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THE EFFECTIVENESS OF USING BIM IN VETERANS ADMINISTRATION HOSPITAL PROJECTS

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Abstract

This study explores the use of Building Information Modelling (BIM) on the design, construction, and operation of hospital projects of the United States Department of Veteran Affairs (VA). Given the complexity and importance of healthcare facilities, the study focuses on how BIM enhances project outcomes, particularly in projects managed by the U.S. Army Corps of Engineers (USACE). Through a survey and interview of key stakeholders, this research examines BIM's role in improving collaboration in a government funded hospital construction projects. Stakeholders, including the VA, architects, engineers, contractors, and healthcare professionals. It investigates how BIM supports better decision-making by streamlining design coordination, detecting conflicts early, ensuring regulatory compliance, and optimizing project costs. Both quantitative and qualitative data collection and analysis methods are used to assess BIM's benefits and limitations throughout the project lifecycle. This research offers actionable insights for construction and healthcare professionals in the VA, promoting wider BIM adoption in future government-funded hospital projects.

Keywords: BIM, Hospital Projects, Veterans Administration, Mixed Method Research.

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1. Introduction

The construction industry is undergoing a major transformation, driven by the adoption of advanced digital tools that enhance traditional methods of project planning and execution. One such innovation is Building Information Modelling (BIM), a technology that offers a multidimensional digital representation of a facility's physical and operational characteristics [1]. BIM has emerged as a key enabler of efficiency, collaboration, and data-driven decision-making, particularly in complex projects such as hospital construction [2]. Healthcare facilities present unique challenges due to their complexity, strict regulatory requirements, and critical operational functions. These demands underscore the need for technologies that can ensure design accuracy, optimize timelines, and reduce costs. BIM addresses these needs by enabling real-time collaboration among architects, engineers, contractors, and healthcare professionals. It enhances design coordination, facilitates clash detection, and supports lifecycle management—from planning and design through construction and operations [3].

This research investigates the effectiveness of BIM implementation in hospital projects, focusing on its impact during the early design phase. By examining multiple projects, particularly those managed by the U.S. Army Corps of Engineers (USACE) for the Veterans Affairs (VA), the study highlights how early integration of BIM can mitigate costly design modifications and project delays. For instance, in the Long Beach, California mental health inpatient/outpatient project, late-stage design changes led to a $57 million cost increase and a nearly three-year delay—challenges that could have been at least partially avoided with earlier BIM use. This research adopts both qualitative and quantitative approaches to evaluate how BIM improves collaboration, cost control, regulatory compliance, sustainability, and stakeholder satisfaction in healthcare infrastructure. A survey of key stakeholders including designers, government employees and contractors participated to provide insights into use of BIM on healthcare projects for the VA. Semi-structured interviews with government engineers and contractors lead to the identification of some key benefits and challenges with adopting BIM for government funded hospital projects. It also identifies key barriers within USACE for BIM adoption in early design stages and

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proposes strategies to overcome them. The findings offer practical guidance for construction and healthcare professionals, particularly in promoting the establishment of dedicated BIM design teams within USACE and other government agencies. The adoption of BIM during early design stages holds the potential to mitigate challenges tied to intricate features in hospital design, thereby contributing to smoother project execution.

2. Literature Review

Building Information Modelling (BIM) is a collaborative and technology-driven approach to construction project management that utilizes digital models and data to comprehensively represent [4] and integrate the physical and functional aspects of a building or infrastructure. Through multidimensional modelling, BIM enhances collaboration among stakeholders [5], improves project coordination, reduces errors through clash detection [1], facilitates accurate cost estimation, and supports informed decision-making at all stages of a project's lifecycle.

2.1. Benefits of BIM in the Hospital Design

In the healthcare sector, where precision and efficiency are of utmost importance, BIM has emerged as a promising tool for optimizing hospital projects. By harnessing the capabilities of BIM during the initial stages of design, healthcare facilities can benefit from improved project outcomes, including reduced construction delays, enhanced cost estimation accuracy, and enhanced coordination among stakeholders [6]. Hospital projects involve numerous stakeholders, intricate designs, and stringent regulatory requirements [7]. Traditional design processes often result in modifications during construction due to inadequate coordination, poor communication, and incomplete or inaccurate design information. By the traditional approaches, information is often dispersed across various documents and drawings, impeding effective collaboration and communication among diverse stakeholders [8]. These modifications can cause delays, cost overruns, and compromise project quality [9]. Therefore, it becomes crucial to adopt innovative approaches like BIM to mitigate these challenges and ensure smooth project delivery. Interoperability of BIM is a key research theme for all industries, enabling information flow throughout the project lifecycle [10]. However, exchanging models between different software platforms remains a challenge for fully integrated and collaborative project teams.

Broadly speaking, contemporary healthcare institutions heavily depend on cutting-edge technologies and sophisticated medical apparatus to deliver effective and top-notch healthcare services. Complex projects require the use of cutting edge tools such as BIM to maximize collaboration and communication amongst participants. The incorporation of Building Information Modelling (BIM) within the healthcare sector has ushered in a paradigm shift in how healthcare facilities are conceived, built, and administered. BIM, characterized by its advanced digital capabilities, provides a synergistic platform that seamlessly combines diverse facets of healthcare facility evolution, thereby elevating effectiveness, precision, and the ultimate results of projects [11]. BIM effectively caters to these requirements through its capacity to facilitate all-encompassing 3D modelling of healthcare facilities, intricately encompassing elements like medical apparatus, utility systems, and patient areas [12]. This level of comprehensive visualization significantly augments the design procedure, empowering stakeholders to detect possible clashes or discrepancies in the early stages, thereby diminishing the probability of revisions and expensive adjustments.

