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BIM-BASED VIRTUAL REALITY VISUALIZATION IN CONSTRUCTION

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CONTENTS

BIM BASED EXTENDED REALITY VISUALIZATION IN THE AEC INDUSTRY

ABSTRACT

The move from ordinary 3D models to BIM models is gaining much tenacity in the architecture, engineering, and construction (AEC) industry and has proven to be one of the most important and powerful technology out there now. Increasing efficiency between individuals and organizations through collaboration, provision of sequential guide, cost control and most importantly to this study; its immersive visualization compatibility. XR offers AEC teams solutions to improve design, teamwork, supervision and delivering a higher quality final product. Visualization breakthroughs, like virtual reality (VR), augmented reality (AR), and mixed reality (MR), have become more democratized and are now accessible to not only large, but small businesses and individuals, respectively.

Hence, the aim of this paper is to establish an XR based workflow, primarily compatible with Revit, ArchiCAD and with VR base head mounted device (HMD) specifically the HTC Vive Pro. The study will review XR solutions to identify answers to technical variables such as what kind of file formats does the workflow support, modes of walk through (e.g., panoramic, 360°, stereoscopic image, etc.), does it have an available student or academic version or pricing plan, does it have other features (e.g., clash detection, model manipulation, etc.) or whether plugins are available that makes it compatible with other software? After the review of more than 20 existing solutions and workflows, a specific workflow is developed for the best and most effective applicability considering the boundary conditions available in educational or small business environments.

Researchers and practitioners can use the workflow developed and presented in this paper as a guide for further academic and practical developments regarding the improvement of XR technology in the industry.

Keywords:

- BIM
- XR (VR, AR, MR)
- Immersive visualization
- AEC

1. INTRODUCTION

Building information modelling (BIM) is currently one of the most trending technology in the AEC industry and its utilization is significantly rising, it has proven to be the future of building design, construction and management. BIM as a process is targeted at the procedure of daily production; at using the most effective technology available that has been proven to increase production; and at the improvement of return on investment (ROI) through refined and standardized processes[1].

When it comes to BIM, the importance of information visualization far exceeds academic interest and ranges up to development and practices; however, it is difficult for end-users without architectural expertise to understand the design information that is shared with them. Traditional approaches usually rely on 2D drawings and text-based information such as specifications, but end-users cannot clearly understand the outcome of different designs without assistance in visualizing. Subject to this constraint, the end-user's feedback can be erratic, leading to unsatisfactory outcomes[2]. XR and game engines are increasingly being perceived as useful platforms for immersing and engaging non-professional users. Although they have been actively investigated in the architecture, engineering, and construction (AEC) research, their link to BIM in the context of enhancing facility management has received limited attention e.g. the integration of these technologies with BIM so that facility managers can review building designs and provide feedback on possible improvements to the building designs[3]. Advanced visualization could potentially address this problem, by further enhancing comprehension of non-technical people from naturally technical BIM models[4] feedbacks collected could potentially improve design.

Internationally, BIM implementation has achieved a significant level in certain developed and developing countries. In US, UK and other European countries, BIM is mandated. Singapore has reached 50% adoption and already required all projects to be submitted via BIM e-submissions. In Native, BIM format since 2016 and the government has issued different guides and code of practices for BIM implementation. In addition, Australia has achieved strong adoption whereby around 42% of Australian SMEs use BIM in level 1 and level 2 and around 5% have tried level 3. Therefore, there is a high competition in construction industries in those countries to adopt technology and transform construction practices from conventional process to BIM-based technology [5].

1.1 BIM VS CAD

While it is possible to import CAD models into games through complicated procedures, CAD formats by nature, lack information that can be visualized and played in design games[6]. It is paramount to understand the difference between the terms BIM and CAD, in the building and construction sector, 'information modelling', is normally defined as the computer representation of a building or structure, including all the relevant information required for the manufacture and construction of the modelled elements. The elements or objects are required to be intelligent and should therefore know what they are and how they should behave in different circumstances and know their own properties and valid relationships[7]; Hence, CAD is simply the use of computer systems to assist with design. When using CAD for building design, you focus on creating drawings. When using BIM, you focus on creating a building model and then the drawings can be generated from the model[8].

1.2 MEMBERS OF THE CONSTRUCTION TEAM.

As BIM is considered as an information technology enabled platform which can integrate inter-disciplinary collaboration, a few major developments have been conducted on the improvement of the platform, including information retrieval, visualization, data exchange, interaction, and interoperability[9]. One of the most valuable functions of BIM is its ability to improve the coordination between multiple design disciplines, thus reducing errors. This information is valuable in the operation and maintenance of building. This design and construction process will shape the building technology systems and ultimately affect how facilities will be managed and how users of the facilities will work, live and communicate, understanding this system is important to the team. Fig 1.1 below describes or illustrates participants of the design and construction team [10].

Another question that can be interesting to answer is "why is immersive visualization important to the construction team?" Using immersive environments for data exploration has been envisioned for a long time. Bryson[11]. Immersive visualization can be applied to MR - including VR and AR - to create experiences that make the user feel surrounded by the experience. This can be experienced on desktop or tablet without the use of HMDs as non-immersive MR, or experienced with the use of HMDs for fully immersive MR. Users can explore a 3D design model from every viewpoint and angle before moving into construction[12].

1.3 COMMON ABBREVIATIONS USED IN THIS PAPER.

XR: Extended reality

MR: Mixed reality

AR: augmented reality

VR: virtual reality

AEC: Architecture engineering and construction

CAD: Computer aided design

AI: Artificial Intelligence

BIM: Building Information modelling

HDM: Head mounted display

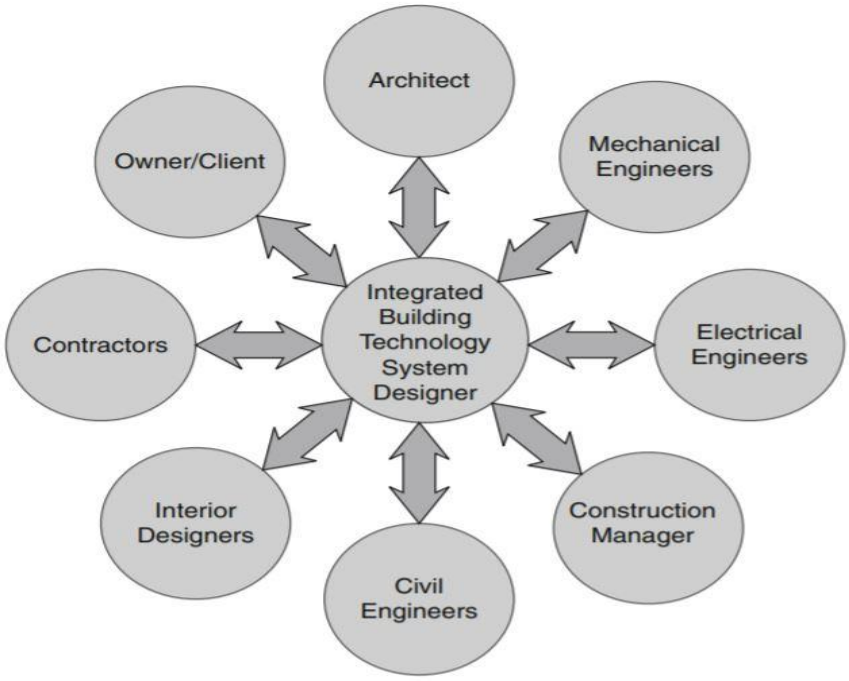


Fig 1.1 The project team[10]

2. METHODOLOGY

It is not enough to see architecture; you must experience it (Rasmussen 1959)[13]. The objective of this research is to create a workflow for the immersive display of BIM models, in order to achieve the research goal an extensive search was carried out on various available applications that support AEC-CAD and BIM file formats.

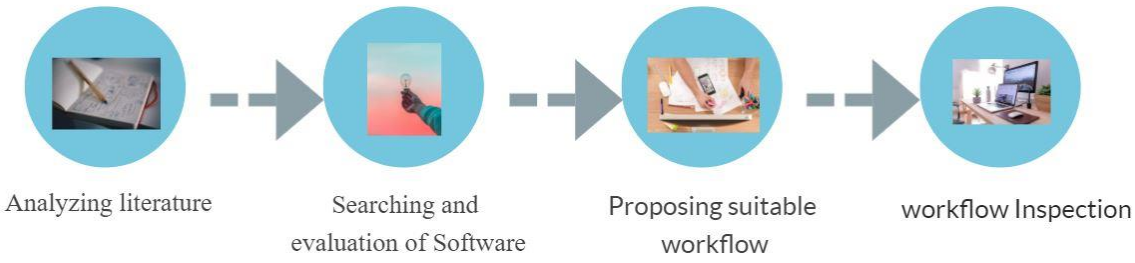


Fig2.1 methods employed by the study process.

Primarily, literatures base on previous work on this topic and other related trends were sourced, this is an essential part of the study, the search results were filtered based on selected keywords; articles and publications were downloaded from science direct and other relevant publishing sites, web pages and personal enquiry from companies.

Subsequently, an extensive search and evaluation was made on available software that can be used to propose a workflow for immersive visualization in the construction industry. This process was carried out through google searches, professional reviews from websites and blogpost from different AEC companies.

Furthermore, after being able to obtain details of available software and compiled a list based on features, functionality and other technical parameters. In this phase, the study has been able to answer the following questions:

1. Are plugins available that makes it compatible with Revit, ArchiCAD? (navisworks, rhino, sketchup)
2. What kind of file formats does it support?
3. Does it have an available student or academic version, how much is the pricing?
4. Supported hardware devices (vive, oculus, mobile, operating systems, etc.)

5. Modes of walk through (panoramic, 360°, stereoscopic image, etc.)
6. Team collaboration possibilities, cloud.
7. Available scientific literature, published case studies, examples?
8. Are forums, tutorials and interactive community available?
9. Does it have other features? (e.g. clash detection)
10. Can it access BIM in VR? (viewing building object data in real time)

Answers to the questions were obtained from the website of producing company and personal inquiry to the sales team. From questions above few software were selected and inspected in the lab.

Workflows were set up, tested and inspected based on BIM software used by the university (Budapest University of Technology and Economics), available VR HMD, and software with available academic plan, and having most feature; however, this setup can used also by companies and other institutions or individuals.

3. LITERATURE

3.1 Importance of immersive visualization

Communication during the design process has a substantial role because; it exchanges messages and conveys ideas to people with different skills and interests. Seventy-five percent of each working day is spent in some form of communication whether it is verbal or visual; communication is the center activity of any project. In an architectural context, the transmission of information to communicate design through visual representation of the real world is very crucial; there is no doubt that presentation techniques can play a major role in how we perceive design as different presentation techniques can easily alter our perception of architecture [14].

The first application of VR technology for the built environment could be traced back to the 1990s when this simulation technology was initially brought to the attention of architects and garnered the interest of other disciplines engaged with architectural engineering to explore more possibilities of VR technology[15]. Hence, the process of design and visualization should be iterative, with changes made as a result of insights gained through visualization propagated into the next version of the design. The iterative nature of this process requires adequate software support and thought processes should not be interrupted by a requirement to translate the design concepts into software terms for visualization[16].

Immersive virtual Environments (IVEs) have also proven to be more realistic learning environments, especially for tasks related to spatial performance such as navigation, path finding, and object perception in comparison to other mediums such as immersive workbenches, computer screens, and hemispherical displays. Virtual environments (including IVEs) are considered important tools for the education and training of AEC professionals in BIM models.

Besides potential improvements in efficiency in terms of time and costs that this technology may offer, the adoption of building representations that are closer to the “experiential-spatial” human experience in the real world would contribute to the development of buildings that really match end-users demands – technical, functional, and symbolic[17].

3.2 Virtual reality

Virtual reality can be described as a set of technologies, which, based on the use of computers, simulates an existing reality or a projected reality (Burdea & Coiffet 1993). This tool allows computer users to be placed in three-dimensional worlds, making it possible for them to interact

with virtual objects at levels until now unknown in information technology: turning handles to open doors; switching lights on and off; driving a prototype car or moving objects in a house [18]. The purpose of VR is to allow a person to experience and manipulate the environment as if it were the real world. The VR subject experiences “hypes” at regular intervals, and they disappear shortly thereafter. With the advent of more powerful graphics hardware and innovative tracking technologies, the topic has been revisited in recent years. According to Gartner's hype cycle, VR has finally reached the “plateau of productivity” [19]. In recent years, Virtual Reality (VR)-based simulators are used to train apprentices in many high-risk industries, such as aviation, firefighting, military, medicine, and manufacturing. The construction industry also has adopted VR-based simulators for various types of training programs. Simulators are used in such areas as safety training, construction management and planning, and equipment training. Many of the major construction equipment manufacturers nowadays provide training simulators that represent the design and characteristics of their equipment [20]. Alcínia et al states, besides dynamic representation, VR helps students and teachers overcome another limitation of static drawings as it allows the interaction of the operator with the representation of the equipment and its parts [21].

3.3. Augmented reality

In recent years, AR has a significant amount of attention by researchers in the AEC industry; The International Data Corporation predicts an enormous market growth of this technology from 0.2 billion USD in 2016 to 48.7 billion USD in 2021 [22]. The concept of AR generally refers to superimposing computer generated virtual objects over real objects/scenes to produce a mixed world. Users can acquire additional information of real world by rendering this mixed overlay in devices such as head mounted displays, see through glasses, and hand held monitors [23]. Researchers commonly define augmented reality as a real-time system. However, we also consider augmented still images to be augmented reality as long as the system does the augmentation in 3D and there is some kind of interaction involved [24].

The power of AR concept lies in the fact that it presents opportunities for users to interact with most interested digital content in a more natural way by virtue of effectual merging of the two environments[23]. There are numerous reasons for the application of AR technologies in industry. For example, the usage of written manuals in the form of booklets is usually inconvenient at the

work place, and then often avoided or neglected by workers that tend to rely on their knowledge and experience [25].

3.4 Mixed reality

New technology that intelligently combines the physical and digital worlds looks set to revolutionize the way civil engineers monitor infrastructure, both during and after construction [26], Mixed Reality (MR) combines the best aspects of VR and AR. VR allows the users to immerse themselves in a digital environment that is completely detached from the real world. AR presents digital content on top of the real-world content. MR allows digital content to be interactive with real-world content. The key term for MR is "flexibility." This aspect makes MR more marketable and "less geeky" than its cousins [27]. Mixed Reality is a blend of physical and digital worlds, unlocking the links between human, computer, and environment interaction. This new reality is based on advancements in computer vision, graphical processing power, display technology, and input systems [28].

