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A Delphi Study Approach to Prioritising BIM Applications for Construction

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ABSTRACT

As the Saudi construction industry undergoes a digital transformation, the proper integration of Building Information Modelling (BIM) tools becomes critical. This study employs three rounds of the Delphi study approach to systematically prioritise BIM applications that are adapted to the specific constraints and potential of the Saudi construction sector. The study intends to reach a consensus on the most significant BIM capabilities that correspond with the Kingdom's growing construction scene by involving a panel of experts from varied stakeholders such as architects, engineers, contractors and policymakers. The study revealed that the utilisation of BIM software for construction projects can facilitate clash detection, cost estimation, safety and construction monitoring, which play a significant role in the successful implementation of BIM and can help reduce costs, save time, safety and improve quality during construction by detecting potential conflicts and errors early in the design phase. Additionally, the utilisation of 4D, which involves project scheduling and construction sequencing and 5D, which involves construction cost estimation, has subsequent positive impacts on construction projects in KSA. The outcomes of the study will provide significant insights to influence strategic decision-making, boost teamwork and improve the overall efficiency and sustainability of Saudi Arabian construction projects.

1. Introduction

The construction sector is characterized by intense competition, necessitating construction companies to exhibit innovation and competitiveness. In light of the obstacles confronting the architecture, engineering and construction (AEC) sector, the implementation of BIM has been acknowledged as a highly effective novel technology [1]. The implementation and integration of BIM in the AEC sector have enabled enhanced collaboration and synchronization among diverse professions and interested parties while also mitigating the prevalence of issues that have historically afflicted the industry [2]. The BIM model comprehensively represents the building elements'

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geometry, spatial relationships, geographic information, quantities and properties. Additionally, it includes cost estimates, material inventories and project schedule information. BIM facilitates efficient collaboration among the various stakeholders involved in a project, thereby enhancing the effectiveness of the project's lifecycle. According to Saka and Chan [3], the BIM process facilitates the integration of various aspects, disciplines and systems into a unified virtual model. The integration enables all stakeholders, including owners, architects, engineers, contractors, subcontractors and suppliers, to collaborate more effectively and precisely than conventional processes. During the model construction process, team members engage in a continuous process of refinement and adjustment in their respective areas [4]. The principal rationale behind the adoption of BIM is to attain equilibrium within the project management triangle, which encompasses scope (features and quality), cost and time. One of the primary concerns of clients in the AEC industry is of utmost significance. The adoption of BIM in construction projects has been found to offer potential benefits in terms of time, cost and quality optimization [1-5].

The construction industry is distinguished by a high level of competition, which requires construction firms to demonstrate ingenuity and competitiveness. The adoption of BIM has been recognized as a promising technological solution in the face of challenges encountered by the AEC industry, as noted by Fazeli *et al.,* [6]. The adoption and incorporation of BIM in the AEC domain have facilitated improved cooperation and harmonization among various disciplines and stakeholders, while also reducing the incidence of longstanding challenges that have plagued the sector [2]. The BIM model provides a comprehensive representation of the geometry, spatial relationships, geographic information, quantities and properties of building elements. Furthermore, the aforementioned comprises projected expenses, an inventory of materials and details regarding the timeline of the project [7].

Saudi Arabia has been a significant contributor to the oil business; however, the government has determined to move onward with Vision 2030 to reduce dependency on oil revenues. Saudi Vision 2030's most prestigious projects, which include the largest megaprojects under the reform programmes, are NEOM, Qiddiya Entertainment City, the Al Murabba Project and the Red Sea luxury tourism development in the megaprojects of Saudi Vision 2030 [8]. BIM provides an opportunity to address the challenges involved with coordinating elements from various stages of infrastructure development, reducing potential difficulties and boosting a sector critical to Saudi Arabia's economy. Through its collaborative capabilities, BIM has shown its potential to empower projects by connecting designers and contractors in real-time, eliminating misinterpretation in papers and delivering enhanced outcomes in the early phases of the project's schedule and cost simulation [9]. BIM has shown tremendous promise to improve the construction project through its high integration across all project stages. Defining the characteristics necessary for effective BIM adoption would benefit the KSA construction industry and help classify the areas that need the greatest development [10]. BIM has not been recognised as an evolving research subject in developing nations since there are few articles available. According to Alaboud *et al.,* [10] study conducted in a number of Middle Eastern countries, despite interest and optimism in BIM, the construction sector is still in the early stages of leveraging the advantages of BIM. Therefore, this study aims to prioritize building information modelling (BIM) applications in the construction industry in Saudi Arabia through a Delphi consultation to implement the prioritized BIM capabilities. The objective of this research is to identify the applications of BIM during the construction phase and determine their respective significance and impact.

