

## Research Article

# A Pilot Implementation and Usability Evaluation of a Database-Supported VR/BIM-Based Communication and Simulation System for Healthcare Design

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| Article Info                         | Abstract                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
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| Article History                      | This study presents the development and pilot implementation of a Database-Supported VR/BIM-Based Communication and Simulation (DVBCS) system designed to enhance design comprehension, stakeholder engagement, and decision-making in the early planning stages of a disaster hospital in Jordan. The system integrates database-structured BIM models, a real-time visualisation environment built with Unreal Engine, and a semi-immersive VR projection setup to provide interactive walkthroughs and workflow simulations. A pilot usability evaluation was conducted with 10 participants, including five healthcare professionals and 5 members of the architectural and engineering team. Data were collected through structured questionnaires, observations, and guided discussions during the VR sessions. Results indicate that the DVBCS system improved users' understanding of spatial configurations, facilitated clearer communication, and supported more efficient identification of design issues compared with traditional design communication methods. Participants reported high satisfaction with the system's visual clarity, interactivity, and usefulness for collaborative review. However, the study also identified limitations related to hardware costs, required training, and the small sample size. As a pilot study, these findings are preliminary but demonstrate the potential of VR/BIM-supported approaches to strengthen communication and reduce design errors in healthcare planning. Future research should include larger samples and controlled comparisons to validate the system's effectiveness further. |
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| Virtual Reality (VR)                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Disaster Hospital Communication      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |



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## 1. Introduction

From a facilities management standpoint, healthcare construction projects have become increasingly complex and demanding [1-3]. Healthcare facilities play an essential role during emergencies, such as natural disasters, where they must remain operational and continue serving a high volume of patients, further heightening the complexity of their planning and design [4, 5]. In this context, well-thought-out

healthcare design is important not only for managing capacity but also for promoting health and ensuring effective service delivery.

In today's healthcare design environment, projects are becoming increasingly complex due to rapid advances in medical technology, evolving patient care demands, and the need for resilient infrastructure capable of responding to emergencies and large-scale health crises. These trends place significant pressure on design teams to produce environments that are both operationally efficient and clinically adaptable. However, conventional 2D drawings are often unable to capture the spatial and functional intricacies required in modern hospitals, leading to misalignment between design intentions and clinical workflows. As a result, more immersive and data-integrated tools are becoming critical for bridging communication gaps and ensuring that design decisions accurately reflect the needs of healthcare staff.

Design teams have traditionally communicated their plans to medical staff using two-dimensional (2D) Computer-aided Design (CAD) drawings, accompanied by related data [6, 7]. These drawings act as a shared visual language to align the various professionals involved. However, despite their value, they are often difficult for medical staff to interpret, largely due to a lack of engineering background [8, 9]. This communication gap can hinder collaborative decision-making during planning. It is essential to involve staff early on, not only to identify issues and collect feedback, but also to foster a sense of involvement and ownership among those who will eventually use the space. Their input can lead to more practical, user-centred designs, ultimately contributing to a more efficient healthcare delivery environment.

Recent studies in digital construction and information management further highlight the limitations of relying on traditional 2D drawings, noting that such representations often lead to misinterpretation, reduced coordination efficiency, and increased risk of design errors in complex building projects, particularly in healthcare environments [10, 11].

In recent years, Building Information Modelling (BIM) has emerged as a widely adopted solution in medical facility construction [12-15]. BIM is built on object-oriented 3D modelling and integrates data within a centralised database, supporting both design and construction phases. It enables more precise planning and helps teams visualise complex systems before they're built. Researchers have shown that BIM supports hospital digitalisation and serves as a vital communication tool throughout development [16-18]. Medical staff can also benefit, as BIM allows them to explore and comment on design spaces more intuitively than traditional 2D drawings [19, 20].

While many studies explore BIM's applications in healthcare, few focus specifically on its integration with virtual reality (VR) in a semi-immersive environment to support communication and simulation during the design process [21, 22]. To address this gap, the current study proposes a system called the Database-supported Virtual Reality/BIM-based Communication and Simulation (DVBCS). The DVBCS system is developed to bridge communication barriers between designers, stakeholders, and clinical staff. By combining the immersive experience of VR with the detailed modelling of BIM, users can explore and interact with healthcare environments during the design phase. A case study involving a hospital design room is conducted to validate the system's effectiveness in practical settings. In addition to offering realistic visualisations, the DVBCS system provides interactive functions that support user engagement, feedback collection, and design validation. As past research suggests, VR can enhance cognitive engagement and facilitate better decision-making early in the design phase [23-26]. What sets this study apart is its emphasis on developing an integrated, database-supported VR-BIM system tailored specifically for semi-immersive environments in healthcare design.

This study addresses the persistent communication gap between design teams and healthcare professionals during the early stages of hospital design. To guide the investigation, the following research questions were formulated:

- 1) How can a database-supported VR/BIM system enhance the clarity and accuracy of design communication in healthcare projects?
- 2) To what extent can such a system improve stakeholder understanding, reduce design errors, and support more informed decision-making during the design phase?

Accordingly, the primary objective of this study is to develop and evaluate a DVBCS system that improves communication, simulation accuracy, and collaborative review during healthcare facility design.