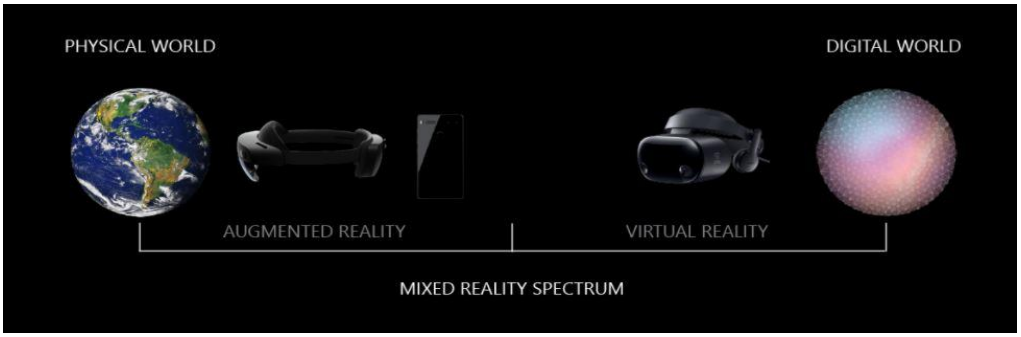


Fig 3.1 *where devices exist on the Mixed Reality spectrum* [28].

Microsoft's HoloLens is a headset that supports applications that mix holographic images with the real environment that the user is in. It scans the user's environment and adds computer-generated surfaces, graphics, and objects into the real scene. Depending on the application, a designer can, e.g., manipulate objects, use voice commands, and move inside the designed environment [29].

3.5 Building Information Model (BIM)

The use of Building Information Modelling (BIM) has increased in recent years, mostly due to the potential of the methodology for improving construction project performance and efficiency[30]. BIM is a process for creating and managing information on a construction project across the project lifecycle. One of the key outputs of this process is the Building Information Model, the digital description of every aspect of the built asset. This model draws on information assembled

collaboratively and updated at key stages of a project. Creating a digital Building Information Model enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset [31]. BIM object consist of product datasheets, technical information combined with dimensions and product geometry; these object are created in a consistent manner to allow designers to use the content with confidence that the object will perform as expected in a BIM environment [32].

A BIM model is different from traditional 3D CAD models in which 3D CAD only describes a facility with independent 3D views, such as plans, sections and elevations. On the contrary, a BIM integrates semantically rich information related to the facility, including all geometric and functional properties during the whole life cycle in a collection of "smart objects" [33].

3.6 The future of BIM

From my previous study BIM is now used widely all over the world in countries such as the United States, United Kingdom, France, Germany, Finland, Denmark, Australia, Malaysia, and Singapore. Discussing the future of integrated BIM, Dennis Neeley, AIA, Product Director, Reed Construction Data, believes that "Owners need to start immediately setting standards for their BIM projects. They need to provide the objects that their designers will use, or they need to get the manufacturers that they work with to provide the objects. They need to be consistent across all projects. Standardization on space designs, assemblies and objects and the data attached and associated is critical [34]. Government are also making headway in ensuring BIM adoption in public projects especially in UK and Finland.

3.7 BIM levels and Standardization

Currently seen as the holy grail, BIM level 3 represents full collaboration between all disciplines by means of using a single, shared project model that is held in a centralized repository. All parties can access and modify that same model, and the benefit is that it removes the final layer of risk for conflicting information [35]. However, most Adopters of BIM are in the level 2 stage.

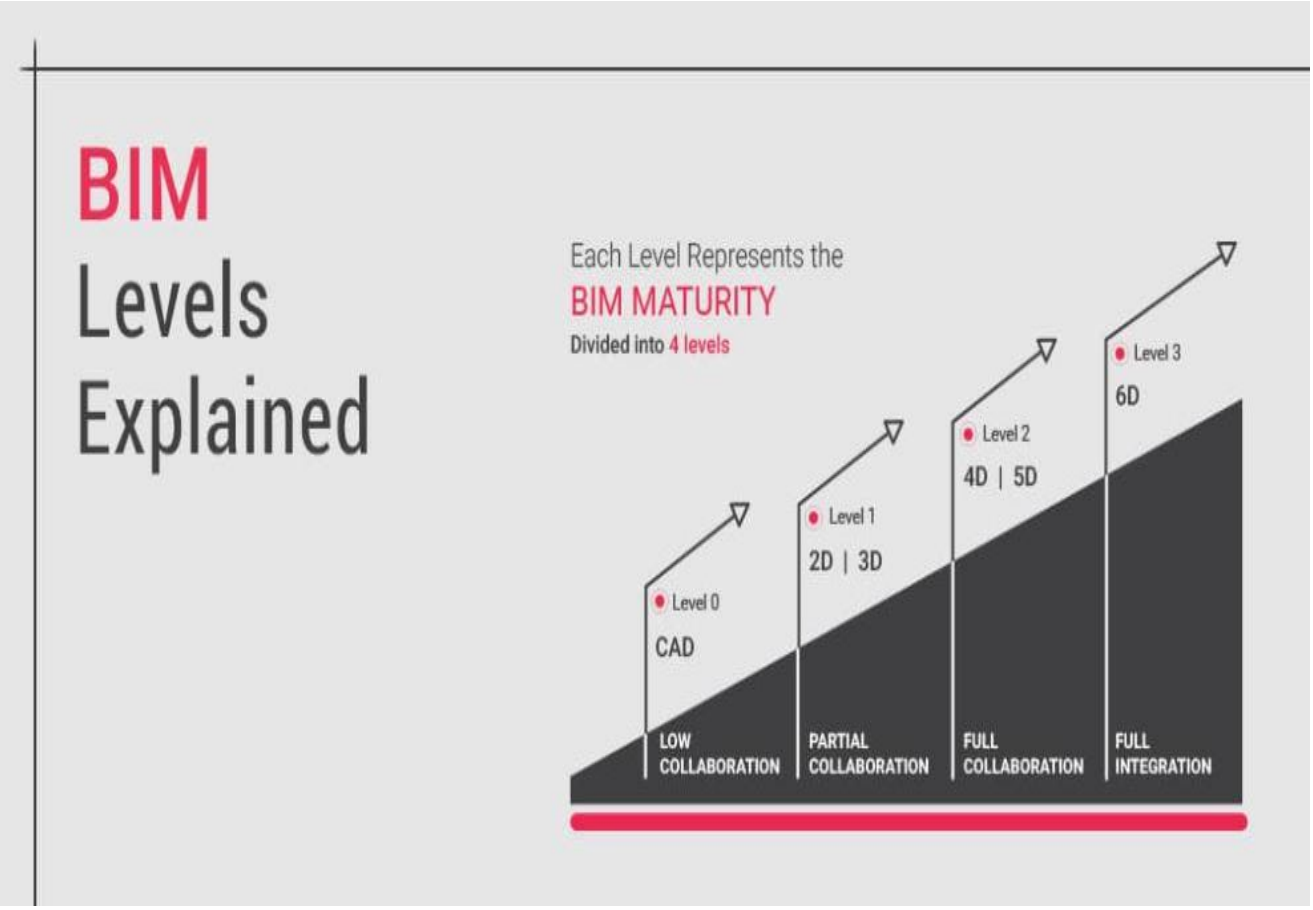


Fig 3.2. BIM maturity levels Explained [36].

BIM is not possible without standardization of building components. Many building component libraries have been developed for different aspects of the building design, such as spatial design, structural design, installations, etc. Often these libraries are included in AEC tools, or they are provided by product suppliers. To support the quest for data exchange models between different AEC tools, standardization efforts have focused on building components. The most widely spread ISO certified building component library is the Industry Foundation Classes (IFC) standard. Building component libraries like IFC have developed from traditional catalogues of building products [37]. There is a rapid growth in the number of supporting technologies, and only a few of which are Industry Foundation Classes (IFC) compatible, which means they can only be integrated with specific tools that accept their data formats [38].

3.8 BIM and XR use cases and rate of adoption

There are several use cases of VR, AR, MR and BIM, which is not limited to only visualization. Moreover, most research are still focus on visualization possibilities.

In the construction industry, there is a lot of machinery involved in the building process, and it requires many hours of training. However, in this technologically advanced generation, an augmented reality headset allows workers to receive direct instructions, and then act accordingly. With the augmented reality headset, it reduces the training costs and downtime utilized because the instructions are more intuitive. Additionally, augmented reality can provide a safer training environment because staff can work with large machinery with reduced risk of injury [39].
BIM provides stakeholders with a remarkable ability to execute a project in a virtual and controlled environment, which was impossible in previous decades [40].

Yelda turkan et al designed and developed a mobile AR platform that could potentially assist in teaching the course structural analysis, which is a core course, thought in every civil engineering and most architecture and construction engineering program. The results of the pilot study indicate that the utilized AR design concepts have potential to contribute to students' learning by providing interactive and 3D visualization features, which support constructive engagement and retention of information in students [41].

An important use case of these technologies is during design, construction and managing building life cycle; immersive visualized environments provide a better communication tool and design initiative. Stakeholders and the entire construction team have a better overview of the project and enhances collaborative reviews.

Construction support, which has four sub-categories construction planning, progress monitoring, construction safety, and operative support;

From a study of J.M Davila Delgado, et al as illustrated in fig 3.3 It presents a visual representations of the use-cases, including the level of adoption of AR and VR per use-case (see Section 4.2 for more information on adoption levels). The intention of the image is to provide visual support to the reader to facilitate the understanding of each use-case [42].

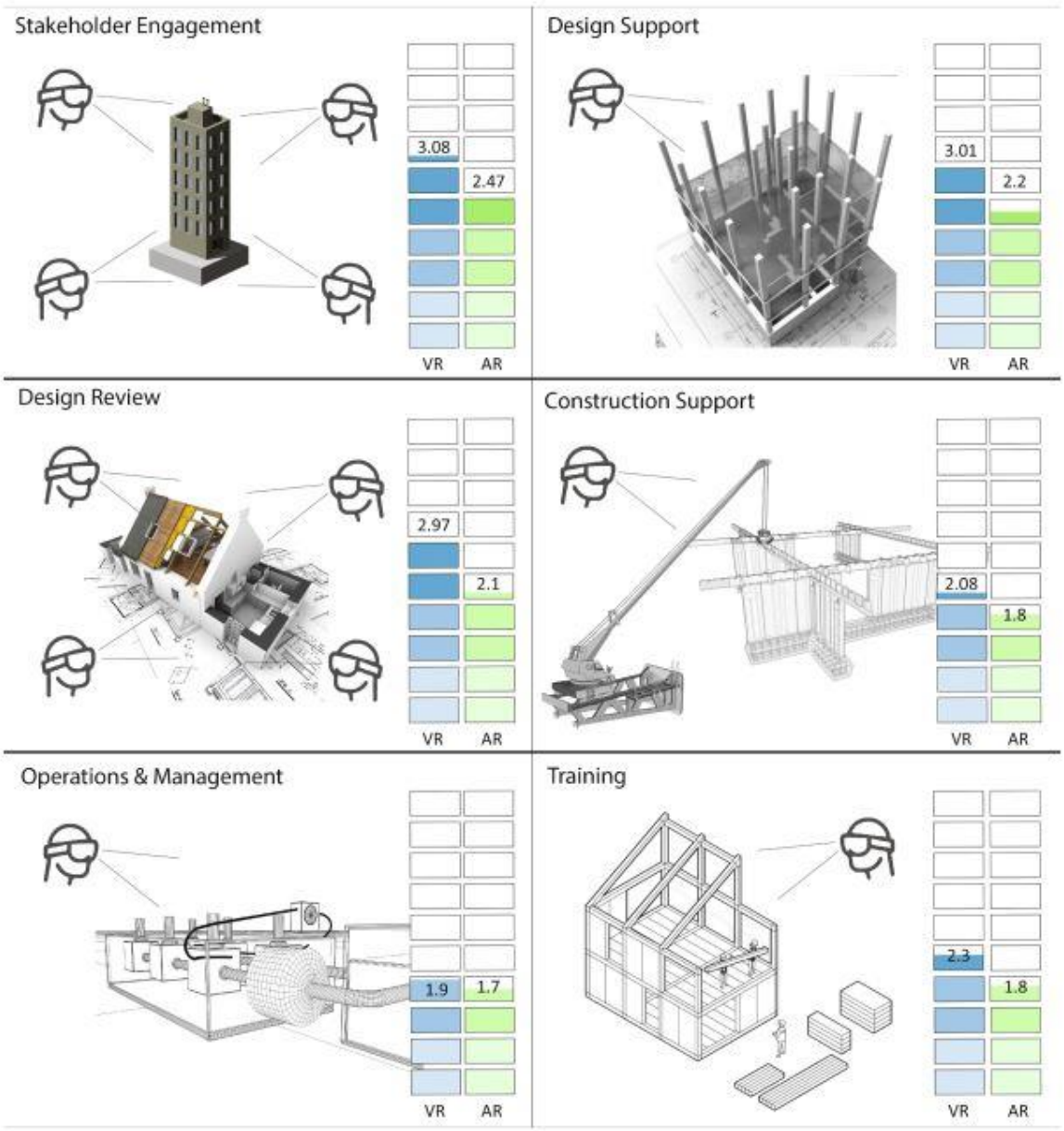


Fig. 3.3 AR and VR cases in the AEC sectors and their estimated levels of adoption. The plots indicate the level of adoption in projects for the given use-case (1 = not used, 2 = early testing, 3 = basic implementation, 4 = partially used, 5 = fully implemented).

4. EVALUATION OF SOFTWARE FOR IMMERSIVE VISUALIZATION

4.1 BIMx

BIMx is a set of desktop and mobile software tools to interactively present the 3D model and 2D documentation of Building Information Models created with ArchiCAD through a much simpler and intuitive interface than ArchiCAD's complex BIM authoring environment's UI. 3D models with 2D drawing sheets exported to BIMx document format can be viewed with native viewer applications developed for Apple iOS, Android, Mac OS X, and Microsoft Windows operating systems [43]. It was awarded as the mobile technology of the year in 2019 and 2018 consecutively at the Construction Computing Awards [44].

Fig 4.1 BIMx on IPad

4.2 IrisVR

IrisVR is a software that offers an immersive VR walkthroughs in one click. with integrations via Prospect plug-in in SketchUp, Revit, Navisworks, Rhino files in Oculus Rift, HTC Vive + 360 panoramas in Gear VR, Cardboard, Daydream, valve index, Pimax, windows MR, and Samsung

odyssey. However, it is not a cross platform application as its desktop setup is only supported on windows OS. The pricing plan starts at $225 and $350 for individuals and workstation respectively, with a free trial of 14 days [45]. IrisVR offers two solutions (fig 4.2) Prospect which enable interaction via PC and scope which is used for viewing panorama in mobile device or HMD.

