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Integration of Virtual Reality (VR) & Building Information Modelling (BIM): A Case Study of Adoption Barriers & Benefits in the Design and Construction Process

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Abstract

Technology is playing a significant role in shaping the construction industry in terms of advancing the processes and showing promising results in better planning of projects, execution of daily operations and supervision of works. However, despite the Ethiopian Construction Industry's (ECI) poor performance in terms of low productivity, time and cost overruns, and inadequate quality/workmanship, utilization remains limited. This study investigates the potential use of Virtual Reality (VR) and Building Information Modelling (BIM) technologies in a design and construction process to bridge the digital and physical construction world and assess the benefits and barriers based on qualitative approach using a case study. Participants from three purposely selected design companies were immersed in a digitally designed and developed VR simulation of one high rise commercial building & one low rise training facility cases by implementing and integrating VR technology with BIM. On the basis of the simulation experience, a follow-up interview and two focus group discussions conducted to examine and gather their exposures on the benefits and challenges associated with design and construction processes. Based on the study, the potential benefits identified during design phase are enhancement of material selection, project coordination, design review, realistic presence, better visualization & aesthetic evaluation. Meanwhile, during the construction phase, better monitoring schedule, reduced on site visit, shop drawing site layout, and improved productivity are determined. Some of the challenges identified are high cost of VR hardware and software, lack of infrastructure, complexity of technologies and public scepticism. This study illustrated the integration and capabilities of BIM with VR in advancing current design and construction practice. The study is expected to contribute in the advancement and utilization of technologies in the Ethiopian Construction Industry to improve performance and productivity.

Key Words: Virtual Reality (VR), Building Information Modelling (BIM), Integration, Ethiopian Construction Industry, Benefits & Barriers

1. Intrdocution

Utilization of new technologies/methods has become one way of gaining a competitive advantage. According to Koh and Wong (2005), the relevance of technology in domestic economic growth has long been acknowledged and has evolved into one of the most important tactics in international or global competition. Newly industrialized countries like South Korea, China, Malaysia, Singapore, Brazil and South Africa are examples that have transformed their economies by enhancing its industries through technological policies, innovation, adoption and utilization (used 'Technology Transfer' as a 'Vehicle for Industrial Development'), (IMF, 2016). The advancement in these nations integrate and adapt innovative technologies from different sectors in increasing productivity, boosting efficiency, improving collaboration and undertaking complex projects. Chen (2019) stress the importance of technological innovation in visualization; enhance & efficient communication; reduced waste & rework, which is confirmed by various empirical studies.

Globally, there are a number of technological advancements ranging from processes, tools, and materials to software & hardware products including Digital & Mobile Software Solutions, Laser Scanning, Wearable & Sensors, 3-D Printing, Building Information Modelling (BIM), Drones and Artificial Intelligence (AI). Although, these wide range of technologies have been researched and implemented in various industries, the construction industry is slow and relatively behind other industry sectors in utilization and adaptation and is not meeting the demand (Dang, 2012). This scenario is even exacerbated in developing countries like Ethiopia. According to Kebede & Mulder (2008), technology transfer in developing nations is poor mainly due to the limited financial resources, which leads to low adaption.

According to Solomon (2018), technology adaption is not being considered seriously in the Ethiopian Construction Industry (ECI), although there is an agreement between clients and foreign contractors to transfer technologies to local contractors and consultants. In addition, the industry in developing countries has relatively limited skills and knowledge on information technology and management to undertake more complex projects such as road, buildings, etc. (Waroonkun, 2008). Mulu (2018) also argues that there is poor performance and willingness in knowing, owning and adopting new technologies in the ECI, while Birhanu (2019) debates that though some Ethiopian construction firms use technologies, the trend is very low.

