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THE EFFECT OF USING VIRTUAL REALITY TECHNOLOGY FOR MEDICAL BUILDINGS CONSTRUCTION

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ABSTRACT

Building information management process creates a great development over the well-known traditional ways of construction. However, despite the noticeable changes offered to architecture, engineering, and construction (AEC) field, there are still some obvious barriers in usage. Lately, Virtual Reality (VR) technology has been presented, It is a connection between the physical and virtual world under the umbrella of cyber-space that effectively tracks the brain to believe of its availability and suspension to the virtual life. This is considered an extension of building information management platform that visualizes an interactive virtual world after creating and manipulating design data. Using VR has a privilege of providing better decision-making and management between projects' stakeholders during the construction process. Therefore, the main aim of the research is to develop a methodology to involve virtual reality technology in construction projects to facilitate different disciplines' coordination and visualization through interaction with the building 3D virtual model.

KEYWORDS: Extended Reality, BIM, Cyber-Space, Medical Buildings Construction, and Coordination.

تأثير استخدام تقنية العالم الافتراضى فى انشاء المبانى الطبية

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الملخص

أحدثت عملية إدارة معلومات البناء تطوراً كبيراً على طرق البناء التقليدية المعروفة. ومع ذلك، على الرغم من التغييرات الملحوظة المقدمة في مجال الهندسة والبناء ، لا تزال هناك بعض العوائق في الاستخدام. في الآونة الأخيرة، تم تقديم تقنية الواقع الافتراضي، إنها اتصال بين العالم المادي الملموس والعالم الافتراضي تحت مظلة الفضاء السيبراني. تقنية العالم الافتراضي هى محاكاة للواقع وتتتبع عقل الانسان بشكل فعال للاعتقاد بوجوده و دمجه في الحياة الافتراضية. ويعتبر ذلك امتداداً لمنصة إدارة معلومات البناء لتصور عالم افتراضي تفاعلي بعد إنشاء بيانات التصميم ومعالجتها. يوفر استخدام الواقع

الافتراضى سهولة اتخاذ القرارات و التنسيق بسكل افضل بين أطراف المشروع المختلفة أثناء عملية البناء. و على هذا النطاق، فإن الهدف الرئيسي للبحث هو تطوير منهجية لادخال تكنولوجيا الواقع الافتراضي في مشاريع البناء من أجل تسهيل التنسيق والتصور بين التخصصات المختلفة من خلال التفاعل مع النموذج افتراضي ثلاثي الأبعاد للبناء.

الكلمات المفتاحية : الواقع الممتد، إدارة معلومات البناء، الفضاء السيبراني، انشاء المبانى الطبية، التنسيق.

1. INTRODUCTION

Nowadays, different types of virtual environments are being used on a huge scale by construction companies to develop work in different project phases. The concept of immersion in a purely digital life or semi-blended reality virtual world is what is known by Metaverse. It is a technological revolution that more and more people are supporting so, is affecting the construction industry by the metaverse just a matter of time? [1] From 2D to 3D Visualization to Artificial Intelligence as in **Fig. 1** is the development that construction leaders need to be updated with to have the ability to be fully involved in the market. Digitalization is one of the main topics in construction nowadays, and this will continue forward. [1]

Fig 1. Development from 2D to 3D visualization ending up with Virtual modeling.

Decision-making is a crucial part of any construction project, the initial decisions made affect all the processes of the building construction, its final shape, and even over a span of years of utilization. Not all construction projects progress as planned but this only happens in very few projects. According to Leinonen & Kähkönen (2000), the primary reason for project defects is sourced at the design and engineering phase.

New techniques and technologies are needed to achieve a more useful and accurate level of work practice. Virtual reality technology is one of these new methods for construction management and planning. By helping visualize construction information, the tool can help project personnel better understand the project as individuals and as a group by providing a consistent shared understanding.

Advanced use of integrated multidisciplinary performance models (BIM models) of design-construction projects to support explicit and public business objectives is called Virtual Design and Construction (VDC). As in **Fig. 2** "At its core, VDC ultimately seeks to bridge the expertise gaps between design, construction, and operations; to realize facilities that are dramatically less wasteful both in assembly and usage; and to create buildings that function to serve their occupants throughout the

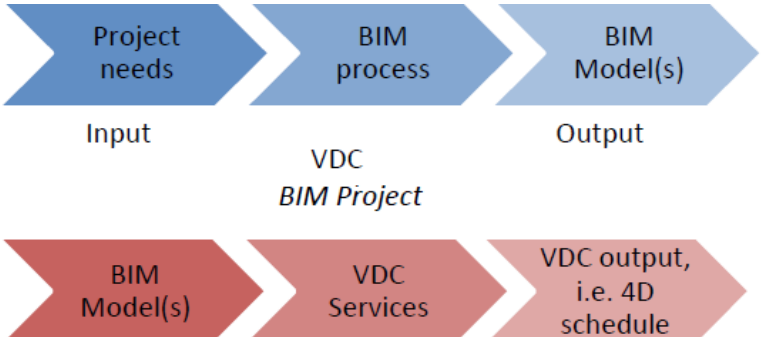


Fig 2. The update of BIM model to a virtual one [2].