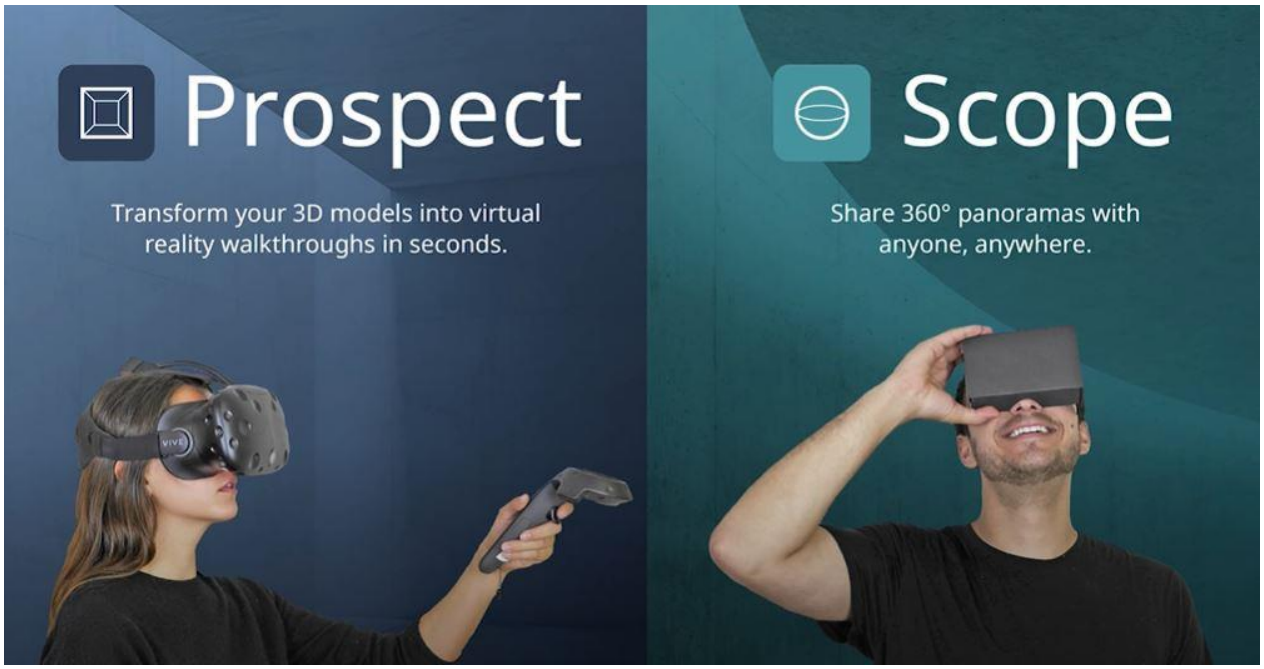


Fig 4.2 IrisVR prospect for PC VR and Scope for mobile device panorama.

4.3 Twinmotion

Easily produce high-quality images, panoramas, and standard or 360° VR videos in seconds! For architecture, construction, urban planning, and landscaping professionals, Twinmotion combines an intuitive icon-driven interface with the power of Unreal Engine [46]. Twinmotion is extremely easy to learn and use, regardless of the size and complexity of the project, the materials, the user's IT knowledge or their preferred BIM modeler. Direct synchronization with Archicad allows users to move from the BIM model to a VR experience in only three clicks. Twinmotion is available on both macOS and Windows in 8 languages: English, French, German, Chinese, Japanese, Korean, Portuguese and Spanish [47]. Twinmotion features direct one-click synchronization with ArchiCAD, Revit, SketchUp Pro, RIKCAD, and Rhino. It is free for students and educators and starts at 600 USD.

Fig 4.3 Twimotion with ArchiCAD model

4.4 Lumion

Lumion is 3D rendering software made especially for architects and designers. All you need is a 3D model of your design and Lumion takes care of the rest, unleashing creativity and helping you show your design complete with shadows, lighting, rich and animated entourage, and photorealistic or conceptual effects. Lumion is intuitive and it seamlessly fits into your current workflows, the basics can be learnt in less than 15 minutes. It is fully compatible with SketchUp, Vectorworks, Revit, AllPlan, Rhino, ArchiCAD, 3DS MAX, and AutoCAD [48]. It can be used for creating Images, videos and 360 panoramas, and the pricing plan starts at €1499 for Lumion 10.5 and €2999 for 10.5 pro.

Fig 4.4 Lumion

4.5 The wild

The Wild is a collaboration platform for teams to experience their work together, from anywhere, in virtual and augmented reality. Integrates with Revit, SketchUp, and BIM 360 workflows. Import can be done from all major 3D file types. Additionally content can be accessed from HTC Vive, Oculus Rift, Oculus Quest, Windows Mixed Reality, AR (iOS), or desktop (Mac or PC). Work and present from anywhere in real time, with up to eight people in a space. Metadata is accessible for all Revit files in your space, for added context in meetings and reviews. The pricing plan is $295, $595 and $1795 monthly for a basic, standard and premium accounts respectively [49].

4.6 Unreal Engine

Unreal Engine's high-fidelity real-time environment lets users rapidly iterate to create the best version of your vision, catch costly design errors early, and communicate your design intent to stakeholders. From immersive VR & AR experiences to glossy brochures and marketing videos, Unreal Engine can be a solution for architectural visualization needs. This software is free for creators outside of the gaming industries, students and educator, for enterprises, it cost $1500 per seat. Its datasmith functionality makes it compatible with many file formats.

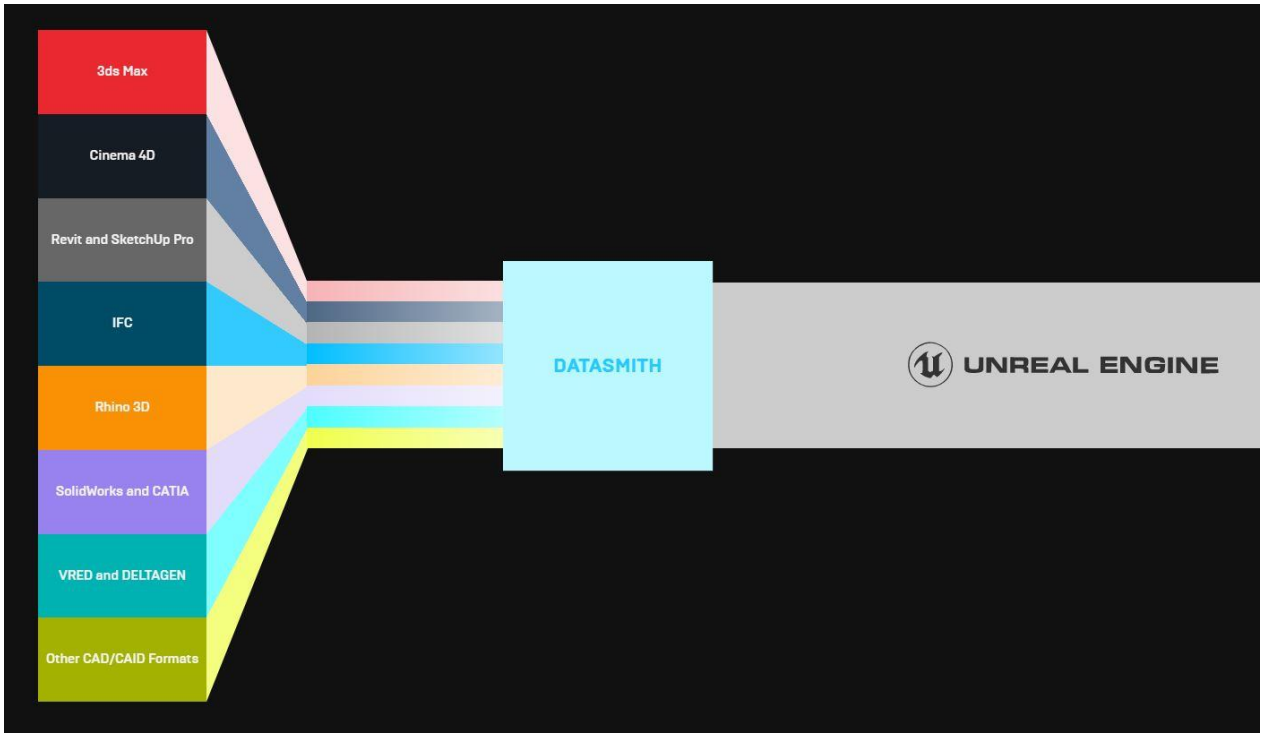


Fig 4.5 unreal Engine pipeline [50].

4.7 Enscape

Enscape is a commercial real-time rendering and virtual reality plug-in. It is mainly used in the architecture, engineering, and construction fields [51]. Enscape integrates seamlessly into design programs including Revit, SketchUp, Rhino, ArchiCAD, and Vectorworks. With the live link between Enscape and CAD programs, users can follow every update to plan instantly. It supports HMD like the Oculus Rift S or HTC Vive in a walk or fly through your project. The pricing is $58.25 Full version license that can be shared on multiple machines and $47 Full version license that is tied to one fixed machine, with a 14 days free trial [52]. A great feature of Enscape is a wide collection of asset library with about 1600-model scene improvement.

Fig 4.6 Enscape features

4.8 Sentio VR

SENTIO VR is a tech company founded in 2016. It has become the first Chilean Startup to join the world-renowned PLUG AND PLAY Tech Center accelerator in Silicon Valley [53]. The platform allows AEC professionals to visualize and present 3D models or 360 images in Virtual Reality using VR Headset like Oculus Go, Oculus Quest, and Samsung Gear VR. It has a plug-in support for Revit, and SketchUp. Sentio VR has a 14 days free trial with a $19, $59, $149 pricing plans for a freelancer, professional and professional package account.

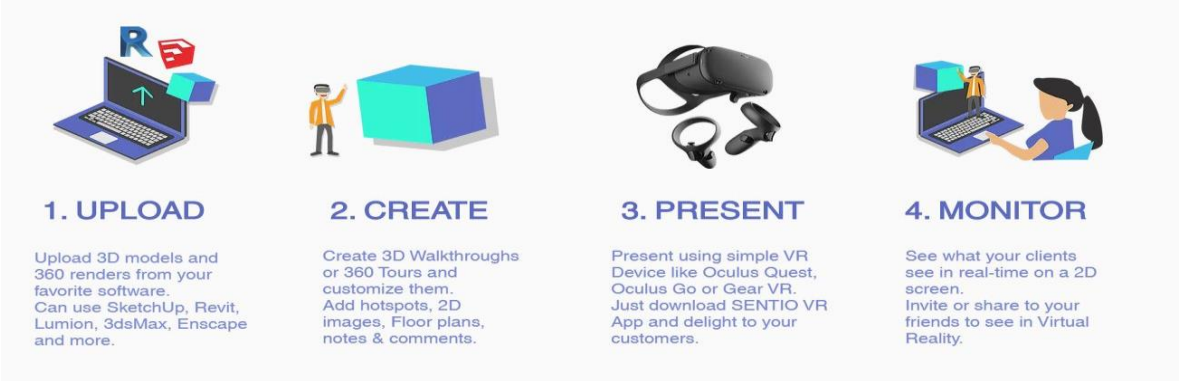


Fig 4.7 Sentio VR workflow [54]

4.9 EyeCAD VR

Eyecad VR has been made up to create renderings, videos and interactive experiences for architecture and design. Photorealistic visuals are ready in real time, with an easy and powerful workflow. It is a cross platform application as it is supported on both Mac and Windows machines. Eyecad VR is compatible with most popular 3D modeling software, including: SketchUp, Rhinoceros, Revit, Cinema 4D, 3D Studio Max and Vectorworks (fig 4.8)with a plug-in for SketchUP, Revit and Rhino, and supports import of SKP, FBX, 3DS, OBJ, DAE file format. With Over 1200 materials and 3D models available. Embedded automatic system to generate environments and weather effects. Eyecad VR is compatible with main virtual reality commercial kits such as Oculus, HTC Vive, Windows Mixed Reality and 360° renderings can interactively be viewed on stand-alone devices such as oculus Go, Vive focus and other devices available in the market.

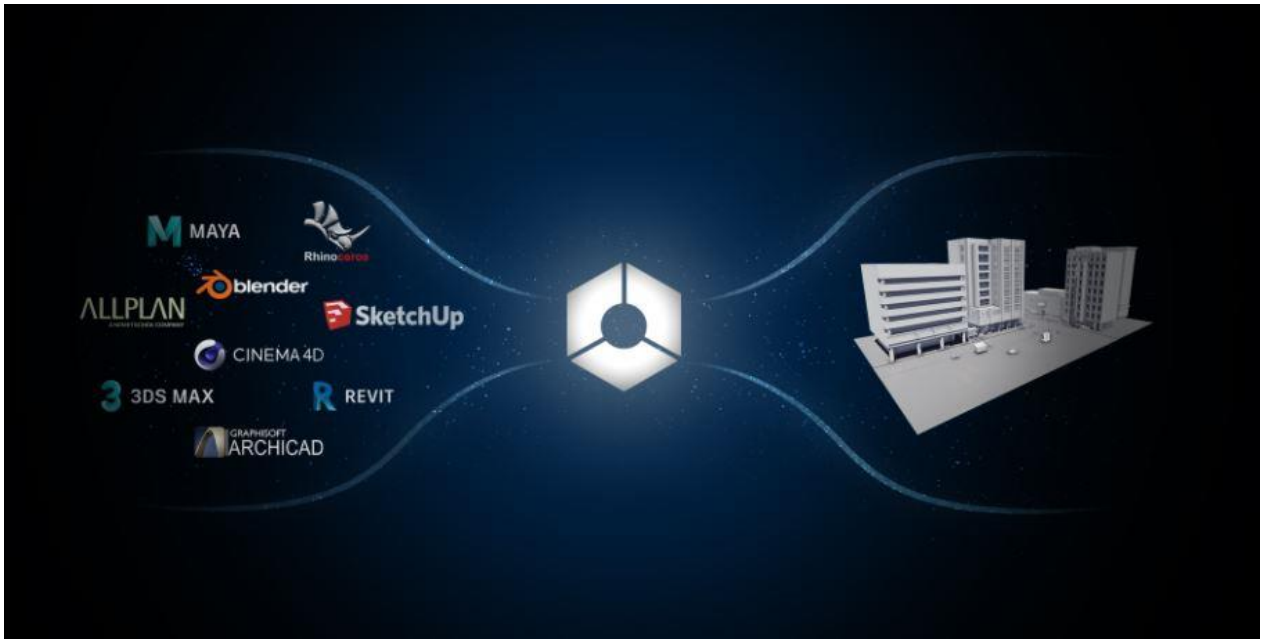


Fig4.8 Eyecad VR [55]

4.10 Naviswork manage

Autodesk Navisworks Manage is a comprehensive project review solution that supports coordination, analysis, and communication of design intent and constructability. Multidisciplinary design data created in a broad range of, digital prototype, and process plant design applications can be combined into a single integrated project model. Interference management tools help design and construction professionals anticipate and minimize potential problems before construction begins,

helping to reduce expensive delays and rework [56]. It has a trial version of 30 days and a paid version starting at $285 monthly. Naviswork manage is used in areas of model review, coordination, quantification, project viewing, model simulation and analysis. The NWC exporter works with a range of products, including AutoCAD- and Revit software-based products, as well as 3ds Max, Bentley MicroStation, and Graphisoft ArchiCAD software. The NWC file format supports transfer of both object geometry and associated metadata [57].

4.11 UNITY Reflect VR

Reflect is 3D real-time immersive visualization software for the AEC industry designed by unity. It has a plug-in integration with Rhino, Revit, Navisworks, and SketchUp (fig4.9). Pricing plan per seat is at $690 and $1800 annually for a unity reflect and unity pro respectively. Viewers can review projects in real-time 3D on PCs, Macs, iOS, and Android devices (including AR), and HTC Vive.

