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Bridging the Gap: Advancing BIM Adoption for Sustainable Construction Practices in the Arab World

[*]Aisha Ewis Yassin Ali[1], Prof. Sherif Mohamed Sabry Elattar[2] and Dr. Mamdouh Ahmed Farag Abdel Khair[3]

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Abstract: The construction sector in the Arab world has been compelled to implement advanced methodologies to meet the growing demand for high-quality, sustainable, and efficient built environments, which is a result of rapid urbanization and population growth. BIM has emerged as a viable solution to resolve these challenges; however, its adoption is still uneven. This study aims to fill the existing knowledge gap in BIM application throughout the building lifecycle in the Arab world. Through the analysis of case studies and stakeholder feedback, the research seeks to deliver actionable insights that will facilitate the adoption of BIM technologies, leading to more efficient, sustainable, and innovative construction practices across the region. Ultimately, this research aspires to contribute to the broader discourse on construction efficiency and sustainability, while providing tailored solutions to the unique challenges faced by the Arab construction sector.

Keywords: *BIM, Building Lifecycle, Construction Practices, Design Scenarios, Monitoring, Evaluation, Stakeholders*

1. Introduction

The global architecture, engineering, and construction (AEC) industries have been revolutionized by Building Information Modeling (BIM). BIM has established itself as a transformative instrument in the construction lifecycle due to its ability to improve information management, streamline project workflows, and enhance collaboration. During the construction process, it facilitates better decision-making, better data and information management, and more collaboration and coordination among project participants [1, 2]. With BIM, a digital model or "twin" of the building can be created and stored before the actual structure is ever constructed. During the design and construction phases, it assists all parties in recognizing and resolving possible problems [1,3]. It also helps with the facility's operation and lifecycle management. Additionally, during the design process, BIM enables the monitoring and evaluation of different design scenarios, reducing the possibilities to the most advantageous in terms of costs, materials, and energy use [4].

1 Architect, Department of Architecture, Fayoum University, Fayoum, Egypt
2 Dean of Faculty of Engineering, Fayoum University, Fayoum, Egypt
3 Professor in Architecture Dep., Faculty of Engineering, Fayoum University, Fayoum, Egypt
1aishaewis1993@gmail.com , 2sma00@fayoum.edu.eg , 3Maf00@fayoum.edu.eg

In developed economies like the USA, UK, and Australia, BIM has gained widespread traction and is recognized for enhancing the accuracy, efficiency, and quality of construction projects [5]. Recent research has demonstrated that BIM can be implemented in a variety of tendering routes to enhance the overall process [6,7]. Numerous governments, including the United States, the United Kingdom, and Australia, have established implementation strategies for the utilization of BIM in construction projects [8]. For example, contractors in North America have implemented BIM at an increasing rate from 2007 to 2012 [9].

The UK government has mandated the use of completely collaborative BIM for government projects (minimum of 5m capital cost) in 2016 in order to reduce project delays and cost overruns, which is a potential progressive shift [10]. The UK Government's decision has placed significant pressure on contractors, who are presently in the process of rapidly transitioning to BIM in order to satisfy the project's specific requirements [11]. The close economic relationship between the UK and the Middle East has resulted in the widespread adoption of BIM, particularly in the Middle East. This is evidenced by the local dominance of British architects, project managers, engineers, and contractors [12]. Furthermore, the Middle East region is home to numerous multinational corporations that maintain numerous offices, which has resulted in a more extensive implementation of BIM in the construction industry [13].

The construction sector in the Arab world has been compelled to implement advanced methodologies to meet the growing demand for high-quality, sustainable, and efficient built environments, which is a result of rapid urbanization and population growth. BIM has emerged as a viable solution to resolve these challenges; however, its adoption is still uneven [13]. To further enhance the building process, developed economies have also embraced additional ideas and technology, such as BIM add-ins and BIM-enabled software. These solutions facilitate improved cooperation and communication among project stakeholders across the project's entire lifecycle, as well as more accurate and efficient data management [14].

Although it is anticipated that BIM would be used to enhance stakeholder collaboration and communication during the course of a project, in reality, this usage of BIM is still an unexplored challenging area. In this research, we aim to investigate how BIM in construction is integrated and adopted in the Arab world across the building lifecycle. This is achieved through the usage of case studies to shed light on present practices, progress obstacles, and improvement prospects to improve knowledge on how to increase BIM's efficacy in the region's construction industry.

