The resultant information is used to develop the planning and scheduling sequence for the construction. On large and complex projects, this improves the process of production and waste reduction (Waly and Thabet, 2003).

Demonstration of technical competence: It involves the marketing of the skills of the organisation. During project proposals and competitions, professionals incorporate the use of virtual reality to demonstrate their competence before clients. They use the technology to show previous schemes, market the design and construction skills of the organisation, as well as give clients the opportunity to understand the processes involved and how best issues arising can be tackled (Whyte, 2007). The use of VR allows the designer, contractor and client to agree on an image of a scheme and promote the sale. They use technology to promote bids and market their company.

Marketing: this entails the ability to sell products and services. Construction companies, who double as developers, by using virtual reality, can market and sell homes from the planning stage before it is finished. To them, this is a significant advantage because the risk of not getting buyers after development is eliminated. The technology gives them a wide range of coverage and advertisement for their models (Mansour, 2018).

Closely related to this, when contractor-developers need to reach an audience for approval, VR could help. For example, one of the organisations studied by Whyte, 2007, was undertaking a banking project. They used virtual reality models in zoning approvals, as well as during town hall meetings to communicate their intentions to the community who might have otherwise opposed the development. The model was also used to raise the profile of the development, obtaining television coverage and showings in news bulletins.

Training: The construction industry has also identified the use of virtual reality as an effective means of training workers**.** The use of simulators in the training of operatives and professionals in a safe environment is immensely helpful in the area of heavy equipment operation (Vahdatikhaki et al., 2019).

Overall, professionals are interested in finding faults and exploring new solutions using virtual reality. It makes it possible for project teams to visualise faults, decisions and to improve their understanding.

2.7 Barriers to Virtual Reality

Slow Adoption: A significant barrier to virtual reality lies in the fact of its newness. The construction industry in several places is usually a slow one when it comes to technological adaptation. It might require organisations to implement strict policies and measures for use, which results in institutional inertia.

Skilled Personnel: The use of virtual reality requires training to make the best of technology (Whyte, 2007). There is a lack of sufficient IT skilled people and general resistance to change from contractors. These are the human barriers associated with the use of technology (Greenwood et al., 2008).

Lack of awareness: construction companies are uncertain of the opportunities out there for them to make them more efficient. There is a lack of awareness of the resources available aside from the traditional ways of handling things. Construction companies are unaware of the competitive advantage they have and the benefits that come with being technologically innovative.

Cultural change: research continues to show that culturally, people have significant issues with IT implementation in the AEC industry (Davis and Songer, 2008 as cited by Greenwood et al., 2008) and helping people understand the changes of the globe is a barrier to overcome.

Lack of Customer Demand: a significant challenge in the adaptation of virtual reality in the construction industry is due to the lack of demand. Customers are not asking for the technology and to a contractor that is a financial and cultural justification not to use it (Greenwood et al., 2008).

Budget Constraints: Virtual Reality technology is gradually becoming affordable compared to when it was introduced. However, it still poses budgetary constraints with its complete implementation because it requires skilled personnel to operate the distinct processes, computer hardware and software, and other forms of advanced technology to function (Whyte, 2003). The technology also seems expensive because of the lack of understanding to the extent of time and money it can save if utilised.

Lack of interest on the part of management: it takes courageous management to agree to use new technology and is hard to find in the construction industry hence a barrier.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Although used in everyday language as a search for insights or more in-depth understanding, research in social science refers to “a *scientific and systematic* search for pertinent information on a specific topic”, often with the aim of uncovering new knowledge (Kothari, 2004).

Systematic inquiry of this nature involves the adoption of an approach that often occupies a space between a particular “philosophy, research designs and specific methods” (Creswell, 2014). Following this, research methodology is the “approaches to systematic inquiry [research] developed within a particular paradigm with associated epistemological assumptions” (Gray, 2013.) – That determines the specific tools that a researcher adopts for the process of data acquisition and analysis.

This chapter discusses the methodology and methods (tools) that the study employs for data collection as well as the analysis of the data.

3.2 Research Paradigm

The methodological paradigm adopted by the research is the Pragmatist paradigm. Pragmatism, which is often adopted as an alternative paradigm, sidesteps the contentious issues of truth and reality that plague the constructivist and positivist paradigms and accepts that there are multiple realities that can be understood using different frameworks, some qualitative, others quantitative. Hence, the main quest for the pragmatist is dealing with practical problems in the ‘‘real world’’ (Creswell and Clark, 2017).

Accordingly, pragmatists are more likely to adopt a mixed-methods approach to research by using quantitative methods to measure some aspects of the phenomenon in question and qualitative methods to measure others.

3.3 Research Design

The research design also called strategy of inquiry refers to the architecture or the blueprint for a particular study. It is used as a means to "integrate the different components of the study in a coherent and logical way" and helps to ensure that, the issue that one sets out to address is thereby, are well resolved (Labaree, 2009).

In line with the pragmatist philosophical paradigm within which the study operates, and in line with previous studies that the study intends to replicate, the study took the path of using a mixed-methods design – first a survey and then qualitative interviews.

3.4 Research Population

The population for this research comprised of experts in the building construction industry, specifically building contractors – construction companies (D1K1, D2K2), design consultants and real estate developers in Ghana. Respondents were selected due to the advanced nature of their operations and their need for advanced technology, which makes them more likely and able to afford such technologies. The term 'construction company' includes any organisation with involvement in the general building (including non-residential building and housebuilding) or civil engineering contracting (Greenwood et al., 2008).