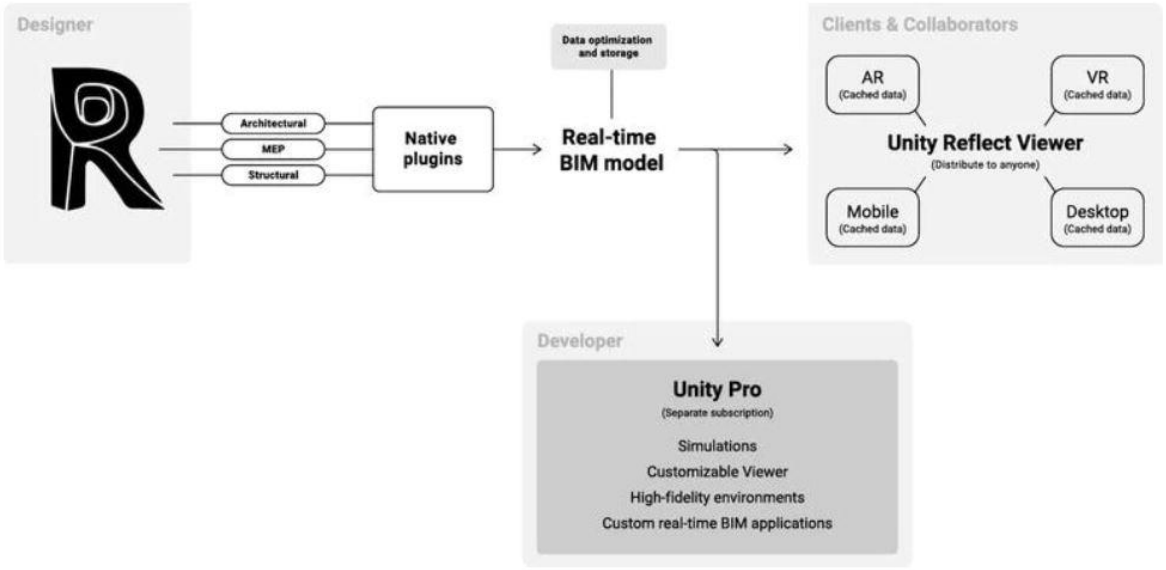


Fig4.9 unity Reflect workflow [58]

4.12 Simlab VR

SimLab's VR Viewer is a free stand-alone application that can view, edit and share interactive VR experiences created by SimLab Composer. With SimLab VR Viewer anybody can live the full

experience with a walk mode and fly mode. Simlab has wide range of 3D CAD application plug-in including Revit, Maya, Autocad, SketchUp, 3DS MAX, Rhino etc.

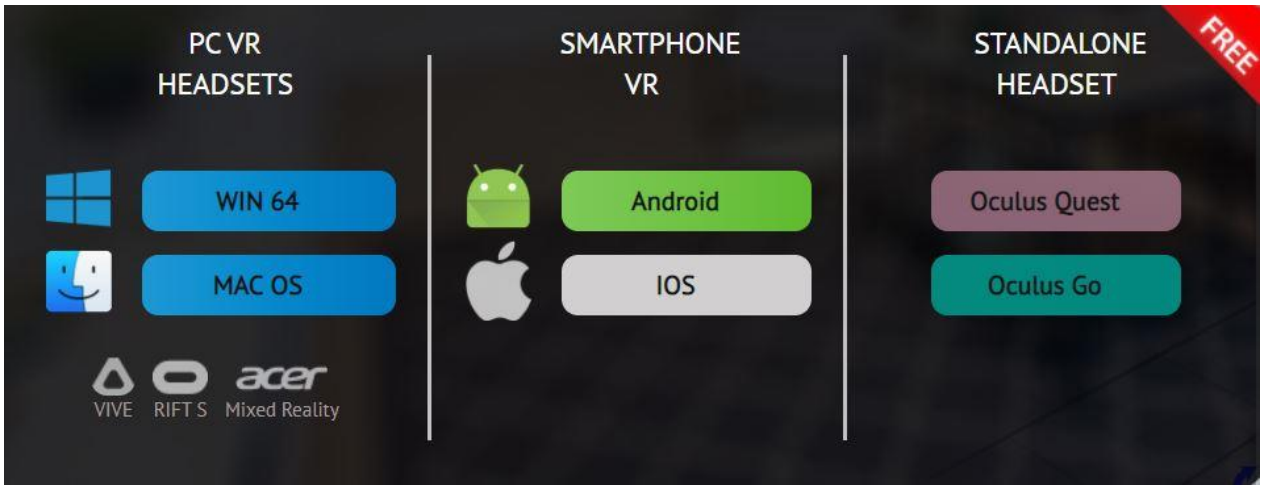


Fig 4.10 Simlab VR supported headset, smartphone and headset [59].

4.13 Modelo

VR experiences can be built in Modelo in minutes and shared easily with collaborators, colleagues, and clients. Modelo is used in AEC industry, real estate and commercial space planning; modelo is free and has a basic plan with more features for $70 per month. It has support for SketchUp, Rhino, Revit, 3DS Max, Naviswork, AutoCAD.

Collaborating on BIM projects is possible in Modelo. BIM properties and elements are automatically imported from compatible application files and support your entire design-build-manage process. The online 3D BIM tool allows users to calculate lightning fast 3D quantity takeoffs and analyze sectional material volumes. Any construction issues can be marked up directly on the design in the browser and team members notified. Project teams can collaborate, stay up-to-date, and access the progress of the project in one centralized, online platform - whether they are on the jobsite or in the office [60].

4.14 Yulio VR

Yulio converts cubemap or 360-photo to VR automatically, it has CAD support plug-in for SketchUp, Rhino, 3DS Max, CETDesigner and Revit. The desktop plugin is not supported on a Mac. Yulio has a free trial period of 30 days after which users can select from a variety of paid options which starts at $189, $594, $420, annually which is for the Yulio jump , Jump+Pro and pro. Users can choose to view model from a Yulio mobile app, web browser or VR Headset.

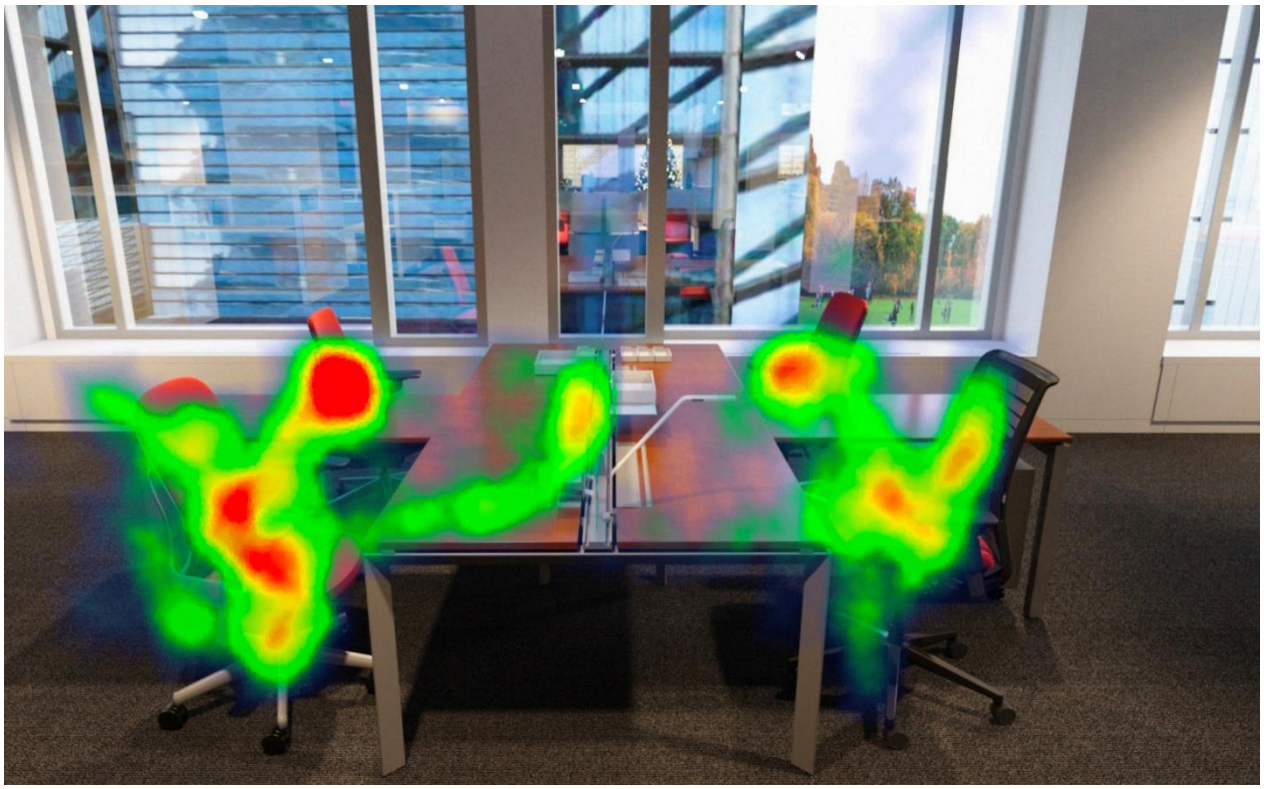


Fig 4.11 Yulio VR heat mapping for gaze tracking

4.15 V-Ray

V-Ray is a biased (statistical bias not subjective bias) computer-generated imagery rendering software application developed by Bulgarian Chaos group. V-Ray is a commercial plug-in for third-party 3D computer graphics software applications and is used for visualizations and computer graphics [61]. This is a cross platform application with support for Mac, Linux and Microsoft Windows. V-Ray has support for 3D applications including Maya, Revit, SketchUp, 3DS Max, Rhino. After a 30 days free trial, the paid version of this software starts at €55 euro monthly for every individual 3D application and a discount for student and educators [62].

4.16 Revizto

Revizto is 2D and 3D collaboration platform with plug-ins for several software packages including ArchiCAD, AutoCAD, Revit, SketchUp, Tekla, Rhino, CADmep, Navisworks, OpenBuildings, VectorWork, Inventor, Microstation, OpenRoads and civil 3D. similarly, it supports file formats such as BCF, DWG, Faro, FBX, IFC, OBJ, PDF, ReCap, and Solibri. A user's subscription starts

at €600 for a starter account, €500 for an account within a team and €400 for an account within a company.

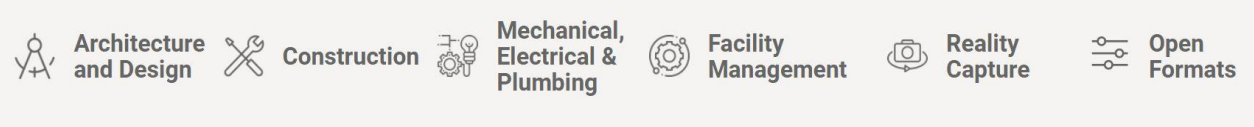


Fig4.12 Revizto [63]

4.17 BIM360

BIM 360 is a unified platform connecting project teams and data in real-time, from design through construction, supporting informed decision-making and leading to more predictable and profitable outcomes.

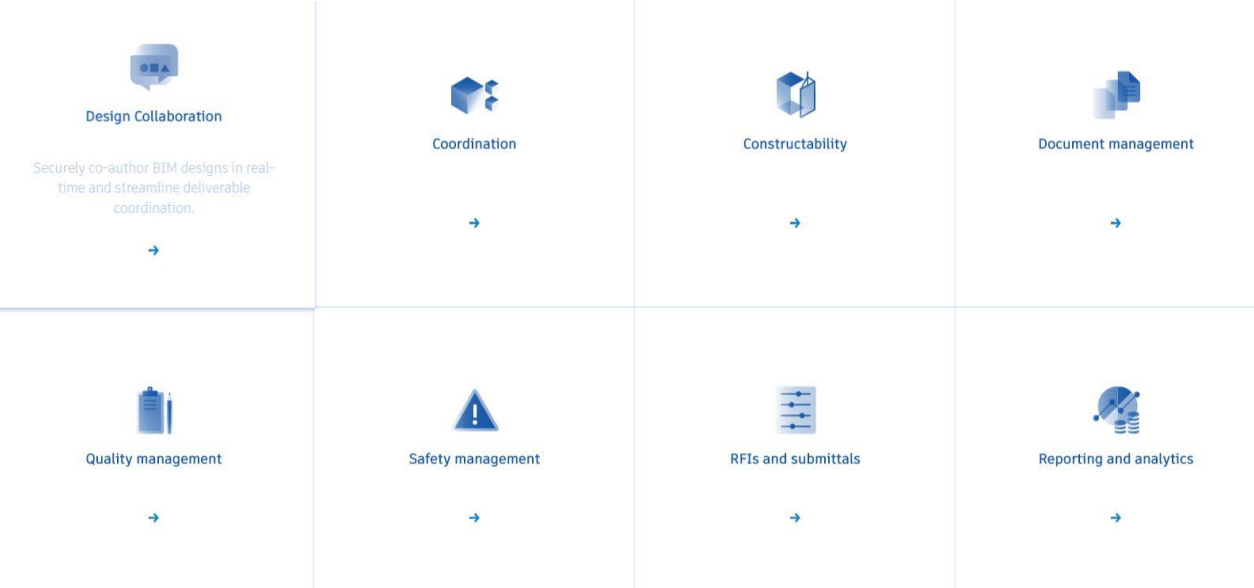


Fig 4.14 BIM360 functionalities [64]

4.18 Fuzor

Fuzor is a multifaceted software with the power to take your project from the conceptual design phase all the way through construction and facilities management. It is a VR solution, a 4D scheduler, a multi-user real time collaboration platform, an analysis tool, and much more [65]. Fuzor supports geometry file types such as FBX, SKP, RCP, IFC, 3DS. Additionally, has support for HTC vive HMD, Oculus, Windows mixed reality. This software offers additional feature including multi-user collaboration, VR annotations, CCTV design and simulation, vehicle and entourage placement, footstep counter measurement, clash analysis and grouping, issue tracker, Hologram and a lot more [66]. Fuzor is a paid application.7

4.19 Insite VR

InsiteVR is a cross-platform VR meeting software for architecture, engineering and construction. After uploading a CAD model, users can start virtual review meetings with colleagues from around the world. InsiteVR supports Revit and Sketchup models and 360 images to be reviewed across Oculus Go, GearVR, Oculus Rift, and VR devices on other platforms. Meeting hosts can gather everyone to them to discuss a particular issue, direct attention using a virtual laser pointer, and leave text annotations in real time. Users can join in remotely and see their colleague's avatars, talk to them through the app, and collaboratively review their Revit, Sketchup, FBX, and OBJ models or 360 Images. InsiteVR comes with a Revit plugin [67]. Insite VR supports BIM files hosted on Autodesk BIM 360 Docs, which supports 70+ different file formats for oculus quest and Resolve.