2. Related Works

BIM is a development in the construction industry that signifies a transition from electronic planning to a model-based process [15]. BIM is employed to generate a model that is not merely a geometric representation, but also includes information and properties that can be accessed by project members at any given time and location.

Typically, 5D models incorporate the coordination of cost estimations with model components, which is why the BIM model can be converted to 4D by associating model components with time timetables [15]. Moreover, 6D is defined as the representation of the As-Built model, an extension of the BIM model for Facilities Management (FM) that incorporates specific data required for the Operation & Maintenance (O&M) stage using information embodied in the rich Project Information Model (PIM) [16].

The 6D BIM can incorporate technical support, plans, and O&M manuals. This is an "As-Built" model that necessitates updating at various stages of the asset's lifecycle. The National Building Specification (NBS) also defines the 6D as a dimension that encompasses information to facilitate facility management and operation actions [16].

A substantial portion of the information necessary to facilitate the execution of a task can be easily obtained through planning in BIM. A structured data model enables designers to analyze the performance of a structure during the initial planning phase and, as a result, to quickly evaluate the various structure options in order to determine the most suitable option for a more environmentally friendly structure. The majority of BIM tools offer a variety of advantages for evaluating the energy and material utilization investigation, as well as the electrical and mechanical components of the structure. The objective is to provide rapid data generation to minimize resource and energy waste [17].

For instance, as part of the BIM programming, Autodesk Ecotect and Revit provide standard devices that process data to elucidate the environmental advantages of the project. This also enables designers and administrators to effectively manage the utilization of energy and material assets. Such software can integrate information to achieve a more sustainable structure by providing an analysis of the solar approach, building design, insulation, and heating and ventilation systems [18].

The adoption and implementation of BIM are increasing. The statistics indicate that numerous countries have recognized the potential of this technological and procedural evolution within the construction industry [19]. In the United States and the United Kingdom, BIM is mandatory (refer to Table 1).

Numerous European nations, including Finland, Denmark, Norway, and Sweden, are recognized as global leaders in BIM. Singapore has been promoting BIM in south Asia since 1997, and it is presently required for various aspects of construction, including building plan approvals and fire safety certifications. BIM is still considered to be in its early phases in Hong Kong, despite its implementation. Nevertheless, it can be asserted that the implementation of BIM in Hong Kong is progressing at a rapid pace. This is due to the fact that clients have begun to recognize a variety of BIM benefits, including the capacity to implement various tests on the BIM model, generate various design options, and detect design faults early to minimize the need for later changes [20].

Table 1. BIM adoption worldwide

	United States of America	2003	National 3D-4D-BIM Program
	Finland	2007	Open-BIM mandate for new buildings
	Norway	2008	Open-BIM mandate
	Denmark	2011	BIM mandate for all government buildings
	Netherlands	2012	Open-BIM mandate for infrastructure
	Austria	2015	Introduction of Open-BIM standards
	Sweden	2015	BIM mandatory for transportation
	United Kingdom	2016	BIM compulsory for government contracts
	France	2017	Announcement of BIM roadmap
	Germany	2017	Phased BIM implementation for infrastructure
	Czech Republic	2017	Launch of BIM program
	European Union	2017	Handbook for the introduction of BIM
	Spain	2018	BIM mandatory for all the public construction tenders.
	Italy	2019	BIM mandate for large public projects
	Russia	2021	BIM mandatory for federal contracts

The Arab region comprises a variety of countries with varying degrees of industrial maturity and technological advancement. The United Arab Emirates, Saudi Arabia, and Qatar have made substantial investments in construction projects and have implemented BIM to enhance project outcomes. In contrast, other Arab nations demonstrate restricted utilization of BIM tools and frameworks due to various obstacles, such as cultural resistance, a shortage of qualified labor, and inadequate regulatory frameworks [13,14].