3.4 1 Sampling

A sample is a subset of a population, and by extension, sampling refers to the process whereby “researchers examine a portion of a larger group of potential participants and use the results to make statements that apply to this broader group or population” (Salkind, 2010). Non- Probability sampling was used to carry out this research. Participants were sampled using a purposive sampling technique. First, the various organizations from which participants belonged to were identified, after which a selection of participants from the lists of persons identified was administered questionnaires. This deliberate means of sampling was convenient because it allowed respondents to be chosen based on the purpose of the research (Kothari, 2004; Creswell, 2009). Hence, professionals who could “yield the most relevant and plentiful data” (Yin, 2018), as well as those with a wide variety of characteristics needed, to “obtain the broadest range of information and perspectives on the subject of study” (Kuzel, 1992) was engaged.

The general population, as mentioned in section 3.4, consisted of experts in the building construction industry, specifically building contractors (D1K1, D2K2), design consultants and real estate developers in Ghana. However, the sample was limited to those located in Accra. As part of the multi-stage sampling technique used in the survey, the final purposively selected participant groups were given questionnaires to elicit the extent of use of Virtual Reality in these various fields. Notwithstanding, snowball sampling was encouraged in this research to achieve the sample size.

A 95% confidence level of sampling is acceptable in most research works. Hence, for a population of 100 persons as used in this study, a sample of 95 persons will be close to an accurate representation of the opinions of the total population (Saunders et al., 2009).

3.5 Research Instrument

"Questionnaires are any written instruments that present respondents with a series of questions or statements to which they are to react either by writing out their answers or selecting from among existing answers" (Brown, 2001)

Questionnaires containing structured closed-ended questions were administered to the selected professionals to obtain a clear and precise understanding of the extent of VR usage as well as the level of operations it is incorporated in. As part of the questionnaires, semi-structured interviews were included in the form of open-ended questions in an attempt to acquire more in-depth data while allowing a free-flowing conversation. This approach aided the researcher to draw out useful themes that were although not initially anticipated (Longhurst, 2003). As far as the use of VR in the building and construction industry was concerned, the use of Liket scales type of questions helped in the cross-examination of perceptions, barriers and opportunities with regard to the use of the technology.

3.6 Data Analysis

The aim of the preliminary survey was to establish the extent of use of Virtual Reality amongst purposively sampled building professional groups. The questionnaires were analysed using descriptive statistics in Microsoft Excel and represented using frequency tables, graphs and charts. Descriptive statistical methods include measures of frequency, measures of central tendency in the form of mean, measure of dispersion using the standard deviation and measure of position by ranks.

CHAPTER 4

RESEARCH FINDINGS AND DISCUSSIONS

4.1 Introduction

This chapter presents the findings and discussions from the field survey conducted regarding the perception of virtual reality in the Ghanaian Building Construction industry. For data analysis, the use of simple descriptive statistics is used.

Questionnaires were distributed to eighty- two (82) individuals in 45 different organisations. However, there were sixty (60) respondents from 43 organisations used in the analysis of this study. Data collected was in three stages and is presented in that order.

- The first stage tackles the demographic data /profile of respondents and their knowledge of the study topic.
- The second stage discusses the users and uses of virtual reality technology in the Ghanaian building industry.
- The third stage presents the in-depth knowledge of the respondents of virtual reality technology and its relevance in the construction industry.

4.2 Descriptive analysis of demographic data

The relevance of the demographics section of the questionnaire is to establish the reliability and authenticity of the data collected. Questions asked in this section of the questionnaire was to obtain necessary information and some related issues from the respondents to present their understanding of the study. Data included in the analysis of the demography were the companies in which the respondents worked, their years of experience in the industry and their roles/job descriptions in the various workplaces. These are to acquire a general idea of expertise of research participants.

Table 4.1 Respondents Profile

1. The organisation of the respondent	Frequency	Percentage (%)
Building Construction and Civil works	32	54.00
Design Consultancy	20	33.00
Real Estate	8	13.00
Total	**60**	**100.0**
2. Years of occupational experience in the building industry		
0-5 years	38	63.33
6-10 years	13	21.67
11-15 years	5	8.30
16-20 years	1	1.70
>20 years	3	5.00
Total	**60**	**100.0**
3. Job Description of respondents		
Architect + Designer	19	31.67
Civil Engineer + Structural Engineer	9	15.00
Quantity Surveyor + Cost Engineers	8	13.33
Project Managers+ Project Architect + Project Coordinator	10	16.67
Construction Manager	1	1.67
Manager + Managing Director + Principal Consultant	6	10.00
Technical Director	2	3.33
Commercial Manager	1	1.67
Researcher and Development officer	2	3.33
Services Engineer	1	1.67
No specific Description	1	1.67
Total	**60**	**100.0**

Source: Field survey, September 2019

Table 4.1, as indicated above, is a representation of the 60 respondents from 43 companies employed in the study. These companies comprise of Building construction companies (54%), Design Consultancy Firms (33%) and Real Estate companies (13%).

The results indicate that the majority of the participants are from the construction firms, which presents a clear indication of the building industry in Ghana. In the analysis of participants experience in section 2 of table 4.1, it reflects that a more significant percentage of the respondents fall within the 1-5years (63.3%) of experience bracket followed by 6 -10 years (21.7%). A higher percentage belonging to the younger age range in no way affects the credibility of the results since technological waves are prone to attract the younger generation. The third section of table 4.1 is an indication of the roles and job description of respondents to aid in the analysis and give a broader indication of the use of virtual reality technology within the building industry professionals. In no particular order, a representation of both site and office workers form a part of data acquired.