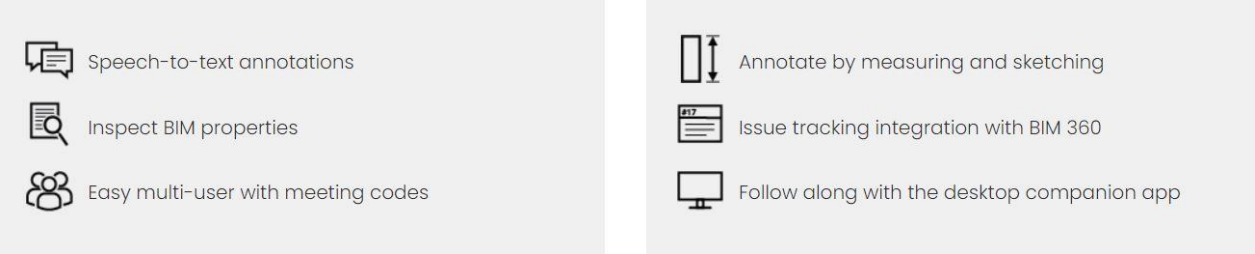


Fig4.13 Insite VR features [68]

4.20 SOFTWARE COMPARISON

Following an extensive search on various websites, the software presented in table 4.1 below was compiled and the best ones for the proposed workflow was chosen from it. This table will further present other available option to other students and researchers interested in the development of this field.

Several software application were sourced and studied to evaluate their features and if it meets the requirement to the answers in the introductory chapter, this requirement was used to filter the software and thus table 4.1 was obtained. During evaluation, the supported file formats by each software program was considered, as it is very important to the study, output platform for visualization, collaboration possibilities, as it is a viable means in BIM enhancement. Some of the information were obtained from forums of the several applications this shows it has wide and active users, hence development and further developments is possible with this software and an extensive learning platform for entry users.

	application	Software Revit ArchiCAD	File Format	Pricing plan Fr. Ed. Pd	HMD Vive Ocu. Win. Mob.	Collab. Y N	Clash Detect. Y N	BIM access Y N	Walkthrough S V F W P
1	BIMx	*	.bimx	*	*	*		*	* * *
2	IrisVR	*	FBX, OBJ, IFC	* *	* * *	*	*	*	*
3	Twinmotion	* *	Datasmith	* * *	* * *	*			* *
4	Lumion	* *	DAE, .SKP .FBX .DWG .DXF .3DS .OBJ .MAX	*	*	*	*	*	* *
5	The wild	*	FBX, OBJ, 3DS, DAE, STL	*	* * *	*	*	*	*
6	Unreal engine		Datasmith	*	* * *	*	*		* *
7	Enscape	* *	SKP, RVT, PLN, VWX	* * *	* * *	*	*	*	* * *
8	Sentio VR	*	SKP, RVT, 3DS, C4D	* *	* *	*	*	*	* *
9	EyeCAD VR	* *	SKP, FBX, 3DS, OBJ, DAE	*	* * *	*	*	*	* * *
10	Naviswork manage	* *	IFC, FBX, DWG, SKP, 3DS	* * *	* * *	*	*	*	* *
11	UNITY Reflect VR	*	Plugin	* * *	* * *	*	*	*	*
12	Simlab VR	*	3DS, DEA, DWF, DWG,FBX,IFC	*	* *	*	*	*	* *
13	Modelo	*	SKP,3DM,RVT, OBJ,STL,FBX, NWD,DWG	* *	*	*	*	*	*
14	Yulio VR	*	SKP, RVT, 3DS, 3DM	* *	* *	*	*	*	* *
15	V-ray	*	3DS,3DM,SKP,maya IFF	* *	* *	*	*		*
16	Revizto	* *	IFC, DWF, FBX, OBJ, BCF, Faro, PDF	*	* *	*	*	*	
17	BIM360	*	IFC, DWG, RVT, FBX	* *		*	*	*	
18	Fuzor	* *	3DS, FBX, PTS, IFC and FARO	*	* * * *	*	*	*	* *
19	Trimble connect	*	IFC, CPA, DWG, RVT, DXF, DGN	* *	* * *	*	*	*	*

Table 4.1. software capable of BIM visualization.

Fr.	Ed.	Pd.	Vive	Ocu.	Win	Mob	Y	N	S	F	W	P	V
Free trials	Educational package or discount	Paid versions	HTC vive HMD	Oculus HMD	Windows MR	Mobile HMD	Yes	No	stereo	Fly mode	Walk mode	panorama	360 video

Table 4.2 abbreviations in Table 4.1

The table 4.2 above describes the variables used in the comparism of the listed software in table 4.1. Hence, because this study was conducted in an academic setting BIM software that was used in the university was given preferences, also based on records from the Construction Computing Awards ArchiCAD and Revit are the top two BIM product of the year [44] for two consecutive years. However, some of the above listed software also support applications such as SketchUP, AutoCAD, Vectorworks, civil3D, Tekla structure etc. In addition, file formats is as well important to discuss in this project as it contributes to one of reasons for the poor adoption of the XR technology in the AEC industry. furthermore, the software programs were categorized base on pricing plans and trial periods; while some are exclusive to only paid versions others have both trial period and also a plan for students and educators. Additionally, the HMD was specifically to HTC Vive, oculus and Windows MR as they are the most popular in the market and this study was conducted with a vive pro device, software program such as BIMx will come in handy as it has a great platform for mobile VR hence it is important to consider a mobile phone enabled HMD. Collaboration potentials was also checked by the comparism and BIM access to check the possibilities of viewing BIM objects in real time. Subsequently, other features such as clash detection and modes of walkthrough was also checked.

5. AVAILABLE HMDs

5.1 HTC VIVE

The HTC Vive is a virtual reality headset developed by HTC and Valve. The headset uses "room scale" tracking technology, allowing the user to move in 3D space and use motion-tracked handheld controllers to interact with the environment.

The HTC Vive was unveiled during HTC's Mobile World Congress keynote in March 2015. Development kits were sent out in August and September 2015, and the first consumer version of the device was released in April 2016 [69]. HTC Vive have variety of HMDs including the cosmos series, Pro Eye series, Pro series and Vive series.

The Vive HMDs use two base stations placed at each corner of the room, which tracks and maps the movement of the user around the room, the headset is connected to a computer with high processing capabilities via a long cable cord. It uses two wireless controllers for navigation and interaction within the virtual environment.

The cosmos series also offers the highest VIVE visual resolution to date with a resolution of 2880 x 1700 pixels combined.

5.2 Oculus

Oculus is a brand of Facebook Technologies, LLC (formerly known as Oculus VR, LLC), a subsidiary of Facebook Inc. The division produces virtual reality headsets, including the Oculus Rift and Oculus Quest lines Oculus's current product line consists of two models, both under the Oculus Quest brand. They are standalone headsets which contain integrated mobile computing hardware and do not require a PC to operate, but can optionally be used with PC-based VR games by connecting them over USB [70].

The oculus quest 2 is a standalone headset, which can be optionally connected to a computer but requires a smartphone application, the oculus rift S has to be connected to a VR compatible computer however, the immersive environment can be controlled with a controller. With 6DOF, the headset tracks the movement of both your head and body, then translates them into VR with realistic precision. No external sensors required.

5.3 PIMAX

Pimax is a technology company specializing in virtual reality hardware products. In 2016 its first product, the Pimax 4K virtual reality headset, was released, becoming the first commercially available 4K headset. On 8th of January 2020, Pimax's flagship headset- world's first dual native 4K consumer VR headset- VISION 8K X featuring high resolution and ultra-wide field of view, 200°(D)/170°(H)/115°(V), was selected as Top Tech of CES: AR/VR by Digital Trends [71].

Pimax has several category of headsets vision 8K X, vision 8K plus, 5K XR, 5K plus and Artisan. Its ultra wide FOV of 200° enhances the immersive experience. The Artisan series, which is the lowest, or entry level on the sets of the Pimax headsets has a 140° FOV greater than HTC vive pro. However, due to the HMD's specification it will require a more power computer in other to run programs with this PC VR headset.

5.4 MICROSOFT HOLOLENS

Microsoft HoloLens, known under development as Project Baraboo, is a pair of mixed reality smartglasses developed and manufactured by Microsoft. HoloLens was the first head-mounted display running the Windows Mixed Reality platform under the Windows 10 computer operating system. The tracking technology used in HoloLens can trace its lineage to Kinect, an add-on for Microsoft's Xbox game console that was introduced in 2010 [72].

The recent product of the mixed reality glasses is the HoloLens 2 a mixed reality augmented reality head-mounted display smartglasses, which is the second generation; it does not use controllers but Two-handed fully articulated model, direct manipulation. Other features include Command and control on-device; natural language with internet connectivity, Enterprise-grade security with iris recognition and real-time tracking

5.5 SAMSUNG HMD ODYSSEY+ (MR)

The Samsung HMD odyssey is a PC VR capable of immersive experiences. HMD odyssey is supported on the Microsoft Windows Mixed Reality Platform. HMD Odyssey+ comes with dual 3.5-inch 3K Dual AMOLED displays with newly added anti screen-door effect (1233PPI). The dual displays offer high resolution up to 1600 X 2800, wide viewing angle of up to 110-degree that provides a wider view. HMD Odyssey+ features exceptional AKG built-in headphone that supports 360-degree spatial audio to immerse users in lifelike surrounding sound environment, taking dynamic gaming audio experience to a new heights. The HMD Odyssey+'s built in Inside-Out

Position tracking, making setup easier without external motion sensors. HMD Odyssey+ also provides flashlight for easier switch between reality and virtual reality [73].

5.6 MAGIC LEAP 1

Magic Leap 1 is a lightweight, wearable computer that brings the physical and digital worlds together as one. It is a mixed reality headset and provides solution to AEC industry via the VIM platform.

VIM enables AEC professionals and their stakeholders to communicate and cooperate on spatial designs in real-time. From conference rooms to job sites, teams can access projects virtually anywhere. By removing 2D screens from an inherently three-dimensional process, VIM will play a significant role in the digitization of the AEC industry [74].

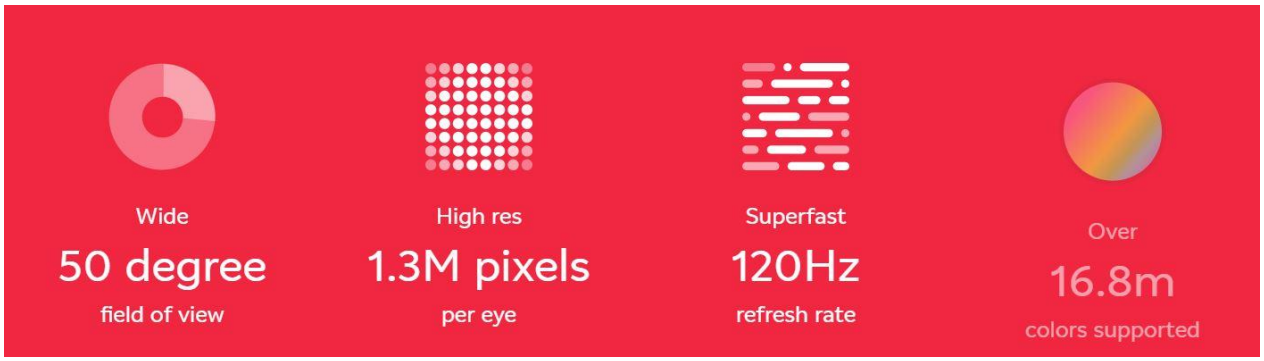


Fig 5.1 Magic leap [75]

5.7 SAMSUNG GEAR VR

The Samsung Gear VR is a virtual reality headset developed by Samsung Electronics, in collaboration with Oculus VR, and manufactured by Samsung. The headset was released on November 27, 2015.

When in use, a compatible Samsung Galaxy device acts as the headset's display and processor, while the Gear VR unit itself acts as the controller, which contains the field of view, as well as a custom inertial measurement unit, or IMU, for rotational tracking, which connects to the smartphone via USB-C or micro-USB. The Gear VR headset also includes a touchpad and back button on the side, as well as a proximity sensor to detect when the headset is on [76].

It is compatible with the following devices Galaxy Note9*, S9, S9+, Note8, S8, S8+, S7, S7 edge, Note5, S6 edge+, S6, S6 edge, A8 Star, A8, A8+, hence, Galaxy Note9 is compatible with Gear VR model number SM-R325NZVC (fig 5.2)

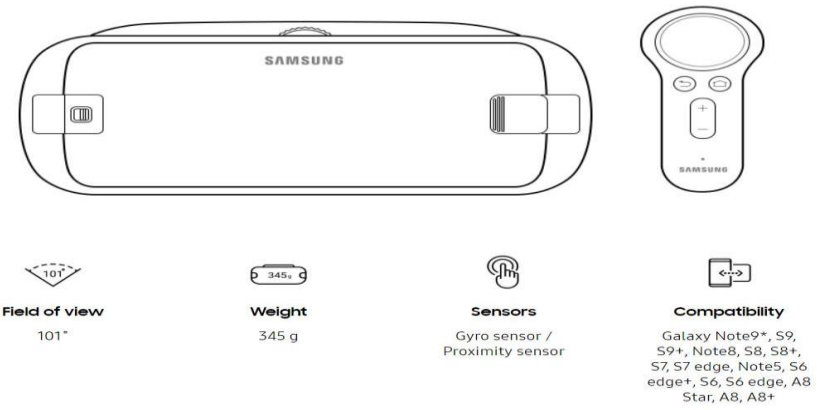


Fig 5.2 Samsung Gear VR [77]

5.8 GOOGLE DAYDREAM

Just like Samsung Gear VR Daydream also offers VR via smartphone (fig 5.3) enabled device and special HMD. The google Daydream is into two category: the smartphone VR and standalone VR. The standalone does not require a PC to run thereby ensuring flexibility and mobility. With the daydream controllers users can easily interact with the immersive environments.

Fig5.3 Daydream ready smartphones [78].

5.9 GOOGLE CARDBOARD

Google Cardboard is a virtual reality (VR) platform developed by Google. Named for its fold-out cardboard viewer into which a smartphone is inserted, the platform is intended as a low-cost system to encourage interest and development in VR applications. Users can either build their own viewer from simple, low-cost components using specifications published by Google, or purchase a pre-manufactured one [79]. With the google cardboard and other smartphone enabled HMDs users can explore or use BIM software programs such as BIM, scope a subsidiary of IrisVR. This will come in handy and encourage VR development in the AEC industry at a very low cost.

5.10 ACER MR HEADSET

This I the windows mixed reality headset developed by Acer, the HMD comes with two motion controllers that follow the standard design of Windows MR controllers, which is the same for all manufacturers. They look a bit like a cross between the Oculus Touch and VIVE controllers. They

big circular band around the top similar to the Touch, but in generally they are more stick shaped like the VIVE [80].

Acer's MR headset lets users blend physical and virtual worlds to take computing experience to a remarkable level where the senses are stimulated and the experience is riveting. A hybrid of both Augmented Reality (AR) and Virtual Reality (VR), Mixed Realty (MR) is far more advanced than Virtual Reality to send you into an unforgetable realm of reality. Acer's new Windows Mixed Reality Headset is designed for comfort, freedom of movement and to unite cutting-edge technology with futuristic practicality to maximize your computing experience. Acer's Mixed Reality Headset lets users walk around and interact with your environment without external sensors.

5.11 SUMMARY OF HMD DEVICES

Currently there are several HMD for both VR and AR in the market as technologies for MR is still under development, the table below (table 4.1) summarizes some of the available devices and their market prices with supported features. The prices are excluding VATs.