2.1. Adoption Status of BIM in UAE

The UAE has been making substantial investments in the infrastructure and construction sectors, which has resulted in a developing interest in BIM as a means of enhancing the efficiency and sustainability of these projects [9]. In the Middle East, the UAE has been a pioneer in the adoption and implementation of BIM [21]. Dubai Municipality (DM) was the first authority in the Middle East to mandate the use of BIM on all new building projects exceeding a specific size, three years prior to the UK BIM mandate in 2016. Subsequently, an update in 2015 introduced additional requirements to the BIM mandate. BIM initiatives are prevalent in other Emirates, such as Abu Dhabi and Sharjah, despite the fact that Dubai is the sole Emirate among the seven UAE Emirates to have a BIM mandate [9,21].

The National Guide for Smart Construction has been implemented by the UAE to delineate the fundamental components of smart construction. This guide employs benchmarking to evaluate the capabilities of contractors and promote collaboration among all parties involved, thereby improving the overall construction process. The utilization of BIM in the UAE is anticipated to rise as a result of these initiatives and requirements [3]. In fact, the UAE is anticipated to have advanced BIM adoption and utilization levels that are comparable to those of developed countries with extensive histories of BIM implementation and culture, such as UK, USA, and Scandinavia, due to its status as an early BIM adopter [22].

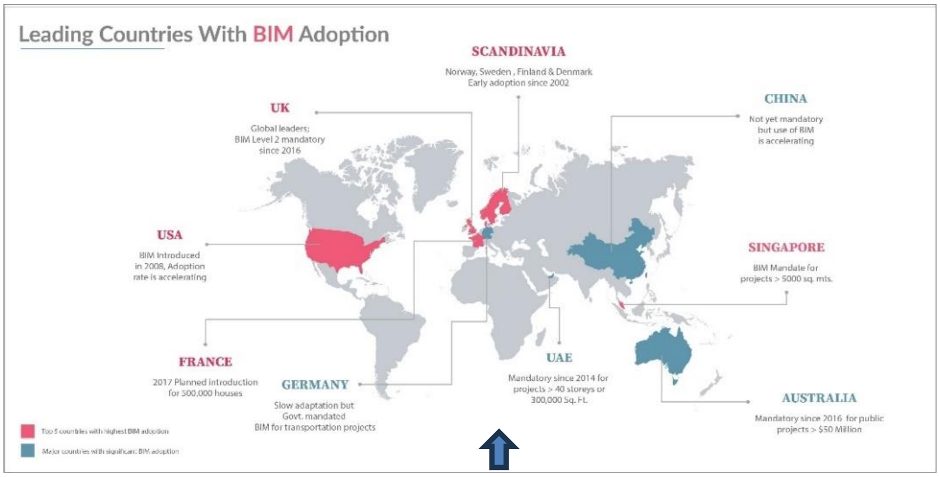

Figure 1. How different countries across the globe are progressing in BIM adoption

Although progress has been made, challenges persist. Barriers, including the high costs associated with technology adoption, variations in BIM competency levels among stakeholders, and a lack of standardized practices, can impede the broader implementation of BIM. Furthermore, there is a requirement for additional training and education to develop a more capable workforce that is proficient in BIM technologies.

2.2. Adoption Status of BIM in KSA

Saudi Arabia has made substantial progress in the adoption of BIM, which is primarily motivated by the necessity to improve the efficacy of its extensive construction sector, particularly in anticipation of the large-scale projects associated with the Saudi Vision 2030 initiative [23]. As part of Vision 2030, the Saudi government has prioritized infrastructure development and modernization. According to reports, the Public Investment Fund and other entities are advocating for the adoption of BIM in public initiatives in order to enhance efficiency and reduce costs [5].

Although BIM methodologies have been implemented in numerous projects, such as the expansion of King Abdulaziz International Airport and the construction of NEOM city, the integration of BIM throughout the construction lifecycle, particularly in the operational and maintenance phases, is still in the process of being refined. The positive impact of BIM on these projects is demonstrated through case studies that emphasize successes in design optimization and project coordination [24].

Cultural resistance to change and varying levels of BIM expertise among contractors and designers are among the primary challenges for BIM in KSA. Additionally, there is a discernible deficiency in the legal and regulatory frameworks that can facilitate the pervasive implementation of BIM. The absence of standardization and specific BIM guidelines further complicates the comprehensive adoption of BIM across all project types [25].