Later sections of the respondents' profile made inquiries of the participant's knowledge of virtual reality technology in the building industry. Responses are as indicated below in figure 10.

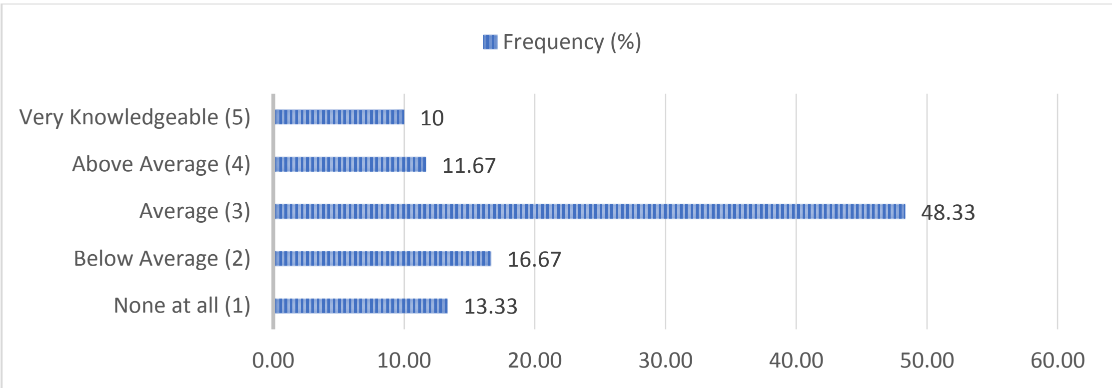

Figure 10 Ranking of Respondents Knowledge about Virtual Reality Technology in Building construction

The chart is an indication of the frequency percentage of respondents who are in the known of the existence of the virtual reality technology and those who are not. The chart indicates that 13.3% of the respondents had no idea of the technology, while 86.7% did.

The 86.7%, which compromises 52 respondents, then becomes the new sample size from a multistage sampling method for subsequent analysis of the findings. The percentage familiar with the virtual reality was feather rated to rank their knowledge of the technology. 48.3% have a fair amount of knowledge, 11.7% above average and 8.3% very knowledgeable of the virtual reality in construction. These percentages represent a total of 68.3% of the total and a higher percentage of the respondents.

4.3 Method for assessing the credibility of responses of research participants

4.3.1 Reliability Test

In order to confirm and validate the credibility of data collected, a reliability test helps to determine that. The test was taken using 22 variables on the Liket scale kind of questions. In effect, a Cronbach alpha test was conducted, and a coefficient of 0.828 was realised. The various relationship measures recorded coefficients ranging from 0.61 - 1.16, with the lowest of 0.61 being the understanding /definition of virtual reality.

4.3.2 Knowledge of virtual reality

The second section of the questionnaire was essential to ensure that the understanding of participants is in line with the definitions of the study and to get an idea of their understanding of the subject matter.

The respondents were asked to rank their level of acceptance to the various definitions of the technology based on the types and characteristics using a Liket scale ranking with 1= Strongly Disagree, and 5 = Strongly agree. Based on the frequencies, a mean score ranking of the meaning of virtual reality as per the understanding of participants is represented in Table 4.2 below.

Table 4.2 Measure of Respondents understanding of Virtual Reality

Respondents Definition/Understanding of virtual reality	Mean	Standard deviation	Ranking
Walk-through and Animations	**3.85**	**1.07**	**1st**
Simulation of an artificially created environment using digital tools such as computers and electronic mouse	**3.73**	**1.03**	**2nd**
The layering or mapping of an artificially created world onto the real existing world	**3.54**	**1.13**	**3rd**
(3Ds)-The use of generic hardware to create non-interactive environments	**3.23**	**1.17**	**4th**
Being able to manipulate the virtual world whiles wearing VR headset	**3.09**	**1.16**	**5th**

The mean score ranking of participants understanding indicates that industry players interpret any form of a computer-generated environment as the virtual reality experience that is in line with the definition of virtual reality by Webster et al. (1996). The understanding of the technology to a significant number does not necessarily require the use of the virtual reality head mount set. Participants consider the use of digital tools and other forms of technology or in plain terms computer-aided design software in creating the virtual world as what the technology is.

However, Virtual Reality (VR) involves simulation of an artificially created environment using digital tools such as computers and electronic mouse and ought to have some level of immersion and interactivity, which is possible by the use of the virtual reality headset. Participants did not seem to have a firm agreement concerning the critical feature of virtual reality, which says the additional feature of immersion and the ability of the user to manipulate and make changes within the artificial world that sets virtual reality apart from traditional computer technological interfaces (Zheng et al., 1998; Webster et al., 1996). Previous studies indicate that virtual reality has been defined as multiple forms of 3Ds or computer-generated imagery in multiple dimensions. Virtual reality has also been viewed as the use of very advanced forms of technology to create artificial environments (Greenwood et al., 2008). Findings, therefore, agree with that of previous studies in the shortfall of industry players as to what the exact definition and requirements of virtual reality.

To further clarify the understanding of participants, the users of the technology were required to indicate the devices they use. From figure 11, it reflects that 82.61% of participants who confirmed their use of the technology were authentic. The outcome is quite an improvement from previous studies carried out because those results indicated a substantial percentage listing visualisation tools, not VR specific due to the misconception.

