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An Analysis of the Qualitative Impacts of Building Information Modelling (BIM) on Life Cycle Cost (LCC): A Qualitative Case Study of the KSA

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Abstract: Building information modelling (BIM) continues gaining popularity in engineering construction as it helps lower the life cycle cost and ensure sustainability. The primary aim of this study was to delve into the effectiveness of BIM implementation in the Kingdom of Saudi Arabia (KSA) construction industry and understand the benefits, challenges, and risks associated with it. The present study has incorporated a qualitative and case study research design to investigate the effectiveness of BIM implementation. To this end, information was gathered through interviews involving BIM experts in the KSA, from which a thematic analysis was derived with the help of NVivo software. The results obtained highlight various benefits, challenges, and risks associated with the implementation of BIM tools, also covering the life cycle cost (LCC) and the procurement and type of contracts, initially referred to during the interviews, indicating that the importance of estimating the LCC in a project is crucial in the design phase, which also informs the decision making. In this case, 96.7% of the participants agreed with this view. Moreover, two case studies were analysed to further demonstrate the effectiveness of BIM adoption. The outcomes of this study have the potential to add significant value to various aspects of engineering practice in the KSA.

Keywords: building information modelling; life cycle cost; BIM; LCC; the Kingdom of Saudi Arabia; KSA; Saudi Arabia

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1. Introduction

In the last several years, a rapid increase in the economic growth of the KSA has been observed, as reflected in the expansion and diversification of industrial activity related to construction. This has required the refinement of planning, design, and management techniques, often using BIM [1,2]. Researchers have highlighted that the assessment of the sustainability of buildings based on probability theory or other mathematical techniques [3,4] should be reinforced by the practical considerations of basic materials, such as green-building materials, for example. The control and anti-corruption commission of the KSA has identified 44% overdue and stalled construction projects in a database, including 1526 developments [5]. Delays in projects often arise from inadequate planning, insufficient information about the project's location and developmental needs, and an unstable chain of command, leading to frequent changes in orders or instructions for developers and constructors. These and other factors hinder the potential and effectiveness of novel technology, such as building information modelling, which has drawn our attention and generated intention to clarify the ways in which BIM could reduce buildings' LCC in the KSA [6].

Previous studies did not consider the impact of costs uncertainty in the LCC analysis, which has drawn the attention of project managers in the KSA. The benefits of BIM enable the optimisation of resources during design, construction, and operations [7]. For instance, BIM facilitates the implementation of strategies to minimise material wastage, leading to reduced overall costs and environmental protection. Latiffi et al. [8] showed examples of construction cost optimisation taking place at the planning phase. As demonstrated by Rashed et al. [9], when expenses are paid in advance and at specific points throughout the building life cycle, such as architects using BIM-360 to assess project costs related to material procurement and shipping, it can lead to higher LCCs. This suggests that careful consideration and optimisation of these paid-in-advance expenses during the planning phase can be crucial for achieving cost efficiency and overall project success. Research has shown that most construction projects in Saudi Arabia prioritise completion over environmental considerations. BIM, when oriented towards LCC, promotes efficient decision-making, collaboration, and resource management in construction, enhancing cost-effectiveness and environmental sustainability. This approach is increasingly favoured in the KSA for cost reduction and sustainable development [10,11].

The KSA is among the largest construction industries globally with multiple developmental projects. According to Shash and Habash [12], the associated industry subsidised a net of 6.35% between 2011 and 2015, which grew to 7.05% in 2022. This has meant a value rise passing from USD 105.6 billion in 2015 to USD 148.5 billion in 2020 [12]. The Kingdom of Saudi Arabia (KSA) is among the largest construction industries globally, with multiple developmental projects. The KSA is determined to accomplish its developmental objectives aimed at "The Saudi Vision 2030". Thus, there is no adequate timing for the KSA to implement the emerging trend of sustainable development that has been observed in different countries, such as the UK, the USA, and Australia, through the adoption of building information modelling. An extensive literature survey highlighted that the KSA is yet to completely explore the potential advantages of BIM even though few progress works have been reported [13–15]. Reports on business [16] indicate that, boasting a market size of USD 120.4 billion in 2021, the construction industry of the KSA is projected to witness an average annual growth rate of 4% or more during 2023–2026. During the forecasted period, the industry growth would be driven by an increase in oil prices and related economic activity. In the past, the growth of the construction sector in the KSA has been driven by investment in renewable transport, research, housing, and energy [17].

Transactions among stakeholders have operated under lump sum and unit price contracts, which were once identified in about 91% and 94% of projects, respectively, and have become the most commonly adopted in Saudi Arabia [12], and certainly, the rule of thumb in governmental units. In the KSA, construction projects undergo five key phases: planning, design, construction, operation, maintenance, and renovation. The planning stage focuses on the project's feasibility and sets its objectives and goals [18–20]. During the design phase, technical specifications are developed by engineers, and the team's responsibilities to achieve project targets are outlined [21,22]. Once construction is done, the operation phase allows investors to regain their initial investment. The renovation phase begins when defects emerge to address these issues. Despite its potential, Saudi Arabia's construction sector faces challenges like the absence of proper BIM guidelines, rising BIM costs, and limited BIM technical expertise [23]. To address these challenges, Saudi Arabia's government and construction authorities are working towards harnessing the advantages of BIM. BIM is now widely applied in global construction industries due to its potential for risk reduction, including financial and schedule-related risks and minimising errors and omissions. It allows for a comprehensive assessment of a project's entire life cycle. Recent trends show a growing emphasis on BIM adoption by engineers and architects, prompting the construction sector to embrace these modern techniques for enhanced safety and productivity [24,25]. The rise of BIM over the past 15 years is attributed to technological advancements, leading to more intricate designs. Notably, in developed countries, BIM now supports not only 3D modelling but also construction management, cost control, safety education, and sustainability [26,27]. BIM technology has instigated a significant transformation in the construction industry concerning both technology and process.

According to the study by Sami Ur Rehman et al. [28], building information modelling is gaining recognition as a tool for improving productivity and innovation in the construction industry. The technique can contribute to the greater sustainability of projects that reciprocate and contribute to eradicating poverty in developing countries [29]. The use of BIM in multiple areas has expanded as researchers realise BIM's potential value [30–35]. Adopting BIM in projects is driven by the need to automate the modelling process, enhance construction documentation, and improve inter-party communication, which brings about design changes. BIM is not limited to design; it also covers construction and facility management, sustainability, energy analysis, and infrastructure design, and it boosts stakeholder collaboration. A primary emphasis is on the use of BIM in energy modelling. However, this cannot be directly termed as the BIM-to-building energy modelling information process (BBIP) [36,37]. Reviewing the comprehensive literature on building information modelling and its implications illustrates that most resources are focused on planning, designing, constructing, operating, and the consumption of energy of the public in 2016, and a more excellent, centred, and devoted archive concerning energy design and its consumption [38–43]. A lack of industry standards, resistance to change, and high software costs can limit the integration of BIM and construction practices on construction mega-projects [44]. However, it is possible to implement BIM and construction practices more effectively by addressing these barriers.

The LCC method evaluates the overall cost of project alternatives and identifies designs with the minimum total project cost. It is essential for stakeholders to be informed about all facets of the construction life cycle, encompassing acquisition, operation, maintenance, and disposal costs, ensuring a comprehensive grasp of potential long-term financial commitments. BIM, as outlined by Alasmari et al. [45], is a modern construction approach allowing users to craft object-based multidimensional parameters vital for managing construction projects throughout their life cycle. Incorporating various techniques and tools, BIM provides procedural frameworks for efficiency, updates, and collaborations. Lu et al. [46] highlighted that BIM's applications span the entire project life cycle, from initial planning and design to construction, functionality, and even renovation or demolition. BIM's versatility encompasses areas such as programming, time planning, budgeting, site assessment, modelling, quantity take-off, project review, certification, standardisation, site design, engineering analysis, project design, documentation, planning, and effective coordination [9,47,48]. These elements contribute to reduced project risks and a higher chance of project success. Nevertheless, there remain persistent challenges that need effective management.

Risk management encompasses a series of steps to identify, evaluate, and address risks. Viana et al. [49] noted that BIM, while beneficial, can also introduce risks, such as legal and investment issues related to its implementation. Opting for low-quality construction materials to cut initial costs can elevate a building's total life cycle cost, especially if the materials are not sustainable. This may result in a structure with lower initial costs but higher maintenance and reduced sustainability. Hence, assessing material sustainability during selection can positively influence the building's maintenance, durability, energy efficiency, and overall sustainability. It is recommended to first estimate a building's life cycle cost to gauge its economic efficiency, considering all cost factors. By using BIM, multi-disciplinary data are unified to create detailed digital models hosted on open cloud platforms for genuine collaboration. BIM's advantages promote greater transparency, sustainable choices, efficient energy use, daylight and thermal design analysis, and clear cost insights [50].