complete usage lifecycle." [2]

1.1. Development Timeline of VR

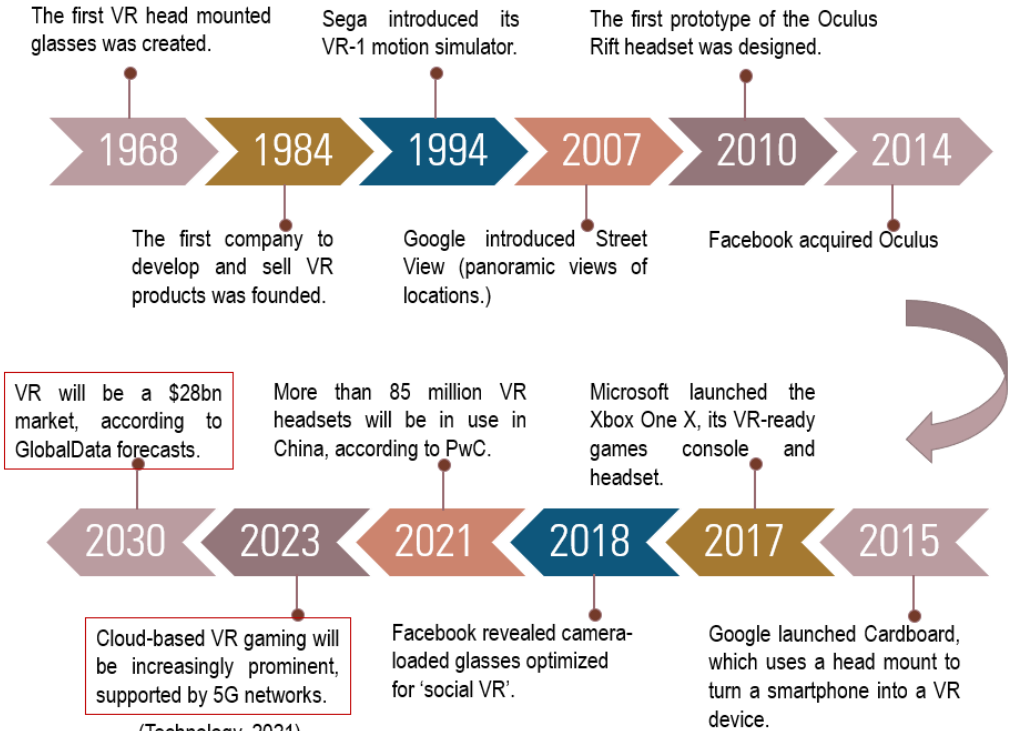


Fig 3. The development of immersive technologies spectrum including Virtual Reality [3,4].

Virtual Reality, Augmented Reality, and Mixed Reality- stretch back to the 1800s. Human immersion in different places attempts have been made since the 19th century as in **Fig. 3** with Charles Wheatstone's stereoscope, but in the 20th century, the concept and technology of VR were created and developed. [3]

1.2. Extended Reality Types Overview

Metaverse is the internet represented in a 3D version, a facility to experience a virtual life as the real physical environment. It is a virtual reality social platform that all sorts of industries are competing to get ahead with. As illustrated in **Fig. 4**, By using Extended reality, the metaverse can shape a mirrored shape of real life that people can interact with economically and socially through avatars. [5]

Fig 4. Buildings overview using Virtuality Continuum.

Extended reality is classified into many categories of reality according to the extent of immersion in the virtual world as in **Table 1**. Augmented Reality, Virtual Reality, Augmented Virtuality, and Mixed Reality are all different shapes of extended Reality that define the virtual world.

Table 1: Represents Extended Reality types [6].

Reality	It is an Integration of the physical world by people's main five senses' perception connected to the brain's nervous system. Face-to-face discussions.
Extended Reality (EX)	It is a way of providing information by using technologies in a more advanced virtual world to ease the enhancement of people's senses.
Augmented Reality (AR)	It is the physical real life that people actually live in with some additions using computers, virtual images, and elements added to it.
Augmented Virtuality (AV)	It is the physical real life in a computer-based technique or a virtual life enhanced by the physical world.
Mixed Reality (MX)	Mixed reality as it is indicated, is a mix between both physical and digitalized worlds. In other words, it is a combination between AR and VR.
Virtual Reality (VR)	Something that is not physically available. Virtual reality is a computer-generated life that tricks the brain physically and mentally to be part of an artificial object's environment.

2. RESEARCH BASICS

Virtual reality has emerged in many fields due to its abilities of simulation, visualization, and interaction. One of the main fields that heavily use VR lately is the AEC field. Virtual reality has been used lately in the design phase on a wide range but not in the construction phase of the project.