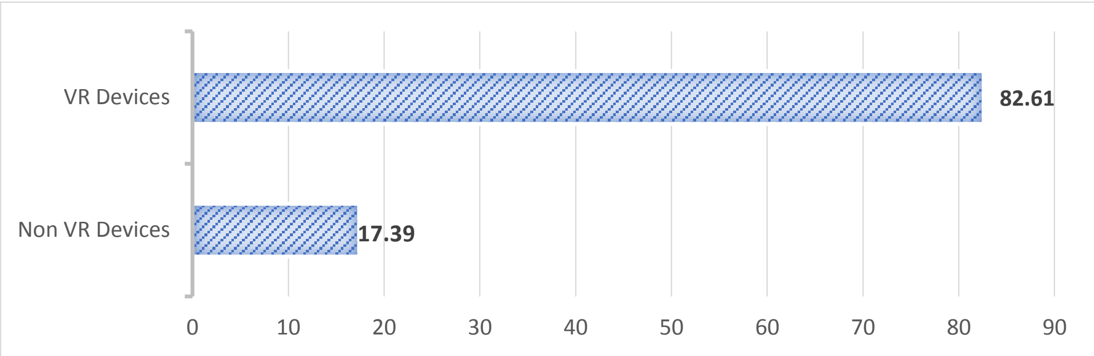

Figure 11 Frequency of the Virtual Reality device against non-virtual reality devices

4.4 OBJECTIVE 1: To identify the users and the extent of VR usage within the Ghanaian Building Construction Industry

The third section of the questionnaire addresses the use of virtual reality technology within the Ghanaian building industry. This part of the survey required the views of users of the technology only to participate. Figure 12 presented below indicates that, 44.25 %, which comprises 23 respondents of 52 participants from the second stage of the multi-stage sample as users of the technology. The respondents who identify as users of the VR technology represent 19 of the 43 organisations who participated in the study. The remaining 29 respondents that is 55.77% are the non-users; however, acknowledgeable their insight into virtual reality technology in building construction.

The users of VR, according to company classification, shows that 21.74% are from the Real Estate companies, 26.09% are part of Design Consultancies, and 52.17% is with the Building Construction companies.

Previous studies have indicated the lead users in the field as consultant engineers, construction contractors, property owners, and facilities managers (Whyte, 2007). It is safe to refer to the respondents' profile and confirm this truth.

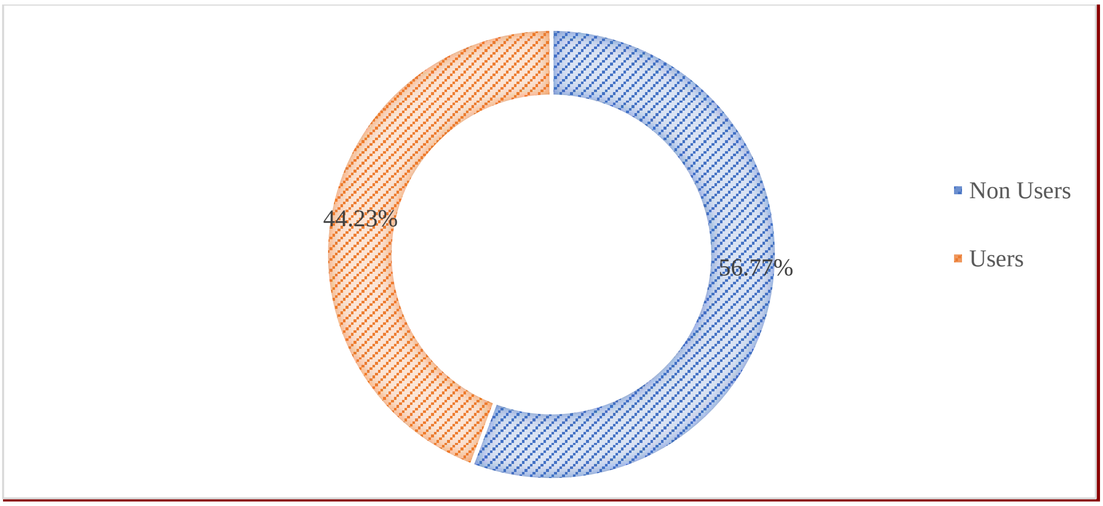

Figure 12 Users of VR in the Ghanaian Building Construction Industry

Figure 13 is a breakdown of the regularity of the use of virtual reality within the various participant organisations. The breakdown is required to determine the extent of use of the Virtual reality technology within the Ghanaian building industry. From the frequency chart, virtual reality seldom used by most organisations. The number of works which incorporate the technology is below 25% as indicated in figure 14 by 48% of the respondents. However, the use of the virtual reality technology on an average is by 30% of the respondents rating between 25%-50% of incorporation in the organisations.