As stated in the research by Al-Yami and Sanni-Anibire [1], adopting BIM in construction projects offers a more excellent opportunity for prefabrication and modularity construction, which results in higher-quality projects. Based on a study by Alasmari et al. [50], a survey conducted in the KSA revealed that 61% of engineers were aware of BIM. Akal et al. [51] highlighted that an essential benefit of BIM is the construction cost estimation before beginning the construction phase. Consequently, sustainability increases when BIM fosters a transparent process in the design phase through advanced analytics to predict the operational performance of the building before construction begins [52–54]. Akhund et al. [55] described that wrong cost estimation or rework in construction projects occurs due to poor planning and cost projections. Rework in projects affects workers' temperaments and increases additional costs and wastage of time. Architects and engineers have proposed effective LCC techniques to lower the cost of project life cycles [1,56]. BIM provides stakeholders with an understanding of the LCC of buildings, including the design, construction, operation, and maintenance phases. Moreover, BIM facilitates stakeholders' understanding of all aspects of a structure, allowing them to estimate the LCC accurately [57]. This highlights the benefits/advantages of BIM incorporation in the construction industry. Moreover, there is no doubt that a BIM approach can enhance sustainability in the construction industry and reduce the LCC.

The integration of engineering tasks in construction can be effectively managed using BIM, as it provides a platform to coordinate and visualise all project phases in 3D. However, in the KSA, there is no standard BIM implementation or universally recognised protocol for information management across a building project's phases. This leads to inadequate LCC considerations, with such projects facing lax regulations. This study was prompted by this identified knowledge gap. This lack of commitment is also reflected in the production of research. A thorough search of the BIM-related literature in the KSA yielded few results in proportion to the number of investigations that have been conducted in countries that lead sustainable developments worldwide. This study examines BIM's qualitative impact on LCC within the specific economic environment of the KSA, despite its widely acknowledged value as a tool. Therefore, this study aims to provide an in-depth qualitative analysis of the impact of BIM on LCC in the KSA, bridging the existing knowledge gap and paving the way for standardised and sustainable construction practices in the KSA.

2. Methodology

2.1. Research Design

This study was conducted using the application of qualitative research design, as the study aimed to evaluate the use of building information modelling on the life cycle cost of sustainable buildings in the KSA. The nature of the research involves results based on non-numeric illustrations of the experiences of others. Through qualitative research, design interviews were conducted to analyse BIM's role in lowering the construction life cycle cost. For this purpose, interviews with expert engineers in the KSA were undertaken to determine the factors influencing the usage of BIM to decrease or lessen the operating LCCs. The research was initiated to gather insights from employees through interviews. The data collected were suitable for the purpose of the study as they accurately capture the perceptions of these employees. The expert architects/engineers were selected for interviews by considering the research purpose. The target population was approached to ensure their reasonable opinions regarding BIM and LCC. Purposive sampling was suggested as suitable since this methodology relies on the measurements and aptitude of the targeted engineers as participants to avail the provision of the information concerned. Furthermore, two case studies were analysed based on the cost information of the two case study projects, and a reflection on the effect of implementing building information modelling (BIM) is presented based on the analysis of the two case studies, as shown in Figure 1.

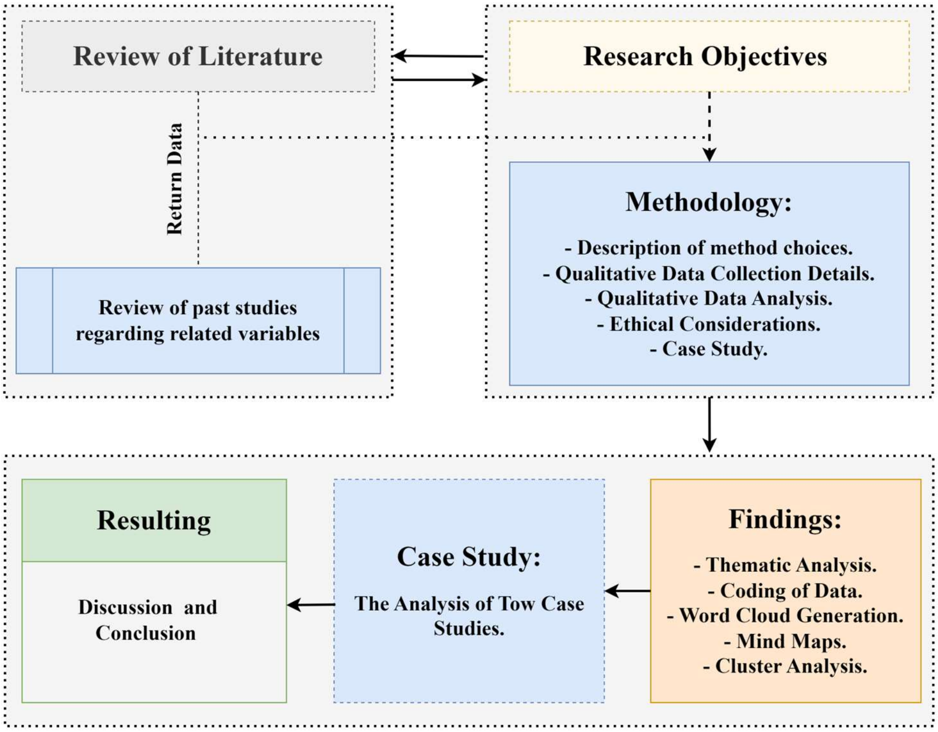

Figure 1. Process of conducting research.

2.2. Data Collection

The data gathered in the research were collected through interviews to confirm the accuracy and adequacy of the engineers with whom discussions were conducted. The researcher thus attained permission from the authoritative representatives of the KSA construction industry. The engineers were well-informed concerning the study's purpose and constructs. The core reason for informing the engineers previously was to gain their feasibility and significance in response to the interview questions asked. The interviews involved 30 experts of BIM and were held between January and March 2022. The experts in BIM were invited and contacted for this and briefed on the nature and purpose of the research, which also ensured that the interviewees were familiar with the subject. The interviews were conducted in four KSA regions, requiring effort and time to travel in the targeted areas, such as the western, eastern, northern, and central regions. The meetings were conducted in Arabic and then translated from Arabic to English. VOZ voice recording software was used to save the discussions. The questions contained queries regarding building information modelling, life cycle estimation, the impact of BIM on LCC, and the impact of the contract types on BIM.

2.3. Data Analysis

The data were analysed using thematic and word cloud analysis. Four themes, identified during the interviews, were established for the analysis. The most frequently uttered words by the target interview candidates were analysed and are depicted in bold pictures. The data analysis included the investigation of complex objects through the identification of central themes. Thus, the research was conducted using codes, ideas, and categories utilising NVivo 2020 software. This software analyses qualitative data from the outset and allows for codification and categorisation. In the successive phase, the researcher reviewed the themes, significant themes were defined and renamed, and results were drawn. The second phase contained word cloud and cluster analysis. Through the word cloud analysis in the second phase, specific words appeared in the textual data source, and bolder and bigger words appeared in the word cloud. The word cloud represents the interview findings visually.

3. Results and Discussion

3.1. Interview Description

Specific criteria were considered for selecting the BIM experts: they played key roles in the construction industry and had experience with BIM; they had tried to use BIM in recent projects; in addition, they had experience in cost management, design, project management, and operational management. The interviews were held face-to-face for efficient interactions with the participants. Table 1 shows the five stages used to structure the discussions.

Table 1. Interview questions directed at the BIM experts.

Section	Description
1	Participant background
2	Building information modelling (BIM)
3	Life cycle cost estimation (LCC)
4	Impact of BIM on LCC
5	Results of the types of contracts on BIM

3.2. Thematic Analysis

Through the identification of the basic themes, complex objects could then be focused on with the help of NVivo. This software allows for categorising information according to codes, ideas, and other subjective considerations. Based on this, the four core themes discussed in the following sections were formulated.

3.3. Coding of Data

Based on their initials, the responses were coded. Table 2 provides their details and identities. The coding procedures were undertaken to ensure uniformity for the qualitative analysis of the study. Utilising NVivo, the coding procedure depicted in Table 2 was completed manually. This coding is basically a description of the participants' position (respective designation of participants), experience in the construction industry, and experience relative to BIM. The core themes helped to conduct the qualitative analysis, as represented in Figure 2.

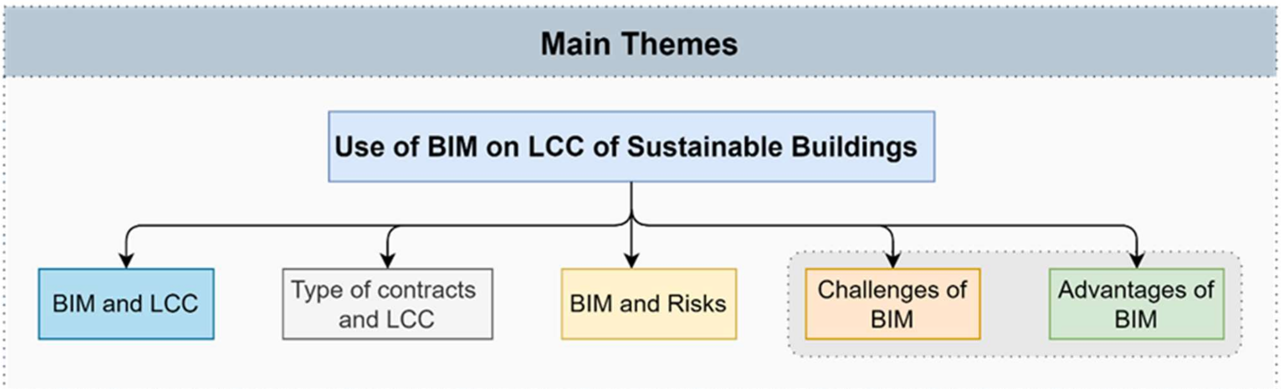

Figure 2. Theme identification.