Thus, technological advancement, research & development, design, utilization, adaption and integration within policies in developing countries like Ethiopian can be a potent tool to spur industrial development & mechanisms for innovation and knowledge transfer from developed countries to developing ones. Rotimi (2018) also asserts that by standing on existing and already advanced products, material or knowledge in developed nations, developing countries can gain insight into the vast wealth of knowledge for innovation. However, since the decision to deploy a technology is a function of a variety of influences, there must be a local base of sufficient knowledge to design, adopt & implement advanced technologies and tools. This study focuses on assessing the implementation & integration of VR with BIM to explore the merits & challenges before laying a single brick the design and construction process in the ECI.

2. Literature Review

Currently, the design and construction process in Ethiopia is most conventional paper-based and semi-digital, whereby designs are being generated in two and three dimensions (2D & 3D) with the absence of digital immersive environment & spatial features integrated into real construction. This practice is characterized by design errors, omissions, re-designs, incomplete drawings and incoherent engineering drawings (Birhanu, 2019; Rotimi, 2018). According to Mabrouk (2019), only 5% of a project's budget is allocated for design, which has a tremendous influence on the remaining 95% of project. This is translated to higher cost as quality deliverables may not be produced in the early design phases due to limited resources leading to modification works in building phase. Similarly, Behailu (2016) argues that implementation and integration of virtual design and construction (VDC) is crucial as 70% of Ethiopian construction projects encounter incomplete drawings and fewer details accounting for 55% of the delays or over budget. Furthermore, Tsegaye (2009) also showed the role of technology in improving building design and construction processes, which is fragmented and a major gap in Ethiopian Construction Industry (ECI).

One of the recent technologies the construction industry is adopting from the entertainment industry is Virtual Reality (VR). As a result, more Ethiopian entertainment companies are implementing VR as the rest of the world attempts to, making it desirable to adapt it for the design and building process in the ECI. Various scholars and organizations have provided numerous definitions from various angles in recent decades, notably on the use and advantages of VR in various ways. According to Sherman and Craig (2002), VR is 'medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world)'. Jain and Kokate (2017) define VR as 'a live, imitative version of the real world with the capacity to add certain elements to the simulated landscape'. For the context of this study, virtual reality (VR) is defined as a three-dimensional (3D) computer-generated simulation that creates a digital twin of architectural design and construction product virtually before a symbolic ground-breaking start, in which a user can go into space, walk and inspect every detail before a construction begins, both view and manipulate its contents.

In the construction industry, VR is first used to create walkthrough systems. Then, VR is utilized to replicate workplaces for the purposes of health & safety training, whereby knowledge and abilities are learned without any real-world repercussions in a virtual environment. Application of VR is showing promising results in design (space modelling, interior design, heating, ventilation & air conditioning, landscaping, ergonomic & functional requirements); construction (site layout and planning, planning & monitoring of construction processes, analyse construction equipment, communicate & train project team); and operating & maintenance (repair & inspection, assess level of preparedness during natural event, simulation, maintenance evaluation, asset information) (Sukereman and Syazwani, 2023). The development and application of VR in the construction industry and other sectors have shown high trends in China, USA, UK, Australia, South Korea, South Africa and Nigeria (Kebede and Mulder, 2008).

In Ethiopia, the Goethe-Institute in Addis Ababa presented Virtual Reality (VR) to the country for introduction and its inaugural in 2018 to promote VR into diverse industries and help entrepreneurs in Ethiopia. Although VR is a developing medium, it has not progressed as much due to various reasons. Relatively VR is utilized in the entertainment & tourism such as game centres and virtual tour of customers at hotels, tour companies and real estate agencies. The ECI on the other hand, has shown limited interest in adopting this modern technology despite its potential. Based on the researchers knowledge and assessment of prior studies, there is limited studies conducted to integrate VR with BIM. Thus, this study investigates the potential through a qualitative approach to explore benefits and barriers using focus group and interviews using a case study for implementing VR in real projects.