Different reasons lead to the need for VR in construction projects especially mega-sized ones as medical buildings, whatever the project phase is. Using VR eases projects' procedures and keeps them faster and easier applied which leads to better final output:

1. Nowadays many projects involve different supervision for each discipline, and as a result communication between project stakeholders becomes difficult.
2. There are always some conflicts in project stakeholders' interests as for the contractor, consultant, and owner.
3. Stakeholders who are not aware of the architectural construction section cannot easily be familiar with or understand the project documents.
4. During projects' construction, many decisions are taken at later times that affect the cost of the project and the process of preceding the construction. In addition, these decisions are not always the best for the project and may be changed later which will affect cost and time.
5. The end product of any project is not always clear to project parties especially those who are not related to the engineering field. Therefore, mockups in the projects are used which affects the project cost, time, and human power negatively. (By Researcher)

3. METHODOLOGY

This research is mainly based on literature review of previous research and applying it to a case study that will test the ability of VR visualization of a BIM-based model for coordination in construction projects. Analytical methodology will be followed as a hierarchy of some steps to highlight the strong points of using Mixed Reality technology over construction traditional ways.

First, the research begins with theoretical content that consists of scientific information about Mixed Reality (MX) and how it is considered a developed step of BIM that reveals many easy ways in the construction field. Secondly, previous experiences that used MX in different ways will be analyzed providing techniques, problems faced, and strategies followed during the construction process to extract guidelines for applying the technology in the field. Finally, this framework from examples analysis will be followed in applying the case study concluding a variety of points related to mixing MX with BIM in construction projects. Consequently, a questionnaire will be held as a rating survey for case study application outputs. As a result, recommendations and future attempts will be given. **Fig. 5**

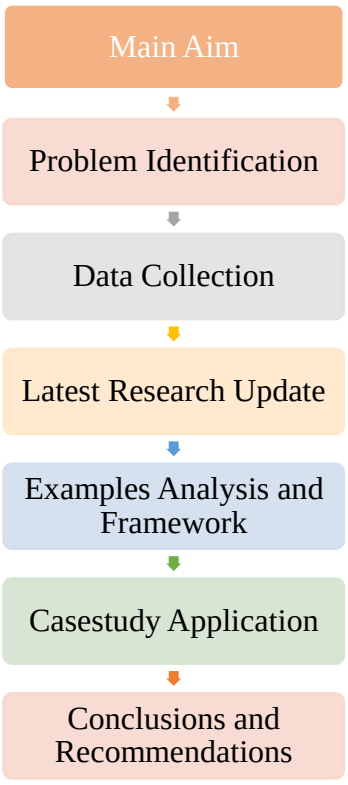


Fig 5. Steps of applying the methodology of the research.

4. VR APPLICATION STRATEGY

AR and VR are the most popular types of mixed reality and are considered to be an immersive technology to offer interactive experiences for users. They are developed and used in different fields but to achieve an accurate application of the technology, some steps should be followed. [7]

4.1. Choose Needed Platform

To develop an AR or VR experience, it is important to target a specific platform to work on and this depends on several aspects that should be considered. Regarding the reasons for the unreal experiences, whether the experiment depends on only AR, VR, or mixed reality, the budget available, and the audiences, different types of platforms suit achieving the experience goals. Mobile devices, standalone headsets, or PC-based systems are different options for unreal experiences but each of them has its pros and cons in terms of accessibility, performance, and compatibility. This is the main step that should identified first to have the ability to follow up. [7]

4.2. Selecting Tools

After specifying the platform, this is developed by choosing the tools that help create the needed application. Various software and hardware tools are available to provide the functionalities of the targeted project or experience. Choosing tools depends mainly on the ones that suit the targeted platform, level of skills of the performers, and also the requirements of the experiment. [7]

4.3. Design and Develop the Model

Defining the main elements of a VR application is what is known as the design phase. It is crucial to specify first how the user interface will look like, preparing the model with all its contents, and how the user will experience the virtual environment in terms of seeing the scene,

feeling it, and behaving in it. Besides, it is important to know how the virtual application itself will meet the user expectations and provide all the security and comfort aspects for the users during the application.

Implementation of the virtual experience is what development means, with the help of the tools chosen from the previous step. The following step is to follow all the guidelines provided with the selected tools and choose the appropriate language needed for the project. [7]

4.4. Test Modeling

Testing phase is to evaluate and improve the VR process. This is achieved by exploring and fixing errors that affect the function of users' experiences negatively. The application should be tested to check the performance quality and then gather feedback using surveys or interviews. [7]

5. PROJECT DESCRIPTION

Arab Academy for Science, Technology and Maritime Transport (AASTMT) aims to build an educational hospital for all medical students in different fields and at the same time provides additional services for the citizens around the place. Different departments are included in (AASTMT) Alamain Hospital, but the study part is focused on the emergency department specifically in the operation theatre zone.