2.3. Adoption Status of BIM in Egypt

The Egyptian government has implemented a variety of initiatives to modernize the construction sector, in accordance with global construction trends. Although there is an increasing interest in BIM, its adoption remains relatively low, with the majority of large-scale projects being the exception. Universities are integrating BIM training into their curricula to cultivate a competent workforce, while certain governmental institutions have begun to suggest BIM-related training programs. Nevertheless, these initiatives continue to have a limited overall impact as a result of a variety of factors, such as economic constraints and inconsistent technology access [9].

Regarding the current situation in Egypt, most companies and offices in the field of construction do not apply BIM in their projects, and for several reasons, including:

- Scarcity of qualified personnel
- The high cost of software and training
- Some designers refuse to learn everything new
- The use of BIM does not represent a competitive value between companies
- Lack of time
- Lack of knowledge of standard standards

Although the Egyptian government did not impose on companies the application of BIM, it is not devoid of some projects to which this modeling was applied, but through self-efforts. Therefore, we note in one of the questionnaires that studies the application of building information modeling on projects in the Middle East region that Egypt It took second place with a rate of 19% after the United Arab Emirates with a rate of 23%, and it is considered the leading country in applying information modeling in the Middle East region [9].

3. Methods

This study implements a qualitative research design, employing a case study approach to examine the adoption of BIM in three critical Arab countries: UAE, KSA, and Egypt. The qualitative approach enables a comprehensive examination of perceptions and experiences of industry professionals with respect to the implementation of BIM and its influence on project outcomes.

3.1. Case Study Selection

Specific case studies were selected based on the following criteria:

- *Geographical Representation*: Case studies in the UAE, KSA, and Egypt to reflect regional differences in BIM adoption.
- *Project Scale and Complexity*: Inclusion of both large-scale and mid-sized projects that illustrate diverse applications of BIM.
- *Industry Stakeholders*: Involvement of various stakeholders, including clients, contractors, and design firms, to provide a holistic view of BIM implementation.

3.2. Data Collection Methods

Relevant project documents such as BIM execution plans, design reports, meeting minutes, and project completion reports were reviewed to complement the interview findings. This analysis provided insights into the formal processes, standards, and benchmarks for BIM implementation.

3.3. Selected Case Studies

Case Study 1: Museum of the Future, Dubai in UAE

The Museum of the Future, an emblematic structure situated in Dubai, is distinguished by its futuristic architecture and innovative design. It is distinguished by its distinctive toroidal shape, which is devoid of visible columns, and its intricate façade, which contains Arabic calligraphy. The architecture firm Killa Design is responsible for its design. The initiative was launched with the objective of establishing a technology and innovation hub that would showcase emerging trends and advocate for sustainability [26].

Figure 2. The ground floor and building levels are depicted in the main section.

<u>Phase of Planning and Design:</u>

BIM was an essential component of the project's planning and design phases from the outset. Revit was predominantly employed for architectural modeling, which enabled the design team to accurately visualize the building's intricate geometry. The BIM model was employed to facilitate collaboration among a variety of stakeholders, such as architects, engineers, and contractors. Real-time updates and modifications were enabled by the cloud-based platform, which substantially improved communication among teams. This facilitated a common comprehension of the design intent and minimized misinterpretations. The design team utilized parametric modeling to account for the building's distinctive curves, guaranteeing that modifications to the design were automatically reflected throughout the entire model. To enhance engagement and solicit feedback from stakeholders and clients during the design phase, high-quality renderings and virtual reality simulations were implemented [26].

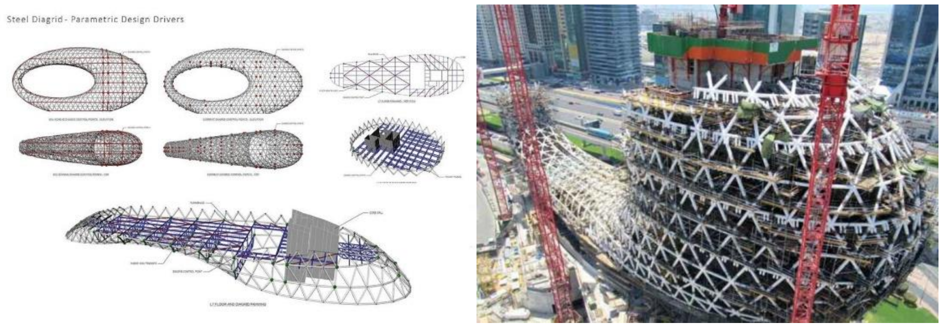

Figure 3. Parametric design drivers – Steel Diagrid.