## **2. Literature Review**

Although VR is increasingly being used to support the design of healthcare environments, the overall effectiveness of VR mockups remains underexplored. While physical mockups have long been part of the design evaluation process, questions persist about how VR compares in terms of value, reliability, and user experience. There is growing interest in further research on this area, particularly to understand how VR mockups can improve design outcomes [27]. In response, some organisations, such as the Health Quality

Council of Alberta, have introduced guidelines to help healthcare design teams weigh the advantages of VR against more traditional methods [28]. This review aims to deepen that discussion by examining the role of VR mockups in current design practice, outlining their potential benefits and drawbacks, and reflecting on how recent advances in immersive technology may shape their future use in healthcare planning.

## 2.1. Technological Elements of the DVBCS System

The DVBCS system integrates three core technological components:

- Database-supported BIM models convert file-based BIM data into structured BIM elements to enable flexible programming and simulation.
- A game-engine platform (Unreal Engine) that provides real-time rendering, interactive features, and smooth navigation through complex healthcare spaces.
- A semi-immersive VR environment, supported by high-resolution projection and gamepad control, designed to offer an accessible interactive experience without the limitations of traditional head-mounted displays.

Together, these elements create a unified platform that supports dynamic visualisation, workflow simulation, and structured feedback collection throughout the design process.

## 2.2. Virtual Reality (VR)

VR mockups have become increasingly prevalent in architectural and healthcare design, yet their classification and application still vary widely. Typically, VR mockups are distinguished into three types: passive, exploratory, and interactive. In passive VR, the environment moves around a stationary user, offering limited engagement. Exploratory VR, by contrast, allows the user to navigate a fixed space freely. The most advanced category of interactive VR enables full user movement and engagement with the virtual environment, often facilitated by head-mounted displays (HMDs) equipped with head- and hand-tracking technologies [29]. This level of immersion allows the display to adjust in real time based on the user's perspective and interaction.

The adoption of VR across various sectors has accelerated over the past two decades, with the market expected to reach \$80 billion by 2025 [30]. In healthcare, VR has already shown efficacy in areas like stroke rehabilitation [31], laparoscopic training, and bronchoscopy procedures [32]. Its use also continues to grow across architectural design, courtrooms, and hospitals, particularly in patient rooms, operating

theatres, and intensive care units [33]. While many of these implementations offer walkthrough capabilities, few provide interactivity. One study by Dunston et al. was notable for enabling users to manipulate furniture, adjust lighting, and test physical clearances all within a virtual environment [34, 35]. Advocates suggest that VR mockups facilitate clearer communication, improve decision-making, and allow simultaneous comparison of design options [36]. Although VR can reduce costs and shorten timelines compared to physical mockups, it is not without limitations. The expense of hardware and the intensive programming required for interactivity present significant barriers. Additional perceptual issues include limited peripheral vision, generally capped at around 60 degrees and the absence of tactile feedback. Although technologies exist to simulate haptics, they are rarely integrated into mockup settings. A recent literature review identified these shortcomings and proposed a structured approach to VR-based design research, recommending task-driven scenarios and a combination of qualitative and quantitative evaluation methods [37].

### **2.3. Scenario Enactment within VR Mockups**

The Simulation-based Mockup Evaluation Framework, developed by the Health Quality Council of Alberta [28], outlines a structured methodology for evaluating healthcare environments using full-scale physical mockups. This framework has gained traction across North America, having been endorsed by the Facilities Guidelines Institute and formally incorporated into the Canadian Standards Association's Z-8000 standard for healthcare facilities. It has been successfully applied in Canada and the United States for operating room evaluations [38], building on earlier simulation efforts in hybrid operating theatres, intensive care units, and assisted living suites. While the framework currently emphasises physical mockups, ongoing advancements in VR technology offer promising opportunities to adapt the process to digital environments. In practice, physical mockups have led to measurable benefits, including estimated cost savings of \$1.7 million and improvements in patient safety, staff efficiency, and spatial functionality [39]. VR mockups are poised to replicate, and potentially surpass, these outcomes by addressing key limitations of physical models, namely high cost, logistical demands, and inflexibility in accommodating design changes. Despite their promise, VR environments currently face challenges such as the need for specialised equipment to enable realistic interaction [40], and limited capacity for multi-user simulation. However, the ability to simulate collaborative workflows is essential for ensuring that healthcare designs effectively support intended processes [41, 42]. Recent software developments, such as those within the

Unity engine, now allow multiple users to interact in real time within the same virtual space, offering a compelling platform for pre-construction design validation and team-based scenario testing [43].

### 3. Materials and Methods

This study aimed to develop a system that enhances the design of disaster-resilient hospitals by combining BIM, advanced rendering technologies, and virtual reality tools. The resulting solution, a database-supported VR/BIM-based communication and simulation system (DVBCS), was developed through a detailed investigation of how these technologies can be integrated effectively. The system was applied and evaluated at Zarqa Governmental Hospital, located in the city of Al-Zarqa, Jordan. The 11-story ward section (of which 4 are underground) has a total gross area of 15,600 square meters with a rectangular layout that runs 10 degrees clockwise along the north-south axis; it's structured to efficiently accommodate outpatient services, medical technology, and inpatient care. The DVBCS system framework is depicted in Figure 1. Participants in this study include the healthcare team (physicians, nurses, and other relevant healthcare stakeholders) and the design team (architects). The primary goal of the suggested system is to provide the healthcare and design teams with an efficient means of communication while they work on the project. The computer hardware, CAVE, projectors, and a gamepad are the four main parts of the DVBCS system hardware (see Figure 2). The user stands at the centre of a circle with a radius of 2172 mm and an angle of 120 degrees, creating an immersive virtual reality environment (see Figure 3). The evaluation of the DVBCS system was conducted as a pilot case study embedded within the design process of a disaster hospital. A total of 10 participants took part in the study, comprising 5 healthcare professionals (including physicians, nurses, and emergency care staff) and 5 members of the architectural and engineering design team involved in the project. These participants were selected for their direct engagement with the hospital's planning and clinical workflow requirements, as well as their central role in design decision-making.