	Name	Refresh Rate	Field of View	Resolution	Sensors/tracking	OS support	Price
	HTC Cosmos	90 Hz	110°	2880x1700	G-sensors, gyroscope	Windows 10 Mac OS	€829
	HTC Vive Pro	90Hz	110°	2880x1600	G-sensors, gyroscope, proximity, eye tracking	Windows Mac OS	€1099
	Oculus Quest 2	90 Hz	-	1832x1920	No sensors / 6 degree of freedom (DOF)	standalone	€349
	Oculus Rift S	80Hz	115°	2560x1440	No sensors / 6DOF	Windows	€449
	Valve Index	144HZ	130°	2880x1600	SteamVR 2.0 sensors	Windows 10, SteamOS, Linux	€1079
	Pimax Artisan VR headset	120Hz	140°	3440x1440	Lighthouse 1.0, 2.0, Nolo Tracking	windows	€449

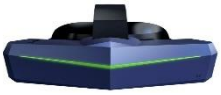
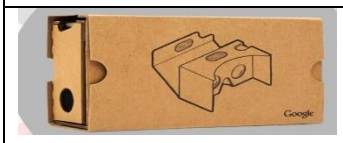
	Pimax Vison 8K plus	110Hz	200°	3840x2160 *2	SteamVR sensor	Windows	€829
	Microsoft HoloLens 2	240Hz	52° Diagonal	2K 3:2 light engine	Accelerometer, Gyroscope, Magnetometer, 4 visible light cameras, 6DOF	Windows	€2990
	Samsung HMD Odyssey+ (MR)	90Hz	110°	2880x1600	6-Axis ACC & Gyro; 3-Axis Compass; Proximity sensor; IPD Sensor	Windows	€239
	ACER MR Headset	90Hz	100°	2880x1440	Accelerometer, Gyro sensor, proximity sensor, Magnetometer,	windows	€512
	Magic Leap 1	120Hz	50°	1.3M pixels per eye	6DOF	Lumin	€1960
	Google Daydream standalone	75Hz	110°	2560x1440	P-Sensor, Gyroscope, Accelerometer Magnetometer	Windows	
	Google daydream View smartVR	60Hz	-	-	Accelerator, gyrometer, proximity	Mobile	€85
	Google Cardboard	60Hz	80°	-	Smartphone sensors	Mobile	€13
	Samsung Gear VR	60Hz	101°	2560x1440	Accelerator, gyro sensor, magnetic	Mobile	€110

Table 4.1 summary of HMD and there market prices

6. PRESENTATION OF BIM TO VR WORKFLOWS

Following the evaluation of several software program for BIM visualization, the following software programs were employed for setting up a workflow, and further inspection was conducted based on proposed environments and having sample cases.

Models from Revit, ArchiCAD, and Naviswork manage was used during the study, IrisVR and Enscape were primarily used for the immersive visualization. Discuss below is the details of the various workflow composed during the study.

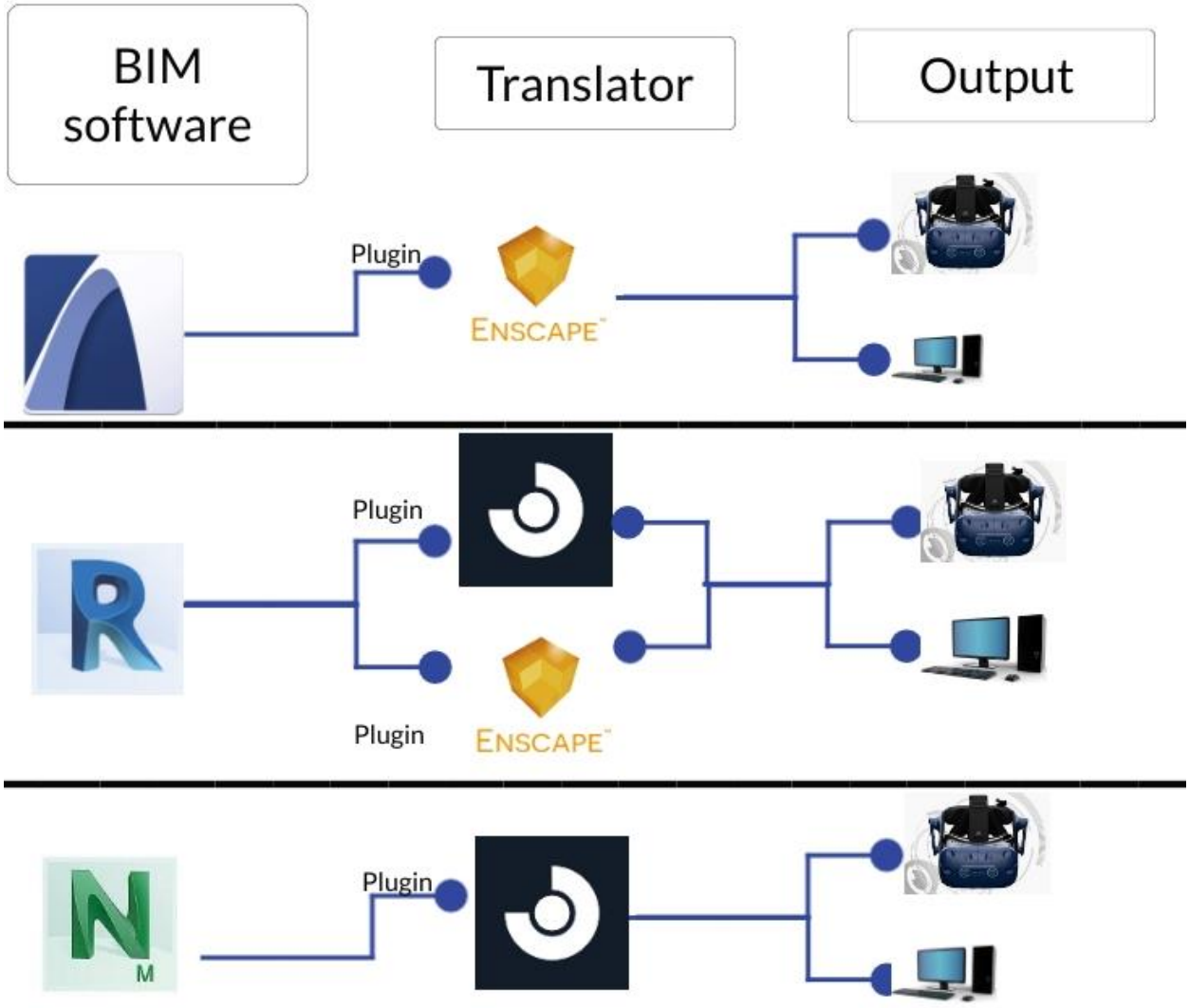


Fig 6.1 General Workflow presented in this study

6.1. BIM SOFTWARE

6.1.1 ARCHICAD

ARCHICAD is a complete design suite with 2D and 3D drafting, visualization and other building information modeling functions for architects, designers and planners. A wide range of software applications are integrated in ARCHICAD to cover most of the design needs of an architectural office, other features include working with parametric data, collaboration and remote access, data interchange, APIs and scripting [81].

ArchiCAD has received several awards as a BIM authoring tool; however, another good feature of this software is the ease of use making it a choice for several architects and designers. Graphisoft makers of ArchiCAD has also developed a solution for visualization, which is BIMx, which is great for mobile device usage.

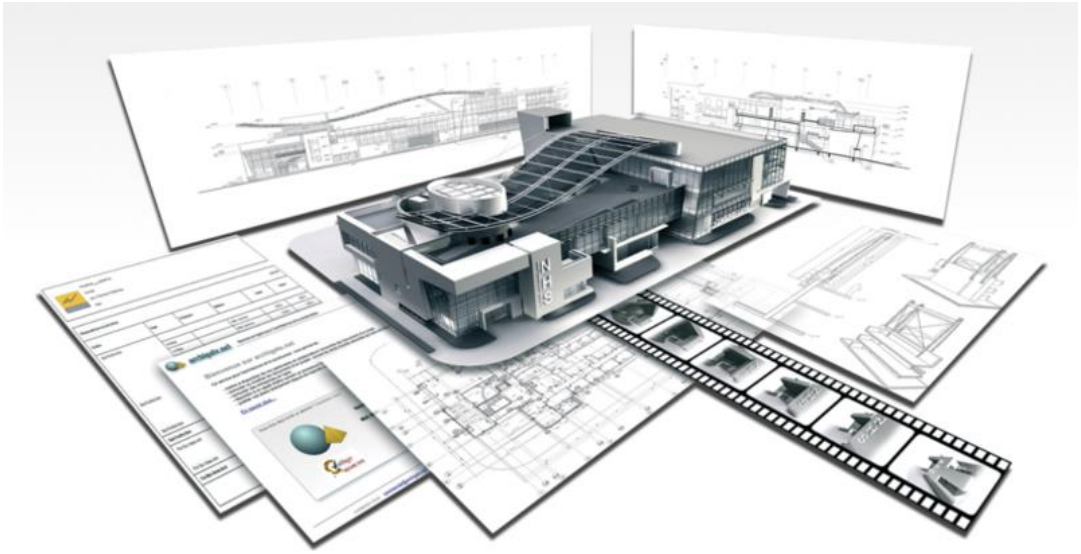


Fig 6.1a Virtual building in ArchiCAD

6.1.2. REVIT

Autodesk Revit is a building information modelling software for architects, landscape architects, structural engineers, mechanical, electrical, and plumbing (MEP) engineers, designers and contractors. The software allows users to design a building and structure and its components in 3D, annotate the model with 2D drafting elements, and access building information from the building model's database. Revit is 4D building information modeling capable with tools to plan and track

various stages in the building's lifecycle, from concept to construction and later maintenance and/or demolition [82].

Revit supports multidiscipline design collaboration, with features including generative design, parametric components, work-sharing, interoperability and IFC, annotations, cloud rendering and

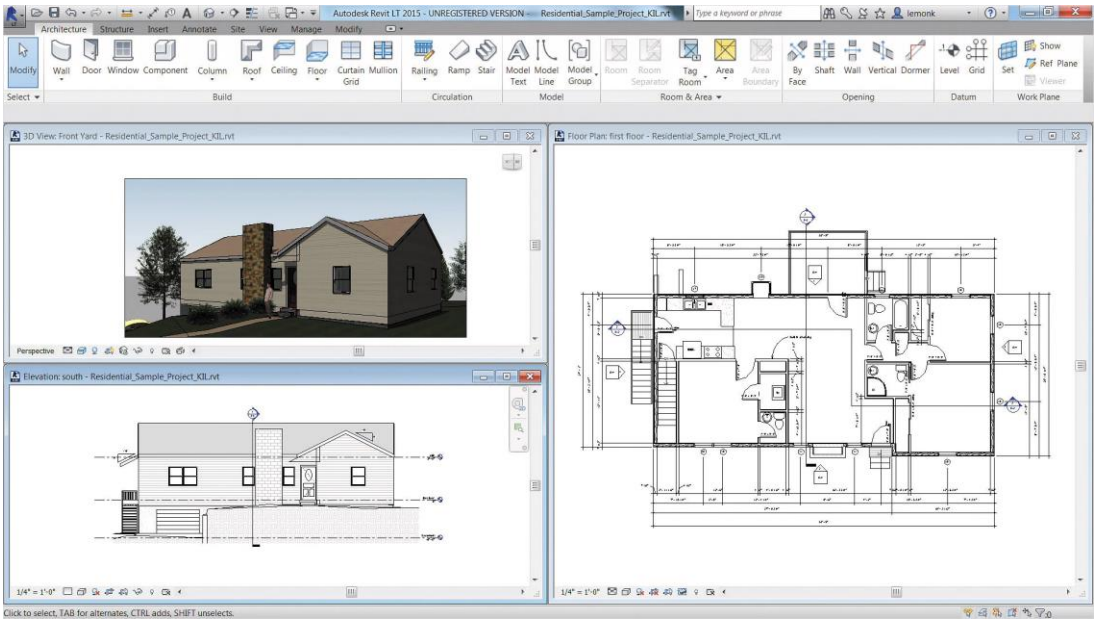


Fig 6.1b Building model in Revit

6.1.3. NAVISWORK MANAGE

Navisworks is a 3D design review package for Microsoft Windows. Used primarily in construction industries to complement 3D design packages (such as Autodesk Revit, AutoCAD, and MicroStation), Navisworks allows users to open and combine 3D models; navigate around them in real-time; and review the model using a set of tools including comments, redlining, viewpoint, and measurements. A selection of plug-ins enhances the package adding interference detection, 4D time simulation, photorealistic rendering and PDF-like publishing [83].

Navisworks Manage is integrated with Autodesk BIM 360 Glue software to help connect the entire project team and streamline BIM project review and coordination workflows. The software combines model coordination with project quantities and schedule to deliver simulation and quantification features, including analysis of time and cost. Entire project models can be published and viewed using Autodesk Navisworks Freedom software.

Navisworks Manage is included as part of the AEC Collection & Product Design & Manufacturing Collection [84].

6.2 ARCHICAD TO ENSCAPE

A sample model was obtained from ArchiCAD, during the study ArchiCAD 24 was installed and used, Enscape was also downloaded for setting up the workflow and inspection. Enscape integrates seamlessly through a plugin into ArchiCAD taking models into VR environments with just two clicks.