Table 2. The interview codes and data of BIM specialists.

No.	Participant Code	Position	Experience in Construction	BIM Experience
1	DAA	Owner of the office of Al-Yusifi Value Engineers	30 years	30 years
2	DAB	Assistant Professor	12 years	12 years
3	DABi	Assistant Professor in the Geomatics Department	15 years	7years
4	DI	Co-Professor	8 years	8 years
5	DMA	Project Office Manager	12 years	4 years
6	DY	Director of the Digital Operations Department	18 years	14 years
7	DYA	Director of the General Administration of Modern Building Methods	11 years	4 years
8	EAM	BIM and Digital Transformation Lead	26 years	12 years
9	EAH	BIM Manager	10 years	10 years
10	EA	Technical Director	22 years	10 years
11	EAA	Director of the Projects Development and Support of District Buildings Department	25 years	2 years
12	EAAO	Director of the Engineering Design Department	21 years	3 years
13	EAD	BIM Specialist	8 years	8 years
14	EB	Project Manager, Civil Engineer	18 years	6 years
15	EF	Structural Engineer	15 years	6 years
16	EH	Head of Studies and Cost Control Department	16 years	11 years
17	EHT	BIM Lead	15 years	7 years
18	EIE	CEO AIDIGITS Group	32 years	25 years
19	EK	Program Manager	5 years	5 years
20	EMAD	Senior BIM manager	8 years	8 years
21	EMAH	Director of Engineering Management	18 years	5 years
22	EMBT	Central Judge and Head of Facility Management	5 years	2 years
23	EMD	Project Manager	19 years	7 years
24	EN	Project Manager	5 years	8 years
25	EO	BIM Manager	21 years	18 years
26	ERF	BIM Specialist	16 years	6 years
27	ESA	Undersecretary for the Presidency in Technical and Operational Affairs	16 years	4 years
28	EY	Project Control Engineer	1.5 years	2 years
29	EZA	Mechanical Engineer Consultant	14 years	2 years
30	FAR	KAFD Maintenance Manager	7 years	5 years

The main arrows in Figure 2 show how each theme relates to the main topic. The definitions of the themes enabled some sub-categorisation, as shown in Table 3. This procedure also enabled us to prioritise the sub-themes. As a result, a total of 168 entries was obtained, as depicted in Figure 3.

Table 3. BIM specialist data and interview codes.

No	Main Themes	Sub-Themes
1	Building information modelling (BIM) and life cycle cost (LCC)	▪ Coordination ▪ Efficiency of LCC ▪ Visualisation ▪ Knowledge of BIM ▪ Value study
2	Type of contracts and LCC	▪ Failure of projects ▪ Contract effect ▪ Owners' choice
3	BIM and Risks	▪ Accuracy of data ▪ Unavailability of data
4	Advantages and Challenges	▪ Automation ▪ Coordination ▪ Lack of regulations ▪ Expensive software

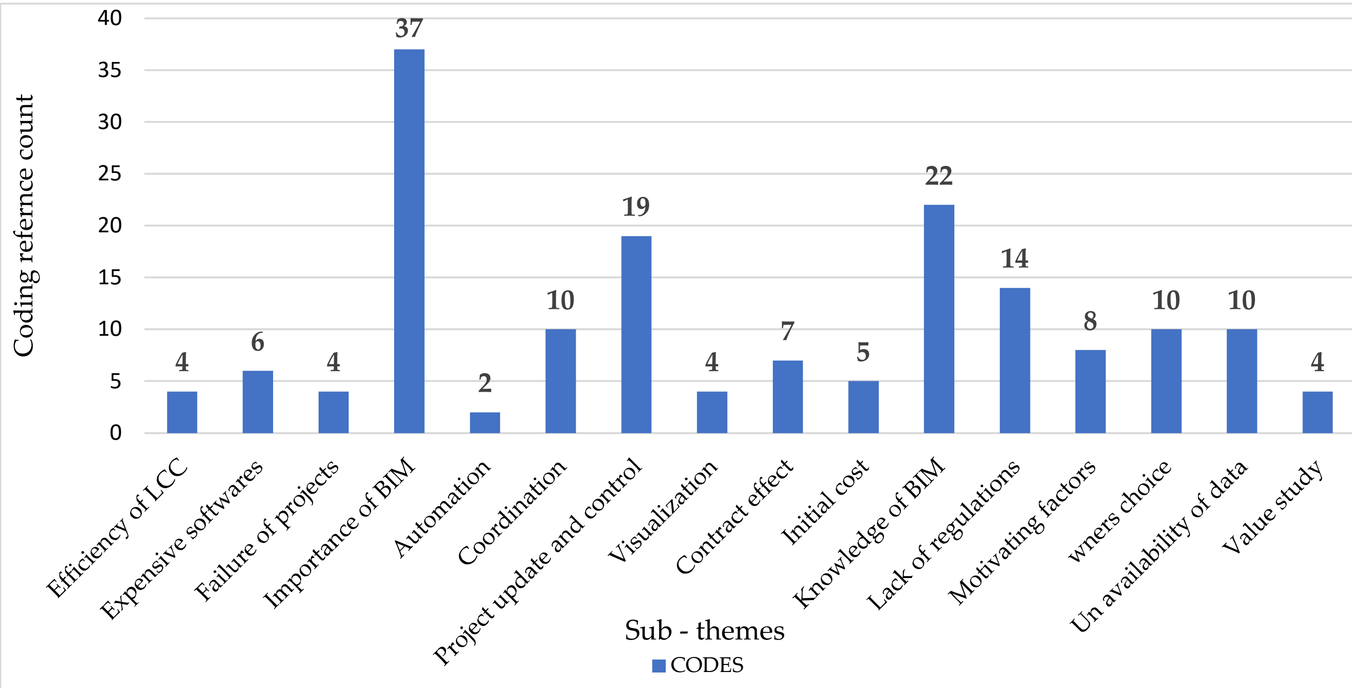

Figure 3. Sub-theme references with coding.

The five primary themes were subdivided into various sub-themes, of which "Importance of BIM" received 38 references in the interviews. A total of 19 and 22 references were obtained for "Project update and control" and "Knowledge of BIM", which emphasises the importance of BIM's role in project management and the necessity for knowledge of it. In contrast, sub-themes such as "Accuracy of data" and "Value study" received fewer mentions, suggesting they are not currently the primary concerns of the industry. In essence, the significance and implications of BIM in project management and knowledge dissemination are highly prioritised by professionals, as shown in Figure 3.

BIM is typically used to produce or manage information covering the building's life cycle. Using the various tools and libraries, each aspect of the construction project is detailed and linked to any other relevant aspect. The use of BIM leads to significant reductions in unnecessary costs and substantial increases in productivity, as it enables the elimination of unneeded activities. These types of savings and other benefits have been identified by the responses—see, for example, the following quote taken from our recording database:

> *"If we consider logic into account, who attains the most from the Revit program? The owner who represents projects? The ministry of finance is thus intended to be the lawmaker, and it is assumed to require all the quantities and costs from the BIM model to be extracted."* (**DY**)

The majority of interviewees agreed that the government in the KSA is liable for implementing BIM for the simple reason that most revenue coming from construction activities increases the GDP, hence fuelling the growth of the KSA.

> *"Each owner of the project is responsible for technology implementation. I think this applies mostly to governmental projects."* (**EAA**)

Figure 4 below presents information captured by other researchers indicating that the importance of estimating life cycle cost in a project is crucial in the design phase, which also informs the decision making. In this case, 96.7% of the participants agreed with this fact. Contrary to this, when asking about the frequency of LCC analysis of real projects, the interviewees stated that 50% of the projects they have engaged with did not include an LCC examination. The rest of them confirmed that LCC analysis had taken place.

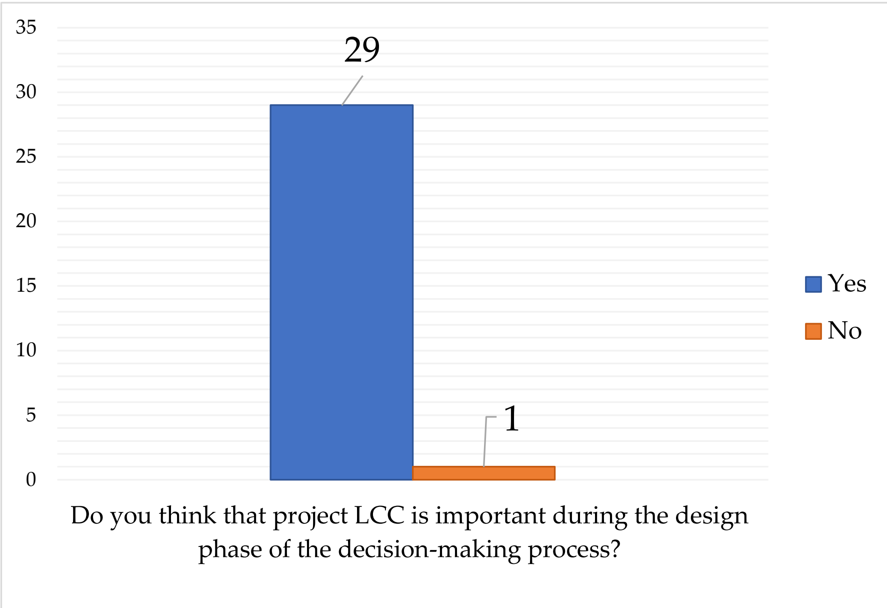

Figure 4. Significance of LCC analysis during the design phase.