1.1 Literature Review

There are many different definitions of BIM in business and academics. There are several definitions of BIM, including object-oriented modelling, project modelling, virtual design and construction, virtual prototyping, integrated project databases and the more contemporary name BIM [11,12]. Bjork and Penttila [13] "project models are conceptual structures specifying what kind of information is used to describe buildings and how such information is structured." BIM synonyms include phrases like n-D modelling, which Salford University uses: An nD model is an extension of the building information model that contains several components of design information necessary at each stage of a building facility's lifecycle [6-14]. BIM is much more than 3D rendering or the transmission of electronic copies of paper documents by implementing BIM. The implementation of risk reduction measures ensures the preservation of design intent, facilitates streamlined quality control and provides access to advanced communication and analytical tools [15]. Succar [11] defined BIM as "a set of interacting policies, processes and technologies producing a methodology to manage the essential building design and project data in digital format throughout the building's lifecycle." BIM "Building Information Modelling (BIM) is the holistic process of creating and managing information for a built asset. Based on an intelligent model and enabled by a cloud platform, BIM integrates structured, multidisciplinary data to produce a digital representation of an asset across its lifecycle, from planning and design to construction and operations [16]."

There is a plethora of observable and actual advantages linked with BIM adoption. These include technological superiority, interoperability capabilities, early building information collection and utilization throughout the building's lifecycle, integrated to the project team [17]. BIM promises more intelligence and interoperability than traditional CAD. Users can share design data and requirements across numerous software tools within a multidisciplinary team by digitising a facility's physical and functional attributes. BIM data is recorded in a database, so design changes may be systematically applied and preserved throughout the project [18]. BIM is a collection of technology and solutions that may increase construction industry cooperation and efficiency in design, construction and maintenance. Thus, BIM unites architecture, engineering and construction knowledge in a fast-growing field. BIM technologies increase parametric modelling platforms, enabling spatial visualisation, building behaviour simulation, project management and AEC team cooperation [19,20].

BIM systems have enabled the collection of detailed information about a building throughout the design phase, from specific components and locations to the connections between those items. BIM incorporates information about the structure of the building, including its geometry, spatial relationships, light analysis, geographic location and the quantities and properties of the building's components, also including their material, specification, fire rating, U-value, fittings, finishes, cost and carbon content. These capabilities enable architects and engineers to keep track of the links between building components and their associated construction-maintenance information. BIM technologies provide interoperability and effective integration by enabling contributions from several professions to the model [21,22].

The development of BIM allowed for an integrated approach to design, construction and maintenance in response to the growing complexity of construction projects. It serves as a platform for collaboration for the numerous parties involved in a project's lifespan. Owners, designers, builders and construction managers may now execute projects more successfully than ever before thanks to BIM. Modern IT/ICT technologies are also very important in AEC pedagogy. Similar to this, BIM is anticipated to combine information to enhance AEC education [23,24]. BIM creates precise quantities for the parts and materials that go into a design. It makes it possible to better coordinate the procurement process throughout the design and construction phases [24].

The BIM model can be used as data for automated fabrication machines that produce prefabricated building components [25]. Additionally, it can be used as an appropriate design model for fabricating building components. When a building model is time-stamped, it is possible to simulate the construction process, identify bottlenecks in the procurement process and propose improvements prior to the start of actual construction. The ability of BIM tools to model complex architectural design concepts allows architects to be more creative. BIM is a critical component of future enhancements to innovative housing and intelligent buildings [26].