Participants were recruited purposively from professionals directly involved in the hospital design process. Invitations were distributed through the project coordination office to healthcare staff and members of the architectural and engineering team who were actively engaged in planning and clinical workflow discussions. Inclusion criteria required that participants (1) had professional experience related to healthcare environments, and (2) were involved in either the design, technical development, or anticipated

operational use of the facility. The final sample comprised five healthcare professionals (physicians, nurses, and emergency-care staff) and five design professionals (architects and engineers). Participation was voluntary, and all participants were informed about the aims and procedures of the study before involvement. Written informed consent was obtained from all participants. The study protocol followed institutional research ethics guidelines, and all data were anonymised before analysis.

Data was gathered using a combination of structured questionnaires, direct observations, and facilitated discussion sessions conducted during the VR walkthroughs. The questionnaires captured participants' assessments of communication clarity, usability of the system interface, spatial comprehension, and the perceived added value of the VR/BIM simulation. Observations documented how participants interacted with the system, including any difficulties encountered and design issues identified. The facilitated discussions collected qualitative feedback on required layout adjustments, circulation issues, and functional needs identified during the VR simulations.

The structured questionnaire was designed to capture participants' perceptions of the DVBCS system across four main domains: (1) communication effectiveness, (2) usability and interface clarity, (3) spatial comprehension and visualisation quality, and (4) perceived usefulness for healthcare design decision-making. Items included statements such as "the system improves my understanding of spatial layout," "the system supports clearer communication with other stakeholders," and "the interface is easy to use." Responses were measured using a five-point Likert scale, where 1 indicated "strongly disagree" and 5 indicated "strongly agree." In addition to closed-ended items, open-ended questions were included to allow participants to elaborate on perceived strengths, limitations, and suggested improvements.

The pilot usability evaluation spanned two months, from January to February 2025. This phase focused specifically on testing the implemented DVBCS system through VR walkthrough sessions, questionnaires, and facilitated discussions with healthcare professionals and design team members. It proceeded in three phases:

- 1) Model Preparation: The architectural BIM model was developed in Autodesk Revit and converted into the database-supported BIM structure used by the DVBCS platform.
- 2) VR Simulation and Walkthrough Sessions: participants navigated through patient rooms, circulation zones, and clinical support areas using the semi-immersive VR environment powered by the Unreal Engine.

3) Evaluation and Feedback Integration: participants completed the structured questionnaires, provided comments on the spatial and functional aspects of the design, and reviewed subsequent revisions implemented by the design team.

The goal of the case study was to assess the usability, communication effectiveness, and practical applicability of the DVBCS system in supporting healthcare design decisions, rather than to conduct controlled experimental comparisons.