The way BIM is executed changes from project to project, even though BIM has now been in the market for a while. As this is the case, construction contracts include an agreement between construction and design services in the construction investment section. When participants of our interviews were asked about the impact of the contract type on LCC, many estimated that the contract type mainly affects the final price but not so much the internal processes of phases.

> *"In my opinion, the contract and types of life cycle cost do not have any effect as every project is different."* (**DY**)

On the other hand, contract clauses oblige all the parties working on a project to share risk and profits in proportion to their own level of engagement and responsibility. For example, in the integrated project delivery (IPD), a subcontractor of essential building elements is invited to finalise a joint agreement with the ordering party. The IPD integrates people, systems, structures of businesses, and practices in a procedure that collectively optimises the results of a project. In this sense, BIM is helpful because it facilitates decision-making and enhances collaboration. The increased use of document creation in BIM has therefore been observed in the construction phase in the design stages, yet some gaps remain in Saudi Arabia's engineering practices, as even when a LCC was in place, extra costs at later stages could not be prevented.

> *"There are some projects in which the (initial) construction cost is not high, but it may be found later that it requires a higher cost. And you come to know at the later stage of maintenance and operations. So, it can be said that cost estimation works only like 60% of the time."* (**EY**)

Figure 5 shows the percentage of respondents who agreed that the type of contract design, application, operation, and their associations affect the final project cost. This figure was as high as 98.7% of the participants.

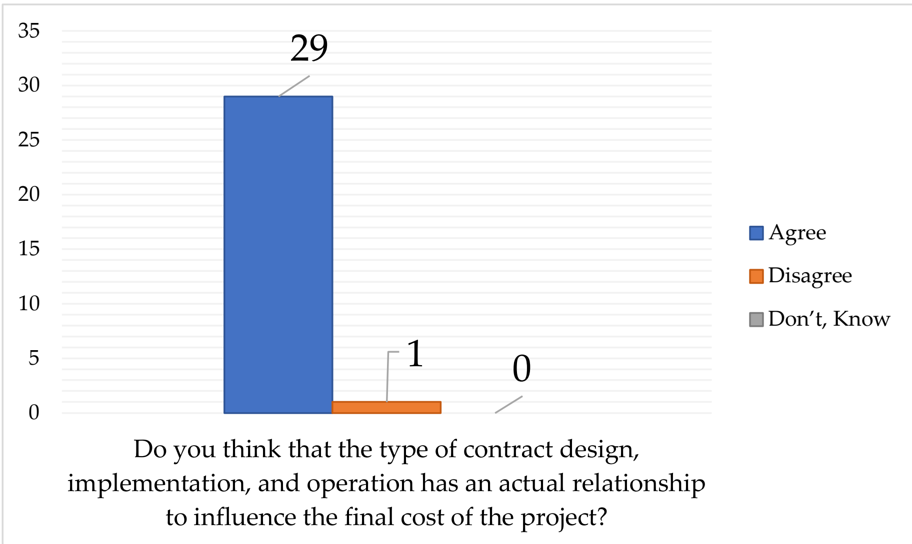

Figure 5. Contract types and final cost.

Notwithstanding the various benefits of using BIM, there are also risks and challenges associated with it that are crucial to consider. A significant risk relates to the transference of data from an old to a new BIM release as data can be lost, hence unconfiguring the project. In addition, significant investment is required for adopting BIM and training employees. This could hinder its use by small to medium enterprises.

> *"In my opinion, the only thing we are missing in KSA are regulations, everything is ready, and awareness has increased. There is greater awareness, but we lack regulations that the imposition of projects with proper regulations and constraints effective outcome can be attained."* (**DAB**)

> *"It is risky to apply BIM if no construction industry regulations exist. The legal provisions for intellectual property, data ownership, and cyber security are lacking in the BIM procedures and policies. There is a lack of standard BIM contract as no system for resolving disputes existed."* (**EMBED**)

The implementation of BIM is constantly increasing because of the favourable outcomes and benefits associated with it. However, its deployment allows users to have higher control over the challenges and risks identified above. As an initial step, BIM users propose that potential risks and challenges be identified first to then develop an effective risk mitigation strategy.

"*The main challenge is that people still use things according to their convenience. This is the old-school social resistance to BIM. There is, however, a small lag in implementing the technology too. If I talk about platforms, the Bentley and Revit have become expensive*." (**DI**)

The early detection of a problem would, therefore, be at the top of priorities. BIM is a novel technology that has been adopted rapidly in the construction business to maximise the aesthetical and durability features intended by designers. Through BIM, it is feasible to design in virtual environments, which opens up plenty of room for design optimisation.

"*The advantages are information sharing with the other stakeholders such as design*." (**EMAD**)

"*I believe that the use of BIM has multiple advantages, the most prominent of which is the attainment of the aim of all stakeholders, including owner, consultant, contractor, or even the PMO. The involvement of stakeholders reduces costs, saves time, and enables faster and wiser management*." (**EMBED**)

The main conclusion drawn from the analysis is the lack of familiarity of stakeholders with BIM. The KSA is expected to be liable and responsible for implementing BIM, but effective regulations, identified as key in the process by stakeholders, are still lacking in the KSA. At this point, there is no instance within the country that acts independently to solve this problem. Figure 6 shows the most frequent keywords captured during the interviews and it can be seen that many of these directly relate to building regulations. Due to their frequent use in the word cloud, the words "cost", "project", and "design" have connotations. In contrast to its conventional association with monetary expenditures, the term "cost" emphasises instead the strategic use of BIM for optimal budgetary planning and value extraction. A project is also more than simply the completion of a task in the traditional sense. The BIM integration strategy represents a comprehensive approach to project life cycle management, which prompts a comprehensive assessment of its extent and scope. Additionally, "design", traditionally associated with aesthetic and structural considerations, emerges as a primary determinant in the decision-making process today. To achieve overarching project goals, integrative design methodologies must be considered.

Figure 6. Word frequency in the interviews.

The existing low awareness among stakeholders regarding the capabilities of BIM for saving costs often results in missed opportunities, especially when it comes to contract development and adding BIM as a part of the contract. However, stakeholders in Saudi Arabia who do not adopt BIM often overlook the additional benefits that could be derived from developing contracts commensurate with adopting BIM. Therefore, contractors and designers must be encouraged to dig deeper into BIM capabilities and exploit those more. The ups and downs experienced by our interviewees from the KSA as related to their experience with BIM yielded the cloud of keywords shown in Figure 7.

Figure 7. Word frequency regarding BIM implementation.

The word cloud frequency analysis presented in the previous section was followed by a cluster analysis. This is a technique through which naturally occurring groups are clustered to then be examined in more detail. This research incorporated clustering as a data mining technique to assess the usefulness of BIM in the LCC of sustainable buildings. The process was guided by the four themes discussed in previous sections. From there, each theme could be unfolded concerning the clusters, the results of which defined what are called mind maps, as seen in Figures 8–11. Using mind maps, the thematic analysis was visually organised according to hierarchy, which exhibits how queries related to the responses from the interviewees, per theme.

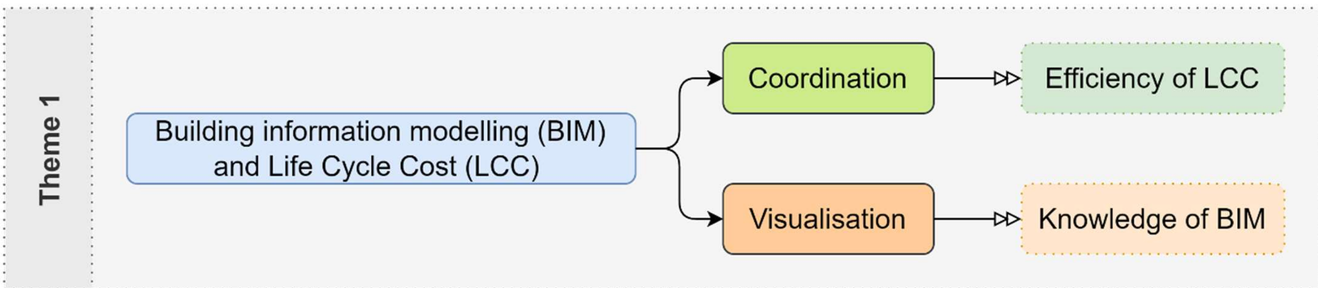

Figure 8. Mind map for Theme 1.