BIM has also been demonstrated to offer important economic benefits. Technology adoption is strongly influenced by economic evidence. The return on investment (ROI) must be considered in such procedures. Numerous studies in the BIM setting have shown high ROI results. It is understood how important BIM-assisted design validation is. According to studies, rework prevention strategies based on first model validation and assessment follow the benefit of BIM in decreasing schedule delays as having the greatest impact on boosting ROI. BIM users have emphasized the advantages of using BIM in both the short and long terms [27].

BIM 4D schedules are practical tools for phasing organizing and communicating planned work to a wide range of stakeholders. Building materials and components may be bought electronically and delivered on-site precisely in the time since all materials and components are present and their amounts are automatically computed. It increases worker productivity. The 3D model gives an adequate image of the working environment and the 4D timetable simplifies comprehension of different needs throughout the project lifecycle. BIM enables the integration of data from manufacturers, contractors and communications into a single fully integrated facility dashboard. Facility managers may use BIM to manage everyday operations and create maintenance schedules. The ability of any real-time visualization system to provide real-time and interactive updates is critical [28]. Despite the numerous potential advantages of using BIM, defined implementation methodologies and predicted future high adoption rates, the overall efficacy of using BIM has not been thoroughly demonstrated [29]. Real-time management of BIM deliverables is a difficult challenge. BIM implementation entails several hazards, including technical, managerial, environmental, financial and legal risks [30,31].

One of the primary obstacles to BIM advancement is BIM tool output's intellectual property and cyber security [32]. Since information sharing makes project data available to team members, cyber security is a problem due to the possibility of unauthorized internet access and copyright infringement [33]. Additionally, developing thorough and transparent re-use and adoption procedures for BIM models, whether by the same team or others. The integrated BIM idea blurs the lines of accountability among project team members. Legal difficulties also emerge; data/design ownership or licensing issues are likely to occur when other parties contribute information. Additionally, co-authorship of BIM models by many BIM model developers complicates joint and separate culpability for any mistakes that occur throughout the project's lifespan. The correctness of the data used to create the BIM model includes significant risk and some liability disclaimer and limited warranty must back up the designers' duty for the accuracy [34]. Table 1 shown the BIM applications implemented in construction industry.

Table 1
BIM applications implemented in construction industry

BIM Capabilities	Reference
Time savings (improved duration, less time spent on project records and interaction and quickly evaluating different choices.)	Ullah *et al.,* [4]
The cost reduction (lowers the total cost of the project, the costs of developing and constructing it and the costs of communicating about it)	Hasan & Rasheed [17]
Cost Estimation (Cost estimating is a fundamental procedure in which a BIM model is employed to produce a precise assessment of the quantities and expenses associated with the construction of a project.)	Ghorbany *et al.,* [7]
Improving the quality (less rework, fewer design mistakes and a better design).	Doumbouya *et al.,* [9]
Project Schedule & Construction Sequencing (The concept of 4D Scheduling involves the integration of a 3D BIM model with the project schedule, thereby incorporating time as the fourth dimension. This integration allows for the simulation and visualisation of the construction sequence.)	Ghorbany *et al.,* [7]
Clash detection (reduced problems with coordination, elimination of the danger of duplication, checks for design inconsistencies at the preliminary construction stage, resolution of tangible conflicts across different disciplines and integrated work progress)	Chan *et al.,* [5]
Rework Reduction (by simulating and displaying building components in an integrated data environment, removing the possibility of design misunderstanding and accurately capturing reality)	Durdyev *et al.,* [2]
Improve Collaboration and communication (conflicts are minimised, several disciplines can work simultaneously, coordination is improved and teamwork is integrated).	Azmi *et al.,* [21]
Constructability (executive, interaction, planning, strategic and site planning, risk, change, safety, value and facility management,)	Khanzadi *et al.,* [41]
Project Logistic Optimization (The project focuses on the optimisation of logistics in managing the movement of tools, materials and equipment from the point of discharge to their designated usage location).	Chan *et al.,* [5]
Project Supply Chain (The Project Supply Chain aims to establish effective feedback channels in remote construction projects and enhance supply chain monitoring through the integration of tracking technologies. This integration is intended to improve visibility throughout the material delivery process).	Durdyev *et al.,* [2]
prefabrication (lower inventory time and acquire materials utilizing)	Azmi *et al.,* [21]
Site Layout Planning (The utilisation of a three-dimensional model of the building allows for collaboration among the owner, constructor and designer prior to the initiation of physical construction).	Hasan & Rasheed [17]
Flexible Project changes (The modifications in flexible projects, concerns regarding coverage, the assortment of tools designed for handling diverse types of information and the utilisation of large-scale models).	Alaboud *et al.,* [10]
Automatic Compliance Checking (The validation of the design phase involves a comparison between Building Information Models and the existing codes and regulations, which are then translated into parametric rules).	Jun *et al.,* [20]