3. Materials & Methods Integration of VR and BIM

Building Information Modelling (BIM) is quickly becoming the standard technique for conveying all phases of Architectural, Engineering & Construction (AEC) details as a database of information that produce multi-dimensional knowledge resource and model (Abruzzini and Abrishami, 2022)). As per Lee & Borrmann (2020), BIM is a powerful tool for creating high-quality 3D model, analysing various design options, detecting clashes with different elements, performing energy simulation, planning & scheduling, achieving quantity take-off, estimating cost, generating procurement plan, coordinating model & improving communication among project teams. BIM encourages all stakeholders to participate & collaborate to achieve a high-quality product in all project phases.

Integration of BIM and VR can improve workflow efficiency in the AEC sector by increasing shared knowledge. As per Ozcan-Deniz (2019), the potential of BIM may be readily filled by VR, which is a digital simulation experienced by a user to see virtual information by immersing a person in a virtual domain environment to interact with 3D models created by a computer. VR may be accomplished by first creating a 3D model of a project and then creating a virtual reality environment. Autodesk Revit, Archi CAD, All Plan, Vector Works, Rhinoceros, Sketch-Up, and 3-D Max are often used software platforms for 3D modelling. In light of the aforementioned reasons and the logical progression that has resulted from the widespread use of BIM, integrating VR data from real world and computer-generated medium can enhance users' experience by imposing real & digital worlds.

In this study, two independent case studies projects (an apartment & a reception) are selected to implement an immersive building project simulator in virtual reality with BIM that can be employed to show the way VR and BIM integrate throughout all processes a reason for an absence of applied research on VR-BIM integration in the ECI design and construction process. Since it is difficult to find built-in software that can convert Revit files into virtual immersive environment technologies, a variety of software was used to analysed two-dimensional drawings and translate the two programs (VR and BIM), including Autodesk Revit, CAD tools, Unity, Enscape, Iris VR, 3D Max, and Lumion 3D rendering tools. The data was then delivered to computer systems, where it is inspected & shared with data created by VR add-ins software, an immersive VR simulation program run. Additionally, a high-processing PC with a 4GB graphics card, an Oculus Rift device, and a phone-compatible VR headset (BNEXT-VR HEADEST) are all utilized.