<u>Phase of Construction:</u>

This structure's construction is extremely complex and unpredictable. This is the reason why all stakeholders were required to transition from a 2D plan to 3D and 4D BIM. The group required a fundamental understanding of and commitment to BIM calculations in order to implement them throughout the entire project lifecycle. Similarly, it is not solely employed to organize the construction. Furthermore, during the Mechanical, Electrical, and Plumbing (MEP) design phase of the project.

BIM tools facilitated the identification of clashes between various building systems, such as mechanical, electrical, and sewage. This proactive strategy reduced the need for costly revisions and on-site delays. Moreover, the BIM model functioned as a central repository for construction management. The model was employed by the project team to monitor progress, manage schedules, and allocate resources, thereby enhancing on-site efficiency.

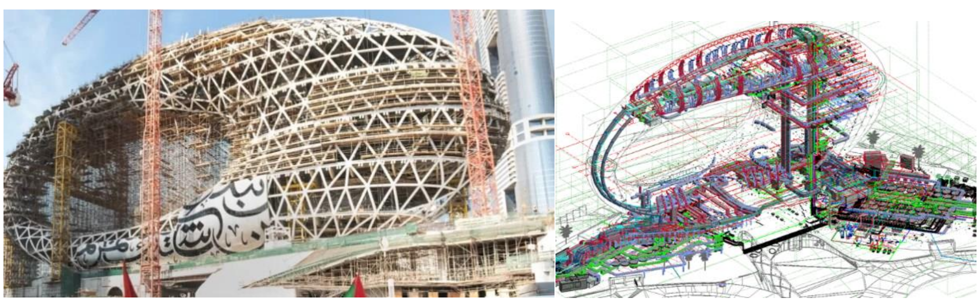

Figure 4. BIM facilitated the identification of clashes between various building systems

A substantial reduction in both time and costs were achieved as a result of the effective implementation of BIM throughout the Museum of the Future's lifecycle. The project was ultimately completed ahead of schedule as a result of the streamlined construction timeline and enhanced coordination, which included the early identification of design issues. Improved relationships among stakeholders were facilitated by collaborative nature of the project, which was facilitated by BIM. Silos and miscommunication were eliminated through the implementation of shared models and real-time updates, which led to a harmonious work environment. The Museum of the Future established a precedent for sustainable practices in the UAE's construction industry. Through the integration of BIM with energy modeling tools, the project team was able to optimize the building's performance, reduce its environmental impact, and obtain LEED certification [26].

Case Study 2: The King Abdulaziz Center for World Culture (Ithra) in KSA

In 2016, this project was completed at the King Abdulaziz Center for World Culture (Ithra) in Dhahran, Saudi Arabia. The project is comprised of numerous components, such as a tower structure with 18 floors that houses a variety of cultural amenities, a keystone, and a plaza. These amenities include an auditorium, a cinema, a library, an exhibition space, a museum, a cinema, an innovation forum, an oasis, a great hall, and an archive. The Snøhetta company designed it in 2007. Thus, the integration of the design and implementation phases of this building necessitated a significant amount of time. King Abdulaziz Cultural Center has been awarded the LEED Gold certification for sustainability [27].