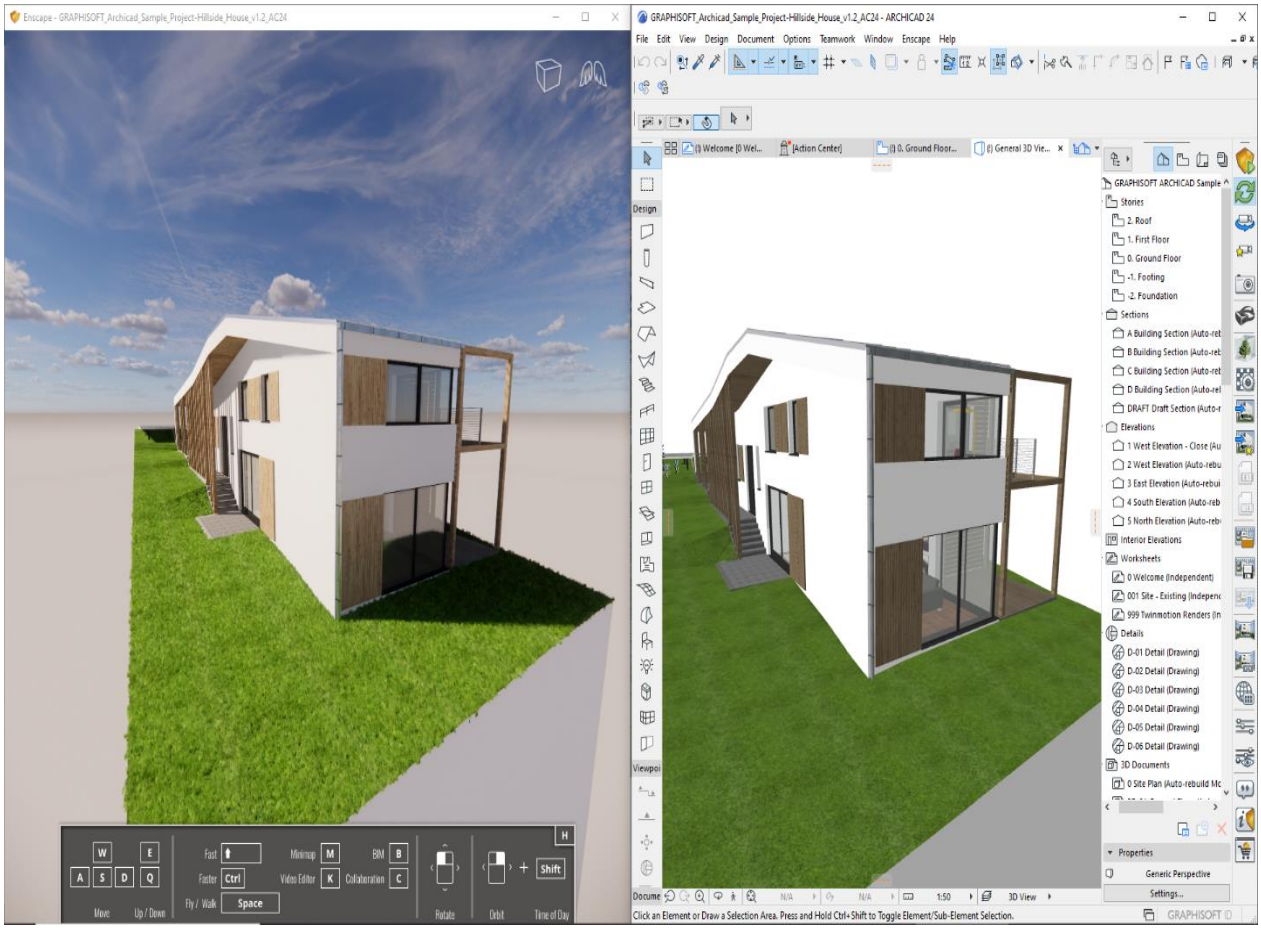


Fig 6.2 Enscape rendered model right, ArchiCAD model left

There are two options that can be considered when using Enscape and ArchiCAD; manipulating models via the desktop interface or Via the HMD devices illustrated fig 6.2. Furthermore, collaboration is also possible when several users can manipulate the design from both the desktop and VR environment. Changes made in ArchiCAD also have effects on the model in real time.

Models can be explored in both fly mode and walk through mode (fig 6.3) and switching between viewpoints via the mini map.

With the Enscape desktop window BIM objects can be accessed, collaboration is also possible but it is exclusive to the desktop interface only. Additionally the Ensacpe toolbar used for manipulating and reviewing the model is in the ArchiCAD program, which can be seen in the far left side of fig 6.2.

Fig 6.3 Navigation menu in VR (right) Inspecting model in Fly mode (left)

Additional feature of the Enscape software is the Light view analysis (fig6.4) for optimized building design. It is possible to calculate illuminance at any given time of the day, this mode informs you as to how much light is hitting a surface and this is displayed as a heatmap.

Lighting control integrated with daylighting is recognised as an important and useful strategy in energy-efficient building designs and operations. Prediction of the internal daylight levels is a key stage in daylighting designs. With the advances in computer technology, the computation of daylight illuminances can be conducted via lighting simulation program

Luminance is simply the intensity of light reflected off objects in a scene and reaching your eye. When mapped with color and texture patterns we can create a rendering that shows the quality of the luminance and therefore how we see the world. Illuminance is a measure of light available at a particular point in the scene. We normally visualize this quantitative value using a color scale that represents the amount of luminous flux, or the ‘lux’ falling on that point (lux is the SI metric equal

to about 10.76 foot-candles (fc)). Rendering automatically formats the color scale with 10 subdivisions between 0 and maximum level in the scene [85].

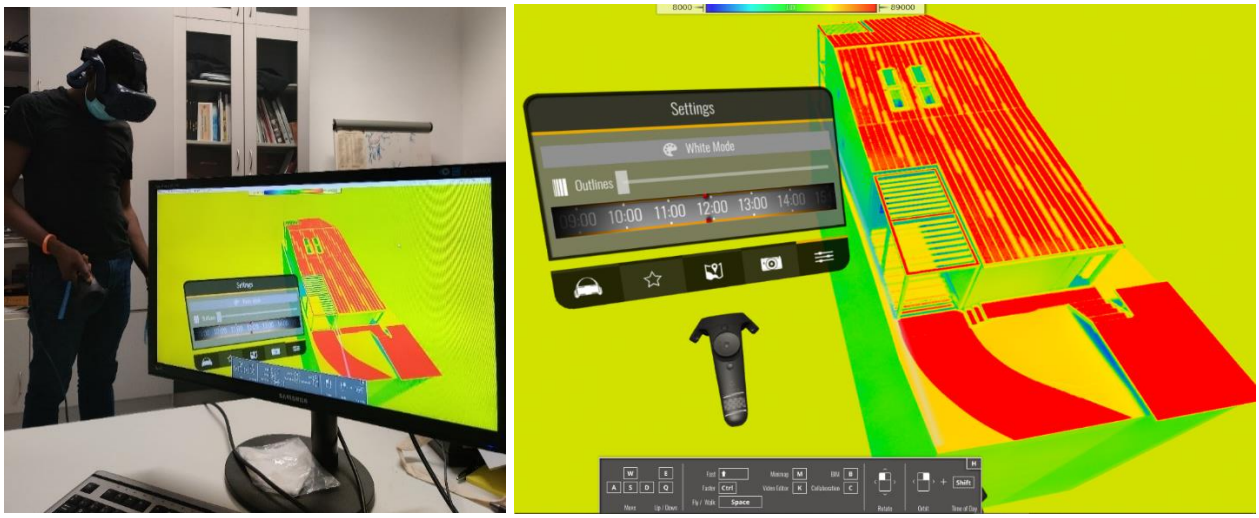


Fig6.4 Enscape Light view mode

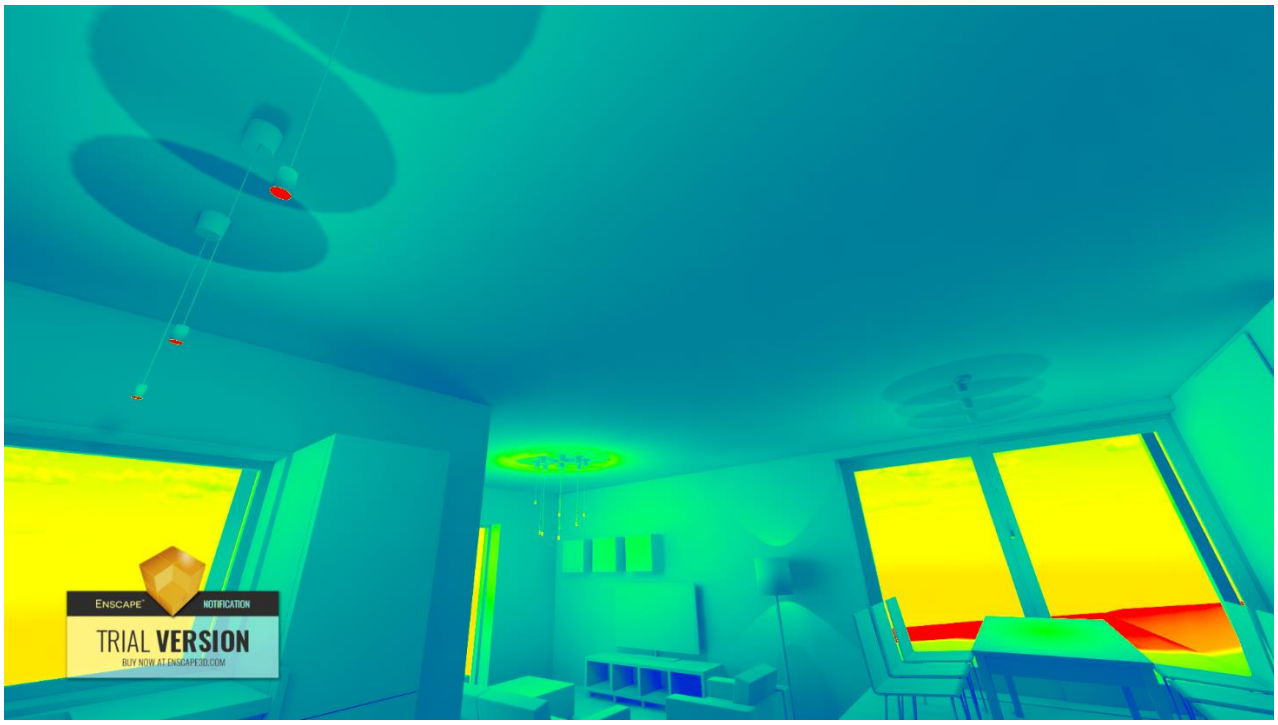


Fig 6.5 Light View mode as seen from a HMD

Furthermore, the software offers variety of assets library (Fig 6.6) which makes rendering more immersive; assets have a real scale without need to rescale to fit in the model. These assets library

include Accessories, animals, construction, furniture, hospital props, lighting , people, street props, vegetation, vehicles.

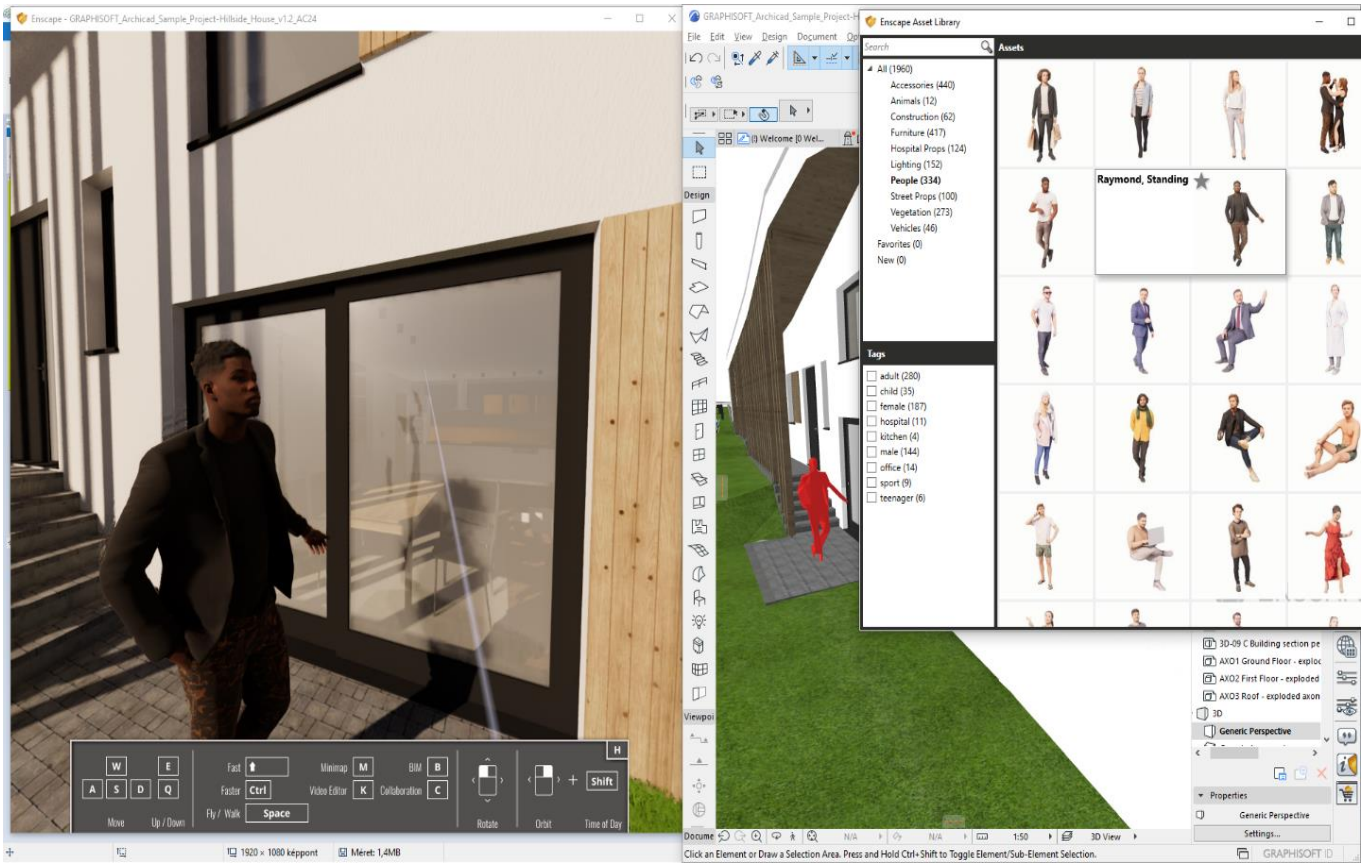


Fig 6.6 inserting a human fig in the model.

Shadow analysis can be conducted as well as observing the amount of light coming out of the building (fig 6.7).

Lighting or illumination is the deliberate use of light to achieve practical or aesthetic effects. Lighting includes the use of both artificial light sources like lamps and light fixtures, as well as natural illumination by capturing daylight. Daylighting (using windows, skylights, or light shelves) is sometimes used as the main source of light during daytime in buildings. This can save energy in place of using artificial lighting, which represents a major component of energy consumption in buildings. Proper lighting can enhance task performance, improve the appearance of an area, or have positive psychological effects on occupants [86].

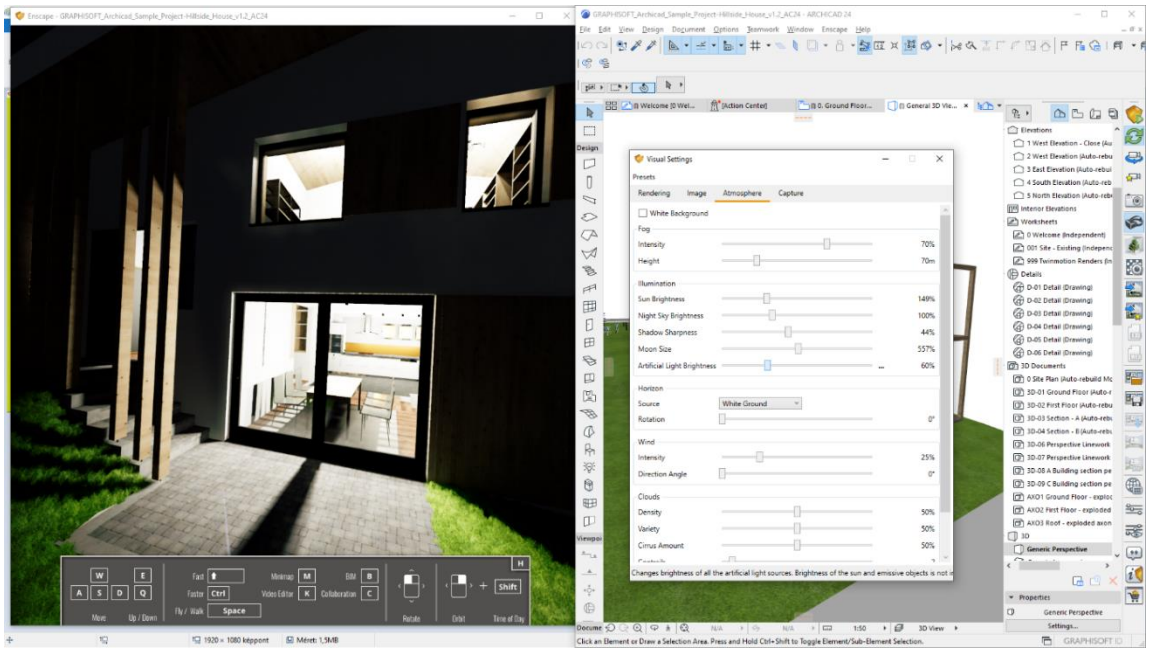


Fig 6.7 Night view scene of the model.