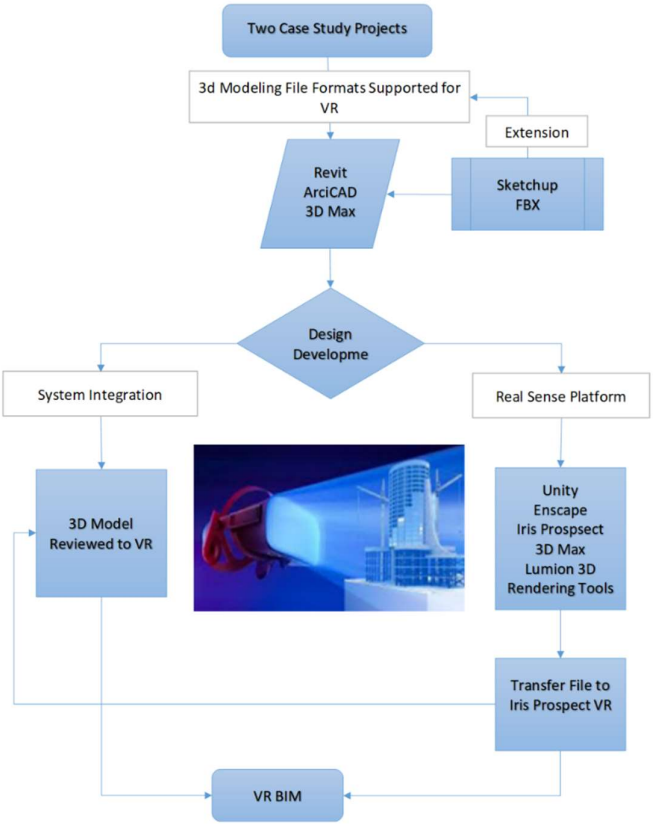


Figure 1 BIM-VR Integration Flowchart

Figure 1 illustrates BIM-VR integration flowchart. The BIM -Virtual immersive visualization environment models design process began with the creation of a 3D model of two case studies (one high-rise building and one low-rise building) in Autodesk Revit. The apartment (Case I) is a 2B+G+14 (two basements, one ground, one mezzanine, five stories of mixed purpose floors, and nine stories of one to three bedroom condos). The structure of Case I design had a mat slab, a reinforced concrete basement RC columns and slabs as well an opportunity to demonstrate the complexity of the enormous scope of the undertaking and inspect each component of the building process. A 3D model with fundamental components including architectural elements (exterior/interior walls, window/door frames, stairs, flooring, roof system, fitting, structural element (foundation slab, beam) and electrical & mechanical system are included. Case II is a reception, which is a 1 storey building includes reception rooms, hall, offices, gym, conference room, staff offices, an event space, waiting area, a café, classrooms, a computer lab, and two bathrooms to demonstrate the realistic features of integration of VR with BIM.

Once the BIM models are developed through Revit, floor plans were enabled for virtual walk-throughs. Then, the models were exported to 3D Max for rendering to define realistic element. Finally, the completed 3D models were transferred into various software platforms such as Unity, Enscape, and IrisVR 2022 Prospect, to allow the 3-D models be incorporated in virtual walk-throughs. The imported design model in IrisVR 2022 Prospect was scrutinized with the Oculus Rift S VR headset. For this study, a head-mounted Oculus Rift is used to simulate virtual reality (VR) and analyse the benefits as well as

challenges and limitations of technology adoption. The gadgets used include HTC VIVE VR system has base stations, hand controllers, VR headset, interface box, VR-capable computer, tracked workspace).

Upon completion of the integration and setup, thirty (30) participants experienced in either BIM or virtual reality technology from three purposely selected (based on utilization of BIM, experience on use of technologies) design firms were immersed in the VR of the two case study models and perceptions were captured through individual interviews and two focus group (FGDs) sessions (where participants work as a team to share information & experience and provide an understanding along with the benefit and challenges faced). The participants are architects and engineers with more than 5 years of experience in the Architecture, Civil Engineering, Construction and Technology Management (including thirteen (13) architects, ten (10) civil engineers, and seven (7) construction & technology management professionals. Twenty three (23) participants are used for training and testing the integrated model, while seven (7) are used for validation.

4. Results & Discussions

Respondents stated that it is an eye opening experience experiencing a three dimensional immersive environment. Upon witnessing a virtual environment for the first time, the majority of participants were uncertain as to whether they could truly view about the settings in a realistic manner, while others were surprised to learn that they could. The participants often began looking around & examining their surroundings, wandering through and inspecting every feature of the two case studies of building projects without giving any regard to the fact that they were experiencing a virtual reality. The following sub-sections summarize the benefits and challenges of BIM-VR integration.

4.1 Benefits of VR-BIM Integration in Design Phase

The potential benefits of implementing and integrating VR and BIM is the fact that it creates an opportunity to be in a virtual immersed environment on a real project, which gives prospects related to a realistic sense of presence in a three-dimensional simulating environment. Experts mention that it is very helpful for client participation, project management, material source selection and evaluation, product aesthetic assessment, a better understanding of what a building will look like once constructed and give a deeper connection to the project. Some of the major benefits identified are discussed briefly.