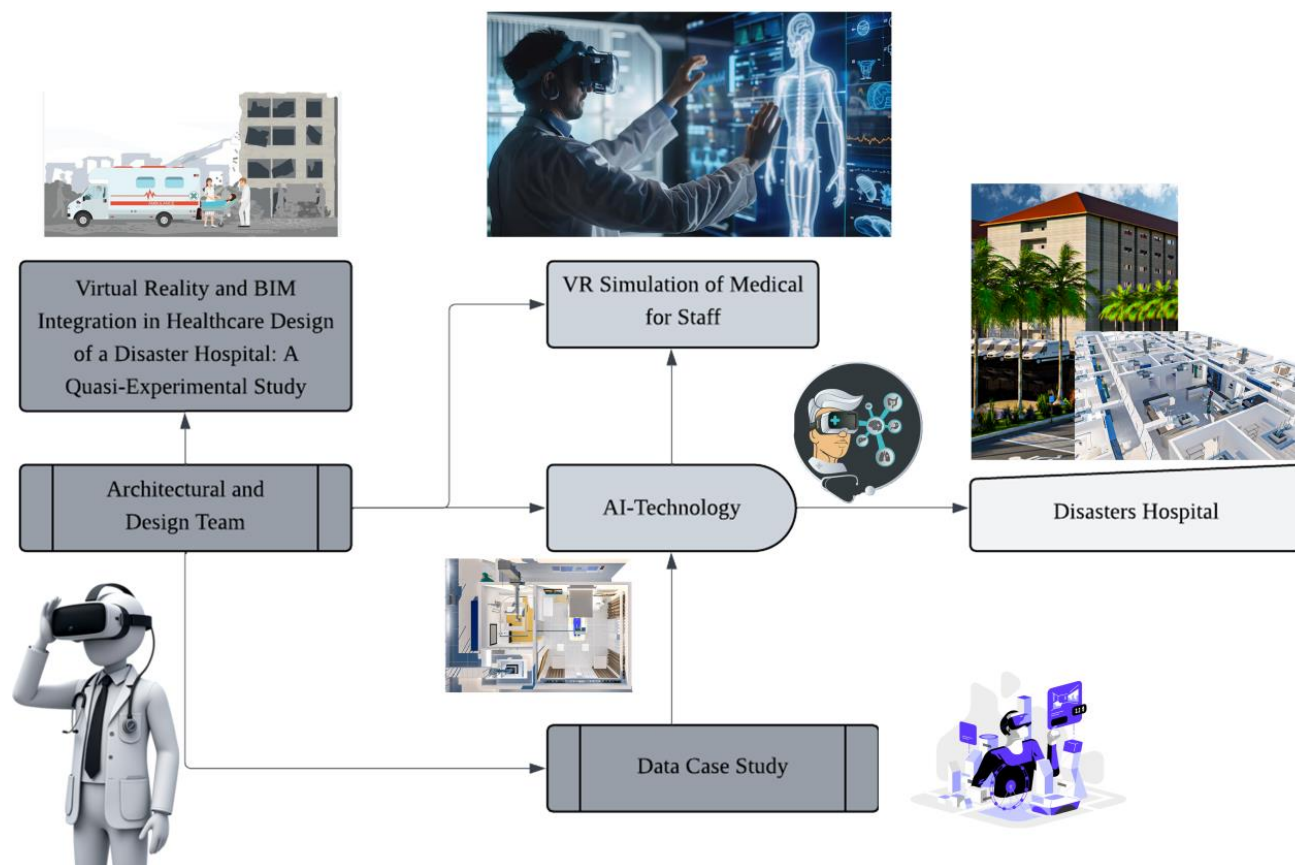


**Figure 1.** DVBCS system's framework

Interviews were conducted with design teams and healthcare teams who participated in the study. The study was conducted in January and February of 2025, a period of two months. The results of interviews and literature reviews are used to identify and summarise the communication and simulation requirements. Customised functionalities were evaluated using relevant commercial software as the selection criterion. Following the identification of the needs for customised functions, all functions are first suggested and subsequently confirmed. Autodesk Revit is used to create the initial BIM model in accordance with those specifications. Additionally, Autodesk 3ds Max simplifies the original BIM model. The model was converted into a game engine in Autodesk 3ds Max using virtual object and element data, which supports VR simulation and the environment.