2. Research Methodology

A novel feature of the methodology was employed by the researchers, which is the application of the Delphi method to identify the BIM capabilities. To achieve the research objectives, a review of the literature on BIM contributions was conducted and Delphi N-Rounds (till internal consistency/consensus is achieved among participants) were employed. Figure 1 shows that the methodology for Delphi study. A total of 33 experts who fulfilled the predetermined panel of expert criteria were identified and invited to participate in the Delphi survey.

This study employs a nine-point Likert scale to gather data from experts. According to Remus *et al.,* [35] the nine-point scale is more reliable and accurate compared to the five-point scale. Delphi used a nine-point Likert scale. The nine-point Likert scale used in the study has the following meanings:

i. 1 = Strongly not Important
ii. 2 = Not Important
iii. 3 = Moderately Important
iv. 4 = Moderately to Strongly Important
v. 5 = Strong
vi. 6 = Strong to Very Strong
vii. 7 = Very Strong
viii. 8 = Very Strong to Important
ix. 9 = extremely important

Furthermore, the data obtained from the Delphi survey was analysed using the Statistical Package for the Social Sciences (SPSS) to determine the Median, Mean and IQR.

The Delphi technique is employed to acquire expert consensus on a given problem [36]. To establish expert consensus, the interquartile range (IQR) of scores was determined. If their IQR is equal to or less than 1.0, experts with high rating factors should agree [37]. If all factors have IQRs of 1.0 or below, the second round is considered final [38]. The Delphi Study requires two to N rounds to explore, create a consensus among experts, understand, resolve disagreements and confirm the outcome with 10 to 100 participants [39].