In the healthcare sector, where patient well-being is paramount, BIM contributes to enhanced safety and sustainability. It allows for the incorporation of energy-efficient designs and strategies, optimizing the use of resources and reducing operational costs over the facility's lifecycle [13]. BIM's capability to simulate the building's performance aids in identifying potential issues related to lighting, airflow, and infection control, ensuring a safe and healthy environment for patients, staff, and visitors. The advantages of BIM span beyond the construction stage and extend into facility management. Given the ever-changing requirements of healthcare facilities, BIM's digital twin concept allows for continuous monitoring and upkeep in real time. Facility managers gain access to comprehensive details regarding equipment, systems, and maintenance timetables, streamlining operations and minimizing periods of inactivity [14].

2.2. Time and Cost Modifications in Hospital Projects

Time and cost modifications are critical considerations in hospital projects and can arise from a multitude of factors that impact the project's timeline and budget, leading to the need for careful management and strategic planning. Efficiently managing time and cost modifications necessitates a forward-thinking and flexible strategy (Din, 2021). Vigilant tracking of project advancement, uninterrupted communication among stakeholders, and prompt decision-making are crucial elements for handling any deviations from the original blueprint. Consistent evaluations of project milestones and financial plans facilitate early identification of potential challenges, creating opportunities for timely interventions and corrective measures. Comprehensive documentation and transparent reporting play a pivotal role in managing time and cost modifications. Accurate record-keeping of change orders, scope adjustments, and associated costs provides a clear audit trail and aids in identifying patterns or trends that can inform future projects.

Factors contributing to time and cost modifications in construction projects are multifaceted and can stem from a complex interplay of various challenges and variables. Hospital projects are susceptible to a multitude of factors that can lead to time and cost modifications. Technological advancements, evolving medical practices, regulatory changes, and stakeholder dynamics are some of the factors that can introduce modifications throughout the project lifecycle [15]. Additionally, unforeseen site conditions, scope changes, and design complexities can further exacerbate the challenge of adhering to initial time and cost projections [16]. Regulatory and permitting processes can introduce delays, particularly if project approvals encounter unexpected roadblocks or revisions. Apart from the traditional permitting and compliance issues for construction projects, hospital projects are required to be certified by the relevant medical board or local public health authority. Additionally, supply chain disruptions, whether caused by global events or local factors, can lead to material shortages, affecting project timelines and potentially driving up costs [17].

Contractual issues, disputes, or negotiations can also trigger modifications, often leading to project delays and potential cost increases. Moreover, maintaining effective communication and coordination among the diverse stakeholders involved in a project is crucial. This might be achieved by using BIM in the project, enabling all stakeholders to have a common understanding of issues on a project. Miscommunication, conflicting priorities, or lack of alignment can lead to misunderstandings and adjustments. Given the intricate array of these influencing elements, the proficient handling of adjustments in project timeframe and budget necessitates a holistic and adaptable strategy. It calls for pre-emptive risk mitigation, constant scrutiny of project advancement, and flexible decision-making to effectively tackle deviations from the initial blueprint [18]. Regular evaluations of project milestones and budgetary parameters empower the early identification of potential challenges. BIM is one of the tools to help by facilitating prompt remedial measures contributing to the overarching success of the project.

2.3. Emerging Technologies used in Hospital Construction Projects

The field of BIM for hospital design is witnessing a dynamic evolution fuelled by a multitude of emerging technologies and innovations. These advancements are revolutionizing the way healthcare facilities are conceptualized, planned, and executed. For instance, the integration of ‘Generative Design’ algorithms within BIM platforms enables architects and designers to explore countless design variations based on specified parameters [19]. This empowers them to optimize space layouts, improve patient flow, and enhance overall operational efficiency. Furthermore, Virtual Reality (VR) and Augmented Reality (AR) are becoming integral tools in hospital design. Design teams can immerse themselves in virtual walkthroughs of spaces, gaining a deeper understanding of spatial arrangements and identifying potential issues before construction commences [20]. AR overlays provide real-time data and information about building components, aiding in accurate on-site decision-making. Additionally, cloud-based collaboration platforms allow seamless sharing and coordination of BIM models among multidisciplinary teams, irrespective of geographical locations. This real-time collaboration accelerates the design review process and minimizes coordination errors, contributing to timely project delivery [21].

A prospective trend in hospital design might entail the fusion of BIM with AI-propelled patient flow simulations. This innovative approach could empower designers to meticulously craft intricate models

delineating hospital layouts, patient mobility, and staff interactivity, thus refining spatial configurations for optimal patient care. By harnessing AI algorithms to scrutinize historical data and prognosticate patient inflow, designers could proactively strategize for scenarios that enhance patient satisfaction, alleviate waiting periods, and ultimately enhance overall operational efficiency [22].

