Building Information Modelling for Construction Delay Management

Essa Alenazi, Zulfikar Adamu

***Abstract*—**The Kingdom of Saudi Arabia (KSA) is not an exception in relying on the growth of its construction industry to support rapid population growth. However, its need for infrastructure development is constrained by low productivity levels and cost overruns caused by factors such as delays to project completion. Delays in delivering a construction project are a global issue and while theories such as Optimism Bias have been used to explain such delays, in KSA, client-related causes of delays are also significant. The objective of this paper is to develop a framework-based approach to explore how the country's construction industry can manage and reduce delays in construction projects through building information modelling (BIM) in order to mitigate the cost consequences of such delays. It comprehensively and systematically reviewed the global literature on the subject and identified gaps, critical delay factors and the specific benefits that BIM can deliver for the delay management. A case study comprising of nine hospital projects that have experienced delay and cost overruns was also carried out. Five critical delay factors related to the clients were identified as candidates that can be mitigated through BIM's benefits. These factors are: Ineffective planning and scheduling of the project; changes during construction by the client; delay in progress payment; slowness in decision making by the client; and poor communication between clients and other stakeholders. In addition, data from the case study projects strongly suggest that optimism bias is present in many of the hospital projects. Further validation via key stakeholder interviews and documentations are planned.

***Keywords*—**BIM, client perspective, delay management, optimism bias, public sector projects.

I. Introduction

CONSTRUCTION is considered to be a pillar of the industry which contributes to the growth of any nation's economy. Saudi Arabia has the largest public-sector construction industry within the Arabian Gulf [1]. Between 2008 and 2013, the KSA government spent about $575 billion on public construction projects [2] and the construction market is expected to reach $610 billion between 2015 and 2020 [3]. According to [4], the construction of essential infrastructure projects is one of central to the future growth ambitions of the KSA government. Some of the building and infrastructure projects currently being constructed by the government include stadia, residential, offices, schools, hospitals, hotels, highways, railways including underground subways [1]. Such projects and the sums budgeted for them underscore the importance of public sector funding in the Saudi construction industry.

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Historically, building construction projects in KSA have generally led to significant economic and social benefits for the government, large and small contractors, as well as the society as a whole. However, delays that prevail in such projects are significant and pose great challenges to their implementation and benefits. Delay in the construction industry's context is described as "time overrun either beyond completion date specified in a contract or beyond the date that parties agree upon for delivery of a project" [5]. Delays are a major problem confronting KSA's public sector construction projects. According to a recent Deloitte report [1], the total value of delayed building construction projects in KSA as of July 2014 stood at US$146 billion, causing pressures on the developmental drive of the oil-rich country. Since the KSA government continues to be the key financer of construction projects and with the growing cases of delays occurring in publically owned projects, there is a need for extensive and continuous investigation of this phenomenon.

Over the years, studies [5]-[9] have been carried out on factors contributing to delays in KSA construction projects. Yet, they have not offered empirical theories or evidence on how this syndrome can be managed [10]. Therefore, there is an opportunity for considering the use of advanced technology-based project management technique in addition to sound theory to assist in delivering KSA's public construction projects on time and within the allocated budget.

The construction industry over the world has exploited many innovations in project management during the previous three decades, particularly those related to use of information technology (IT) [11]. The current and most promising of such technologies is framed as BIM [12]. This modelling process has many dimensions including: 3D models that assist in projecting visual designs by a graphic illustration of the building systems and components in three-dimensional virtual space; 4D models which can generate the construction schedule and sequence; 5D models used for cost information and estimation; as well as 6D models which are used for as-built facility management. However, there are several viewpoints of BIM; and one view is that BIM can be described as a computer model that is developed to illustrate the project's lifecycle from start to finish [13]. Other perspectives to BIM are provided by studies such as [14] where it is considered as a process used in construction projects for enhancing efficiency and achieving projected objectives on time. BIM can nevertheless be implemented to obtain quicker design and construction resulting from the digital representation and management of building information over its whole lifecycle [15]. A compromise definition could be that BIM is the process and practice of virtual design and construction throughout a building's lifecycle. It is a vehicle for sharing knowledge and enables communication amongst project stakeholders by providing a reliable platform for exchanging data and information digitally instead of paper-based exchanges.

Despite all of BIM advantages that have been highlighted above, there is a general lack of research in using BIM for construction delay management specifically for mitigating the cost consequences of such delays. The need for such research in this field will be helpful especially in determining which aspects could be transferred to the KSA construction industry which continues to suffer from delays.