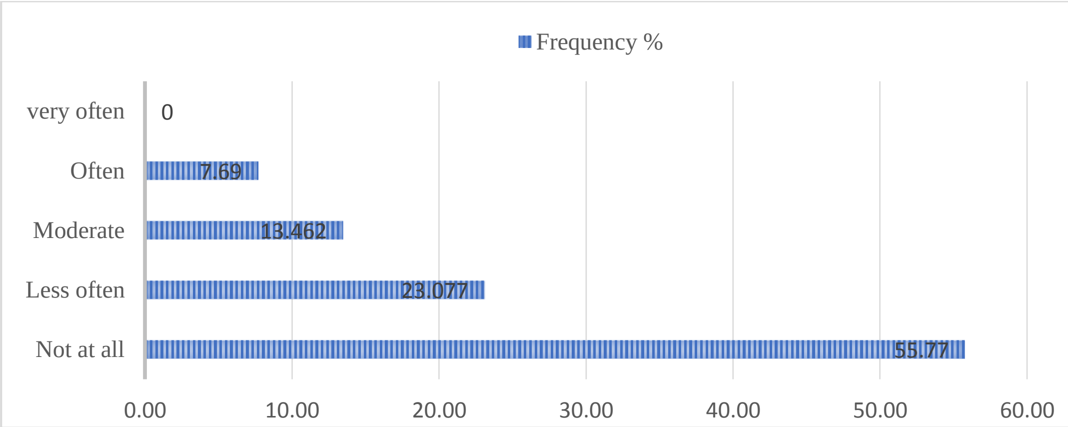

Figure 13 Frequency of the use of Virtual Reality in various organisations

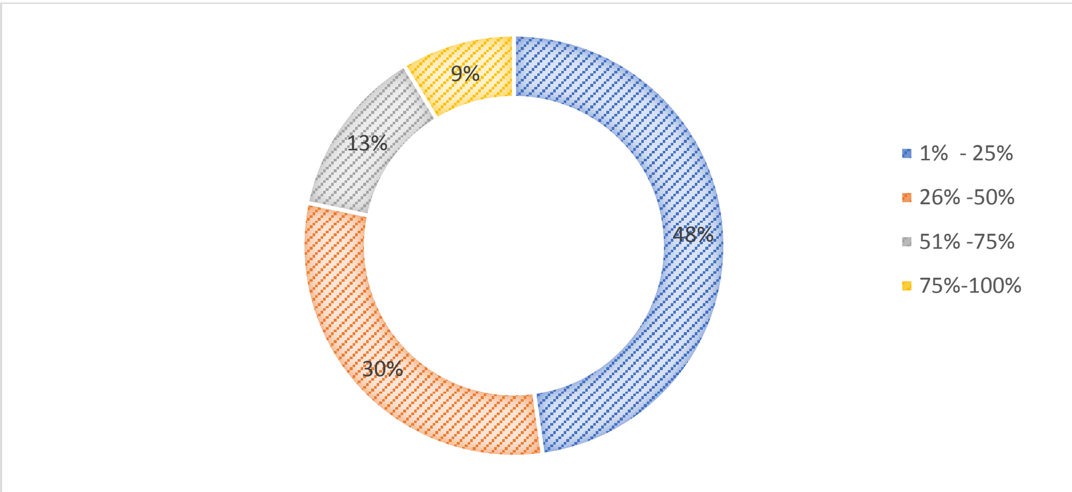

Figure 14 Level of incorporation of VR in organisational processes

The purpose of virtual reality within the various organisations and by the participants is ranked in table 4.3 below using the mean score and standard deviation. The most often use of virtual reality in the Ghanaian building industry is in the Final visualisation process with a mean score of 3.78. The use of the technology in Client meetings with a mean score of 3.57 follows and in the Design process with a mean score of 3.43 ranks third. The least ranked in the use of virtual reality by participants is in Construction safety training and safety evaluation with a mean score of 1.87, the rare use of the technology. Literature indicates that virtual reality in the construction industry has significantly been used for the creation of 3Ds and in models simulations to show its optimisation. The experience for the industry has been the potential for real-time viewing offered by the technology (Whyte, 2007).

Findings of Spaeth, A.B. and Khali, R., 2018, “the place of VR technology in UK architectural practice” compared to those of the Ghanaian Building Construction industry, firstly placed the use of VR for client meetings as the most used function followed by visualisation and in the design process.

Table 4.3 Measure of the use of VR in the Ghanaian building industry

The uses of VR	**Mean Score**	**Standard deviation**	**Ranking**
A. Final visualization	**3.78**	**1.45**	**1st**
B. Client meetings	**3.57**	**1.38**	**2nd**
C. Design process	**3.43**	**1.65**	**3rd**
D. Site layout and planning	**3.04**	**1.46**	**4th**
E. Automated project planning approaches	**2.91**	**1.41**	**5th**
F. Resource optimization	**2.78**	**1.31**	**6th**
G. Evaluation of construction scenarios	**2.78**	**1.54**	**7th**
H. Improving the existing processes	**2.65**	**1.27**	**8th**
I. Design constructability through VCE	**2.56**	**1.44**	**9th**
J. Planning and monitoring of construction processes	**2.52**	**1.38**	**10th**
K. In the improvement of construction education	**2.35**	**1.23**	**11th**
L. Construction scheduling	**2.09**	**1.04**	**12th**
M. Construction safety training and safety evaluation	**1.87**	**1.01**	**13th**

The virtual reality output of the Ghanaian building industry is mostly live walkthroughs followed by the production of exterior model files and the least output being 360 panoramic images.

Results indicate that 43.49% of VR users in the industry use PC tethered devices such as the HTC vive and Oculus rift, 8.70% use the VR space domes, 26.09% use Mobile VR and 17.39% incorporate other means. The remaining 4.33% incorporate multiple devices in their operations.

26.09% of the users achieved advanced form of interactivity with models, 60.87% achieved very basic forms and 13.04% did not achieve any forms of interactivity.