Project construction is divided into many phases as in **Fig. 6**. The first phase was related to the Outpatient department which is already finished with the traditional construction ways. The second phase is the emergency department, only the structural skeleton was constructed. The target of the research is to be applied to a zone that is not constructed yet for the mechanical systems or the final user output to show the effects of using VR on the construction process over the traditional methods.

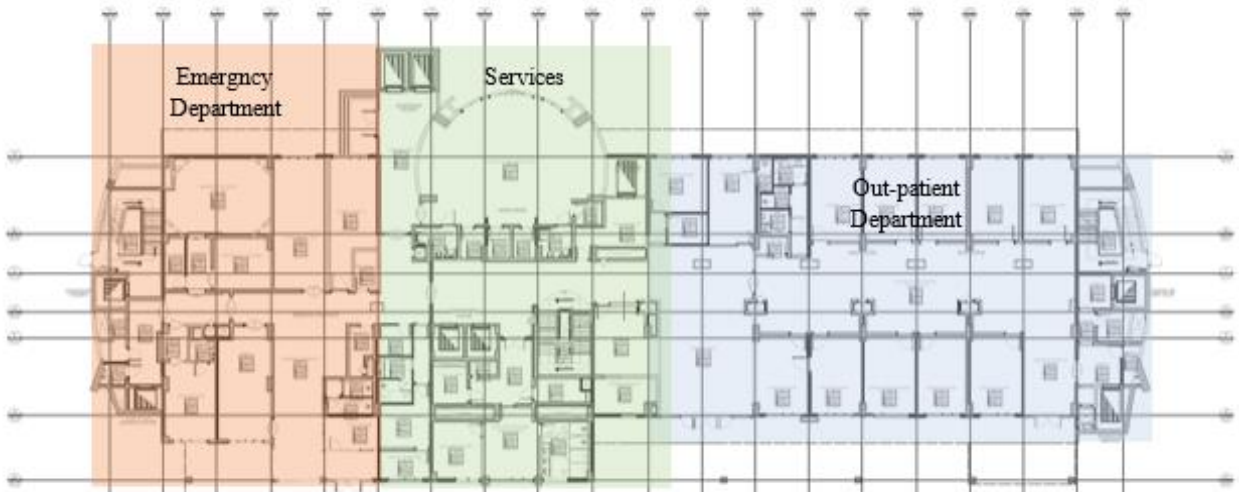


Fig 6. Highlighting the hospital's ground floor departments.

As shown in **Fig. 7**, the emergency operation zone consists of four rooms, the operation theater itself, and three more rooms serving it. Firstly, the scrub-up space used for staff members' sanitization, preparation, and recovery room that is specified for preparing patients for emergency operations and then settling them in it for recovery time. The last space is an equipment store room for the needed serving tools.

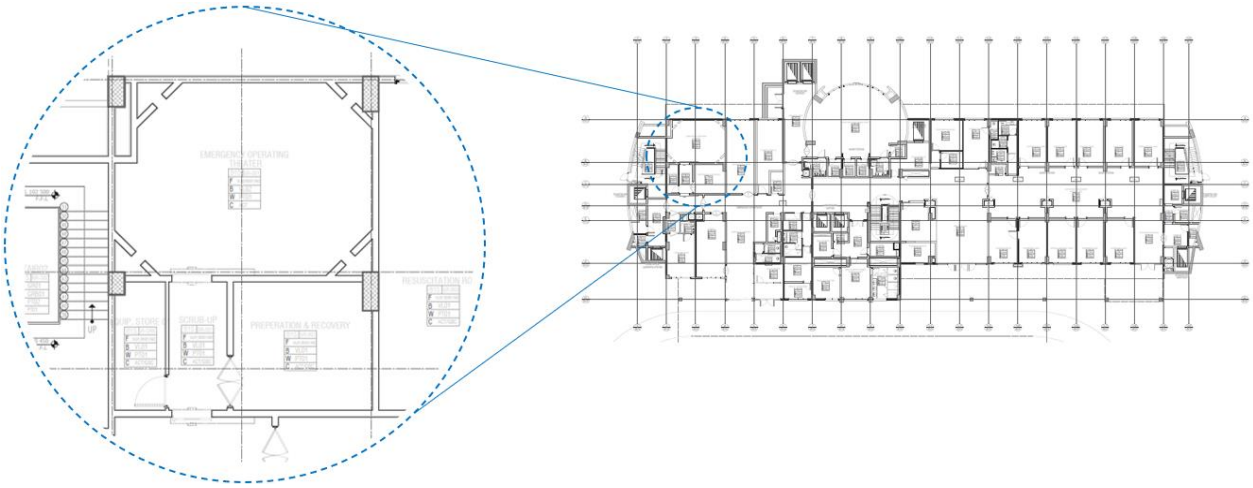


Fig 7. Zooming into the emergency operation room zone showing its components.