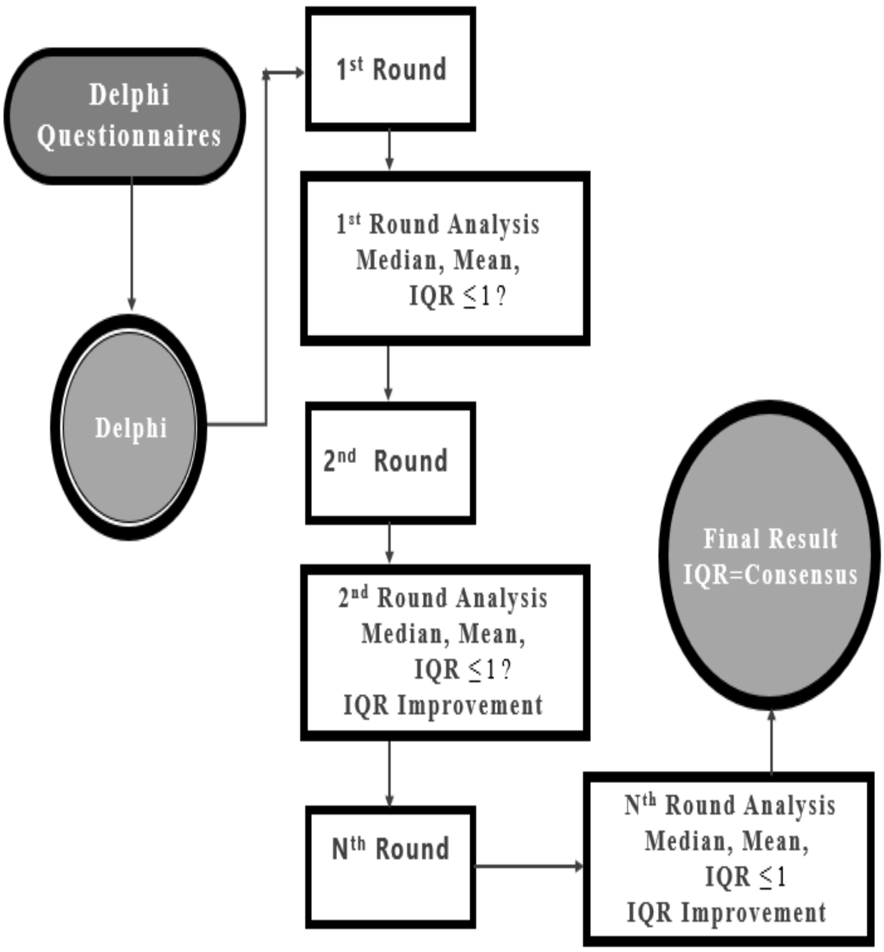

Fig. 1. Methodology for Delphi study

3. Results

A total of 33 experts that met the Delphi survey criteria were selected. The Delphi study specialists had over ten years of KSA infrastructure construction expertise. Fei and Khan [40], established an "expert" as someone with at least ten years of building experience. KSA constriction specialists were invited and Figure 2 shows the demographic profile of respondents. The experts (Engineers, Architects) working for clients are 19.23%, consultants 46.15% and for contractors 34.16%. Having bachelor degree 46.15%, master degree 38.46% and PhD 15.38%. working experiences 11-15 years 46.15% and experience above 16 years 53.85%.