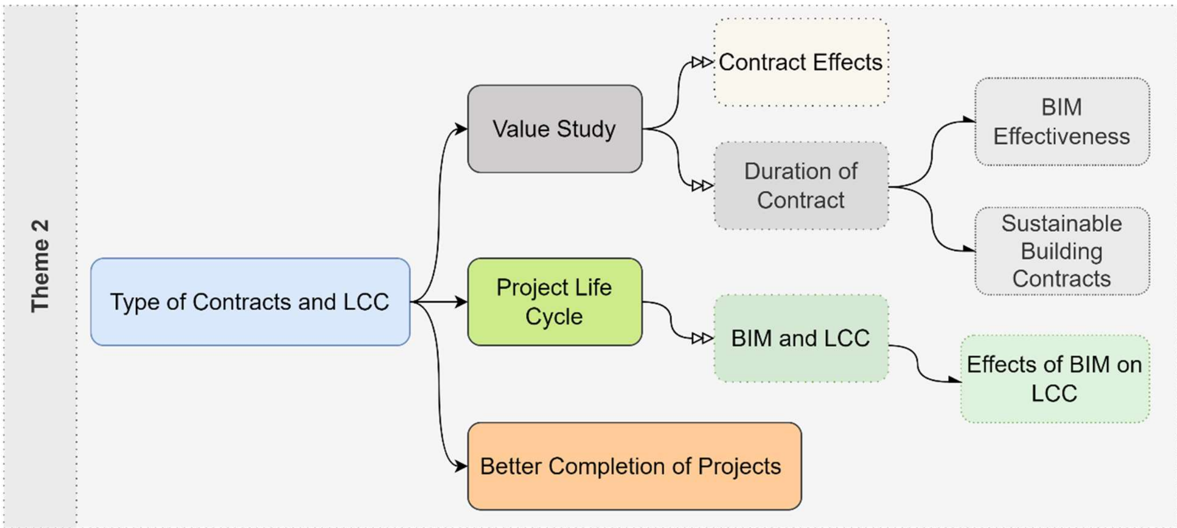

Figure 9. Mind map for the theme 2.

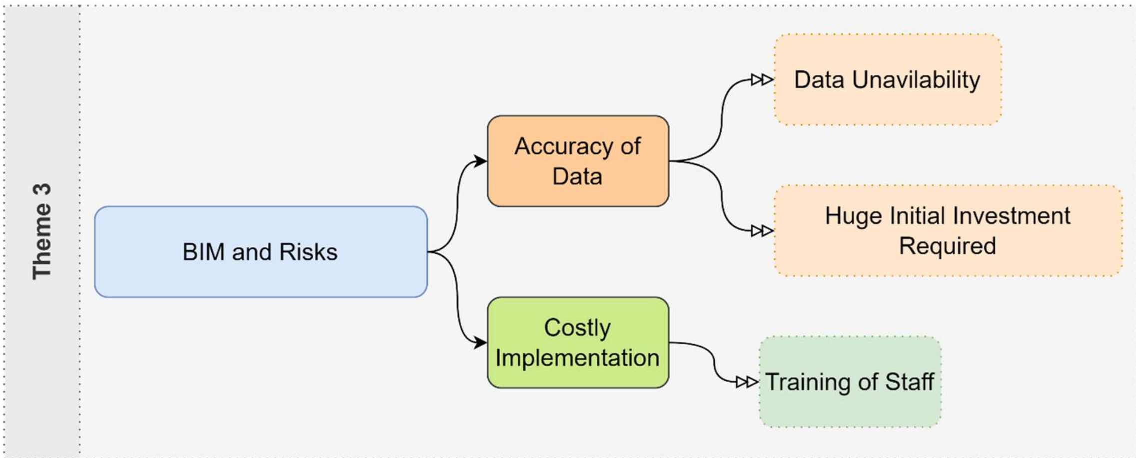

Figure 10. Mind map for Theme 3.

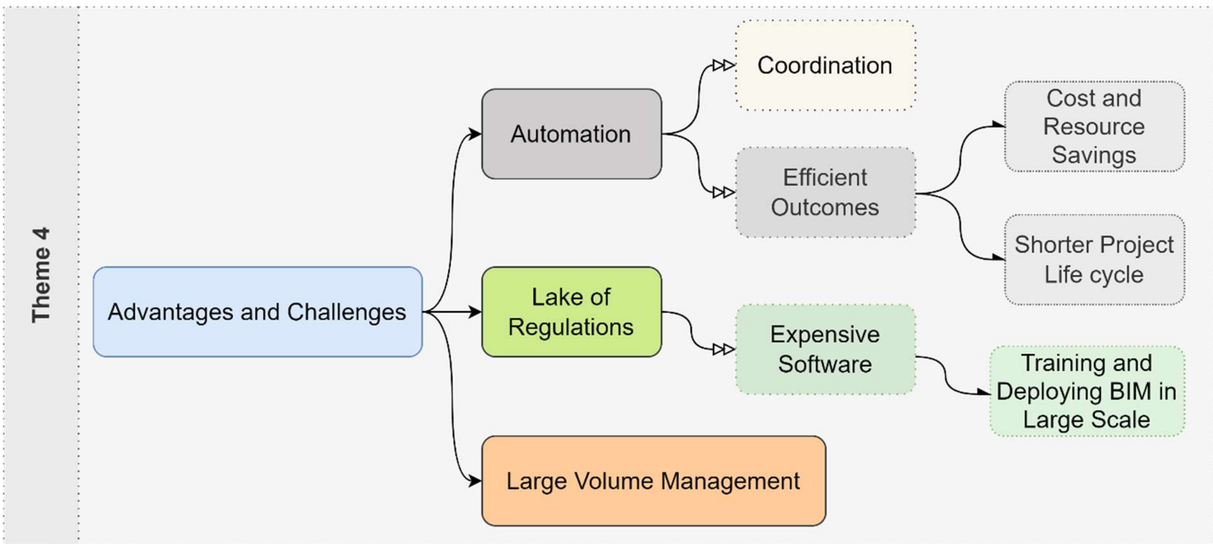

Figure 11. Mind map for Theme 4.

Figure 8 refers to the main theme, namely building information modelling and life cycle cost. The figure shows four sub-themes that were derived from it; these are LCC, knowledge of BIM, visualisation, and coordination. BIM's comprehensive modelling capabilities facilitate the importance of holistic financial planning throughout a project's life cycle by integrating the LCC.

Figure 9 shows multiple sub-themes related to the types of contracts and LCC. The sub-themes included the duration of contracts, value study, BIM and LCC, BIM effectiveness and better completion of projects, amongst others. Note that sustainable building contracts could potentially enhance the existing suite of types of contracts and LCC.

The third main theme analysed was the use of BIM and associated risks, for which four sub-themes were identified, as shown in Figure 10. These sub-themes show that data accuracy could be an issue. Other sub-themes included costly application, training costs, huge initial investment required, and the unavailability of data.

As discussed previously, BIM generates various benefits that are inevitably accompanied by multiple challenges, including lack of regulations, large management resources, costly software, training, and deploying BIM at large scales. In this analysis, automation was seen as among its more recognised advantages. The mind map shown in Figure 11 also includes efficient outcomes and coordination, by which the life cycle of projects (planning–design–construction) becomes shorter, which increases cost and revenue. Through effective coordination and the pursuit of efficient outcomes, the traditional project life cycle can be significantly shortened. In addition to reducing costs, this can also result in earlier revenue generation and enhance the financial viability of the project.

3.4. Case Studies in the KSA

3.4.1. Case Study 1: Residential Project (900 units) in the KSA

In this case study, approximately 900 residential structures were equipped with essential building equipment that allowed building operations to be carried out. As part of this project, 900 residential units were constructed, along with fences, external gates, and groundwater tanks. Moreover, the site was levelled, which included determining how the housing units relate to the levels of the roads. This can be seen in Figure 12.

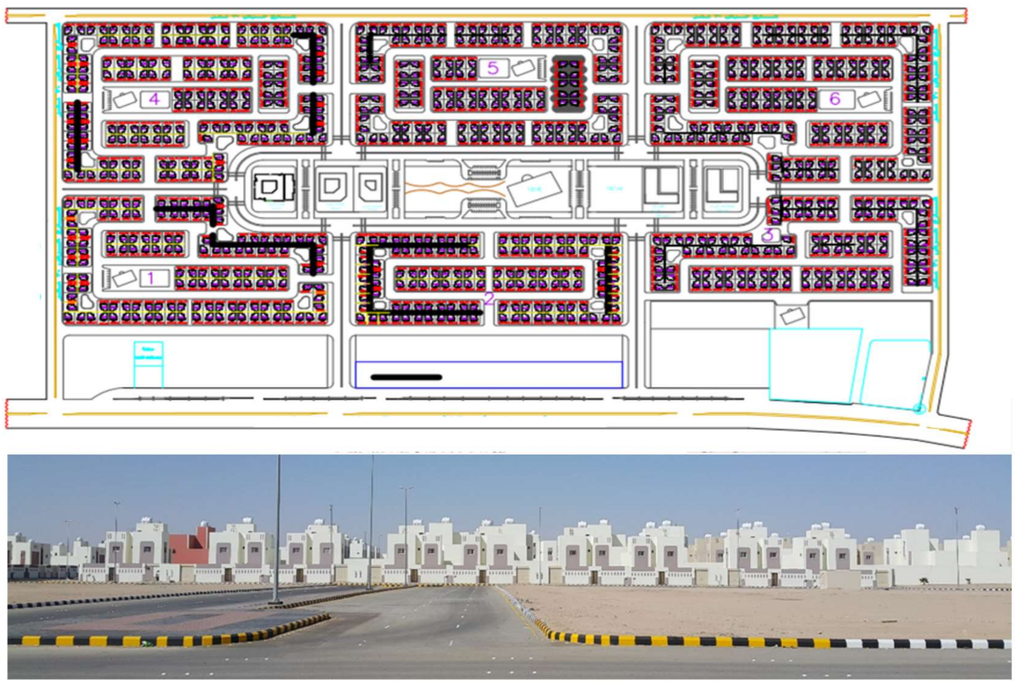

Figure 12. The site plane and panoramic elevation of the project.