The scope part of the research will be supplied with all different types of electro-mechanical systems to serve their crucial functions at a high quality all the time. This is divided into electrical, mechanical, fire fighting, and medical gasses systems as in **Fig. 8**. Electrical systems consist of power cable trays and light current cable trunks. Mechanical systems are classified into: 1. HVAC chilling water and exhaust system, 2. water supply system then 3. water drainage system. Fire fighting and fire alarms are also included in the emergency zone in addition to medical gasses piping system which is also provided as this is only specialized for medical projects.

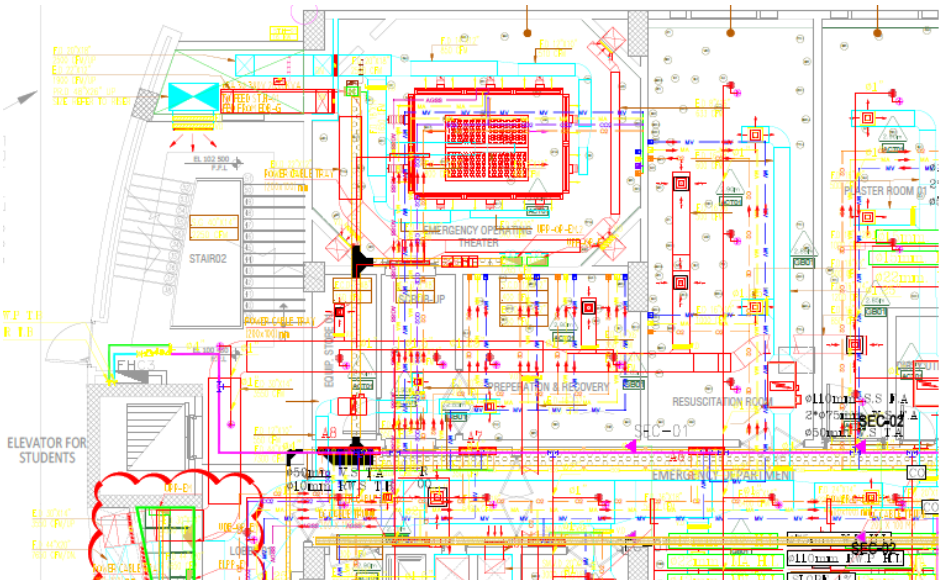


Fig 8. Composite ceiling plan showing all systems used in the emergency zone.

6. CASE STUDY CHALLENGES

Aligning with the project's aspects related to the emergency department construction and especially the emergency operation theatre zone, some provocations are taken into consideration during the application of the case study.

a. Project's second phase time schedule is very tight, and the VR experiment should be made before site construction starts, so it was very challenging to create a 3d model for each discipline to be able to follow up before the beginning of actual site work.

b. Virtual reality technology is a new one for all the project crew, it takes time to learn how to deal with the associated software and the headset itself.

c. The operating theatre itself will be fully imported by an external specialized supplier, so it was difficult to apply all its requirements as a modeling phase within this time limit.

d. One more important challenge and the basis of the research is to detect the clashes between disciplines where design drawings have many conflicts between the different systems. (By Researcher)

7. MAIN APPLICATION STEPS

VR was known as the visually coupled system as its roots return to the aerospace of the defense industry then the technology spread around in different fields as medical applications, visualizations, and others. Considering the construction field, the most famous use attempts of VR go to the design and construction processes. The first use usually is a walkthrough system and this what was happened to the construction sector, then more applications have been developed as Site layout planning, monitoring, and evaluating the construction processes and scenarios [8].

The goal of the research is to reveal the ability of VR tools in coordination and decision-making and to what extent VR is validated to facilitate visualization processes and data exchange between different project parties even those not related to the AEC industry. Following the VR strategy, steps of applying the case study were built as shown below in **Fig. 9** :