II. Aim and Objective of This Study

The aim of this paper is to develop a framework using BIM to mitigate delays in KSA construction projects In particular, the proposed framework could help reduce the cost consequences of delay in construction projects. To achieve this aim, the following objectives have been outlined as: (i) to comprehensively review global literature on the subject and identify gaps, critical delay factors and the specific benefits that BIM can deliver for delay management; (ii) to map the essential benefits of BIM for delay management with the critical delay factors (CDF) related to clients; (iii) to develop a framework based on the above objectives for using BIM to mitigate delays and associated risks in Saudi construction industry.

III. Research Methodology

Due to the nature of this research, an exploratory and qualitative approach was applied. A literature review is considered to be a fundamental methodology for obtaining in-depth understanding of a research topic. Therefore, a systematic examination of existing body of knowledge on the subject matter can provide the researcher with a solid foundation to identify the current gaps as well as stimulate and inspire future research. Thus, in this research paper, a systematic review, as well as a case study, was carried out comprising of nine hospital projects that have experienced delay and cost overruns. The systematic review was employed to meet the first objective of the study focusing on leading journals that publish construction project management research. Furthermore, to ensure a sufficiently thorough and focused coverage of the research domain, the following Journals were essential: International Journal of Project Management (IJPM); Project Management Journal (PMJ); and Construction Management & Economics (CME).

The keywords used to explore the literature were a combination of BIM and Delay management in construction projects. The country selection was worldwide and not limited to Saudi Araba. The papers were further trimmed to those between 1999 and 2015 which were considered relevant to BIM, the main causes of delay in construction projects globally as well as delays in the Saudi context. These papers were scanned at three levels, titles, abstract and keywords. The keywords combination was searched in different databases including Science Direct, Google Scholar, a Web of Science, Scopus, and ProQuest. A total of 200 articles were returned from the initial interrogation, out of which 45 papers were found to be related to BIM and 40 papers for delay management in construction.

IV. Delay in Construction Projects and Theory of Optimism Bias

A. Delays in Global Context

The various UK government driven reports (e.g. [16]-[18]) have highlighted problems facing construction industry leading to cost and time overruns, site safety, lack of adoption of new methods, etc. Other studies [5], [6], [8] have shown that there are several factors and causes of delays in the construction industry. In addition, some scholars [5], [19], [77] tried to identify common links between delays in order to categorise them. For instance, with regards to Malaysian construction industry, delays are a serious problem for both owners and contractors. This study included all factors causing a delay with respect to three major categories of stakeholders: contractor, consultant, and owner. They identified the main external factors causing delays within construction projects were caused by the unavailability of equipment, tools in the market and a lack of materials. Furthermore, poor weather conditions and delays in materials transportation were considered as a serious issue that causes delay.

In another study, [20] analysed the reasons behind delays and cost increase within Kuwait private residential construction projects. A questionnaire survey was deployed to explore delay factors, and to investigate the owner-experienced problems within construction stage. The study identified that the main three factors causing delays were financial constraints; change orders, and lack of experience in construction. On the other hand, other factors were identified from the study including material-related issues, contractor-related issues, and owners' financial constraints. A well-organised pre-planning would decrease the amount of delay time. The study recommended that to achieve a better quality and complete set of drawings, as well as to avoid delays, owners need to invest more time and money during the design stage.

According to [21] on the context of Jordanian construction industry, poor design plans which did not consider adverse weather, site conditions, problems with the quantities of raw materials was considered as the main issue that causes delays. An investigation [22] indicated several of factors which resulted in construction project delays. These included limited contractor experience, owner interference, levels of productivity, financial issues, improper planning, delayed decision-making as well as problems with subcontractors. Further research [23] based on the context of in Nigeria construction industry identified that shortage of materials, poor financial and project management, and price volatility were the main causes of delays.

In a case study of construction delays in Oman, [24] identified three main causes of delays to construction projects. The client was mainly responsible for most of the delays. Issues related to the design process including change orders by the client during the design stage were identified as the major causes of delay, as well as delays of progress payment by the client. Other factors causing delays were included such as; the slow decision-making process by the client, cash flow issues, and labour problems.

B. Delays in Saudi Context

In the KSA, incidents and frequency of building construction delays have remained a major concern. Construction projects delays in KSA public sector are attributed to Client/Owner, Contractor, and Consultant related factors. However, this study focuses on main factors contributing to delays related to the clients. (Table I). This focus is, first, linked to the central role of government as a major client in KSA. Secondly, clients have the power to change the scope of the project during the construction stage, with effects for consultants and contractors who are secondary in terms of final decisions. Table I summarises the most recent studies carried out on construction delays in KSA. It shows the title, study, delay factors related to the clients, objectives, methods, and the techniques used in order to manage the delays.