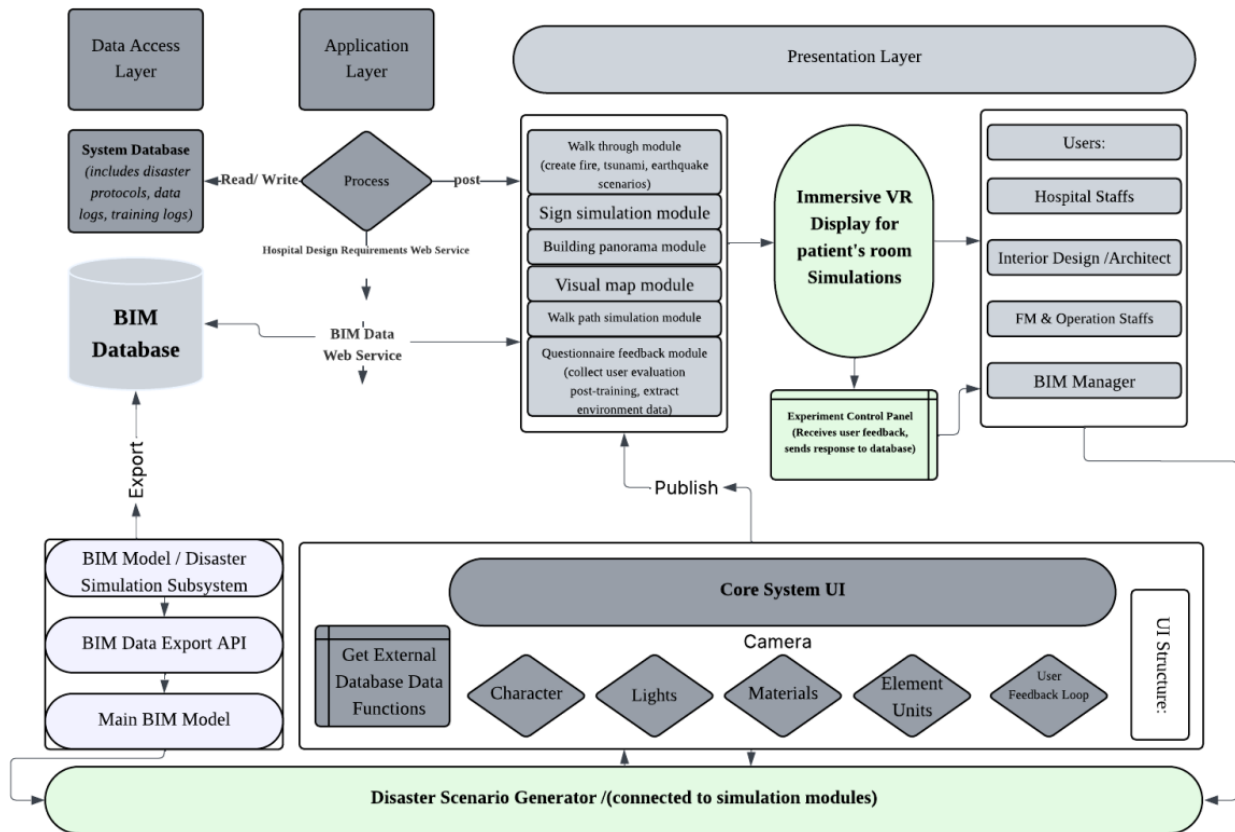


Figure 2. DVBCS system hardware

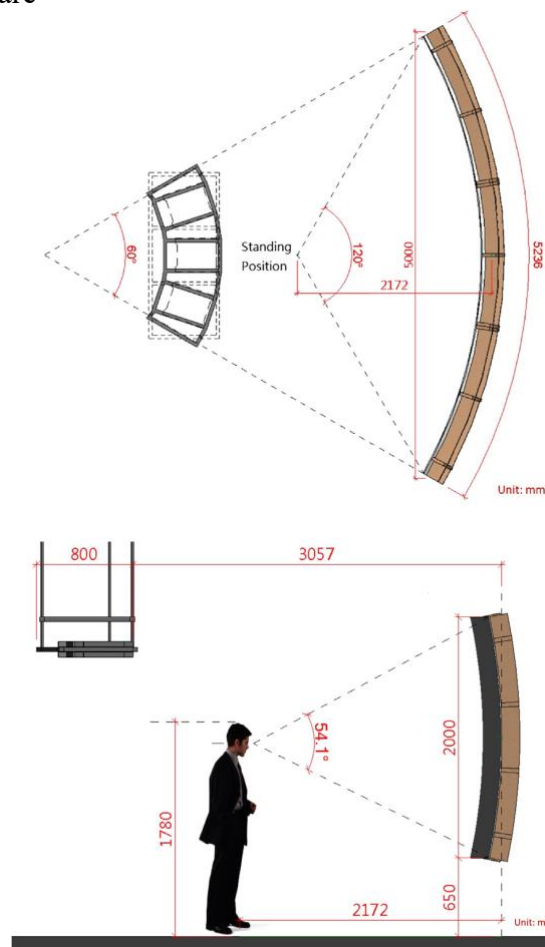


Figure 3. Immersive virtual reality environment design

Quantitative questionnaire data were analysed using descriptive statistics. Mean values and standard deviations were calculated for each evaluation item to summarise central tendency and response variability. Due to the pilot nature of the study and the small sample size, inferential statistical testing was not performed. Qualitative data from facilitated discussions and observational notes were analysed using a basic thematic coding approach. Two members of the research team independently reviewed the written notes and open-ended responses, identified recurring concepts, and grouped them into preliminary categories related to communication, usability, and design feedback. Discrepancies in coding were discussed until consensus was reached. These themes were then used to contextualise and interpret the quantitative findings.

### 3.1. System Development

The BIM models used in the study were developed in Autodesk Revit, which served as the primary platform for generating the architectural and equipment models. These models were then processed through the DVBCS data-export module, which converted the file-based BIM components into database-supported BIM elements for further integration. For real-time visualisation and simulation, the system employed Unreal Engine, selected for its ability to handle high-complexity models and support custom interaction scripting.

The VR environment was set up as a semi-immersive projection system, consisting of six high-resolution projectors arranged to create a wide field of view without requiring a head-mounted display. User interaction within the VR space was achieved through a gamepad controller, enabling movement, viewpoint adjustment, and interaction with selected elements. This setup was designed to minimise motion sickness and allow multiple observers to engage collectively in the design review process.

The operational workflow begins with creating the BIM model in Revit and then exporting BIM elements to the DVBCS database. The game engine then retrieves these elements, applies lighting, materials, and scale adjustments, and generates the VR environment used for stakeholder review. During the design sessions, medical staff and design teams navigate the virtual spaces, evaluate spatial configurations, and provide feedback. Their comments are documented and linked to the corresponding BIM elements, enabling the design team to revise the model and iterate the simulation accordingly. This cyclical process ensures continuous alignment between clinical requirements and design decisions.

### **3.2. BIM Model Operation Subsystem**

In this stage of the system, a custom API exports BIM model element data to a dedicated database. The DVBCS platform keeps this data in sync with updates from the main BIM source, ensuring that any changes are reflected in the game engine without delay. Because models with complex curves can be difficult to process in real time, these are simplified into polygon-based forms, and their scale is adjusted for compatibility. Engineers typically use tools like 3ds Max to export the models as .fbx files, which helps reduce visual issues such as overlapping shadows. However, since the .fbx format doesn't include object information, key data such as object type, size, material, and ID is stored separately in the BIM database. The game engine then uses these IDs to retrieve relevant details via the BIM Data Web Services, while Revit's API supports extracting the parameters needed for export.

### **3.3. Game Engine Operation Subsystem**

In this part of the system, Unreal Engine was the game engine of choice for this simulation. It was used to render and create a responsive VR environment that visually represents BIM data. Unreal was selected largely because it handles large scenes with many elements and materials more efficiently than some alternatives. Here, the engine plays a dual role: it renders the 3D environment in real time and serves as a bridge for interactive functions. Before importing models into the engine, the BIM elements are simplified and scaled appropriately, with the model's base point fixed at the origin (0, 0, 0). The BIM content is split into levels, and then materials, lighting setups, and camera views are added to create a more lifelike experience. Both sunlight and artificial lighting are controlled by adjusting parameters such as angle and distance. However, with caution to avoid overloading the system, because excessive BIM detail can reduce system performance. To avoid that, elements are merged or optimised to reduce the number of rendered polygons, which improves frame rates. The VR environment was intended for single-user, semi-immersive interaction, and the design included simple interactive features such as opening doors or switching lights. Once those visual and functional parts are in place, additional settings such as light reflections, material behaviour, and rendering quality are finalised to complete the virtual scene.

### **3.4. Functional Components of the DVBCS Framework**

The DVBCS framework combines BIM and VR technologies to improve communication and evaluation throughout the healthcare design process. It offers five core components: walkthrough, sign simulation, building panorama, working path simulation, and feedback collection. Through the

walkthrough function, users can navigate the VR version of the design and judge whether it aligns with their needs or expectations. For signage and wayfinding, the system allows medical staff and planners to preview and refine route options by testing signs for location, visibility, and effectiveness across different user types. The panoramic view module provides a full 360-degree visualisation of the building layout, and since users can easily get disoriented in a virtual space, a map-based positioning feature helps track their location. Pathway simulations are also supported, enabling the design team to trace movement along specific routes or rooms, calculate travel time and distance, and evaluate how efficiently the space supports different workflows. These simulations are saved and colour-coded to help distinguish roles and functions. Finally, the system includes a feedback module that allows medical professionals to share comments through questionnaires after exploring the design. Their input is collected in a structured format that can later be summarised and analysed using standard tools like Excel, helping inform revisions and future improvements.