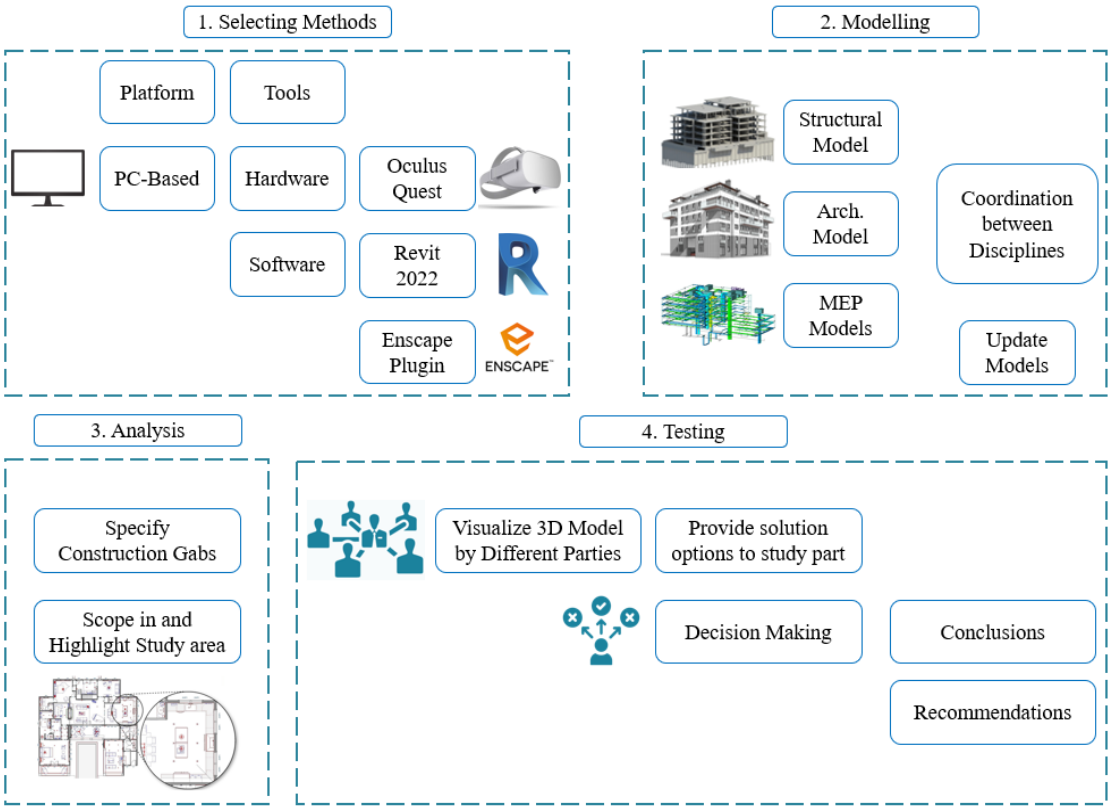


Fig 9. VR Application Strategy on the selected case study.

7.1. Selecting Methods

Selecting methods is the first step of the process so according to project output needs and the presence of different platforms, a PC-based platform was chosen. Consequently, this gives a

wide range of hardware and software selection. For the hardware, the main limitation was in the local market which provides mainly the Oculus Quest headset which was sufficient enough.

Revit provides many options that make it the preferable option to use, it has an easy-to-use interface with simple abbreviations for each operation that helps in minimizing work time. Additionally, the organization of the operation menus is according to the workflow of the actual site work application. It also helps in generating high-quality associative drawing documents.

7.2. Modeling

To export a well-developed building using the BIM process, it is important to pass through main stages which are:

a. PhaseI: Building Information Model
b. Phase II: Building Assembly Model
c. Phase III: Building Operation Optimization

Following BIM standards of 3d modeling and according to the scale and type of the hospital project, it was preferred to distribute all disciplines in the modeling process due to the level of complications and details needed to reach LOD 400. Five separate Revit models are divided into separate Revit modeling files and then are linked together to prepare for the following step as follows:

a. Structural Model
b. Architectural Model
c. Water Supply and Drainage Systems Model
d. HVAC and Exhaust Systems
e. Firefighting and Fire Alarm Models
f. Electric and Light Current Systems Model
g. Medical Gasses System Model

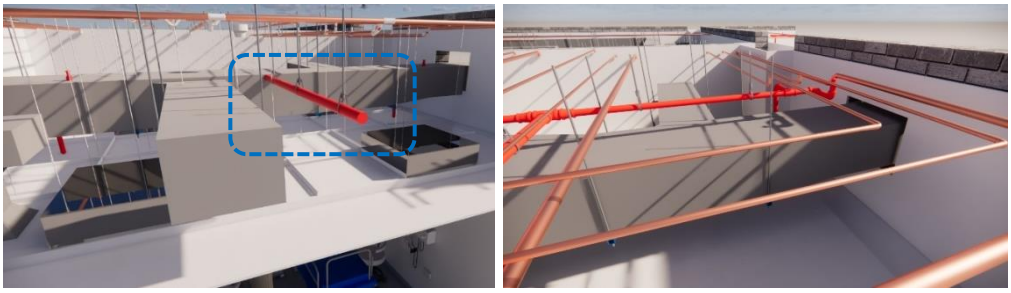
This stage mainly depends on merging different disciplines' models together to study the clashes that appear as a result of the design phase. This is the most important step and is considered as an objective of applying the BIM process. Converting from design to implementation phase as a virtual simulation provides all parties the facilities to communicate easily and manage the work accurately.

7.3. Analysis and Testing

According to the differences between construction projects, it is usually needed to involve project managers to apply their experience for problem solutions. This type of supervision may avoid the problems entirely and may lead to more defects. The ability to participate in problem-solving in the planning phase shows different advantages to construction sites. According to the practical virtual reality experience made in the construction site by different bodies, some clashes in the design between all the disciplines are discussed for the project stakeholders as in **Table 2, Table 3, and Table 4** to be able to find the ideal decisions for the project avoiding any conflict of interest between all the parties.