TABLE I
PREVIOUS STUDIES ABOUT CONSTRUCTION PROJECT DELAYS IN KSA

Title and Study	Client-related Factors	Objectives, *methods and **outcomes
Delay in public utility projects in Saudi Arabia; [8]	1. Delay in progress payments by the owner 2. Assigning the contract to the 3. Lowest bidder without regards to qualification. 4. The owner tends to underestimate a project's duration. 5. Changes in the scope of the projects.	1. Assess the frequency of delayed projects 2. Assess the extent of delay in project duration 3. Identify the responsibility for project delay. *This study used questionnaire survey.* ***General recommendations*
Causes of delay in large construction projects; [5]	1. Delay in progress payments by owner 2. Change orders by owner during construction 3. Late in revising and approving design documents by owner 4. Delay in approving shop drawings and sample materials 5. Poor communication and coordination by owner and other parties 6.Slowness in decision-making process by owner 7.Conflicts between joint-ownership of the project 8. Unavailability of incentives for contractor for finishing ahead of schedule 9. Suspension of work by owner	1. Identify the causes of delays in construction 2. Test the importance of the causes of delay between each two groups of parties. 3. Study the differences in perceptions of the three major parties *This study used Literature review and questionnaire survey* ***General recommendations*
Causes of delays in Saudi Arabian public sector construction projects; [6]	1. Lack of finance to complete the work by the client 2. Non-Payment of contractor claim 3. Suspension of work by the owner 4. Delay in issuance of change orders by the owner 5. Slow decision making by the owner 6. Delay in progress payments by the owner 7. Poor communication with the construction parties and government authorities 8. Owner's failure to coordinate with Government authorities during planning	1. Identify the causes of delays in construction 2. Test the importance of the causes of delay between each two groups of parties *Literature review and questionnaire survey* ***General recommendations*
Addressing crucial risk factors in the middle east construction industries: A comparative study of Saudi Arabia and Jordan; [53]	1. Lack of coordination with contractors 2. poor planning and scheduling of the project 3. Delay in the approval of contractor submittals to the owner 4. Changes in the scope of the project 5. Breach or modifications of contract by owner 6. Poor qualifications and supervision of owner's engineer 7 Slow decision-making process of the owner	1. To outline the main causes of delay in public building projects. 2. To rank each factor according to its frequency of occurrence and degree of impact. *A combination of qualitative and quantitative methods using questionnaire survey.* ***Develop a risk management framework to mitigate the impact of those delay factors for sustainable building construction*

C. Optimism Bias: Theory and Application in Delays

It has been thought that one important reason for the faltering and/or delay of construction projects is the phenomenon known as "optimism bias" which occurs due to the 'optimistic' underestimating of project duration or cost. Optimism bias in the construction industry as defined by [25] is the tendency to underestimate a project's costs and duration and/or to overestimate its benefits; it can be used to identify the difference between the appraisal estimate and the outcome which can be (expressed as a percentage).

To demonstrate optimism bias, a study was conducted by [25] to review large public procurement projects outcomes in the UK for two decades. The study aimed to offer a guideline for the public sector on how to reduce excessive optimism in project estimates and the results clearly demonstrated that the high levels of optimism in the projects' estimates were due cost and duration being underestimated while benefits were overestimated. The study also indicated project risk areas that participated in increased costs and overruns in terms of time. The study suggested that to achieve delivering projects within budget and time, optimism bias should be minimised in project estimates.

There are a number of studies indicating that projects in KSA exceed their budget and allocated time [5]-[9]. Although it is generally understood that all major construction projects are exposed to considerable risk, such risks are often treated as a norm, rather than as an exception. Nevertheless, it is hypothesised here that some project planners in KSA, even with full consideration of expected risks, do not adequately take into account the contingencies for time and costs in initial budgeting. Another plausible reason could be that winning jobs (in the case of contractors) or satisfying socio-political interests (in the case of clients) exerts a pressure to be over-optimistic about the time and cost of delivery. These arguments are supported by the theory of optimism bias which according to [26] suggest that it is caused by (a) a mixture of the organisation of the decision-making process; and (b) the strategic behaviour of those involved this process, e.g. contractors or clients in the case of KSA.

The author's experience of the KSA construction industry optimism bias can occur due to the absence of a structured decision-making framework at a strategic level and a lack of appropriate check and balance system. Also, wealth generated through oil profits has led to a lack of focus on price control and strict governance. In developed countries, emphasis on accurate price forecasting tends to increase after global recessions [27]. In KSA, a combination of socio-political factors and oil-driven wealth has created a climate where there is little interest or motivation in avoiding optimism bias. The lack of check and balance in the decision-making process, as well as the behaviour of the key players involved in this process, could, therefore, be responsible for optimism bias in the country's public-sector projects. To better understand optimism bias, [25] have grouped the causes of optimism bias into four major categories as shown in Table II.