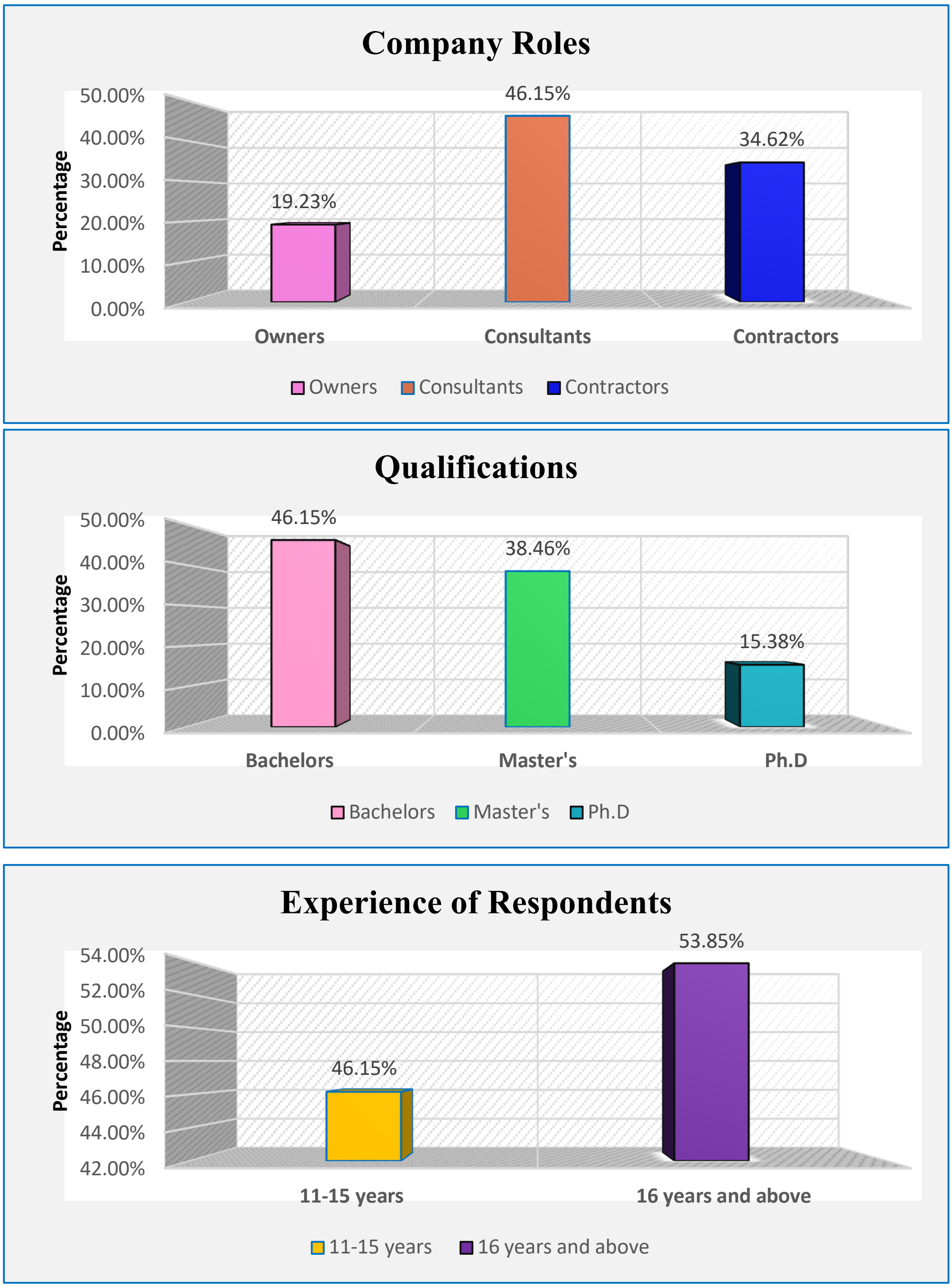

Fig. 2. Demographic characteristics of participates

3.1 Result of Delphi Survey Round 1

In round one, the panel members (n = 33) were requested to rate the degree of importance of each identifiable BIM application using a nine-point Likert scale. Table 2 presents each item's relative importance of BIM applications in the first round of the Delphi survey and determines the median, mean and IQR for round two.

Table 2
Delphi round 1 results of BIM applications

BIM Applications	Median	Mean	IQR	Rank
Clash Detection	9.000	8.363	1	1
Project Schedule & Construction Sequencing	7.000	6.454	3.5	5
Project Coordination	7.000	6.303	4	6
Integration of Subcontractor & Supplier Data	7.000	5.969	4.5	9
Safety	7.000	6.575	5	4
Cost Estimation	8.000	7.787	1	2
Site Layout Planning	7.000	6.181	4	8
Prefabrication	6.000	5.515	3.50	11
Construction Monitoring	8.000	6.606	4	3
Project Supply Chain	6.000	5.333	2	13
Flexible Project changes	6.000	5.484	4	12
Project Logistic Optimization	5.000	5.030	3	14
Rework Reduction	4.000	4.727	2	15
Constructability Improvement	6.000	5.818	4	10
Automatic Compliance Checking	7.000	6.242	4	7

In the first round of 15 BIM applications, only one item was rated 9.000 medians, two items were 8.000 and six items were 7.000. Moreover, the mean also calculated the rank of the BIM applications, where "Clash Detection" is the first rank, "Cost Estimation" is second in two positions, "Construction Monitoring" is third, "Safety" is fourth, "Project Coordination" is fifth and "Constructability Improvement" was the tenth rank on the first round of the Delphi survey.

3.2 Result of Delphi Survey Round 2

In the second round, participants were encouraged to compare their answers with the group and update or justify their choices. As a result, Table 3 includes Delphi rounds and the improved IQR and mean improved compared to round one. Moreover, the second round, "Clash Detection," secured the first position with a mean value of 8.484, "Cost Estimation" remains second-ranked with a mean value of 7.818, "Safety" with a mean value of 7.242 ranked fourth and "Integration of Subcontractor and Supplier Data" jumped to the tenth position with a mean value of 6.394.