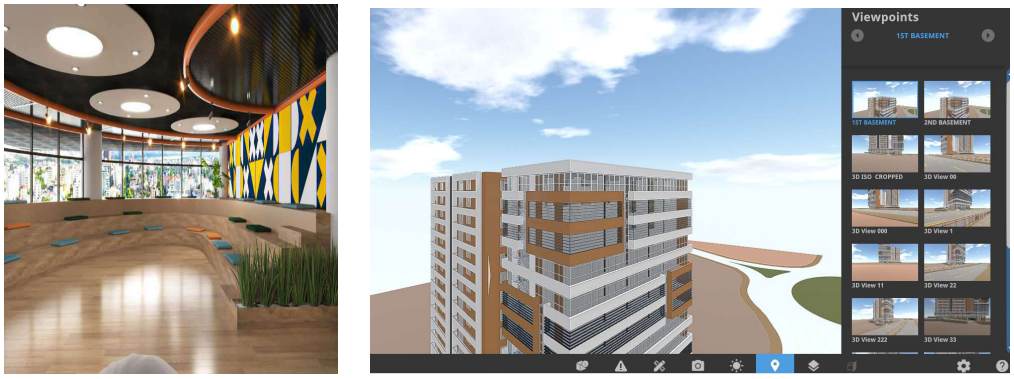


Figure 2 Immersive Realistic Sense of Presence in VR Simulation

Realistic Presence & Aesthetic Evaluation

Twenty five (25) participants acknowledged that clients, 13 designers & 17 contractors can walk around and interact with building elements that provide an actual sense of presence with a significant amount of reality and accuracy. It provides a real sense of presentation of the building projects and by far the most effective at stimulating feelings and sensations with better understanding or visualization of drawings as well as the work & vision of designers. The experience can persuade users' imaginations and feel that they are actually in a realm that they have created in building the projects (Figure 2).

In general, 24 out of 30 respondents agree that incorporating VR into a design processes feels more realistic and represents the true concept of a proposed design and perceives the space's dimensions. It also gives a clearer picture or helps visualize the construction and allows an enhanced association to a project.

Design Review

Seventeen (17) of participants who work as Architects and BIM Managers agreed that VR helps to assess essential design revisions before construction commences. Participants claim that using VR enables architects and engineers to make intelligent decisions and specify any necessary design modifications or adjustments prior to construction. As a result, it will be less costly, saving time and cost. Participants from contractor side also that asserted that VR enables users a better understanding of the project; minimizes uncertainties; and allows clients to raise unanticipated problems and/or concerns that can be supervised and resolved in the design stage rather than discovering during a construction phase, which may lead to change orders & avoids rework.

Participants consider that VR offers an insight in observing functions of designs through real-world settings. Early in the design phase, this helps detect mistakes or issues. VR also allows the users to reduce paper work errors in the drafting of 2D representations, whereby the changes made get recorded in virtual reality design software. Thus, fixing errors before production is crucial and hence the need for design reviews to evaluate the design against detailed requirements is a plus.

Project Coordination

The other benefit that was raised through the FGD is project coordination. It is possible for misunderstandings and mistakes to occur since architects, engineers, and contractors have different views on project design. However, VR has the potential to improve these inefficiencies and enhance communication between these teams. Managing stakeholder engagement improves project coordination and VR can help track important decisions and activities from meetings as well as strengthening collaboration and communication. Moreover, real-time communication and cooperation among project stakeholders are made possible through virtual reality annotation. This includes keeping updates on project plans, timetables, work hours, budgets, and expenditures. It also entails planning and taking part in discussions with stakeholders and making sure that project deadlines are met on time. This improves project coordination, eliminates mistakes, and simplifies communication.

Material Selection & Evaluation

Another benefit mentioned by participants is selection and evaluation of material sources. It allows architects to see how a design performs in immersed simulation environments, which enables a designer to examine the impact of materials on final output. VR makes it

possible to view a finished product in real sense of an actual world. Figure 3 illustrates virtual indoor scenarios or design options evaluations through an immersive environment.



Figure 3 Materials Selection Utilizing VR

For example, in lighting design, selection of materials when exposed to direct sunshine or introduction of artificial lighting or a combination of both is made simpler by the fact that VR grants access of these scenarios by simulating the surroundings (Figure 4).