The residential units have three bedrooms, a sitting room, a living room, three bathrooms, and a kitchen. The units' building area is around 294 square meters, and they have one and a half floors. A reinforced concrete slab was used in the construction process. The 350 kg/m^3-concrete one-way hardy slabs consist of concrete blocks of 25 mm inserted into each other to form a slab. This stack of blocks was then secured by arranging formwork around them and adding reinforcement between them every 60 cm. Two 8 mm iron bars were used to connect the wall horizontally every 60 cm. See Figure 13.

Figure 13. The design of the residential units' ground floor, first-floor plane, and perspective.

The project was expected to be completed by 2012, according to the contract. However, two additional terms delayed the project by three years. As a result of the expanding scope of work, project costs increased. As a result of the project owner agreeing to extend the first extension period for 16 months, the project budget increased by USD 7,019,257.98. Additional items that were not covered by the contract were also extended for another 18 months, resulting in a project cost of USD 1,635,840.5.

In 2015, costs increased by 9.89%, while the contract implementation period increased by (1003 days), which accounted for about 92.87 per cent of the primary contract period. This project delivery was delayed significantly due to the need to conduct a thorough analysis and study of the project. This resulted in several changes and additions that caused a delay in its completion. See Table 4.

Table 4. Information on implementing the project.

Information of Project			
Project Contract Value USD 86,740,933.6	Contract Period 1080 Days	Final Project Value USD 95,327,964.06	Increase in Cost 9.89%
Consultant Contract Value USD 5,426,034	Area 1,185,000 m^2	Type of Contract Unit Price	Level of BIM Used 2D
Contract Signing Date 26 July 2009	First Receipt of Project according to Contract 17 July 2012	Final Receipt of Project 16 April 2015	Extra time of Contract Period 1003 Days

The disadvantage of not using BIM: In this case, several changes were made during the design and implementation phases of the project due to the lack of the use of BIM:

1. Approximately USD 8,657,721.81 was spent on the new works that did not have a parallel in the contract. See Table 5.
2. As a result of the lack of an optimal topography survey and level survey of the site, and the lack of a 3D model of the survey area, the owner of the project added a new item (retaining walls). The new item was implemented by square meters of reinforced concrete (reinforced concrete foundation, retaining walls). In order to meet the requirements of the differences in levels among the housing units, a revised clause was implemented.
3. Due to the lack of use of BIM, an item was added (automatic vertical rolling garage doors size 3 × 2.7) for 900 units, which needed to be remembered when engineering calculated quantities manually.
4. The owner of the project added a new item (a wooden frame to hold the window air conditioner and kitchen hood). The specifications were that it was made of solid Swedish wood, a thickness of one inch, and a width that matched the wall thickness, for 900 units.
5. The project's owner added cast iron covers to the project. Cast iron was used in the covers of tanks with dimensions of 60 × 60 cm, weighing no less than 80 kg, for 900 units.
6. The owner of the project added concrete colour tile flooring for outdoor use to the project. The supply and installation of concrete colour tile flooring for outdoor use had dimensions of 40 × 40 × 4 cm. This was to create a walking path with a normal cement layer ten centimetres below it.

Table 5. Information on the cost for the changes in scope of the project.

The Changes Scope of the Project	Cost
The value of the additional work was unparalleled in the contract	USD 7,019,257.98
The value of the project increased	USD 1,635,840.50
Project savings value	USD 0.00
Total	USD 8,655,098.48

According to the case study, the delay was caused mainly by inadequate planning by the project owner and a lack of as-built drawings during the study and design phases. In consequence, the costs of project elements increased. Moreover, the process of offering the project as a public competition and procuring it introduced a strong focus on the cost of bids. This focus neglected the effects of technical data on the project and the bidders. In consequence, the orders of the project when it was under implementation frequently changed.

3.4.2. Case Study 2: King Abdulaziz Center for World Culture (Ithra) in the KSA

This project was completed in the King Abdulaziz Center for World Culture (Ithra) in Dhahran city in the Kingdom of Saudi Arabia in 2016. The project consists of several components, including one tower building with 18 floors: (a variety of cultural amenities, keystone, and plaza, including an auditorium, a cinema, a library, an exhibition space, a museum, a cinema, an innovation forum, an oasis, a great hall, and an archive). In 2007, It was designed by the Snøhetta company. Consequently, integrating the design and implementation phases of such a building took considerable time. The King Abdulaziz Cultural Center achieved the LEED Gold certification of sustainability. See Figure 14.

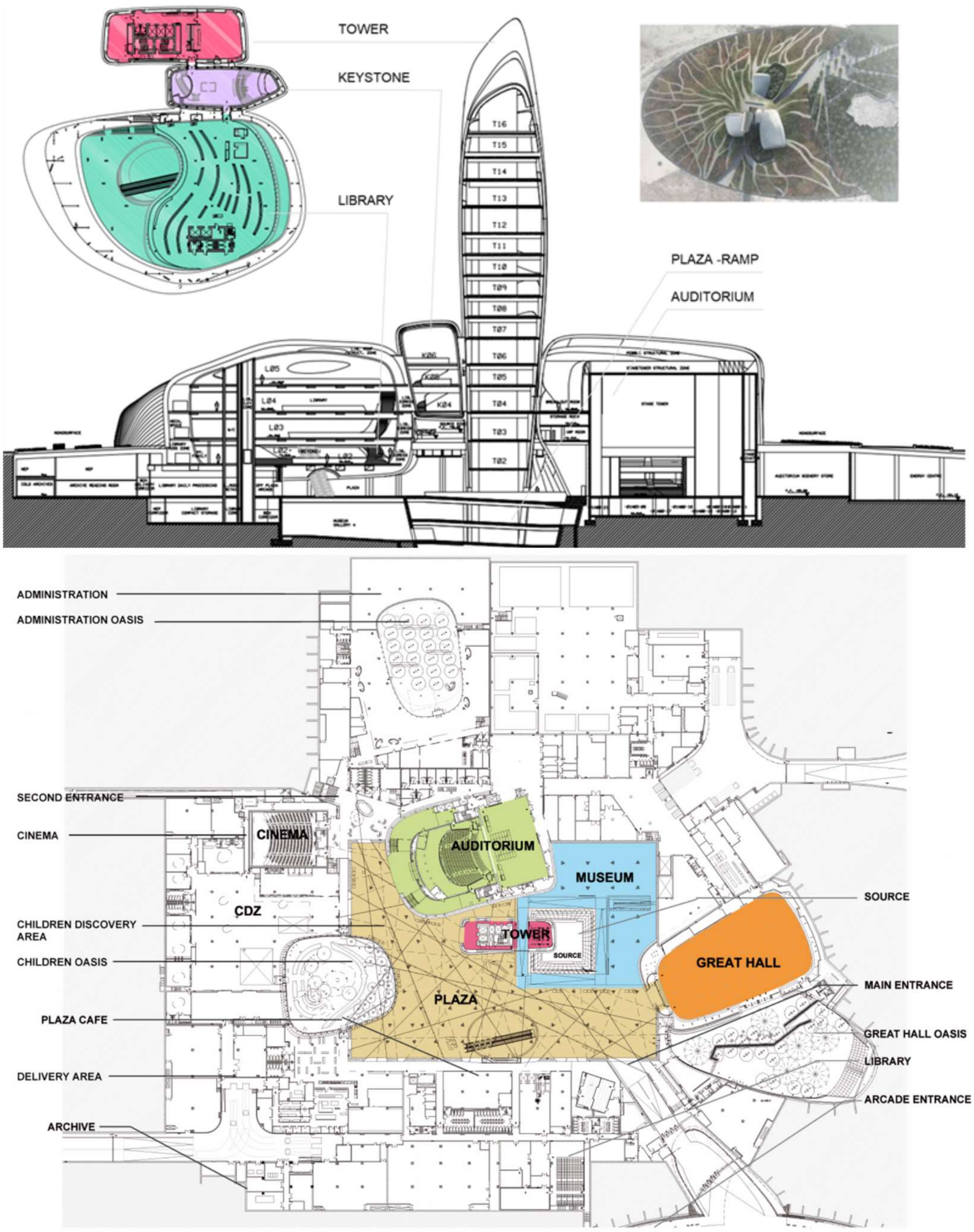

Figure 14. Main section showing building levels and ground floor.