Table 2: Explaining Details of the First Issue.

Issue No. 01	
Location	Preparation and Recovery Room
Clash	Conflict between HVAC exhaust and firefighting systems. The exhaust air duct height is clashing with the pipes supplying fire-fighting sprinklers.
Solution	Center of firefighting pipes levels changed from 3450 mm to 3630 mm above the finish floor level and changes were made to their routings to avoid the HVAC exhaust duct, to be able to provide space for each system for fixations and maintenance later, with respecting the availability of other systems which are considered mainly in the electrical conduits and medical gasses pipes. **Fig. 10**



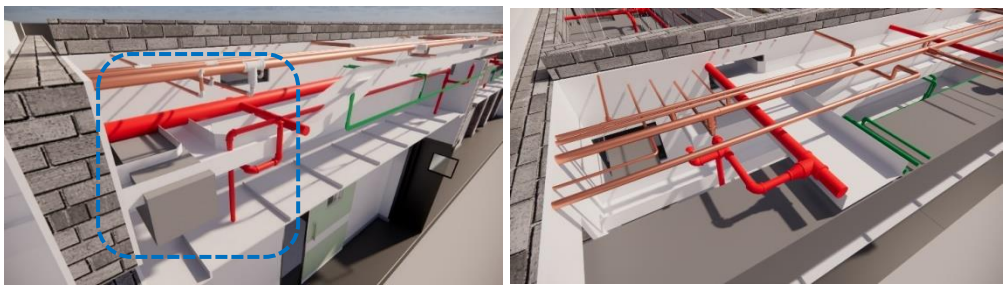
a. Clashes between HVAC ducts and firefighting pipes

b. The updated routings and heights of the firefighting pipes.

Fig 10. Figures clarifying the first clash.

Table 3: Explaining Details of the Second Issue.

Issue No. 02	
Location	Emergency department main corridor.
Clash	Conflict between HVAC air supply, firefighting systems, and electric cable tray. HVAC air supply duct clashes with the cable tray. Firefighting pipes clash with both the cable tray and HVAC air supply duct.
Solution	Levels of all systems are redesigned to be coordinated with other systems. Besides, the cable tray is divided into two routes, one for the power system and one for the light current system. The main firefighting pipe location is changed to be at the other side of the corridor to avoid conflict with the cable tray that its location is changed as well to keep the position of the fire sprinkler the same in accordance with the ceiling tiling. **Fig. 11**



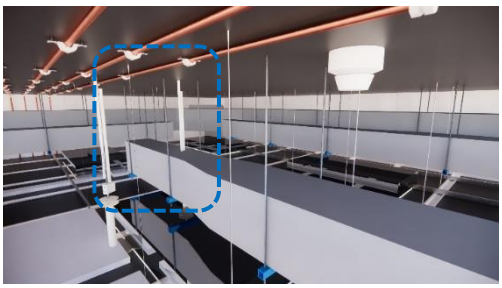
a. Clashes between HVAC ducts, cable trays, and fire-fighting pipes.

b. The updated routings and heights of the systems

Fig 11. Figures clarifying the second clash.

Table 4: Explaining Details of the Third Issue.

Issue No. 03	
Location	Main Operation Room
Clash	There is a conflict between medical devices' ceiling fixations with ceiling lighting and HVAC air supply duct.
Solution	According to the air diffusers' locations in the ceiling design that should not be changed, the supply air duct will be split into two separate ducts, each one supplies two diffusers to allow medical devices fixation in the center of the ceiling. Conflict between devices' fixations and lighting units will be on hold until the final design as a whole room is received. **Fig. 12**



a. Medical instrument fixations conflict with ceiling lighting fixtures and with HVAC duct.

b. Splitting HVAC duct into two separate ones.

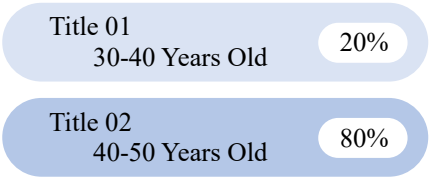
Fig 12. Figures clarifying the third clash.

8. QUESTIONNAIRE

The case study was held twice, one was made by the owner representative and one by the site construction manager in the presence of all the project parties to ease the discussion process and achieve more accurate decisions. To be able to integrate more of the final users into the project, VR was used to show surgeons how the final project was going to look like because most of them don't have the technicality to be able to read construction plans. Allowing the surgeons to provide their experiences and give feedback on the design is essential for a successful output and a better overall understanding of how the room is going to function. Five representatives of all parties are asked for their opinions on a set of questions as a survey reflecting the quality of the experience.