4.5 OBJECTIVE 2: To identify the opportunities associated with the use of VR in the Building Construction Industry

Another section of the questionnaire addresses the significance of the various opportunities associated with the use of virtual reality in the building industry. Marketing ranks 1st with a mean score of 4.08 as the most significant opportunity that VR technology offers. Industry users do not see virtual reality as a subject of interest in itself. Instead, they are concerned with reducing risk, increasing technological innovation and improving business processes, making savings and by extension, increasing profits (Whyte, 2007). This list may not confirm the order of the operations of users, instead, confirms the business and marketing urge of the building construction industry.

Table 4.4 Measure of the opportunities associated with the use of VR

Opportunities associated with the use of VR	Mean score	Standard deviation	Ranking
A. Marketing	**4.08**	**1.15**	**1st**
B. Design review	**3.94**	**1.04**	**2nd**
C. Training	**3.92**	**1.12**	**3rd**
D. Coordinating detail design	**3.69**	**1.08**	**4th**
E. Simulating site operation to identify problems	**3.67**	**1.06**	**5th**
F. Demonstrating technical competence	**3.54**	**1.20**	**6th**
G. Planning and Scheduling Construction	**3.37**	**1.16**	**7th**

Table 4.5 shows a representation of factors considered relevant by users in the implementation of VR within the building construction industry. The ability of the technology to gel with existing systems such as computers ranked first as very important in the implementation of VR. Its compatibility gained it a positive reaction followed by the user-friendliness ability and time needed in production of scenes. However, industry players did not consider highly of its cost control capability. These findings are in agreement with that of Spaeth, A.B. and Khali, R., 2018, "the place of VR technology in UK architectural practice". Users are unconvinced of the cost implication of the technology comparable to the cost control capabilities if offers in the industrial processes.

It enforces the lack of awareness of the potential of the technology within the industry, as the technology could aid in building prototyping hence a useful means of risk and workability projections on the part of builders.

Table 4.5 Measure of factors considered necessary in the implementation of Virtual Reality

Opportunities associated with the use of VR	Mean score	Standard deviation	Ranking
A. Compatibility with systems	**3.61**	**0.83**	**1st**
B. User-Friendliness	**3.48**	**0.92**	**2nd**
C. Production Time	**3.44**	**0.80**	**3rd**
D. Cost Control	**3.33**	**0.86**	**4th**

4.6 OBJECTIVE 3: To identify the barriers to the adoption of VR technology within the Ghanaian building industry

This section of the survey indicates that the significant barrier to the adoption of virtual reality technology in the Ghanaian building industry is a lack of awareness with the highest mean score ranking of 4.45. The outcome is in confirmation of earlier studies carried out in four countries by Greenwood et al., 2008. The study reflected the significant barrier to the implementation of virtual reality at the organisational level as a lack of awareness the benefits the technology had to offer. Budget constraints toppled in second place with a mean score of 4.23. Virtual reality has considered an expensive technology right from its construction (Brooks, 1999). This perception over the years has served as an obstacle to its adoption, and it requires a complete acquisition in hardware and software to it to function. (Whyte, 2007). The third and fourth significant barriers are the culture towards technology and a slow process in the adoption of new things. These barriers had mean scores of 4.15 and 4.15, respectively. The lack of interest on the part of management was ranked the least likely barrier with a mean score of 3.63.

Table 4.6 Measure of the Barriers associated with the use of VR

Barriers	Mean score	Standard deviation	Ranking
A. Lack of awareness	**4.25**	**0.81**	**1st**
B. Budget Constraints	**4.23**	**0.96**	**2nd**
C. Poor cultural attitude towards Technology	**4.15**	**0.92**	**3rd**
D. Slow Adoption	**4.13**	**0.74**	**4th**
E. Lack of Customer Demand	**3.75**	**1.10**	**5th**
F. Lack of interest on the part of the management	**3.63**	**1.09**	**6th**

4.7 OBJECTIVE 4: To identify strategies to overcome the barriers to the adoption of VR technology

Table 4.6 below presents the strategies as ranked by respondents to overcome the barriers of the adoption and implementation of VR technology. The request of the use of virtual reality by clients ranked the most significant with a mean score of 4.08, followed by the move by the industry with a mean score of 3.96. The second-ranked has been considered in other studies as the most effective means of implementation. Adoption of new technology is considered the responsibility of the organisation in taking advantage of the benefits it has to offer (Bouchlaghem et al., 2005 as cited by Greenwood et al., 2008). Similarly, adoption is a social issue, and just as CAD is made a requirement in many organisations, so can VR.

Table 4.7 Measure of the Strategy to Overcome the Barriers to the implementation of VR

Strategies	Mean score	Standard deviation	Ranking
A. Client Request	**4.08**	**1.03**	**1st**
B. Industry requirement (Formal)	**3.96**	**1.07**	**2nd**
C. Government policy (Formal)	**3.33**	**1.29**	**3rd**

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATION

5.1 Introduction

The research report captures the perception of the use of virtual reality technology within the Ghanaian building industry. The study focuses on key industry players, which includes the building construction and civil works contractors, design consultancy firms and real estate companies.

This final chapter summarises the concerns and discussions captured in the study. The chapter presents a summary of the processes in achieving the research objectives and the contribution of the study to knowledge.

5.2 Summary of findings

This aim of the paper was to examine the use of virtual reality in the building construction sector in Ghana. In order to achieve this, data was collected from the building industry professionals.