The King Abdulaziz project utilised BIM during both the design and implementation phases. As a result, the project's final cost was as expected, and there was no delay in the implementation schedule. In view of the fact that scheduling is so imperative to the success of a project, it is essential that schedules be properly classified. This is so that they can be included in the estimation. Especially with larger projects, calculating all of the elements from a 2D plan can be time-consuming. Consequently, BIM enabled the design process to be more collaborative and allowed for the creation of 3D, 4D, 5D, and 6D in this project. See Table 6.

Table 6. Information on implementing the project (Ithra).

Information of Project King Abdulaziz Center for World Culture (Ithra)			
Project contract value USD 400,000,000	Contract period 2008–2016	Final Project Value USD 400,000,000	Increase in Cost 0%
Consultant contract value Consulting by Saudi Aramco	Area 100,000 m^2	Type of contract Unit Price	Levels of BIM Used 4D, 5D, 6D
Contract Signing Date 20 May 2008	First Receipt of Project according to Contract 20 October 2016	Final Receipt of Project 20 October 2016	Extra time of Contract Period 0

The structure of the building includes polygonal steel grids enclosed by steel supports and reinforced concrete slabs in an envelope structure. Seele [58] indicated that individually shaped stainless-steel tubes are tightly wrapped around the subtle curves of the building's exterior cladding, which totals 350 km (stainless steel tube facade: 30,260 sqm, standing seam facade: 28,600 sqm). Accordingly, the Seele company [58] completed most of the construction work before moving each phase of the implementation process to the preparation phase. The planning process included detailing a 3D model, defining parameters, managing risks, integrating material expertise, and integrating logistics expertise. See Figure 15.

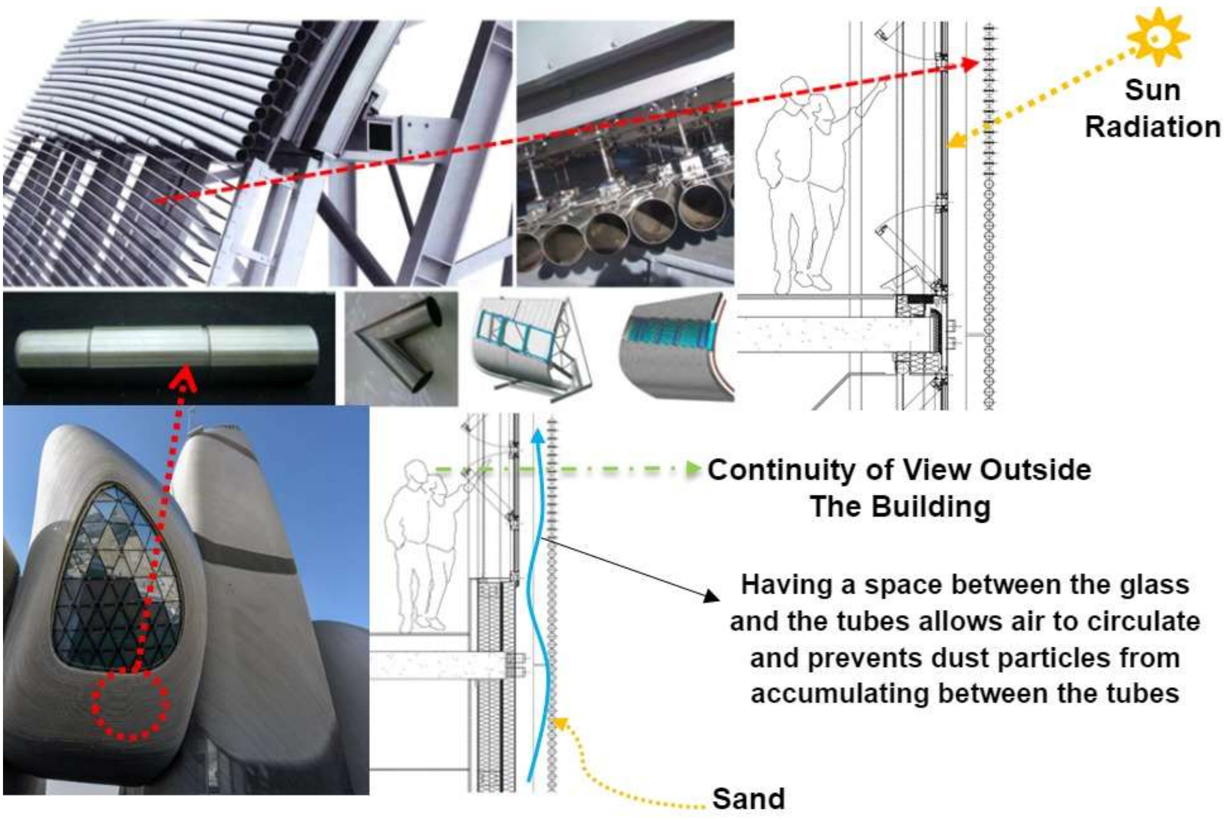

Figure 15. Explanation of the proposed design for the building's exterior facade.

As a result of adopting BIM for the Ithra project design phase, the designers were able to identify potential clashes in the design and mitigate them, ultimately improving the design's overall effectiveness. Although quantifying the exact amount saved is challenging, the adoption of BIM undeniably contributed to the overall efficiency and cost-effectiveness of the project. For this project, several engineering software programs compatible with BIM were used, including Revit software and Tekla software, to coordinate the structural, mechanical, and electrical systems. See Figure 16.

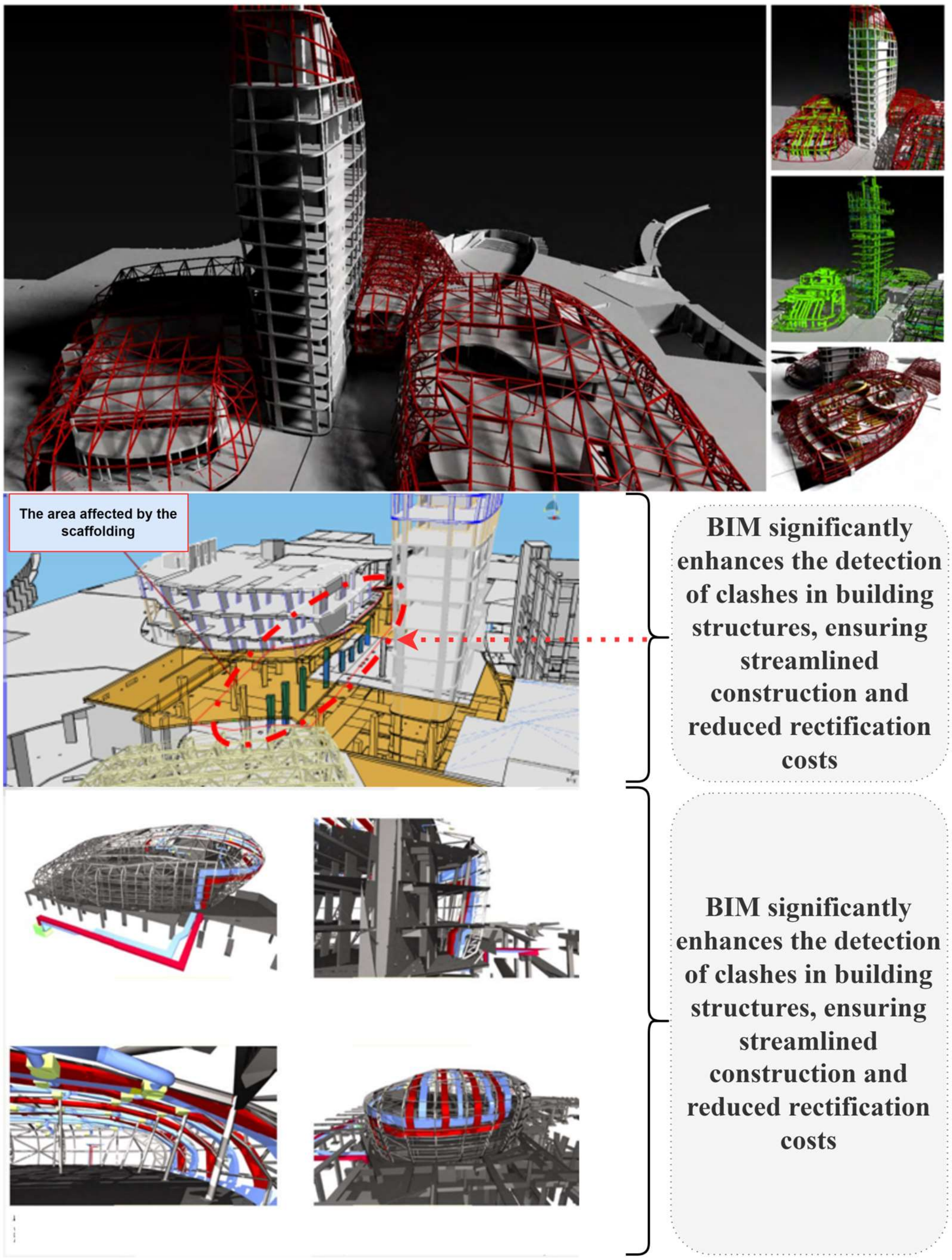

Figure 16. BIM collaboration to avoid clashes among engineering systems.