Resources such as online courses, webinars, and industry conferences play a pivotal role in staying updated with these emerging technologies. Websites like the National Institute of Building Sciences (NIBS) and the BuildingSMART alliance offer valuable insights into the latest trends and innovations in BIM for healthcare design. Professional organizations like the American Society for Health Care Engineering (ASHE) also provide a platform for knowledge exchange and networking among industry peers. In summary, the infusion of Emerging Technologies and Innovations into BIM for Hospital Design is reshaping the healthcare built environment. From AI-driven design optimization to immersive VR experiences, these tools are propelling the industry towards unprecedented levels of efficiency, sustainability, and patient-centred design.

3. Methodology

This research employs a mixed methods approach to comprehensively investigate the benefits of implementing Building Information Modelling (BIM) in hospital construction projects. Mixed methods are particularly suitable for this study as they allow for a deeper understanding of the multifaceted nature of BIM adoption in the healthcare sector, capturing both quantitative and qualitative insights. When conducting a comprehensive evaluation of the advantages and limitations of implementing BIM in healthcare infrastructure projects, it becomes imperative to adopt a mixed methods approach [23]. This approach enables researchers to seamlessly integrate diverse data types, resulting in a more comprehensive understanding of the complexities associated with BIM implementation in the healthcare sector. Moreover, the mixed methods approach plays a significant role in enriching the credibility and reliability of research findings. Quantitative methods offer precise numerical data, thereby enhancing result accuracy [24]. Qualitative approaches are excellent at uncovering hidden insights and offering a comprehensive view of complex research challenges. When combined, these two methodologies work together to provide a sharper and more dependable comprehension of the research problem.

3.1. Qualitative Data Collection

The qualitative phase involved conducting semi-structured interviews with key stakeholders involved in government funded hospital construction projects where BIM has been utilized. Purposive sampling was employed to select participants, ensuring representation from architects, contractors, healthcare administrators, and other relevant stakeholders. Eight participants, representing both government agencies and private sector entities took part in a series of semi-structured interviews conducted by web-based video chat platform ‘Zoom’. Interviews averaged 20 minutes per participant. Participants were asked 5 open-ended, broad questions about the topic of BIM use in government funded hospital projects. Interview data was coded using open-coding technique and analysed using thematic analyses methods.

3.2. Quantitative Data Collection

The quantitative data collection was conducted using a broader survey distributed to a larger sample of healthcare professionals involved in VA hospital projects utilizing BIM. The survey instrument was developed based on the findings from the qualitative phase and relevant literature [25]. Probability sampling techniques were employed to ensure a representative sample. Respondents were asked to rate the perceived benefits, limitations and adoptability issues of BIM on government funded hospital projects, on a Likert scale. The data was analysed using descriptive statistical methods. The survey used 45 questions and was answered by 77 participants. The participants included 59% government employees and 41% from private industry. Participants were asked to describe their title and the data showed a wide cross-section including designers, contractors, sub-contractors, owner’s representatives and engineers.

4. Results

This research involved a mixed method approach, using both qualitative and quantitative data. The data and analysis from the semi-structured interviews with 8 subject matter experts was used to develop a survey aimed a wider audience.

4.1. Qualitative Data

The main thrust of questions posed to interview participants were aimed at understanding the benefits and challenges of using BIM on government funded hospital projects. The results of thematic analysis after coding the data are presented through the lens of benefits and challenges of using BIM on hospital projects.

4.1.1. Benefits of using BIM in Hospital Projects

Interview data showed six main themes that are beneficial in using BIM for hospital projects, as shown in Figure 1.

- Improved Design: BIM significantly enhances the design process through enhanced visualization, allowing stakeholders to better understand the spatial relationships and aesthetics of the proposed hospital. This improved understanding enables early decision-making on design elements, reducing the likelihood of costly revisions later. The collaborative nature of BIM fosters a collaborative design environment where architects, engineers, and other specialists can work concurrently on a shared model, leading to more integrated, efficient, and ultimately higher-quality design that better meet the needs of patients and staff.
- Communication: BIM serves as a powerful communication tool by providing an early digital representation of the hospital project, making complex designs more accessible to all stakeholders, regardless of their technical expertise. This digital model provides a basis for clear communication among the design team, contractors, and hospital administrators, ensuring everyone is on the same page. By facilitating a shared understanding, BIM helps avoid confusion in various phases of the project and ensures that all stakeholders see the big picture, leading to smoother collaboration and fewer misunderstandings.
- Conflict Detection & Risk Mitigation: One of the key advantages of BIM is its ability to perform clash detection, which identifies potential spatial conflicts between different building systems (e.g., HVAC ducts intersecting with structural beams) in the digital model. This reduces costly rework during construction by resolving issues virtually before they manifest on site. By proactively identifying and mitigating risks and conflicts, BIM also reduces project delays and budget overruns, contributing to more predictable and successful project delivery for the hospital.
- Construction Management: BIM provides valuable tools for optimizing the construction process. It aids in scheduling construction tasks by linking the 3D model with time-related information (4D BIM). This enables 4D scheduling and simulation, allowing project teams to visualize the construction sequence and identify potential bottlenecks. Furthermore, BIM facilitates what-if analysis, enabling teams to evaluate different construction strategies and their impact on schedule and cost, leading to more efficient and well-managed hospital construction projects.
- Cost Saving & Accurate Estimates: By enabling accurate quantity extraction of materials and components directly from the digital model and integrating price and product databases, BIM empowers project teams to develop more precise cost estimates early in the design phase. This proactive approach helps minimize conflicts and deficiencies during construction, which can lead to expensive change orders and rework, ultimately resulting in significant cost savings and more reliable financial planning for the hospital project.
- Building Lifecycle & Facility Management: BIM extends its value beyond the initial construction phase by providing a rich repository of product information about installed systems and materials. This detailed data supports informed decision-making regarding future renovations and expansions. Furthermore, the digital model facilitates efficient facility operation by providing a central source of

information for maintenance schedules, equipment locations, and system performance, contributing to reduced operational costs and improved asset management throughout the hospital's lifecycle.