From the study conducted, results reflect the uncertainty of participants concerning the true definition of virtual reality technology as a means to deep immersion. Walkthroughs and animations recorded the highest mean ranking. It, therefore, concludes that this is the best understanding of virtual reality to respondents.

5.2.1. Objective 1: To identify the users and the extent of VR usage within the Ghanaian Building Industry.

The users of virtual reality technology within the Ghanaian building industry comprise of building and civil works contractors, design consultants and real estate developers. From the study, the majority of participants belonged to the building construction industry: which subsequently presents them as significant users of the VR technology. The use of virtual reality is incorporated in 1%-25% of general works within the organisations. Interactivity levels of outputs are categorised as very basic, and the outcomes are mostly live walkthroughs and Exterior model files. Devices used by most are PC tethered or Mobile VR. Final visualisation with a mean score of 3.78 ranked the most judicious use of VR within the organisations.

5.2.2. Objective 2: To identify the opportunities associated with the use of VR in the Building Construction Industry

The most significant opportunities VR has to offer the Ghanaian building industry include the purposes of marketing, in design reviews and training. These were highly ranked with mean scores of 4.08, 3.94 and 3.92, respectively.

Virtual reality serves as lenses into the artificial world hence provides non-industry professionals with a better understanding of the abstract or 2-dimensional nature of things. Prospective clients can understand the complex language of the building industry in an interactive way.

Building professionals have the opportunity to review designs at early stages on screens and not wait until the construction stage to make inputs. Finally, VR gives companies the chance to train and retrain staff with lower risks in many conveniences.

5.2.3. Objective 3: To identify the barriers to the adoption of VR technology within the Ghanaian Building Industry

The study provides insights into barriers stalling the adoption of VR technology in the Ghanaian building industry. A lack of awareness is a likely major obstacle coupled with budgetary constraints. Participants mainly had a fair idea of what the technology entailed but was not confident in their views. There is also the effects of attitudes towards change being a factor. During interactions with participants, it was realised that professionals had a mind-set of sticking to traditional means because it was functional and met the requirements. They, therefore, did not see the need to pick up a newer technology when the earlier way had not failed. This culture is causing the slow adoption of the system in the industry.

5.2.4. Objective 4: To identify strategies to overcome the barriers to the adoption of VR technology in the Ghanaian Building Industry

The request for the use of VR technology by clients ranks the most helpful strategy for its implementation. Industry professionals believe that clients are the most appropriate boost to get the technology in vogue. The alternative to this will be for VR technology as an industry requirement. Government policies are not considered to be highly regarded in the implementation of VR technology in comparison to the former.

5.3 Conclusion and Recommendations

The advancement of the building industry will improve the livelihood of many, and that fact cannot be underrated. The introduction of computer-aided design and processes brought great ease to the industry through the time required for works and, so will the use of virtual reality. The Ghanaian building industry is entirely exposed to the use of Virtual Reality and yet no aware of its full potentials in the industry by many. Virtual reality has a lot to offer the building industry, and this study presents a great avenue to create awareness of its capabilities.

5.4 Limitations and delimitations of the study

Limitations faced while conducting the study is the time-related constraints. This made it very challenging in interactions with research participants as busy schedules affected response rates. Many face-to-face interactions are encouraged in the future.

The sample size for the study was small comparative to the numbers in the building industry. In future, it is recommended that a larger sample be considered to achieve a more accurate perception.

5.5 Directions for future research

Future research should consider a larger sample size that will result in more reliable and generalizable findings. Other research should go beyond the use of Virtual Reality to study the use of other digital interactive technologies created for the industry, such as Building Information Modelling (BIM).

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APPENDIX

SURVEY QUESTIONNAIRE: PERSPECTIVE ON THE USE OF VIRTUAL REALITY (VR) IN THE GHANAIAN BUILDING INDUSTRY

Dear Sir/Madam
I am undertaking a research study in partial fulfilment of a Masters Degree in Construction Management with KNUST and I would like you to participate.
The aim of this study is to examine the use of virtual reality in the building construction sector in Ghana.
The objectives are as follows:
1. To assess the extent of VR usage within the Ghanaian Building Industry
2. To identify the opportunities associated with the use of VR in the Building Construction Industry
3. To identify the barriers to the adoption of VR technology within the Ghanaian building industry
4. To identify strategies to overcome the barriers to the adoption of VR technology

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* Required

PROFILE OF RESPONDENT AND COMPANY

1. **Name of Company** *

2. **Job title of respondent** *

3. **Specialisation (if any)**

4. **Revenue/ Annual Turnover (Range)**
Mark only one oval.
- ◯ Below GHS1 million
- ◯ GHS 1 million - GHS 2 million
- ◯ Above GHS 2 million

5. **Practice size/ number of employees**

6. **Company Classification** *
Mark only one oval.
- ◯ D1K1
- ◯ D2K2
- ◯ Design Consultancy
- ◯ Real Estate

DEMOGRAPHY

7. **Gender** *
Mark only one oval.

- Female
- Male

8. **Age** *
Mark only one oval.

- 18 – 35
- 36 – 45
- 46 – 60
- 61+

9. **Educational background** *
Mark only one oval.

- Junior High
- Senior High
- Tertiary
- Post-Graduate

10. **Occupational experience (years)** *
Mark only one oval.