Based on the case studies, it has been concluded that the lead management of the owner needs to promote BIM adoption across all project processes, and strategies should be developed in order to facilitate the maturation of the BIM execution plan during the design, construction, and operation phases. Significantly, the use of BIM during the project phases is expected to eliminate the majority of the delays mentioned above. Through the use of BIM, stakeholders are protected from delays, omissions, and errors in drawings.

Additionally, BIM facilitates decision-making, assists in detecting clashes, and enhances communication among all stakeholders during all phases of a project. This study addresses delays related to clients, delays in decision-making, delays in bid submission, and poor coordination. Moreover, the results of the comparison between the study cases, which are summarised in Table 7, confirm the effectiveness of BIM.

Table 7. An overview of the results of the case studies.

Case Studies	Type of Project	Type of Contract	Levels of BIM	Increase in Cost	Increase in Days of Project
Case Study 1	Residential	Unit Price	2D	9.89%	Yes
Case Study 2	Tower	Unit Price	4D, 5D,6D	0%	No

The combination of the two case studies illustrates how BIM can transform construction and project management. Without BIM, projects may experience unforeseen delays and cost overruns, as demonstrated in the first example. However, BIM can help projects adhere strictly to schedules and budgets, as demonstrated in the second example. BIM provides a comprehensive overview of a project with its multi-dimensional approach, ranging from 3D visualisations to 6D sustainability representations. Additionally, BIM serves as an effective tool for risk management, anticipating and effectively addressing changes in a project's scope, thereby enhancing interdisciplinary collaboration and reducing potential misunderstandings among stakeholders. For large-scale projects in particular, BIM streamlines both the design and execution phases. It not only reduces errors but also offers more precise estimates of project costs and timelines compared to traditional methods. As a result of the case studies, it is evident that BIM plays an essential role in ensuring that projects are completed on time and within budget.

The results of our qualitative analysis show that practical training, awareness, and, most significantly, proper regulations are required for maximising benefits when using BIM. The literature review already highlighted the important contributions of the construction industry to the GDP in the KSA. After our analysis, it becomes clearer that the upgrading and innovating of construction processes is of paramount importance to observe sound finances in the future. In many industrialised countries, BIM has made its name in architecture, construction, and engineering, but most countries are reluctant to join this trend because of the heavy cost associated with its implementation. The regulatory bodies or governmental authorities of such countries are held liable for promoting the best practice seen in other countries. Project coordination and communication also improve with the application of BIM. The present study aimed to analyse the advantages of BIM, challenges with its implementation, and the association between BIM and LCC.

The present research presents a comprehensive analysis, and based on interviews with the respondents, this research provides evidence that BIM and LCC are closely associated. Notably, the findings reveal that BIM ensures greater transparency in the design phase of projects for the parties liable for considering the material sustainability and design principles before the contractors even break ground. In addition, there are multiple categories of contracts in the construction industry in which the owner has the freedom to select arrangements to settle with the contractors to undertake their projects later. However, the adoption of BIM in the construction industry of Saudi Arabia exhibits the huge challenge of increased installation and training costs associated with its application. Despite these challenges, BIM has been beneficial in the Kingdom by providing better estimates, reducing uncertainties during construction, and improving the quality of finished projects.

The challenges also include a lack of appropriate guidelines regarding BIM, increased BIM investments and insufficient BIM technical knowledge and information. The present study also entails information regarding high life cycle costs. However, choosing construction materials by engineers is usually constrained by the strict requirements of the budget. For this purpose, the construction industry of the KSA ensures a significantly better evaluation of the long-term cost efficiency of a project to avoid the problem of higher life cycle costs. As a result, the material selection for a new construction project is generally based on a person's experience, suggestions, or the producer's knowledge. In addition, an analysis of case studies was also performed to evaluate the effectiveness of BIM implementation in real-world projects. The results demonstrate that for the first case of the residential project in KSA, there were many disadvantages due to not using BIM. Consequently, by not using BIM, the project's cost and time increased. The analysis of this case also declared that the delay resulted mainly due to the inadequate planning carried out by the owner of the project and a lack of adequate building drawings during the design and study phases. As a result, the project element cost increased. The results of the second case identify the importance and benefits of implementing BIM. The results highlight that the management of the projects must emphasise the promotion of BIM across all of the processes of projects. Effective strategies are, therefore, required for the facilitation of BIM adoption during the designing phase, the construction phase, and the operation phases. Furthermore, effective usage of BIM also results in the elimination of major project delays, as indicated by case study analysis.

The study holds greater significance because construction industries flourish globally, entailing a central portion of GDP. This adds valuable insights for researchers by contributing to the BIM literature. Numerous global studies have been conducted to explore BIM and its adoption, demonstrating its established presence internationally. However, in the context of the KSA, BIM can be seen as a novel technique. There is a noticeable scarcity of localised literature in this field, with only a few studies elaborating on its pros and cons and overall impact on project accomplishment in the KSA. Therefore, further research is needed to fully understand and optimise the use of BIM within the specific context of the KSA. This study adds valuable information on building information modelling to the literature; although the study is based in the KSA, the results can also be generalised to other contexts. The practical benefits of this study are also prominently significant because sustainability and LCC are two main consequences of implementing BIM, which engineers and architects can implement while designing a project. Through this research, the engineers can also gain insights regarding challenges and risk mitigations for BIM incorporation in the construction industry. Globally, the GDP of many countries is associated directly with their construction industries, the betterment of which leads to an overall increase in and improvement of the economy. Lowering the life cycle cost of projects is the main issue because of the wrong projected estimation of the project cost. Through this study, it was shown that the inculcation of BIM ensures a feasible roadmap to exert control over project life cycle cost while aiming to achieve sustainable buildings. Thus, policymakers in the KSA and the global construction industry can also benefit from this study, as construction projects can be made better and more effectively by considering sustainability and lowering LCC by adopting BIM to provoke the concept of green buildings. Moreover, this research also highlights the global need for training employees to use BIM. The results of this research could be of benefit to policymakers or regulatory authorities involved in the construction industry. By integrating BIM into their innovative construction procedures, they could enhance employee awareness of BIM, thus reducing employee resistance to using BIM.

4. Conclusions

In this study, the ways in which BIM contributes to optimising the aspects of cost and performance of infrastructure are explored. The current research began with a literature review to understand previous investigations. Fieldwork was then conducted to gather opinions from those responsible for planning, designing, constructing, and managing construction projects. A qualitative research design was implemented, which was carried out by conducting interviews with 30 BIM experts of the KSA, and then the data were processed with the use of NVivo. It was found that 96.7 per cent of the interviewees agreed that life cycle cost estimation is of crucial importance during the project design phase. Although LCC analysis has been acknowledged theoretically, 50% of experienced project managers have failed to incorporate it into their projects. This indicates a significant gap between acknowledgement and practical implementation. Furthermore, 98.7% of the participants recognised that contract design, application, and operation have an important impact on project costs. Our findings confirm several BIM benefits reported before and some additional ones, as well as the risk and challenges that accompany the use of this technology. Construction professionals who were interviewed during this study believe that BIM immediately features an ability to minimise management effort, fosters communication and coordination amongst project developers, and helps them to identify errors at early stages, which reduces costs and improves quality. BIM contributes to improving the life cycle of infrastructure, attained through consistent time management and strategic decision making.

The research also analysed two case studies to evaluate and compare the usage of BIM and its effectiveness. The results of the case study indicate that the project in which BIM was not utilised experienced several demerits, exerting an overall negative impact on the project, with project delays, cost increments, etc. However, the results of the second case highlight that by adopting BIM, the stakeholders were safeguarded against project delays, errors, and omissions in the drawings. Furthermore, the results of the case study also explain that BIM facilitates decision-making, helps in identifying clashes, and increases the flow of communication among all stakeholders during the project phases. Moreover, there is a significant contribution made by the direct comparison between the two projects (BIM-enabled and non-enabled). Several studies have discussed the benefits of BIM through literature reviews, but this study presents a direct, comparative analysis that highlights tangible differences in the results. As previously discussed, BIM enhances the efficiency and productivity in the project life cycle management process. This study provides empirical evidence supporting this theory in the Saudi context. According to BIM experts, BIM provides a few tangible advantages, including cost savings and the ability to plan and manage projects in depth, which supports earlier academic assertions.

Future researchers can distinguish the research mechanism and target another context other than Saudi Arabia. Furthermore, the primary challenge faced by the construction industry when adopting BIM is the cost. Recognising this, future research can aim to address this issue, providing recommendations to either reduce or eliminate these BIM-related expenses. The training and ease-of-use for employees regarding BIM remains an area of research, as it has been identified as a challenge in adopting BIM for construction projects. Future researchers can address the problem by studying various feasible techniques to train employees to increase their comfort with using and operationalising BIM. The content analysis based on data from different countries' construction industries can also be insightful for future researchers.

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