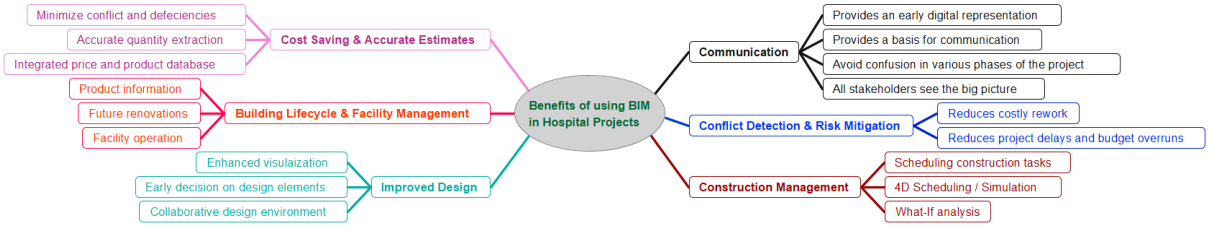

Fig. 1. Benefits of using BIM in Hospital Projects

4.1.2. Challenges of using BIM in Hospital Projects

Similarly, the data was analysed to identify the challenges associated with using BIM on hospital projects. Several themes emerged from the data, as shown in Figure 2.

- Data Management: Handling large volumes of complex hospital data can be difficult. Hospitals generate vast amounts of data, including patient information, medical equipment specifications, and building systems data. Managing this data effectively within a BIM environment, ensuring accuracy, accessibility, and organization, can be a significant challenge.
- Hospital Complexity: Hospitals have intricate systems, making BIM implementation challenging. Hospitals are complex facilities with highly integrated and specialized systems, including HVAC, plumbing, electrical, medical gases, and IT networks. Modelling and coordinating these systems in BIM requires a high level of expertise and can be more complex than other building types.
- Longer Planning Phase: BIM implementation often requires more upfront planning time. To effectively utilize BIM, project teams need to invest more time in the initial planning phase. This includes defining BIM goals, establishing workflows, developing BIM execution plans, and coordinating between different stakeholders.
- Skills Gap: A lack of trained professionals can hinder effective BIM use. The construction industry faces a shortage of professionals with the necessary BIM skills and expertise. This skills gap can limit the effective implementation and utilization of BIM on hospital projects, requiring investment in training and education.
- Initial Investment Cost: The cost of software, hardware, and training can be high. Implementing BIM requires significant upfront investment in software licenses, hardware upgrades, and training programs for project team members. This initial cost can be a barrier for some organizations, especially smaller contractors and healthcare providers.
- Vendor Lock-in: Dependency on specific BIM software vendors can create challenges. Different BIM software vendors use proprietary file formats, which can create interoperability issues and lead to vendor lock-in. This can make it difficult to exchange data between different project teams and software platforms.
- Lack of Awareness: Some stakeholders may lack understanding of BIM benefits. Some stakeholders, including hospital administrators, may not fully understand the benefits of BIM and its potential to improve project outcomes. This lack of awareness can lead to resistance to adoption and a reluctance to invest in BIM.
- Change Resistance: Resistance to adopting new workflows can impede implementation. The adoption of BIM often requires significant changes to traditional workflows and processes. Resistance to these changes from project team members and organizations can hinder the successful implementation of BIM.
- Data Security: Protecting sensitive hospital data within BIM is crucial. Hospitals handle sensitive patient data, and ensuring the security of this data within a BIM environment is critical. This requires

robust data security measures and protocols to protect against unauthorized access and data breaches.

- Fast-Paced Technological Advances: Keeping up with rapid BIM technology changes is difficult. BIM technology is constantly evolving, with new software, tools, and workflows emerging regularly. Keeping up with these rapid technological advances and ensuring that project teams have the latest skills and knowledge can be challenging.

Fig. 2. Challenges of using BIM in Hospital Projects

4.2. Quantitative Data

Interview data was used to develop a survey for a broader audience to establish consensus on the state of use of design in hospital projects. Participants were presented with a series of statements that they had to evaluate on a Likert scale. The options provided for each statement included 'Strongly Agree', 'Somewhat Agree', 'Neutral', 'Somewhat Disagree' and 'Strongly Agree'. The results from the survey are presented specific themes of 'Benefits', 'Challenges' and 'Other Issues'.

4.2.1. Benefits – Design Outcomes

Data indicates several key ways in which Building Information Modeling (BIM) enhances hospital design outcomes, as shown in Figure 3.