Figure 4 Lighting Design & Material Selections in the BIM-based VR Prototype

4.2 Benefits of VR-BIM Integration in Construction Phase

With respect to the potential benefits of utilizing and integrating virtual reality in a construction process, Twenty three (23) of the participants consider that VR can positively influence construction projects as well as successfully completing projects through better site preparation & layout, scheduling, project execution, increased efficiency and productivity, improve collaboration among teams, reduced on-site visits, and reliable estimations. A brief discussion of the findings are discussed below:

Improved Productivity

The introduction of VR has a potential on boosting efficiency and improving productivity of construction projects. Utilizing of virtual reality can enable all stakeholders to view real-world 3D models that will contain information about the future product and provide immersive walk around and an opportunity to view a clear picture of their projects instead of misleading paper drawings. VR can lead to improved construction project management by reducing modification, avoiding uncertainty earlier, minimizing miscommunication and allowing stakeholders to communicate virtually, coordinate projects, monitor changes, detect errors, and make adjustments through a proactive plan.

Shop Drawing & Site Layout

Another advantage of VR identified during a construction phase is site layout and design. The majority of participants agree

that designing a site layout and structural design working drawings (shop drawings) are crucial activities that affect how well a project can be executed. Project teams able to collaborate jointly on the same dynamic three-dimensional elements in simulative environment and are better informed on tasks and/or activities in designing a site layout and preparing shop drawings (Figure 5).



Figure 5 Site Layout (Traditional vs. VR-Based)

Significant percentages of participants indicate that design representations that are used for on-site projects typically provide 2D representations as PDF extensions or drawings by hand that are susceptible to mistakes. However, integration of VR & simulations in a construction process helps setup optimal utilization of sites (arranging equipment positions or material delivery, material dumping areas resource storage & stockpiles, accessibility to site and exit to a project and offices) can be generated that can be easily visualized. Thus, a 3D model can help map out each stage of the construction process, by taking into account a site's changing edge circumstances, enables foresight of the site and the prediction of issues and conflicts prior to the commencement of work, which will impact a project's final outcome. Thus, drawings generated with a VR model are extremely detailed and significantly different from the level of detail developed through conventional 2D PDF.

Reduced on Site Visit

Participants argued that VR can also reduce on site visits. A high percentage of participants agreed with one participant's assertion that VR minimizes on-site visits throughout a construction progress phase and makes it simpler to create and compile reports based on project progress. VR site visits built in a software device is intended for simple and faster recording of reality on small-scale to large construction sites. Progress may be recorded and reported using immersive 360° images that are immediately added to virtual project exploration files. All images fit the site design, showing actual progress without requiring site visits or further effort. Full immersive photography is created by synchronizing 360° photos with plans of the site, computer-aided design (CAD) drawings, or 3D building information modelling in order to record both as-built and pre-existing circumstances. It also allows easy documentation and storage of important information. Clients can actually travel within minutes using VR gear. Fortunately, when problems & challenges arise on site, solutions can be prepared without the need for presence on a project site, which reduces transportation or site visits costs. Thus, stakeholders can manage an actual work environment remotely by employing a mobile device and integration of VR with 3D surveillance cameras.

Monitoring Schedule

The activity schedule determines the success of a project. Construction schedule is a difficult process that requires a high level of detail for each activity to be carried out from inception to completion. The majority of participants recognize the importance as one can view every aspect of work operations using 3D simulation embedded during construction process. Construction project planning may be made more efficient at the start and operational levels as such digital representation can provide animated sequences of a construction process as well as a visual depiction of the construction site. It brings up all construction activity sequences for schedule review and assisting in the visualization of unexpected activities from the schedule using a walkthrough.

4.3 Barriers of VR-BIM Integration

Participants were also interviewed to share their opinions on the barriers to VR technology integration in the design and construction process in the Ethiopian Construction Industry (ECI). 21 out of 30 participants mentioned the absence of easy access to all packages of this technology (VR gear and accessories) as one of the most significant barriers. Participants also noted that lack of appropriate skills and expertise, complexity (numerous applications), societal resistance & public scepticisms (acceptance, cultural, generational gaps, resistance to change), capital cost of devices (affordability of software and hardware devices) need for high computing machines, limited internet connectivity/ telecom infrastructure, compatibility with mobile devices as challenges. In addition, lack of policies, were also raised as obstacles.