#### 4. Results and Discussions

To examine the functionality of the proposed system, a preliminary case study was conducted using the design of a disaster hospital intended to accommodate 243 patient beds and approximately 525 medical staff. The hospital was planned to offer specialised healthcare services, requiring the design to reflect not only spatial efficiency but also the practical needs of clinical staff. However, many medical personnel struggled to interpret the design effectively through conventional two-dimensional drawings, which made it difficult to provide feedback and contributed to a communication disconnect between the design team, stakeholders, and healthcare workers. To bridge this gap, the DVBCS system was introduced as a tool to enhance communication and visualisation of design during the planning phase. The architectural model covered 12,400 square meters across eight floors, with the DVBCS system primarily applied to the first-floor patient rooms. Figure 4 shows the main BIM model of the disaster hospital in the case study. Figure 5 illustrates the BIM model for the 9th floor of the disaster hospital. This system enabled the design team to present their work more effectively to medical staff and stakeholders after developing BIM models for the entire hospital, including the ninth floor and selected patient rooms. The models were optimised and translated into a VR-compatible format for use within the DVBCS environment (see Figures 6 and 7). Figure 6 presents the BIM model of the first floor. In contrast, Figure 7 illustrates the corresponding VR-integrated model used for interactive walkthroughs. In practice, the DVBCS system was used within a

dedicated meeting space, enabling more meaningful discussion. Figure 8 shows real-time interaction with the design environment.



**Figure 4.** The BIM model of the proposed disaster hospital was used as the base dataset for DVBCS system development



**Figure 5.** The BIM model of the ninth floor of the disaster hospital, showing the spatial organisation of clinical and support areas

The communication system enabled design teams to convey the layout and intent of the patient room clearly and accessibly. Healthcare staff and stakeholders could explore the design and assess whether it aligned with their functional and operational needs. The system illustrated not only the spatial configuration

but also aspects such as colour schemes and lighting design, helping users visualise the atmosphere and practical use of the space. By integrating a simple map tool into the virtual environment, users could understand their location within the design and move easily between areas of interest. With a single click, they could navigate directly to specific locations, making it easier to engage with and evaluate the design more informally and intuitively.



**Figure 6.** The BIM model of the first floor of the disaster hospital, prepared for integration into the DVBCS virtual environment

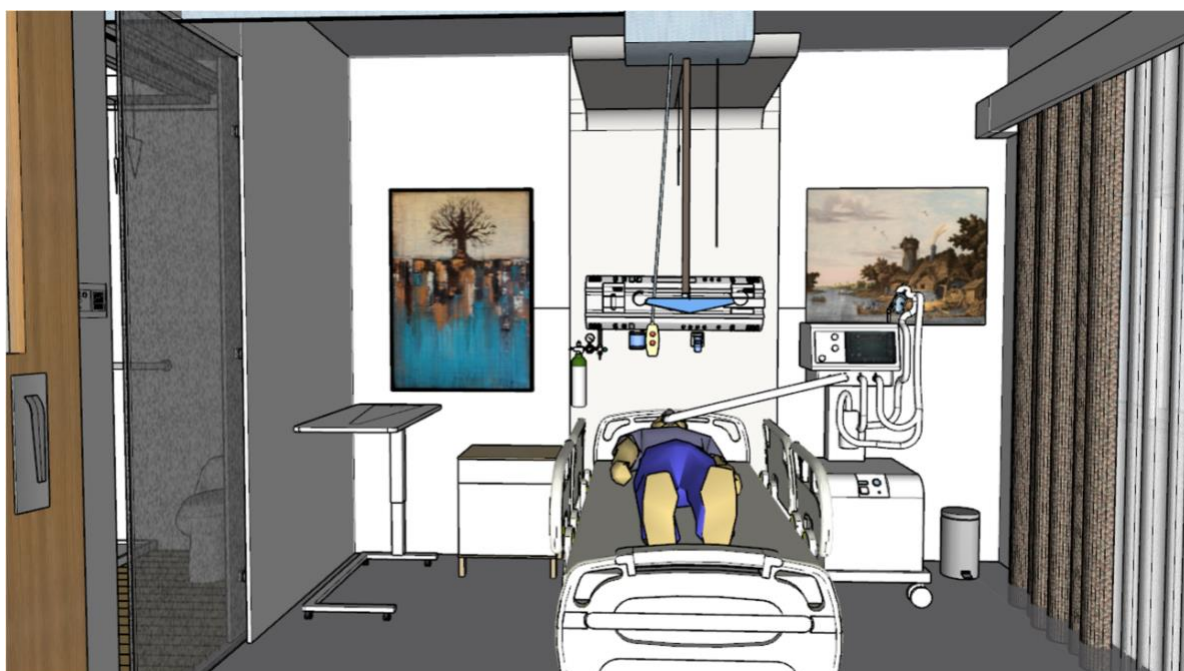


**Figure 7.** The VR-integrated BIM model of a patient room, demonstrating real-time visualisation and interactive walkthrough within the DVBCS system

During the development of the outpatient examination room, the design was shared with medical staff and healthcare stakeholders through the communication system, allowing them to explore and engage with the space in a VR setting. This immersive environment enabled users to experience the room's layout and functionality firsthand, offering practical insights and suggestions based on their professional needs. Stakeholders also interacted with the simulation of the waiting area, evaluating aspects such as spatial arrangement and furniture type. One particularly challenging component was hospital signage; it was addressed through the same platform (see Figure 7). Instead of relying on abstract drawings, staff could view and assess proposed sign placements and sizes within the VR environment, using both panoramic and walkthrough tools. This process allowed them to identify and correct issues early, ensuring that the final signage design met practical requirements. Their feedback was incorporated directly into BIM, allowing for real-time updates and minimising the risk of rework. By integrating user feedback throughout the design process, the system improved the clarity and functionality of signage and spatial layouts, resulting in more effective healthcare environments.