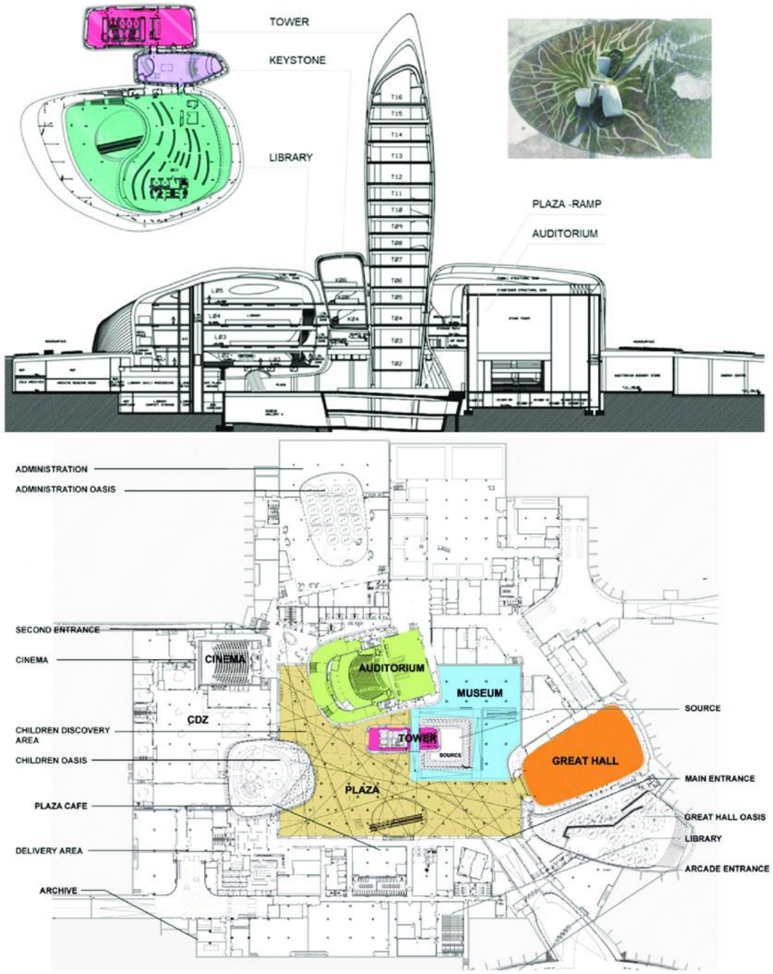

Figure 5. The ground floor and building levels are depicted in the main section.

BIM was employed in the design and implementation phases of the King Abdulaziz project. Consequently, the project's ultimate cost was as anticipated, and the implementation schedule was completed on time. Given that scheduling is so critical to the success of a project, schedules must be accurately classified. The purpose of this is to incorporate them into the estimation. Calculating all of the elements from a 2D plan can be time-consuming, particularly for larger undertakings. As a result, BIM facilitated the development of 3D, 4D, 5D, and 6D models in this project, thereby facilitating a more collaborative design process [27].

The building's envelope structure is composed of polygonal steel grids that are enclosed by steel supports and reinforced concrete slabs. According to Seele company, the exterior cladding of the building is enclosed by 350 km of individually shaped stainless-steel tubes that are tightly wound around the subtle curves. The stainless-steel tube facade spans 30,260 sqm, while the standing seam facade spans 28,600 sqm. Consequently, the Seele company concluded the majority of the construction work before transitioning each phase of the implementation process to the preparation phase. The planning process encompassed the following: detail a 3D model, define parameters, manage risks, integrate material expertise, and integrate logistical expertise.

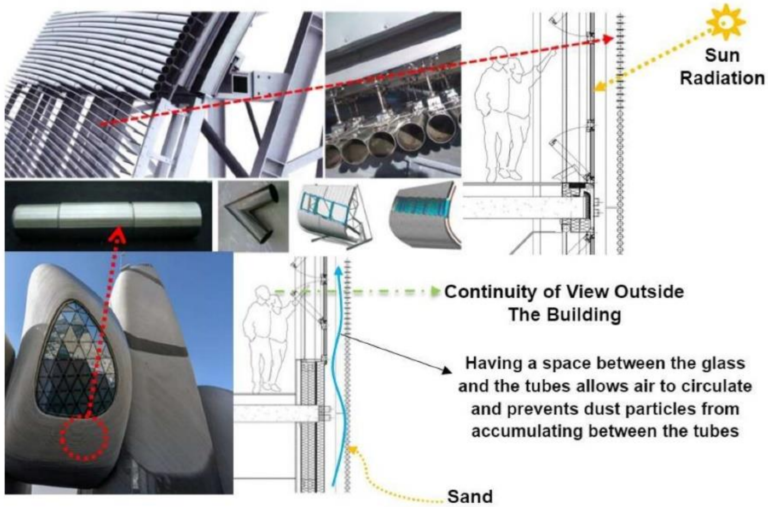

Figure 6. The exterior facade design that has been suggested for the building.

The designers were able to identify potential clashes in the design and mitigate them as a result of implementing BIM during the Ithra project design phase, thereby enhancing the design's overall efficacy. The project's overall efficacy and cost-effectiveness were undoubtedly enhanced by the implementation of BIM. In order to coordinate the structural, mechanical, and electrical systems for this project, a variety of engineering software programs that are compatible with BIM were employed, such as Revit and Tekla software [27].