TABLE II
CAUSES OF OPTIMISM BIAS

CAUSES OF OPTIMISM BIAS	EXAMPLE
Technical causes	Imperfect information (inadequate data, inaccurate forecast and new or unproven technology) Change in project scope or inadequate business case. Poor management often reflected in the poor documentation.
Psychological causes	Tendency for humans and organisations to favour optimism appraisal optimism Projects promoters are overly optimistic about projects outcomes.
Economic causes	Construction companies and consultants have interest's in advancing projects
Political-Institutional causes	Interests, power, and institutions Actors may deliberately lie in order to see their projects/ interest realised

Given the four causes (and examples) of optimism bias, many of the conditions necessary to address optimism bias, in KSA can be said to be lacking. Anecdotal evidence suggests a situation has developed, due to previous political-institutional situations where avoidance of optimism bias has only been of interest to a few stakeholders. Total budget allocation for projects is often perceived as flexible due to fiscal indiscipline lack of incentives for design teams to ensure project costs are not exceeded throughout the capital expenditure phase. Best practices as reviewed from various case studies [26] suggest the use of a number of measures to address optimism bias as outlined below;

1. The formal requirement for high-quality cost and risk assessment at early project stages.
2. Independent appraisal of costs supported by necessary enforcement regime.
3. Introduction of fiscal incentives against cost overruns
4. The Clear emphasis from project clients on realistic budgeting and penalties for over budgeting.

V. Building Information Modelling

The concept of BIM was introduced by Professor Charles M. Eastman in the 1970s [28]. It was anticipated that by providing a visual platform to enhance coordination and through various functionalities such as design coordination, BIM could help resolve various communication and collaboration challenges facing construction. BIM provides a methodical process and practice of virtual design and construction throughout a facility's lifecycle. It is a platform for sharing knowledge and communication between project participants. It goes well beyond the useful application of 3D Computer Aided Design (CAD).

BIM provides a digital representation of physical and functional features of a facility helping to create a common knowledge resource for information sharing and a reliable basis for decisions during project life-cycle [29]. It was stated [12] that "BIM is an activity …not just a technology change, but also a process change". Hence, it is believed that construction disputes which are often caused by communication and coordination issues can be assisted by BIM through visual clarity and with enhanced communication about complex features, for example, through clash detection.

Studies have shown that it is possible to minimise some causes of project delays through BIM modelling which can allow the integration of various kinds of information with the base 3D model. For instance, linking project schedule with 3D model leads to 4D BIM, which provides visual clarity on key steps involved in the construction process. Likewise, augmenting BIM models with costing information can improve cost reliability [12]. All of these can help eliminate factors that eventually lead to construction delays. Researchers [15] have further elaborated on some key benefits of BIM system and demonstrated how information can be extracted at any required stage and updated automatically. This provides transparency leading to the elimination of co-ordination problems, thus, lead to construction project delays. Moreover, others [30] stated, how can BIM speedily and automatically generate cost schedules such as the cost plans and Bill of Quantities (BOQ), based on the cost estimation and measurement rules , leading to cost to buy, tender or life-cycle cost. This automated functionality of BIM allows for provision of accurate cost and time information and requires further exploration

Various scholars (e.g. [12] and [31]) have highlighted inefficiencies resulting from manual paper-based processes as one of the key reason causing project delays so the automation offered by BIM has been helpful. Traditional project management processes are huge paper-based requiring an accurate record of measurements, data entry, quantity take-offs, project scheduling, monitoring and cost control and management of contract documentation. Such manual tasks are nevertheless error prone and could lead to project delays [15]. Similar concerns are discussed [32], who stressed that various site based activities such as site meetings, works inspections, record keeping and monitoring are done using paper-based processes, hence it can be expected that work and time pressures could lead to a compromise in quality, leading to potential delays.

In summary, there are a number of ways in which BIM helps in solving these multi-faced problems relating to delay and cost overruns. First, it promotes a more practical design review because, in construction projects, design changes and errors are some of the issues that affect the cost and schedule [33]. Implementation of BIM will increase the productivity of the delivery processes of the constructed facility [15]. BIM has the ability to minimise early construction issues and reduces the tendency of requesting for information (RFI), change in design, team conflicts and rebuilding. Designers will have the ability to make design decisions based on the spatial experience of these models, which can have a substantial impact on the construction cost. Additionally, faster and more effective processes can be achieved throughout using BIM. An investigation carried out by McGraw-Hill Constructions about BIM revealed that more than 48% of the owners claimed that overall project output was highly beneficial. The RFI's and reported coordination problems were very few. The flow of information was easier with the application of BIM and there can be more value added [15].