6.3 REVIT TO IRISVR

With a model from Autodesk 21, IrisVR plugin was installed on the computer, which automatically exports Revit models into VR via Prospect. Prospect is an IrisVR solution that offers VR walkthrough experience. Models have to be exported first into Prospect and launched from the prospect interface. It takes some few minutes depending on the processing power of the computer and size of the model. Prospect offers a wide range of tools for both the VR environment and desktop application.

Fig 6.8 Revit model in prospect and settings tab

As seen the settings tab users can make edits to the graphics switching between materials type, controller settings and additionally get a tutorial for a walkthrough to new users.

With Prospect, more features are supported in the immersive environment, and can be visualized through the HMD and controlled not just on the desktop interface, nevertheless, changes made in the model via Revit is not synchronized with the model. Navigation can be either Walk through or fly mode, with the available tools, users can adjust the sun setting as illustrated in fig 6.9 and time of the year this can be useful in shadow analysis. With the Viewport settings (as seen in fig 6.10) users can teleport to different part of the model.

Fig 6.9 Sun setting adjustment

Next to the view port settings is the visibility settings, users can switch on/off layers base on different category, this option enable users to view only desired layers or object in the model. With this feature, users can focus on a particular aspect of the model in other to make better corrective measures or better design decision, the visibility settings can be seen in fig 6.11 below.

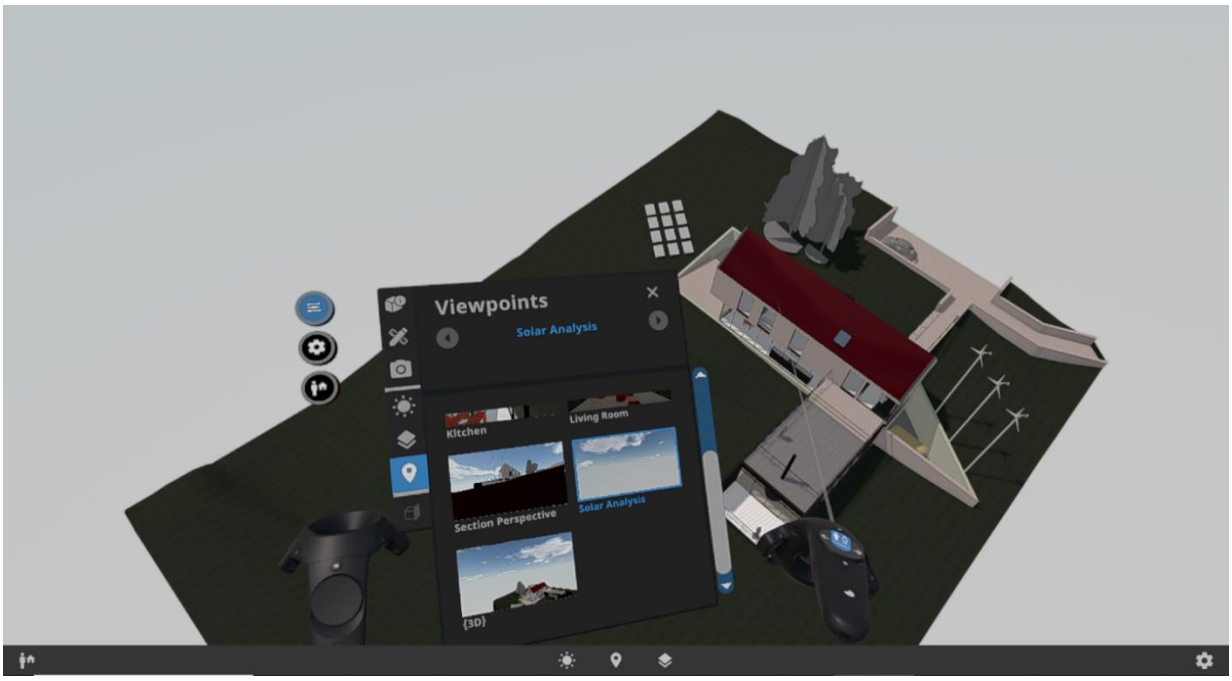


Fig 6.10 Viewport settings showing the view for solar analysis

Fig 6.11. Visibility settings showing different layers of the model

For collaborative and report purposes screenshots can be taken directly from the immersive environment, using the photo tool and a single click with the controllers. Images in fig 6.12a/b displays a user, taking photo from the VR environment.

Fig 6.12a User within the virtual environment taking photos

Fig 6.12b capture photo as seen from the desktop viewer

Importantly to this study to consider in this current workflow is the in VR annotation feature and element inspection tool. Users within the virtual environment can use the annotation to measure distances as well as draw on surfaces either with the brush tool or make call out with the shape tool; this can be useful during design review as illustrated in fig 6.13. Clicking on the brush tool will reveal a few options. First, you will have the option of choosing between a Projected or Handheld brush. Using the brush in handheld mode will allow users to draw in three-dimensional space around them. Switching to Projected mode allows users to draw on surfaces at a distance. You may also adjust the thickness and color of the brush within the

Fig 6.13 Annotation tool in use, taking distance measure and comments

As in fig 6.14 below, the Inspect element tool is a feature not available in Enscape, however, with this feature users can view properties of various elements and objects of the BIM model in real time within the immersive environment.

The Inspect Element tool helps users explore BIM data associated with any given element in their model, and easily document actionable items associated with them. This metadata provides much of the information necessary to quickly get back into your model for revisions.

Fig 6.14 Inspect Element view BIM properties of the solar panel.

6.4 NAVISWORK MANAGE TO VR

Naviswork a BIM base authoring software capable of running a crash detection, models can be imported into Naviswork from Revit or ArchiCAD using file exporter plugin which is available for both software applications. In this study, native Naviswork sample model was used to conduct a clash detection and then view in VR.

The prospect plugin is also installed into Naviswork, which enables export to VR seamless. After running clash detection on the model, the results are exported as viewports (fig 6.15), which then can be visualized in VR; this process takes more time than the export of models from Revit or ArchiCAD.

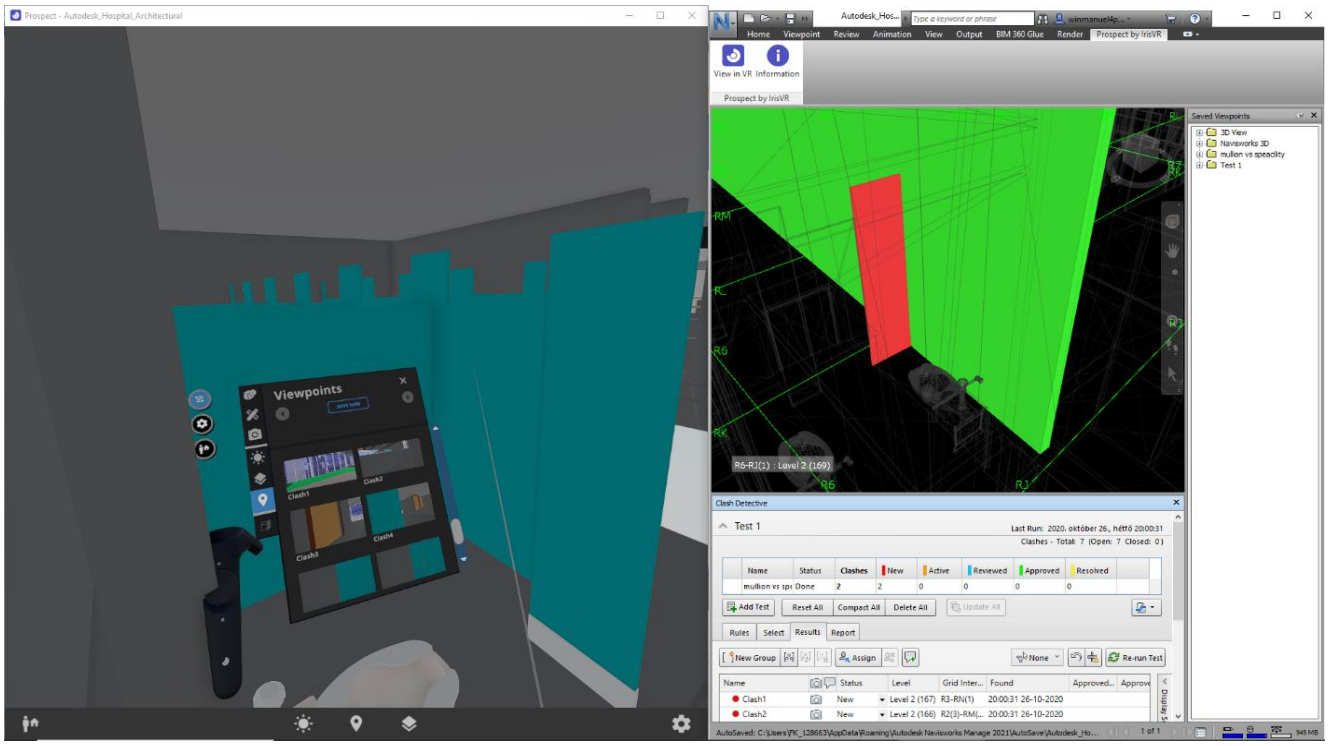


Fig 6.15 Navigating through a clash detection report in VR

In fig 6.16 below and inspection is carried after loading the clash results in VR, with the elemnt inspect tool, it can be seen that the speaciality equipment positioned wrongly which is going through the mullion bar.

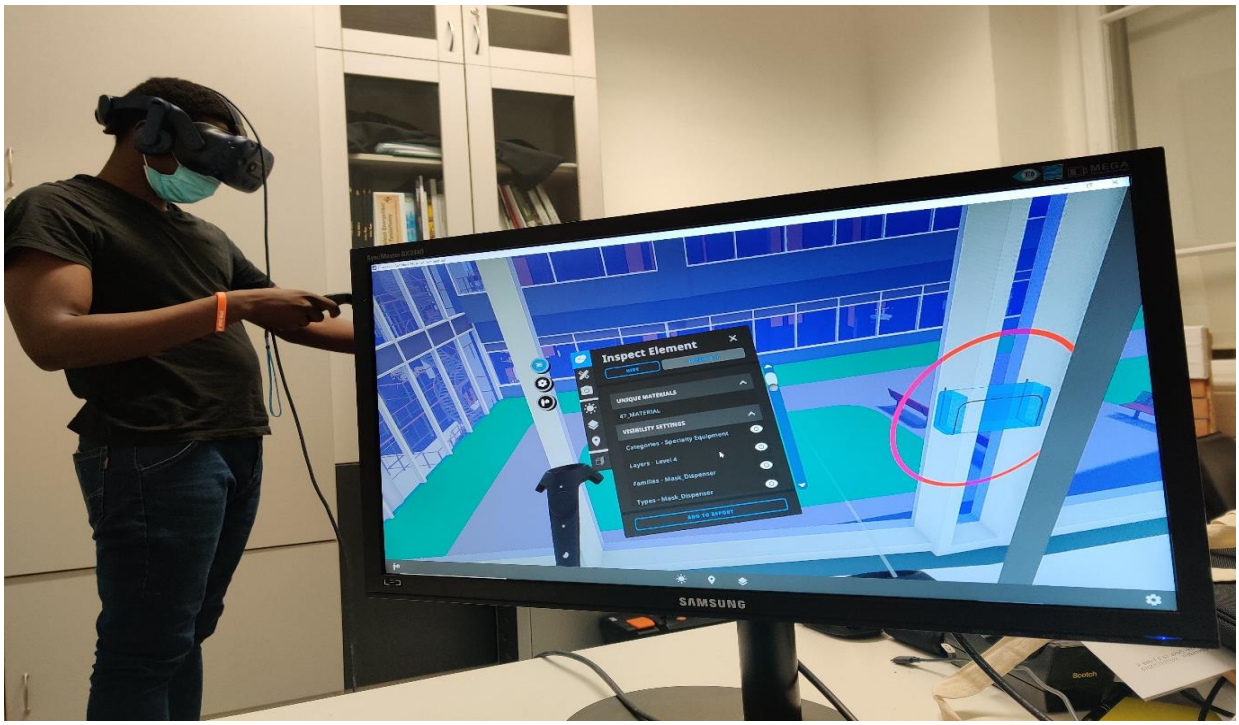


Fig 6.16 inspecting a crash detection result.

In fig 6.17 the visualized image shows that parts of the floor was missing and a marker was placed to mark the error which needs to corrected on the actual model.

Fig 6.17 Crash detection result indicating missing parts of floor

6.5 INTEROPERABILITY AND IFC

Interoperability is very significant in this study as well as all AEC practices, with a lot of BIM authoring tools used by different professionals and within the construction team, it is important to have a viable means of communication between everyone involved. From the workflow described above, Enscape has support for both Revit and ArchiCAD, subsequently, models from these software programs can also be imported to Navisworks and then to IrisVR, IrisVR has support for Revit but not ArchiCAD; however, using the IFC file format models can also be imported into Prospect.

An IFC file is a model file created in the Industry Foundation Classes (IFC) format, which is an open file format used by Building Information Modeling (BIM) programs. It contains a model of a building or facility, including spatial elements, materials, and shapes [87].

7. CONCLUSION

The main contribution of this paper is developing a workflow for the visualization of BIM data and has explored several other possibilities that can be tried out in future research.

Subsequently there has been a significant increase in the acceptance of BIM in the AEC industry. Thus, many studies attempted to integrate BIM and immersive technologies to improve current workflow efficiency, there are still issues of interoperability between VR tools and BIM data. Considerable efforts are required for the design-to-VR process and poor data synchronization. These issues are attracting increasingly attention in recent years.

Nonetheless, this study has shown that communication among software has improved within the past year; there still exist a number of limitations that can improve the capabilities of VR/AR technologies for AEC professionals. In particular, there is no fitting approach for importing all BIM information into a VR platform. Importing BIM models into a 3D engine is a challenge because some of the building information (i.e., material library) might be lost during the export and import process.

There is a great improvement in the HMDs as size and specifications is significantly improving, however the prices presented in this study is excluding tax which is subjected to laws base on different country.

Enscape and IrisVR have been analysed as visualization software programs in this study, thus the following conclusions can be gathered: Enscape offers great rendering quality as it is more immersive, with its wide variety of its assets library and its easy process in illuminance analysis, which is a bit complex in other BIM tools. IrisVR as complementary to Enscape in this study has a more collaborative approach to BIM models, annotations and its material properties feature is more intuitive with prospect and supports a more wider range of file formats and BIM authoring software.

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