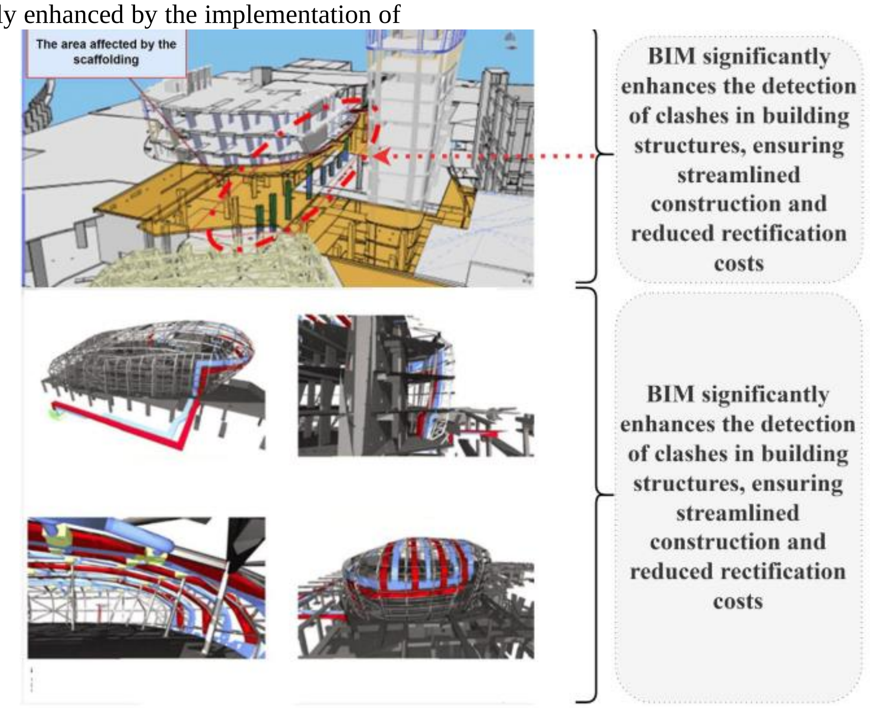

Figure 7. Collaboration among engineering systems to prevent clashes through BIM.

4. Discussion

BIM is generally employed to generate or monitor data that pertains to the building's life cycle. Each aspect of the construction project is meticulously detailed and connected to any other pertinent aspect through the use of a variety of tools and libraries. BIM facilitates the elimination of superfluous activities, resulting in substantial increases in productivity and substantial reductions in unnecessary costs.

BIM has made a reputation for itself in the fields of architecture, construction, and engineering; however, the substantial costs associated with its implementation have discouraged the majority of countries from adopting this trend. The regulatory bodies or governmental authorities of these countries are held accountable for promoting the best practices observed in other countries. The application of BIM also enhances project coordination and communication. The objectives of the current investigation were to evaluate the benefits of BIM and the obstacles associated with its effective implementation.

The current study offers a thorough examination, presenting evidence that BIM promotes increased transparency during the design phase of projects for the parties responsible for evaluating the material sustainability and design principles prior to the contractors' commencement of projects. Furthermore, there are numerous categories of contracts in the construction industry that allow the owner to determine the arrangements with the contractors to complete their projects at a later time. Nevertheless, the substantial challenge of increased installation and training costs associated with its implementation is demonstrated by the adoption of BIM in the construction industry of Saudi Arabia.

In spite of these obstacles, BIM has been advantageous in the Kingdom by enhancing the quality of completed projects, reducing uncertainties during construction, and providing more accurate estimates. Inadequate BIM technical knowledge and information, increased BIM investments, and a dearth of appropriate guidelines regarding BIM are also among the challenges in KSA.

Design development, design documentation, and construction are the stages in which UAE BIM is most frequently employed, while the facility management (FM) stage is the least frequently utilized. The benefits it offers to consultants and contractors, including the quicker and more efficient production of shop drawings in a 3D environment, improved quality of outcomes, and better coordination, are likely the reason. As a result of these advantages, numerous consultants and contractors implement BIM regardless of whether it is included in the project's scope.