The second objective of this paper was to map the relevant benefits of BIM for delay management (Table III) with the CDF related to the clients identified in Table IV in Section VI. The benefits of BIM for delay management (Table III) is based on several studies conducted on the subject.

TABLE III
BENEFITS OF BIM FOR DELAY MANAGEMENT

BENEFITS OF BIM FOR DELAY MANAGEMENT	AUTHORS
B1: Improve design quality and verify consistency to the design intent easily, which prevents expensive delays	[12], [28], [34]
B2: Earlier and more accurate visualisations of a design to the owner for better understanding of proposals	[12], [28], [15], [35]
B3: Support decision making regarding the design	[34], [92], [93]
B4: Improve the design and installation of MEP services on any construction project systems as well as their coordination with other building systems	[12], [28]
B5: Early quantity take-offs and cost estimating during the design stage with continuous updating as changes are made to the model.	[12], [28], [45]
B6: Improve understanding the sequence of construction activities and project duration	[36], [37]
B7: Improve visualization of construction details	[38], [93]
B8: Improve supply chain process	[39], [59]
B9: Increase the ability to resolve requests for information (RFIs) in real time.	[37], [40]
B10: Improve communication (information exchange among stakeholders)	[12], [39], [61], [98]
B11: Reduce project duration and cost of construction	[34], [37]
B12: More accurate scheduling and cost estimation	[37], [41]
B13: Quick reaction to design changes (change orders facilitation)	[12], [28], [39]
B14: Clash detection (reduce clashes)	[34], [35], [37]

VI. MANAGING THE DELAY FACTORS RELATED TO THE CLIENT USING BIM

For planning and scheduling of construction projects, project planners have often used different methods such as Critical Path Method (CPM), Programme Evaluation and Review Technique (PERT) and Gantt Charts. However, given a huge number of variables affecting construction projects, use of such techniques have had limited successes. Also, given quantitative and technical nature of these tools, limited numbers of team members engage with these tools leading to limited success. Lack of broader involvement leads to lack of engagement of team members about project schedules, leading often to schedule delays.

Based on a comprehensive review of the literature on studies about the causes of construction delay in KSA, the critical factors contributing to construction delays in KSA, as identified across different studies, have been summarised (Table I). Consequently, this study identified five CDF (Table IV) that can be managed through BIM.

Subsequently, the CDF and the different potential ways of managing them have been developed (Table V).

TABLE IV
CDF RELATED TO THE CLIENTS

CLIENT-RELATED FACTORS	AUTHORS
CDF1: Ineffective planning and scheduling of the project	[5], [6], [8], [53]
CDF2: Delay in progress payment by the client	[5], [6], [8]
CDF3: Changes during construction by client	[5]; [6]; [8] [53]
CDF4: Slowness in decision making by client	[5]; [6]; [53].
CDF5: Poor communication and coordination between construction parties	[5]; [6]; [53].

From the mapping exercise (Table V) it can be deduced that some delay factors can be matched to more benefits of BIM than others. The CDF and how they relate to specific benefits has been explained in Section VI A-E.

A. CDF1: Ineffective Planning and Scheduling of Construction Projects

Prior studies have noted the importance of BIM for managing schedules and planning for delays in construction projects. Based on the summary of evidence (Table V), management of risk associated with construction projects delays can be avoided by using BIM in planning and scheduling phase in following five ways: improve understanding of the sequence of construction activities and project duration (B6); early quantity take-offs and costs estimating during the design stages through continuously updating the changes to the model (B5); reduce project duration and cost of construction (B11); improve communication and information exchange among stakeholders (B10); and accuracy in scheduling (4D) and cost estimation (5D) (B12).

TABLE V
MAPPING DELAY FACTORS WITH THE BENEFITS OF BIM

		Client-related Factors					
		CDF1	CDF2	CDF3	CDF4	CDF5	TOTAL
Benefits of BIM for delay management	B1			x			1
	B2			x	x		2
	B3			x	x		2
	B4			x		x	2
	B5	x		x			2
	B6	x			x	x	3
	B7			x	x	x	3
	B8		x				1
	B9		x	x			2
	B10	x		x	x	x	4
	B11	x					1
	B12	x	x		x		3
	B13			x			1
	B14					x	1
	Total	5	3	9	6	5	

B12: BIM can efficiency at the design stages while continuously updating the quantity take-offs and cost estimates. As established in the literature review, using CPM in scheduling, monitoring and controlling project delays [42], [43] in conjunction with BIM is useful for quantity take-offs and cost estimation right from the conceptual design stages of a construction project. Some investigators [31] have concluded that BIM digitally enhances the capability to automatically generate quantity take-offs that have traditionally been very time to consume for quantity surveyors. Moreover, researchers such as [31], [44], [45] contended that more accurate cost estimating and quantity take-offs can be digitally done by sequencing the construction activities of a construction process.