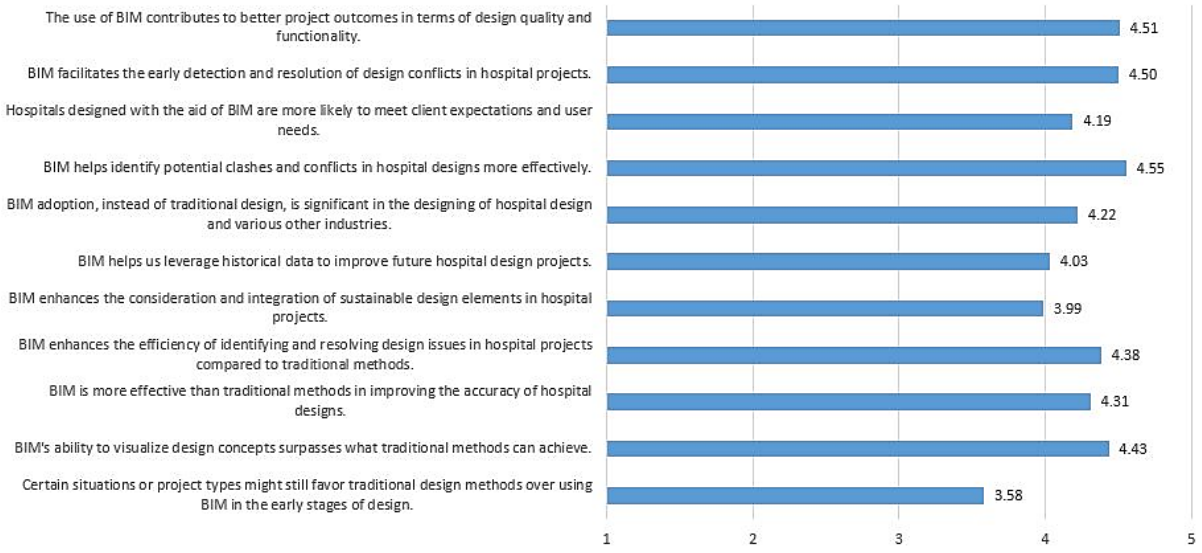

Fig. 3. Benefits of Using BIM on Hospital Projects – Design Outcomes

It emphasizes that BIM's ability to visualize design concepts is a significant improvement over traditional methods (4.43). The data suggests that BIM improves the accuracy of hospital designs (4.31) and enhances the efficiency of identifying and resolving design issues (4.38). Furthermore, BIM supports the integration of sustainable design elements (3.99) and facilitates the use of historical data to inform future projects (4.03). The adoption of BIM is seen as significant in hospital design and other industries (4.22). Finally, BIM is considered effective in identifying potential clashes and conflicts (4.55), ultimately leading to designs that better meet client expectations and user needs (4.19), and overall project quality and functionality (4.51).

4.2.2. Benefits – Early Design Decisions

Making early design decisions can potentially minimize changes and benefit the project, as shown in Figure 4. It indicates that there is a strong belief that BIM's role in the early design stages of hospitals

will become even more essential in the coming years (4.39). Respondents agree that BIM provides better visualization and understanding of hospital design concepts during the early stages (4.58), and improves the accuracy of hospital designs (4.32). Furthermore, the data suggests that using BIM leads to more informed decisions during these critical early stages (4.40), and influences the ability to minimize changes or modifications (4.09). Finally, respondents believe that owners should prioritize the adoption of BIM tools in their early design stages (4.09).

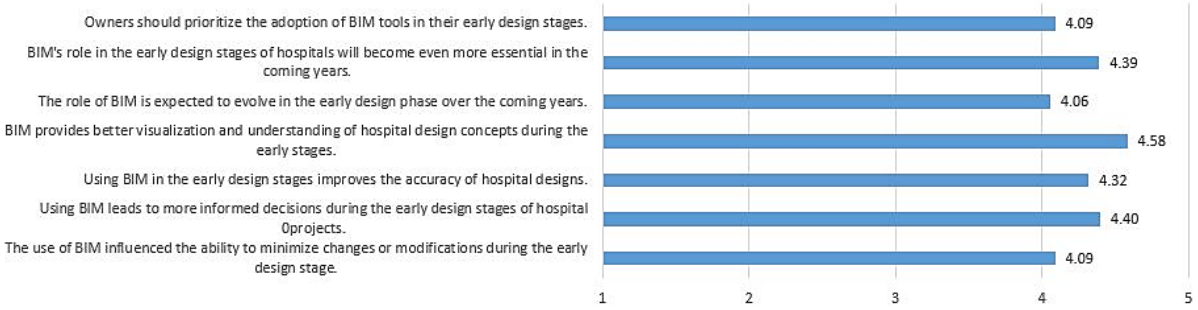

Fig. 4. Benefits of Using BIM on Hospital Projects – Design Outcomes

4.2.3. Benefits – Collaboration

BIM enables collaboration amongst the various stakeholders of hospital projects, as evidenced by the data presented in Figure 5. Respondents strongly agree that BIM enhances collaboration and coordination among hospital design stakeholders (4.52). The data indicates that BIM encourages interdisciplinary collaboration between architects, engineers, and other stakeholders (4.45), and fosters a shared understanding of design intent among different disciplines (4.38). Furthermore, respondents believe that BIM enables better collaboration among different stakeholders compared to traditional methods (4.21) and enhances communication between different design disciplines in projects (4.43).