There is no singular BIM solution that can be implemented in all scenarios. Rather, there is a diverse array of BIM tools and applications available on the market, each with a unique application or area of expertise. In specific fields or for specific duties, certain software may be more prevalent or frequently employed. This emphasizes the wide variety of BIM tools and software that are accessible, each of which provides a unique set of features, capabilities, and functionalities. Consequently, it is crucial to select the most suitable tool for the requirements of the project.

Furthermore, it may be necessary to prioritize the long-term advantages of BIM in the UAE, with a greater emphasis on the design and construction phases of a project. Consequently, it is imperative to enhance BIM awareness and education, establish BIM standards and regulations, and emphasize the long-term advantages of BIM in the region to enhance its adoption and utilization in the facility management and operation stages of the UAE.

The current investigation also includes data on the elevated costs associated with the life cycle. Nevertheless, engineers are typically restricted by the stringent budgetary constraints when selecting construction materials. To prevent the issue of increased life cycle costs, the construction industry ensures a substantially better evaluation of the long-term cost efficiency of a project. Consequently, the selection of materials for a new construction project is typically determined by the producer's expertise, recommendations, or personal experience.

Furthermore, the results indicate that the project's cost and time were elevated as a consequence of the absence of BIM. The delay was primarily caused by the proprietor of the project's inadequate planning and the absence of sufficient building drawings during the design and study phases, according to the analysis. Consequently, the cost of the project element increased.

The findings underscore the necessity for project management to prioritize the implementation of BIM in all phases of the project. Therefore, in order to facilitate the adoption of BIM during the design, construction, and operation phases, it is necessary to implement effective strategies. Additionally, the eradication of significant project delays is a consequence of the effective implementation of BIM, as demonstrated by case study analysis.

BIM is crucial in this research due to its capacity to facilitate improved design interpretation, evaluation of design alternatives, and analysis, early detection, and resolution of conflicts between building components. BIM is an essential component of any project, as it enhances the functionality of Mechanical Electrical Plumbing (MEP) and Fire Protection (FP).

It is important to acknowledge that the UAE and KSA are regional leaders in the implementation of BIM; however, there is still significant potential for growth and development. There are numerous obstacles that remain to be overcome, such as the absence of BIM education and training programs, the absence of standardization and integration with other technologies, and the absence of data-sharing and collaboration among stakeholders.

Best practices for BIM implementation in the region and areas for enhancement could be identified using the results of this analysis. The analysis indicates that the projects of developed countries had a more structured BIM implementation process, a higher level of software integration, and a more effective data administration and sharing system. This could offer significant insights for future BIM adoption strategies.

5. Conclusions and Recommendations

In order to facilitate the maturation of the BIM execution plan during the design, construction, and operation phases, the lead management of the owner must promote BIM adoption across all project processes, as indicated by the case studies. Strategies should be devised to achieve this goal. It is anticipated that the majority of the delays previously mentioned will be eliminated by the implementation of BIM during the project phases. By employing BIM, stakeholders are safeguarded from errors in drawings, delays, and omissions. In addition, BIM facilitates decision-making, aids in the identification of conflicts, and improves communication among all stakeholders throughout the entire project.

The integration of the case studies demonstrates the potential of BIM to revolutionize project management and construction. Projects may encounter unexpected delays and cost overruns in the absence of BIM. Nevertheless, BIM can assist in ensuring that projects adhere to their budgets and schedules in a strict manner. BIM's multi-dimensional approach, which encompasses 3D visualizations and 6D sustainability representations, offers a comprehensive overview of a project. Furthermore, BIM is a highly effective risk management instrument that effectively anticipates and addresses changes in a project's scope, thereby enhancing interdisciplinary collaboration and reducing the likelihood of misunderstandings among stakeholders. BIM optimizes the design and execution phases, particularly for large-scale projects. In comparison to conventional methodologies, it not only minimizes errors but also provides more accurate estimates of project costs and timelines. The case studies have demonstrated that BIM is crucial in guaranteeing that projects are concluded within budget and on schedule.

6. Limitations

While this study offers valuable insights, it is not without limitations. The qualitative approach facilitates depth but may limit generalizability. Additionally, case studies are subject to potential biases inherent in the selection of participants and the dynamics of the construction industry. Therefore, findings should be contextualized within the broader landscape of BIM adoption in the Arab region.

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