Table 3
Delphi round 2 results of BIM applications

BIM Applications	Round 1			Round 2		
	Median	Mean	IQR	Median	Mean	IQR
Clash Detection	9.000	8.363	1.00	9.000	8.484	1.00
Project Schedule & Construction Sequencing	7.000	6.454	3.5	7.000	6.969	2.00
Project Coordination	7.000	6.303	4.00	6.000	6.545	2.00
Integration of Subcontractor & Supplier Data	7.000	5.969	4.5	7.000	6.394	3.00
Safety	7.000	6.575	5.00	7.000	7.242	3.00
Cost Estimation	8.000	7.787	1.00	8.000	7.818	1.50
Site Layout Planning	7.000	6.181	4.00	7.000	6.606	3.00
Prefabrication	6.000	5.515	3.50	6.000	6.030	2.50
Construction Monitoring	8.000	6.606	4.00	8.000	6.878	3.50
Project Supply Chain	6.000	5.333	2.00	6.000	5.787	1.00
Flexible Project changes	6.000	5.484	4.00	6.000	5.697	2.50
Project Logistic Optimization	5.000	5.030	3.00	5.000	5.515	2.00
Rework Reduction	4.000	4.727	2.00	5.000	5.303	2.00
Constructability Improvement	6.000	5.818	4.00	6.000	5.848	2.50
Automatic Compliance Checking	7.000	6.242	4.00	7.000	6.515	3.00

Round two of the Delphi survey improved the overall consensus. However, more rounds are required until experts achieve consensus (IQR = 1 or IQR < 1) on all items in BIM applications.

3.3 Result of Delphi Survey Round 3

The primary objective of the third round of the Delphi method is to establish a consensus among the panel of experts and closely monitor the stability of the response. The inclusion of a third-round questionnaire permits the re-evaluation of several parameters. The third-round questionnaire facilitates the comparison of group responses with the first individual responses obtained in the third round. The provision of information aims to influence an individual's perspective in the event that they align with the collective viewpoint. When experts get feedback, they may modify their judgements in order to reconcile any discrepancies between their own opinions and the collective opinion of the group. In the particular case, it is anticipated that the interquartile range (IQR) will have a reduced width compared to the preceding iteration. The data analysis was conducted using the median and IQR criteria to assess the rating of each variable as well as its level of consistency. Consequently, Table 4, which outlines BIM applications, incorporates Delphi rounds. Additionally, the IQR for all components was found to be equal to or below 1. Therefore, the Delphi third round is the conclusive stage of the Delphi consultation process.

Table 4
Delphi round 3 results of BIM applications

BIM Applications	Round 2			Round 3			
	Median	Mean	IQR	Median	Mean	IQR	Rank
Clash Detection	9.000	8.484	1.00	9.000	8.545	1.00	1
Project Schedule & Construction Sequencing	7.000	6.969	2.00	7.000	7.333	1.00	7
Project Coordination	6.000	6.545	2.00	7.000	7.363	1.00	6
Integration of Subcontractor & Supplier Data	7.000	6.393	3.00	7.000	7.212	1.00	8
Safety	7.000	7.242	3.00	8.000	8.212	1.00	2
Cost Estimation	8.000	7.818	1.50	8.000	7.939	0.00	3
Site Layout Planning	7.000	6.606	3.00	7.000	7.454	1.00	5
Prefabrication	6.000	6.030	2.50	7.000	6.939	0.00	10
Construction Monitoring	8.000	6.878	3.50	7.000	7.485	1.00	4
Project Supply Chain	6.000	5.787	1.00	6.000	5.969	0.00	11
Flexible Project changes	6.000	5.697	2.50	6.000	5.818	1.00	14
Project Logistic Optimization	5.000	5.515	2.00	6.000	5.878	0.00	13
Rework Reduction	5.000	5.303	2.00	6.000	5.787	1.00	15
Constructability Improvement	6.000	5.848	2.50	6.000	5.939	1.00	12
Automatic Compliance Checking	7.000	6.515	3.00	7.000	7.090	1.00	9

In the third round of eleven BIM applications, secured IQR =1 (average consensus) and four KPIs IQR ≤ 1 (high consensus) and mean improved compared to round two. Moreover, the third and final round, “Clash Detection,” secured the top position with a mean value of 8.545; "Safety,” with a mean value of 8.212, ranked second; “Construction Monitoring” and “Site Layout Planning” jumped to third. Fourth positions with 7.939 and 7.485, respectively, “Site Layout Planning” ranked fifth with a mean value of 7.455 and Prefabrication ranked tenth with a mean value of 6.939 on the third and final round of the Delphi survey.