**Figure 8.** Application of the DVBCS system during a design review session, showing real-time interaction with the virtual hospital environment

In most healthcare projects, patient room designs are typically reviewed using 2D drawings or full-scale mockups at a 1:50 scale. However, these traditional approaches are often time-consuming and costly. To address this, we used the DVBCS system, which enabled stakeholders, including medical staff, to review the patient room layout in a virtual reality setting. They could explore the space using walkthroughs and 360-degree views, making it easier to assess elements such as colour choices, lighting, ceiling height, and overall layout (see Figure 9). After experiencing the design virtually, the staff provided feedback, including the need for larger windows and more room for family members. These comments were then used to update the digital model. The updated version was made available for further review through the same system. To evaluate internal route efficiency, we used the walking-path simulation module. This feature lets users simulate work paths, recording movement patterns, time, and distances, which were later analysed to improve the layout. Paths were colour-coded for clarity, and hospital signage was also tested in the VR setting. Medical staff participated in these sessions and provided feedback on the signage's location and clarity. Adjustments were made accordingly. In addition, the system included a questionnaire tool that allowed staff to submit structured feedback on the designs. Their responses were analysed and summarised using Excel to guide design improvements. Overall, this approach improved collaboration, reduced miscommunication, and made the design process more responsive to user needs at the disaster hospital.



**Figure 9.** Signage and wayfinding simulation within the DVBCS environment was used to evaluate visibility, placement, and navigation clarity

The development of the DVBCS system, integrating virtual reality, a game engine, and BIM technologies, was conducted over 5 months before the pilot study. This development phase involved system architecture design, BIM model preparation, database integration, and the implementation of interactive VR functionalities. Following this development stage, a two-month pilot usability evaluation was conducted to examine the system's effectiveness in supporting healthcare design communication. System engineers were responsible for creating and testing the platform, while BIM engineers developed the architectural models required for simulation. The system was designed to support communication and decision-making during the design phase of healthcare facilities, particularly between clinical staff (including physicians, nurses, and other stakeholders) and the architectural team. To evaluate how well the system met its objectives, a structured questionnaire was administered to 10 professionals from both fields. Participants were asked to evaluate the system's functions, performance stability, interface usability, and their willingness to use it in future healthcare design processes. Findings showed a high level of satisfaction: the average approval rate was 80% among designers and 90% among healthcare users. When asked specifically about the functionality, design team members gave an average score of 4.85.

Regarding interface satisfaction and communication support, the design team reported a mean score of 4.65. These results suggest that the platform was generally well-received, with slightly higher approval among end users. A comparison with earlier communication methods is provided in Table 1, while Table 2 presents evaluation details from users and design professionals, respectively.

**Table 1.** Comparison between traditional communication methods and the DVBCS system

| Aspect                            | 2D Drawings                                                | Physical Mockups                                           | DVBCS System (Proposed)                                           |
|-----------------------------------|------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------|
| Visualisation capability          | Abstract representation; limited spatial depth and realism | Full-scale or scaled physical representation; high realism | Immersive, real-time 3D visualisation with interactive navigation |
| Understanding by healthcare staff | Often difficult due to technical drawings                  | Generally clear but requires physical interpretation       | High clarity through walkthroughs, panoramas, and simulations     |
| Time and cost requirements        | Low production cost, but high risk of misinterpretation    | High cost and long preparation time                        | Moderate development cost; rapid modification and reuse           |
| Design modification               | Requires redrawing and coordination across files           | Difficult and costly once constructed                      | Rapid digital updates linked to BIM models                        |
| Support for workflow simulation   | Not supported                                              | Limited, scenario-based only                               | Integrated walking-path and signage simulation                    |
| Communication effectiveness       | Limited, one-directional                                   | Improved, but constrained by physical setup                | High, interactive, and collaborative                              |

**Table 2.** Results of the system evaluation for users and design teams

| <b>System usage</b>                                    | <b>Mean score</b> |
|--------------------------------------------------------|-------------------|
| Ease of effective communication                        | 5.00              |
| User interface                                         | 4.65              |
| Willingness to utilise the system for communication    | 4.65              |
| <b>System capability</b>                               | <b>Mean score</b> |
| Improve the gap in understanding of the design result  | 5.00              |
| Illustrates the requirement clearly                    | 4.65              |
| Understands the design result clearly                  | 5.00              |
| Provides a VR/BIM go through in a VR environment       | 4.65              |
| Enhances the look around in a virtual world            | 4.75              |
| Enhances the find-path functionality effectively       | 4.85              |
| Enhances the sign functionality effectively            | 4.85              |
| Enhances the illustration of visual design effectively | 4.65              |
| Enhances presentation for the user's requirements      | 4.75              |
| Enhances design inspection performance effectively.    | 5.00              |

Note: feedback on a five-point scale questionnaire is used to determine the mean score: 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