4.4 Reliability & Validity

As discussed in the methodology section, seven (7) out of thirty (30) 2 more experienced BIM managers and 5 who are more familiar with VR and working VR rendering for interior design validate the development of VR integration with and participants' responses based on focus group discussions are utilized for validation of the study. Participants responded to interview questions and reviewed two case studies that compared 2-D drawings with virtual reality 3-D models in design & construction process. The participants also identified possible drawbacks associated with utilizing two-dimensional documentation such as risk of design flaws & discrepancies and less information presentation. Participants also mentioned that while using conventional 2D drawings, they were unable to see how design would change in real time or identify design and fitting issues. Participants also complained their inability to visualize how design would operate in real life.

On the contrary, participants' comparisons of VR-BIM model in 2D and 3D drawings when employed in a simulated environment demonstrates VR’s capability to clearly reveal the true future of projects. Participants' indicated that the 3D model, as opposed to conventional 2D drawings increased understanding of designs; enhanced ability to spot mistakes; and the capability to predict site limits through better examination of different circumstances. The validators also argued that the simulation visualization created with VR-BIM is easier to customize, while providing details on upcoming building projects and allowing an interactive tour.

In addition, the participants in the validation procedure concur with findings of the study with respect to challenges & barriers in deploying such a technology. One of the reasons stated for the slow adoption is the fact that construction projects are unique, complicated and not-repetitive. Furthermore, the high cost of VR hardware

and software (affordability), lack of infrastructure, complexity of technologies, public scepticism, and issues with accessibility are major barriers. However, VR is proving a new potential in the AEC industry enabling architects & engineers to walk through designs before a single brick is set, which is useful for identifying mistakes, potential issues, and making changes (Davila et al., 2020). As per Shafiq & Afzal (2020), VR also allows better degree of accuracy and collaboration between team members, reduces expensive errors & delays and increases communication between team members from project design to final inspections. Immersing oneself in a virtual world also allows clients comprehend complicated construction projects and experience the project from different angles, which is very valuable to project stakeholders. The researcher confined the focus group discussions and businesses to those situated in Addis Ababa.

5. Conclusion

This study attempted to implement and integrate VR with BIM to assess the use and performance in design and construction phases of the Ethiopia Construction Industry (ECI). It explored the integration through three-dimensional Revit models through Iris Prospect VR and system integrated diagrams of two building cases for dynamic exhibition of real-world scenarios. Then, the study captured potential benefits and examined the efficiency of the technology. The study also determined the barriers and challenges through focus group discussions and interviews of those situated in Addis Ababa architects, engineers and construction managers from three purposely selected design firms. The findings of study and analysis are conducted through N-Vivo10 and QSR International 2021.

Based on the study, the benefits of integrating VR and BIM in the ECI during design phase include enhancement of material selection & evaluation; better project coordination; improved design review; realistic presence; enhanced visualization & aesthetic evaluation, while in the construction phase, it promotes monitoring of schedule; reduced on-site visit; detailed shop drawing site layout; and improved productivity. On the other hand, the constraints associated with employing modern technology like VR and BIM include limited utilization & implementation of innovative technology; high cost/ initial investment of gadgets, trainings, software & hardware; lack of adequate guidelines & polices; lack of technical knowledge & competency; and awareness & resistance to change.

Overall, the integration of VR-BIM is found to be helpful for all stakeholders including clients, designers (architects and engineers) and construction managers. The study has shown the potential of VR and BIM to significantly alter perceptions of construction projects before construction works commences and is expected to minimize design errors, identify constructability issues and minimize change orders. Thus, more applied and action research should be carried out to examine and understand the potential benefits in advancing and improving performance of design & construction processes (boost efficiency, productivity, reduce costs and enhance quality), thereby move the construction industry to the next level. Thus, research & development on technology and processes through design, utilization, adaption and integration supported by policies in developing countries like Ethiopian can be a potent tool to spur industrial development & mechanisms for innovation and knowledge transfer.

Conflict of Interest

We hereby confirm that we do not have any conflict of interest nor submitted the manuscript anywhere else.

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