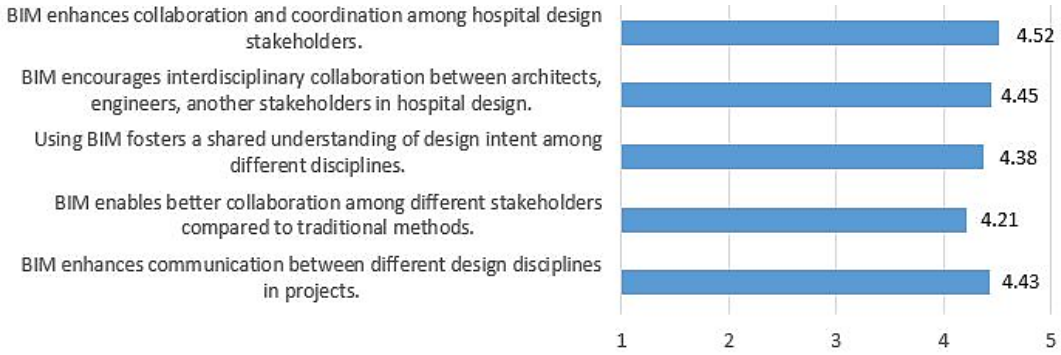

Fig. 5. Benefits of Using BIM on Hospital Projects – Collaboration

4.2.4. Benefits – Project Management

From a contractors' perspective, BIM can facilitate project management in construction of hospitals projects, as shown in Figure 6. BIM shortens the decision-making process by offering more accurate data (4.12) and streamlines the process of incorporating changes and revisions during the early stages (4.22). The data also indicates that BIM enhances the accuracy and precision of cost estimation during the initial phases (4.00) and leads to time savings compared to traditional methods (4.13). Finally, respondents agree that BIM increases efficiency in project management when utilized in hospital design (3.91).

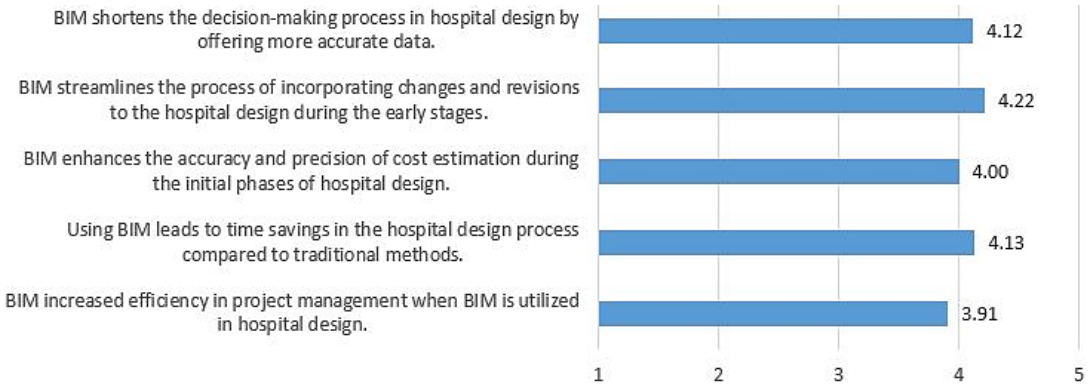

Fig. 6. Benefits of Using BIM on Hospital Projects – Collaboration

4.2.5. Challenges

Implementing BIM on hospital projects can come with its own challenges, as shown in Figure 7. Data indicates that a significant challenge is the substantial investment required in terms of training and technology (4.43). Additionally, there are perceived limitations or barriers that could hinder the full realization of the benefits of BIM in hospital design (4.43), and that implementing BIM in the early stages of hospital design comes with its own set of challenges (4.21). Finally, the data shows that resistance from project stakeholders when proposing the use of BIM in the early designing is also a factor but seems to indicate that attitudes in the industry are changing and stakeholders are increasingly open to the idea of using BIM on hospital projects (2.77).

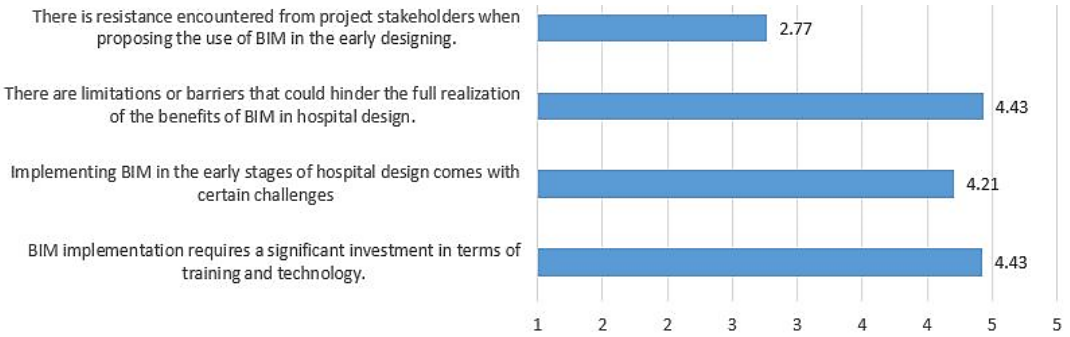

Fig. 7. Challenges of Using BIM on Hospital Projects

4.2.6. Other Issues

A few other issues identified in the survey are highlighted in Figure 8. Respondents generally agree that BIM facilitates better engagement with hospital stakeholders such as doctors, administrators, and patients during the design process (4.06), and helps address stakeholder concerns and preferences more effectively (3.91). The data indicates that organizations actively promote the adoption of BIM for hospital design projects (4.38) and that the integration of BIM tools is seamless within their hospital design workflow (4.31). However, the figure also suggests that adequate training and education are necessary for the effective utilization of BIM tools in the early design phase (3.58).