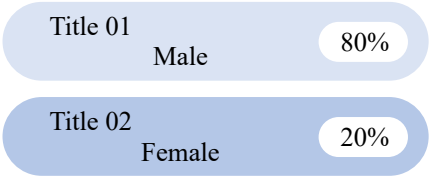
1. Specify your age range.

a. 20-30 years old b. 30-40 years old c. 40-50 years old d. 40-50 years old



2. Gender.

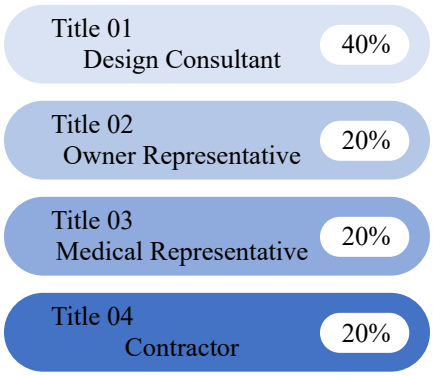
a. Male b. Female



3. Specify your relationship with Arab Academy Alamein Hospital.

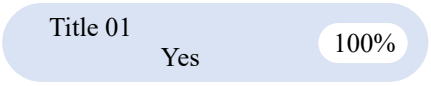
a. Design Consultant b. Construction Consultant c. Owner Representative

d. Medical Department Representative e. Contractor f. Others



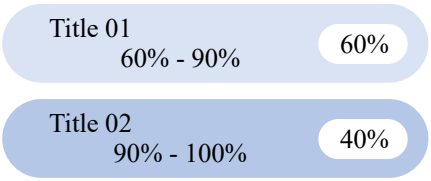
4. Did you do a Virtual reality experiment or have been available during the experiment to coordinate between all building disciplines?

a. Yes b. No



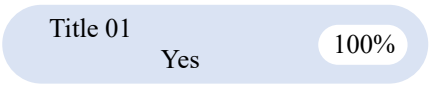
5. After doing a Virtual reality experiment, what percentage describes its success in comparison with the traditional ways used in construction projects?

a. 0% -30% b. 30% - 60% c. 60% - 90% d. 90% - 100%



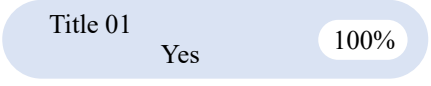
6. From your point of view, is there an advantage of using Virtual reality over the traditional ways for coordination between different parties in construction projects?

a. Yes b. No



7. Does using virtual reality help in coordination between building systems and provide faster and more precise decisions?

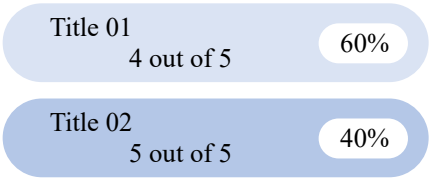
a. Yes b. No



8. How much do you rate the usage of virtual reality as a part of the construction process in the hospital emergency department?

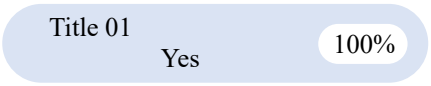
   a. 0 out of 5 b. 1 out of 5 c. 2 out of 5 d. 3 out of 5

   e. 4 out of 5 f. 5 out of 5



9. Do you recommend virtual reality technology for upcoming construction projects?

   a. Yes b. No



Following the previous inquiries, each party is requested to discuss the benefits of adopting VR. A SWOT analysis was created based on the responses:

Strength

1. Efficiency increase (reduce time and cost), and productivity (reduce errors, facilitates work)
2. Enable collaboration remotely and Facilitate monitoring of the projects.
3. Ease understanding of huge amounts of data and more accurate decision-making.

Weakness

1. Significant initial cost.
2. Time is needed for the administrative procedures of adopting VR.
3. Few project teams can practice this technology efficiently.

Opportunities

1. Possibility to be used in different project types.
2. Learning of professional staff and Creative and improved end-user experience.
3. Large investments may be made by industries and organizations in VR projects.

Threats

1. Project managers may refuse the application of the new technology.
2. Cybersickness.

9. SUMMARY AND CONCLUSION

Including technology in all fields has a significant attention for a long time. VR as an immersive technology is one of the main new trends that have huge effects on all industries. Using VR nowadays is a noticeable issue in the AEC field and is used in different project stages due to its benefits. However it is widely spread, it is developing at a slower rate in the construction industry.

In conclusion, the scope of the research is to create an immersive interactive collaborative model to reveal the ability to include new technology in the construction phase in mega-sized projects as hospital buildings. The 3d virtual model provides a double twin for the real building

before it is being available, thus all can visualize the model with all its elements, aiming for faster decision-making and minimizing the time taken in the traditional ways for conflicts' solutions. This finally creates a new projection for the construction industry with the intention of improving quality and decreasing cost, and labor power needed. As much as changing the ways of processing the projects, using virtual reality changes the way stakeholders think about the project as well.

10. CONFLICT OF INTEREST

The authors have no financial interest to declare in relation to the content of this article.

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