- 1 – 5
- 6 – 10
- 11 – 15
- 16 - 20
- 20+

11. **Rate your knowledge about Virtual Reality in construction** *
Mark only one oval.

- None at all *Stop filling out this form.*
- Below Average
- Average
- Above Average
- Very Knowledgeable

VIRTUAL REALITY TECHNOLOGY

12. **How often do you use Virtual Reality in your practice?** *
Mark only one oval.

- Not at all *After the last question in this section, skip to question 20.*
- Less often
- Moderate
- Often
- Very often

13. **Score on a Likert scale of 1 to 5 your understanding of Virtual Reality** *
Mark only one oval per row.

	Highly Disagree	Disagree	Not sure	Agree	Highly Agree
Being able to manipulate the virtual world whiles wearing VR headset	◯	◯	◯	◯	◯
The layering or mapping of an artificially created world onto the real existing world	◯	◯	◯	◯	◯
(3Ds)-The use of generic hardware to create non-interactive environments	◯	◯	◯	◯	◯
Simulation of an artificially created environment using digital tools such as computers and electronic mouse	◯	◯	◯	◯	◯
Walk-through and Animations	◯	◯	◯	◯	◯

EXTENT OF VIRTUAL REALITY USAGE

Please skip this section if you are a NON-VR USER

14. **What kind of Virtual Reality devices do you use?** *
Check all that apply.

- [ ] PC tethered (e.g. Rift, HTC vive)
- [ ] VR space domes
- [ ] Mobile VR (Google Cardboard)
- [ ] Other: ____________________

15. **What kind of Virtual Reality outputs do you produce?** *
Check all that apply.

- [ ] Live walk through
- [ ] Exterior model files
- [ ] 360 panoramic images
- [ ] Other: ____________________

16. **How many projects, as a rough percentage, would you say employ Virtual Reality in your practice?** *
Mark only one oval.

◯ 1% - 25%
◯ 26% -50%
◯ 51% -75%
◯ 75%-100%

17. **Score on a Likert scale of 1 to 5 the uses of Virtual Reality in your organisation** *

Mark only one oval per row.

	Not at all	Less often	Neutral	Often	Very Often
In the improvement of construction education	◯	◯	◯	◯	◯
Construction safety training and safety evaluation	◯	◯	◯	◯	◯
Automated project planning approaches	◯	◯	◯	◯	◯
To check design constructability through VCE	◯	◯	◯	◯	◯
Construction scheduling	◯	◯	◯	◯	◯
Improving the existing processes	◯	◯	◯	◯	◯
Resource optimization	◯	◯	◯	◯	◯
Site layout and planning	◯	◯	◯	◯	◯
Planning and monitoring of construction processes	◯	◯	◯	◯	◯
Evaluation of construction scenarios	◯	◯	◯	◯	◯
Final visualization	◯	◯	◯	◯	◯
Design process	◯	◯	◯	◯	◯
Client meetings	◯	◯	◯	◯	◯

18. **What VR/ visualization programs do you use?** *

____

19. **What is the level of interactivity achievable within your output?** *

Mark only one oval.

◯ Advanced

◯ Basic

◯ None

OPPORTUNITIES

20. **Score on a Likert scale of 1 to 5 the significant areas of opportunities for the usage of Virtual Reality in the Ghanaian Construction Industry** *

Mark only one oval per row.

	Highly insignificant	Insignificant	Moderately significant	Significant	Highly significant
Simulating site operation to identify problems	◯	◯	◯	◯	◯
Co-ordinating detail design	◯	◯	◯	◯	◯
Design review	◯	◯	◯	◯	◯
Planning and Scheduling Construction	◯	◯	◯	◯	◯
Demonstrating technical competence	◯	◯	◯	◯	◯
Marketing	◯	◯	◯	◯	◯
Training	◯	◯	◯	◯	◯

21. **What factors do you consider to be the most important in Virtual Reality implementation** *
Mark only one oval per row.

	Least Important	Slightly important	Moderately important	Very important	Most Important
Cost Control	◯	◯	◯	◯	◯
User-Friendliness	◯	◯	◯	◯	◯
Compatibility with systems	◯	◯	◯	◯	◯
Production Time	◯	◯	◯	◯	◯

BARRIERS

22. **Score on a scale 1-5 the following barriers to the implementation of Virtual Reality in the construction industry** *
Mark only one oval per row.

	Highly unlikely	Unlikely	Moderately likely	Likely	Higher likely
Slow Adoption	◯	◯	◯	◯	◯
Lack of awareness	◯	◯	◯	◯	◯
Poor cultural attitude towards Technology	◯	◯	◯	◯	◯
Lack of Customer Demand	◯	◯	◯	◯	◯
Budget Constraints	◯	◯	◯	◯	◯
Lack of interest on the part of the management	◯	◯	◯	◯	◯

STRATEGIES TO THE IMPLEMENTATION OF VIRTUAL REALITY

23. **Do you think the use of Virtual Reality should be promoted in the Ghanaian Construction Industry?** *
Mark only one oval.

◯ Yes
◯ No

24. **Score on a scale 1-5 the strategies you think is most helpful in promoting the use of Virtual Reality in the Ghanaian Construction Industry** *
Mark only one oval per row.

	Not helpful	Slightly helpful	Partially helpful	Helpful	Highly Helpful
Government policy (Formal)	◯	◯	◯	◯	◯
Industry requirement (Formal)	◯	◯	◯	◯	◯
Client Request	◯	◯	◯	◯	◯