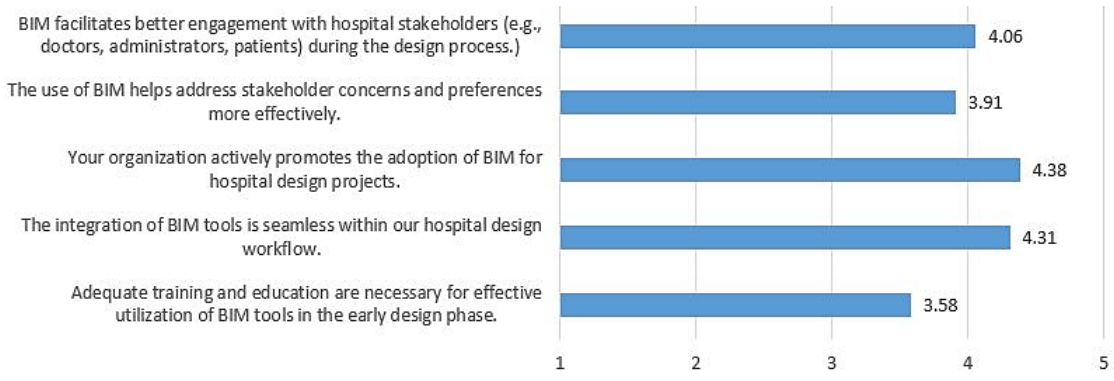

Fig. 8. Other Issues Concerning Use BIM on Hospital Projects

5. Conclusions and Recommendations

This mixed-methods study examined the effectiveness of Building Information Modelling (BIM) in hospital projects, with a specific focus on projects for the Veterans Administration (VA) and managed by the U.S. Army Corps of Engineers (USACE). The research synthesized qualitative insights from interviews with key stakeholders and quantitative data from a broader survey of healthcare professionals involved in VA hospital projects utilizing BIM. This approach provided a comprehensive understanding of the multifaceted nature of BIM adoption in the healthcare sector, moving beyond just statistical data to reveal the underlying factors, challenges, and opportunities that influence BIM's successful integration in hospital infrastructure projects. The findings of this research highlight BIM's transformative potential to enhance the design, construction, and operation of healthcare facilities, while also acknowledging the challenges and barriers that hinder its widespread adoption.

The qualitative data from interviews revealed several key benefits of using BIM in hospital projects. BIM improves design outcomes by enhancing visualization, enabling early decision-making, and fostering collaboration among stakeholders. The enhanced collaborative environment that BIM fosters ensures a shared understanding from a project's inception, mitigating miscommunication and potential design discrepancies. The 3D, and sometimes 4D (time) and 5D (cost) visualizations offered by BIM, help stakeholders to better understand the design concept, facilitating more informed decisions and earlier issue identification. BIM also serves as a powerful communication tool, ensuring that all parties involved have a clear understanding of the project. Furthermore, BIM facilitates conflict detection and risk mitigation, such as identifying clashes between structural elements and MEP systems, which reduces costly rework and project delays. BIM optimizes construction management by aiding in scheduling, simulation, and what-if analysis. Additionally, BIM contributes to cost savings and accurate estimates through precise quantity extraction and integration of price and product databases. Finally, BIM extends its value beyond the construction phase by supporting building lifecycle and facility management, providing a rich repository of information for future renovations and efficient operations. BIM's ability to incorporate vast amounts of project-related data, such as equipment specifications and maintenance schedules, provides a comprehensive view of the project and its lifecycle. BIM also enables more accurate design and construction documentation, reducing errors and omissions, and leading to better-built hospitals with fewer post-construction issues. Moreover, BIM aids in the phasing and planning of hospital construction projects by visualizing how different phases interact, thus streamlining the construction process. BIM tools can also simulate and analyse a building's energy performance, informing decisions about sustainable design elements for long-term energy and cost savings. BIM can also assist in ensuring compliance with local building codes and regulations, which is crucial for healthcare facilities.

The quantitative data from the survey further supports these findings and provides a broader understanding of the perceived benefits of BIM in hospital projects. Respondents indicated that BIM significantly enhances design outcomes, particularly in terms of visualization, accuracy, and issue resolution. They also acknowledged BIM's crucial role in early design decisions, leading to more informed choices and minimizing changes or modifications. The finding that BIM leads to more informed early design decisions is significant because it contributes to creating functional, efficient, safe, and cost-effective healthcare facilities, benefiting providers and patients. Moreover, BIM was found to foster collaboration among stakeholders, improve project management, and streamline decision-making, cost estimation, and change management. BIM's accurate cost estimates, derived from the design, allow for better budget planning and cost control from the project's outset.