The development of the DVBCS system involved integrating BIM, game engine, and VR technologies within a semi-immersive environment to enhance design communication in healthcare projects. To improve the visual and interactive quality of the system, the development team implemented a real-time game engine, allowing users to engage with the space more intuitively. The case study feedback revealed several key advantages. Healthcare professionals and stakeholders found that DVBCS provided clearer spatial understanding than traditional 2D drawings or 1:50 mockups, leading to more meaningful engagement. The system also shortened communication loops and accelerated the overall design process. Notably, the combination of BIM and VR offered richer simulation experiences than using BIM alone. A distinctive feature of DVBCS is its walking path simulation module, which records and reuses movement data to support more in-depth workflow analysis, something rarely addressed in other studies or commercial tools. The questionnaire module, supported by the system's database, enabled structured feedback collection linked directly to design simulations. To reduce the likelihood of VR-induced motion sickness, a semi-immersive approach was used; importantly, no participants reported discomfort during the study.

Additionally, the system enabled a clearer visual representation of design outcomes, allowing design teams to respond more effectively to medical staff's needs. This, in turn, encouraged greater staff

participation and improved their understanding of the proposed environments. Through its real-time, interactive 3D features and walkthrough capabilities, the DVBCS system provided a highly effective platform for visual communication. For wayfinding elements, users could compare various sign designs within the VR space, helping identify the most suitable options. Finally, integrating 360-degree panoramic views enabled all participants to explore the design comprehensively, contributing to more informed decision-making across the project team.

This case study identified several limitations in the use of the DVBCS system, highlighting both technical and practical challenges. One major barrier to implementation is the initial cost of hardware and software, which can discourage investment, especially when senior management support is lacking. Without such backing, design teams and project owners may hesitate to adopt VR/BIM-based communication tools. Another limitation is the time required to revise BIM models in response to repeated feedback from healthcare professionals. Although the system allows for flexible updates, this process can be time-consuming. A further issue noted during the case was the inability to save final discussion summaries within the system, suggesting the need for future development to include this feature. The modelling process, whether modifying existing models or creating new ones, also demands significant time, which may not always be feasible within real project timelines.

Additionally, the system currently functions as a standalone tool, with no web-based collaboration features, limiting its use in remote or distributed project teams. Looking ahead, several suggestions can be made. First, while file-based BIM models were used for this study, transitioning to database-driven BIM applications may enhance both communication and simulation. Second, using a semi-immersive VR setup helps reduce the discomfort of digital motion sickness, an approach supported by the case study findings. Third, while the system maintains object-level data, more interactive features, such as selecting elements to view detailed information, could be introduced, though performance trade-offs must be considered. Merging complex objects could help manage system load. Also, even though multi-user functionality is possible through game engines, this study focused on single-user sessions to guide group discussions. Future work should explore multi-user environments for real-time collaboration. Finally, the effectiveness of DVBCS depends on the availability of existing file-based BIM models. Without them, design teams may be reluctant to adopt the system, making reusable database-based BIM models a practical alternative for simulation and communication.

Although the DVBCS system demonstrated meaningful improvements in communication and design comprehension, several methodological and technical limitations must be acknowledged. First, the study involved a small sample of 10 participants, limiting the generalizability of the findings. While the group included both clinical staff and design professionals, the limited number of participants means that the results should be interpreted as preliminary and exploratory. Second, the study did not include a formal control group, nor did it incorporate pre-/post-comparisons with traditional 2D drawings or physical mockups. Likewise, the evaluation relied primarily on descriptive statistics rather than inferential analysis. For these reasons, the study is more accurately characterised as a pilot implementation and usability evaluation. Third, the VR environment requires specialised hardware, technical support, and user training, which may pose barriers for organisations with limited resources. These limitations highlight the need for future research to adopt more rigorous experimental designs, such as controlled comparisons, larger participant samples, and quantitative performance testing to verify and expand upon the outcomes observed in this initial pilot study.

## 5. Conclusions

Engaging multiple stakeholders, including design teams, medical staff, and healthcare administrators in the early stages of hospital design is crucial, yet conventional 2D drawings often fail to communicate spatial relationships and design intent effectively. To address this issue, the present study developed a DVBCS (Database-supported VR/BIM-based Communication and Simulation) system that combines database-driven BIM models, virtual reality, and game engine technologies within a semi-immersive environment. Instead of relying on traditional file-based BIM models, the approach dissects them into discrete elements stored in a structured database, enabling more flexible programming and responsive simulation. A key advantage of this system is its semi-immersive interface, which uses high-resolution projectors to enable direct user interaction without the need for head-mounted displays. Four distinctive features emerged from the case study: the projection-based setup for accessibility, integration of a gamepad for navigation, real-time analysis and feedback mechanisms for simulation results, and a database-connected module for path simulation and questionnaire-based input. Applied to the design of a disaster hospital, the DVBCS system enhanced stakeholder understanding, reduced communication barriers, and improved simulation of operational workflows.

In contrast to traditional mockups and static plans, users reported greater clarity in reviewing spatial

configurations, lighting, circulation routes, and material choices. Moreover, the system proved effective for simulating emergency planning and facility operations, highlighting its utility beyond design review. Feedback gathered through integrated questionnaires indicated that participants found the platform engaging and insightful. Looking ahead, the integration of multi-user support would further enhance the system's potential, especially for collaborative decision-making in complex healthcare environments. As game engines inherently support multi-user frameworks, future work should explore network-based deployment of DVBCS to allow real-time communication among dispersed project teams.

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