B5: Sequencing and automation of construction activities in BIM help to improve the understanding of the critical path of activities and project duration [92], [62], [15] reported that sequencing the construction activities is a new paradigm for Visual Interactive Modelling of a construction process for contractors on site. Sequencing the activities can also lead to clash prevention on a construction site where many contractors are working simultaneously [46] because a construction project typically has several organisations/trades working at the same time [88]. Coordination between these organisations requires good means of communication. A study [98] found that adopting BIM helps to moderate the communication and the management issues in isolated construction projects.

B10: Construction projects often suffer from poor communication and coordination between those parties. BIM is seen as an enabler of communication [47]-[49] between parties and it helps coordination for effective planning and scheduling of a construction project. Communication through BIM facilitates the efficiency of contractors helping them to reduce project duration and cost through scheduling and enhanced cost estimation [50], [51] during the construction and fabrication phase. Despite having countless benefits of BIM to mitigate delays of ineffective planning and scheduling in construction projects, currently, BIM only offers the 4D time sequencing programme data and 5D cost estimation features. Thus, the advancement of BIM offers accuracy in time scheduling and costing for construction project [52], [61] without predictive or forensic analytics.

B. CDF2: Delay in Progress Payment by Client

Managing the progress payment is a common delay factor caused by clients in construction projects. The role of delayed progress payment is advanced by several studies ([5], [6], [8], [53]). These studies in Saudi Arabian context blame delay in progress payment for damaging the relationships between clients, contractors, and sub-contractors. Similar views are found in recent studies [53]-[55] who identified delayed progress payments as a critical factor of construction delay in KSA. The studies reveal that delay in progress payments by clients must be managed efficiently to protect and strengthen the relationship between clients, contractors, and sub-contractors. This suggestion emphasises the timeliness and importance of the current study. The above analysis reveals three main points where BIM could potentially help to manage the delay in progress payments by clients for maintaining the harmonious relationship between the affected parties: (a) improve supply chain process (B8); (b) increase the ability to resolve RFIs in real time (B9); and (c) improve accurate scheduling 4D and cost 5D estimation (B12).

B8: BIM adoption ensures the level of e-readiness, technology and processes are in place within a construction supply chain for clients and other operators [56]. It has been pointed out [57] that BIM cumulatively enhances a trajectory view and helps with analysis of supply chain integration.

B9: BIM increases information readiness and ability to resolve the request for real-time information [58]. In another study [59] it was stated that through BIM, the client can monitor work in progress during the construction phase and hence, authorise monthly progress payments to the contractors. Moreover, clients can also monitor construction performance and damages [60], [62]. In other words, BIM helps with monitoring the construction process in real time and ensures that works progress normally and therefore losses due to delay in progress payments by clients can be avoided.

B12: As aforementioned, BIM opens the opportunity for more accurate scheduling [52], cost estimation [63] and budgeting [58] through 5D estimation of materials cost.

C. CDF3: Changes during Construction by Clients

Changes during construction are another critical factor of delay in a construction project. Changes requested by clients during construction can change the workflow, contract price, and sometimes the entire construction process leading to delays [64], [65]. Changes by the client have unforeseen risks such as delays in construction projects and loss of finances [66], [55], [67]. Change orders concerning unforeseen conditions are normally due to physical conditions varying from what was previously decided within the original contract [68]. To mitigate the types of risks associated with this CDF, BIM helps to ensure improved design coordination, implementation, maintenance, and delivery for construction projects [69]. This CDF (CDF3) was deduced as the most to benefit from BIM with nine possible ways (Table V) through which delays due to client changes can be minimised. These include: improve design quality and verification of consistency in the design intent which prevents expensive delays (B1); early and more accurate visualisations of a design by the owner for better understanding of proposals (B2); support decision-making regarding the design (B3); improve the design and installation of MEP services on any construction project systems as well as their coordination with other building systems (B4); early quantity take-offs and cost estimating during the design stages with continuously updating as changes are made to the model (B5); improve visualisation of construction details (B7); increase the ability to resolve requests for information (RFIs) in real time (B9); improve communication and information exchange among stakeholders (B10); and quick reaction to design changes (change orders facilitation) (B13).