4. Discussion

The findings of this research were compared to the findings of previous studies conducted by Khanzadi *et al.,* [41]. The primary BIM applications were ranked as project coordination, project schedule and construction sequencing, clash detection, integration of subcontractor and supplier data, safety, site layout planning and prefabrication. Furthermore, Cost estimation, planning, site analysis and coordination are the main BIM applications with the highest significance, according to a study by Rojas *et al.,* [42]. Dan *et al.,* [22] conducted a study on the most impactful applications of BIM, which include enhanced design visualisation, clash detection, design coordination, improved decision-making and minimising uncertainties. Although the present research shows that clash detection, safety, cost estimation, construction monitoring and site layout planning are the top five BIM applications for Saudi Arabian construction projects.

Moreover, the results were to compare in order to evaluate the position of the Saudi Arabia BIM scenario in relation to the global BIM priority, the study presents a depiction of the fifteen identified applications of BIM. Additionally, the study incorporates the findings of the McGraw-Hill Smart Market Reports [41-43] on the business value of BIM for construction projects for different countries. UK, Canada, Japan, South Korea and Saudi Arabia are the five countries to prioritise the clash detection. Brazil and Germany have placed cost estimation as the top priority, while KSA has ranked it as the second priority. In comparison to other categories, including construction monitoring, project scheduling and construction sequencing, site layout planning, integration of subcontractor and supplier data, Automatic Compliance Checking and prefabrication, the observed variations in the category under consideration are relatively limited and the trends are generally consistent. The project coordination was prioritized by Iran, France, Australia and the US, while KSA ranked it as the fourth-highest priority.

Furthermore, a similar study conducted by Akter *et al.,* [44] for Bangladesh's construction industry and findings revealed the top five significant BIM capabilities were "improved quality of construction", "safety improvement", "reduced environmental impact during project life-cycle, "increased productivity and customer satisfaction" and "lower cost of construction". Maliha *et al.,* [45] conducted research to prioritized the BIM application for the Palestine construction industry and found that the BIM has a positive impact for construction professionals to improve the time management, cost management, Integration management and communication management. Numerous studies conducted to evaluate the significates of BIM for construction industry and found that the BIM models provide offsite prefabrication, predicting environmental analysis and simulation [46,47]. This study concludes, as validated by the Delphi study, that BIM implementation has a significant impact on the construction team and project's ability to integrate, communicate and monitor the project to complete within cost, time and achieve the specified quality.

5. Conclusion

This study attempts to address a critical gap in the existing literature, notably the dearth of research on the prioritisation of BIM for construction projects in KSA, using a Delphi study. This study is a pioneering effort in its sector, drawing on previous literature on BIM elements in the construction industry. The study's findings revealed compelling outcomes that illustrate the perspectives of design and construction specialists in the KSA on the benefits of BIM for various indicators of construction project performance. The three-rounds of Delphi survey of this study revealed the top five BIM capabilities are: Clash Detection, Safety, Cost Estimation, Construction Monitoring and Site Layout Planning. The study assisted establish an obvious understanding of BIM's substantial contribution to improving construction time and cost estimations, which aids in schedule management to reduce cost and overruns. Furthermore, BIM enables construction team members identify clash detection, which reduces errors and rework, multidimensional visualisation aids in the control of quality and safety management.

The objective is to establish a basis for future studies and present managerial perspectives on the implementation of BIM with respect to prioritised applications. Although it may seem excessively hopeful to implement BIM under the present conditions, its importance is extensive when considered from a practical and analytical perspective.

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