However, the study also identified several challenges associated with BIM implementation in hospital projects. These challenges include difficulties in data management due to the large volumes of complex hospital data, the intricate nature of hospital systems, and the need for longer planning phases. Hospitals must have effective data management strategies in place to organize and access information efficiently. The lack of trained professionals and the high initial investment cost in software, hardware, training, and infrastructure were also cited as significant barriers. Resistance from staff accustomed to

traditional design and construction methods, and the time and cost associated with training or retraining staff, can also hinder BIM adoption. Additionally, issues such as vendor lock-in, lack of awareness among some hospital administrators and decision-makers, resistance to change, data security concerns, and the fast pace of technological advancements pose challenges to BIM adoption. Many hospitals have legacy systems that may not easily integrate with BIM, creating data compatibility issues. The complexity of hospital structures, with their numerous systems and special requirements, also makes adapting BIM more challenging than in other building types. Furthermore, ensuring that BIM models and data adhere to the strict regulations and standards that hospitals must follow can be a complex process. Smaller healthcare facilities or projects with lower budgets may also face challenges, as they may not see the same cost-benefit ratio from BIM as larger, more complex projects.

Other issues identified in the survey highlight the importance of stakeholder engagement, organizational support, seamless integration of BIM tools, and adequate training and education for effective BIM utilization. Respondents generally agreed that BIM facilitates better engagement with hospital stakeholders and helps address their concerns and preferences. They also indicated that their organizations actively promote BIM adoption and that BIM tools are seamlessly integrated into their design workflow. However, they emphasized the need for adequate training and education to ensure the effective utilization of BIM tools, particularly in the early design phase.

5.1. Recommendations

Based on the findings of this research, several recommendations can be made to promote the broader adoption and effective implementation of BIM in hospital projects, particularly within the VA and USACE:

- Establish dedicated BIM design teams: Both USACE and other government agencies should establish dedicated BIM design teams comprising professionals with the necessary skills and expertise to effectively utilize BIM throughout the project lifecycle. These teams should be responsible for developing and implementing BIM execution plans, providing ongoing training and support to project teams, and ensuring quality control and compliance with BIM standards.
- Provide comprehensive training and education: To address the skills gap and ensure effective BIM utilization, prioritize ongoing training and education for hospital staff, architects, engineers, and contractors, covering BIM fundamentals of BIM, as well as advanced topics such as 4D scheduling, clash detection, and lifecycle management, and should be tailored to the specific needs of different stakeholders.
- Promote early BIM adoption: The findings of this study highlight the significant benefits of early BIM adoption in hospital projects. Therefore, project owners, including the VA, should prioritize the use of BIM in the early design stages. This can be achieved by incorporating BIM requirements into project contracts, providing incentives for early BIM adoption, and educating stakeholders about the benefits of early BIM implementation.
- Address data management challenges: To overcome the challenges associated with managing large volumes of complex hospital data, robust data management strategies and protocols should be developed. This includes establishing data standards, ensuring data interoperability, and implementing secure data storage and retrieval systems.
- Mitigate vendor lock-in: To avoid vendor lock-in and promote collaboration among different project teams, open BIM standards and interoperability should be prioritized. Government agencies should encourage the use of open standards and require BIM software vendors to support data exchange between different platforms.
- Enhance stakeholder awareness: To address the lack of awareness among some stakeholders, targeted education and outreach efforts should be implemented. These efforts should highlight the benefits of BIM, showcase successful case studies, and provide opportunities for stakeholders to learn about BIM through workshops, conferences, and online resources.
- Foster a culture of change: To overcome resistance to change and promote BIM adoption, organizations should foster a culture that embraces innovation and collaboration. This can be

achieved by providing leadership support, encouraging experimentation, and recognizing and rewarding successful BIM implementation.

- Ensure data security: Given the sensitive nature of patient data in hospital projects, robust data security measures should be implemented within the BIM environment. This requires establishing robust data security measures and protocols to protect sensitive project information and ensure compliance with healthcare regulations, such as HIPAA.
- Stay abreast of technological advancements: To keep up with the rapid pace of technological advancements in BIM, ongoing professional development and knowledge sharing are essential. Organizations should encourage their staff to attend conferences, participate in online forums, and pursue continuing education opportunities to stay informed about the latest BIM tools and workflows.
- Promote collaboration and communication: Effective communication and collaboration among all stakeholders are crucial for successful BIM implementation. Project teams should establish clear communication protocols, utilize collaborative platforms, and conduct regular meetings to ensure that all parties are aligned and informed throughout the project lifecycle. A collaborative culture, where all stakeholders work together from a project's inception, is essential, and organizations should promote interdisciplinary coordination between healthcare planners, architects, and engineers to ensure that the hospital's design and functionality meet the needs of patients and staff.

By implementing these recommendations, the VA, USACE, and other stakeholders can harness the full potential of BIM to improve the design, construction, and operation of hospital projects. This will lead to the creation of healthcare facilities that are not only functional and efficient, but also safe, cost-effective, and adaptable to future needs, ultimately leading to better outcomes for patients, staff, and the healthcare system as a whole. It is also important to emphasize the importance of using BIM for facility management and maintenance throughout the entire lifecycle of the hospital, including renovations and expansions. Finally, organizations should continuously monitor and keep abreast of healthcare regulations and standards and verify that BIM models and data conform to these mandates.

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