B1: BIM can help to improve the design quality and verify consistency of the design so as to prevent delays in construction projects [70]. As mentioned previously, sequencing the process activities in construction design provides accurate visualisations to the clients for a better understanding of materials and cost estimation [63] as well as budgeting [58]. A study [64] has pointed out that adopting BIM also helps in efficiently modifying workflow and resource allocation (such as people). As discussed above the efficient visualisation through BIM also provide an opportunity to support decision-making in design, if it needed changes. Furthermore, BIM improves the design and installation of MEP services [97]. Continuously updating the model if any changes are made during the design stage which helps to earlier consideration of quantity take-offs and cost estimation, so that the changes in design can be linked to resource limitations [71], [31].

B5: The accurate visualisation of quantity take-offs, materials, cost and budgeting has enhanced the potential of mitigating delays in construction [13], [98]. Moreover, accurate visualisation improves and streamlines communication [95], not just between clients, contractors, and sub-contractors but also between workers and supervisors [49]. [72], [73] stated that use of BIM enhances coordination, productivity, planning and construction process. As discussed earlier, good communication and BIM jointly increase the capability, ability, and availability of real-time information.

Considering the studies above, the essential benefits of BIM linked to client changes provide an opportunity for informed decision-making when clients demand variations from the original intent. Nevertheless, slowness of decision-making by clients is still a problematic issue that causes delays [5], [74], [75], [76]; [99]. This issue is explored in the next section.

D. CDF4: Slowness in Decision-Making by Client

Slowness in decision-making by the client is another critical factor that increases the risk of high cost and prolonged project duration consequently leads to the risk of project failure [77]. Dulaimi, et al [78] ranked 'slowness in decision-making by client' is the third most critical factor out of forty-two. Moreover, many other researchers ([76], [77], [79], [80], [81]) also ranked 'slowness in decision-making' in their top ten critical factors of delay in construction. Faridi and El-Sayegh [82] blamed considerable number drawings of project design and inadequate planning and visualisation as the cause of slowness in decision-making by clients. Many other recent studies [76], [80], [99] continue to raise the issue of slowness in decision-making as a cause of delay in construction projects. Nevertheless, since the evolution of BIM, researchers have claimed that BIM has increased the potential of quickness in the decision-making process of clients. The current stage of BIM offers following six ways of improving the speed of decision-making by clients: earlier and more accurate visualisations of a design to the owner for better understanding of proposals (B2); support decision-making regarding the design (B3); improve understanding the sequence of construction activities and project duration (B6); improve visualisation of construction details (B7); improve communication and information exchange among stakeholders (B10); and more accurate scheduling 4D and cost 5D estimation (B12).

B7: Visual representation through BIM discards the uncontrollable drawings that hinder the client's ability to understand and quickly make authoritative decisions [83]. Improved visualisation of construction details (such as cost estimation, construction processes and materials) through virtual sequencing of construction activities and project duration is helpful towards decision making. It also provides more accurate scheduling and cost estimation that improves communication between the clients, contractors, and sub-contractors [95]. Having efficient and effective communication and visual information among stakeholders enhances the speed which everyone is able to make decisions regarding the design [83]-[85]. However, poor management of communication and coordination between the clients, contractors, sub-contractors, supervisors, and workers can still be an issue that leads to delays in a construction project [19].

E. CDF5: Poor Communication and Coordination between Construction Parties

Poor and inconsistent communication in a construction project is a critical issue [86] because inadequate coordination of several organisations working on a construction project at any point in time is undesirable [76] [87]). Poor communication in construction projects results in poor planning and poor design, emanating from involves the inadequate exchange of information between the client or owner, consultants, contractors, external approving authorities, sub-contractors, and suppliers [89]. Several studies have linked poor management of communication as a cause of delay in construction projects ([5], [6], [53]). Adoption of BIM has the potential to improve communication management practices in following five ways: improve the design and installation of MEP services on any construction project systems as well as their coordination with other building systems (B4); improve understanding the sequence of construction activities and project duration (B6); improve visualisation of construction details (B7); improve communication and information exchange among stakeholders (B10); improve communication and coordination through the 3D BIM feature of clash detection in early stages (B14).

Poor communication generally manifests as poor coordination of data and information that leads to overdesign and errors in estimation [89]. This overdesign and errors lead to changes in design. The reasons for poor communication could be the varying interpretation and improper coordination of project data and information [89]. This leads to late decisions and finalisation of changes in design leading to bad decisions taken through varying interpretations [90], [91].

B6: BIM can help to improve the coordination of data and information while sequencing the construction activities and time duration for each activity [92], [93]. Current use of BIM has shown potential to merge and integrate different data sets and generate a visual interpretation of construction details [93], [94] as well as foster streamlined communication [96]. As aforementioned, sequencing activities can improve installation of MEP services on a construction project for enhanced coordination with other building systems [97]. Another important feature of BIM is that it has a 3D design visualisation function tool which can help to enhance automatic interface detection (clash detection) [99]. A study [15] also reported that clash detection can save up to 10% of project cost because it can help to detect possible collisions between building elements at the outset. By identifying where inconsistencies lie, clash detection can help improve communication between the stakeholders and lead to the completion of projects on time.

Clearly, substantial studies found in peer reviewed literature support the use of BIM for managing the identified cri CDF. On this basis, a case study was carried out to further investigate the problem (including optimism bias and client-related causes of delay) as well as to validate some of the benefits that BIM provides as identified in the literature.

VII. Case Study

A case study of nine hospital projects recently completed on behalf of the Ministry of Health (MOH) in Saudi Arabia was carried out. The hospitals are of various capacities and located in different regions, with different contract sums, cost overruns and periods of delay (Table VI). In the case of Project #6 and #7, it is observed that although both hospitals are located in Riyadh, have the same capacity (200 beds) and were started in the same month/year (June 2012), they differ significantly in contract sum, contract period, the length of delay and the additional costs. Specifically, Project #6 had a contract sum of SR 222 million, a 36-month contract period, which was delayed by 12 months with additional cost of SR 22 million, whereas Project #7 had a contract sum of SR 157 million with a 24-month contract period, which was delayed by 18 months at an additional cost of SR 105 million. The similarities between these two projects raise some questions about the significant differences in their delay period (i.e. a difference of 6 months) as well as the additional cost of up to SR 83 million for Project #7. However, given that Project #7 had 12 months' lesser completion time (and neglecting possible differences in construction materials) it can be argued that optimism bias was responsible for underestimating this project's cost and duration. As both projects were commissioned within a matter of days by the same MOH in the same city and month (June 2012), further investigation is required to understand how such marked differences were possible in the first place.

Similarly, Projects #3 and #4 are 200-bed hospitals that have similar project costs and similar contract duration, yet they have different delay period (25 months for Project #3 and 17 months for Project #4). The cost overruns are also different by a difference of SR 60 million (87% difference). The significant differences in their cost overruns might be explained by the remote location of Project #4, even though it had a lesser period of delay. Other factors that may have played a role in their differences could include: lack of skilled labour and local contractors or different materials used in construction, etc.

Moreover, Project #1 and Project #2 have the same capacity (100 beds) and where started in the same year (2012), they differ significantly in contract sum, contract period, the length of delay and the additional costs. However, Project #1 is located in the Eastern Province (Abqaiq) while Project #2 is located in Makkah Province. The similarities between these projects (in terms of capacity and start dates) raise questions similar to those mentioned earlier about the significant differences in their delay period as well as the additional cost. One factor could be location, given that Makkah is a more urban and popular city with global visitors (i.e. Muslim Hajj) hence, the cost of construction in Project #2 might be higher. Nevertheless, Project #1 had 11 months' lesser completion time and as such, it can still be argued that optimism bias was responsible for underestimating its projects cost and duration.

Further investigation is required and planned in the next Phase of the research in order to explore these differences.

Regarding the officially reported causes of the delay in these hospital projects, the data collected (Table VI) shows that with the exception of 'Errors in design' almost of these projects suffering from the same delay factors that are often related to the client for example, 'Delay in progress payment'; 'Change order and delay in approving'; as well as Lack of finance to complete the work by the client. It is not expected that these delay factors have the same impact or weight in all the projects. Further investigation would be required to rank these factors according to their perceived degree of impact as well as to identify other unreported.

Overall, data from these nine projects used in the case study does not show any strong correlation between additional cost, additional time and clinical capacity. With the exception of the Riyadh-based projects (Project #6 and #7), it is hypothesised that location and associated consequences like logistics and labour could be one hidden factor behind the observed differences.

VIII. Analysis

The mapping of several ways in which BIM provides benefits for managing critical factors of delay (Table V) reveals some interesting findings. Not all delay factors derive many benefits from BIM and not all benefits of BIM are applicable to delay factors. These two issues have been summarised below:

The delay factors that benefit most from BIM: it is noticeable that delays due to changes made by the client during construction (DF3) is the critical factor that benefits the most from as many as nine aspects of BIM process and technology. Other factors that benefit significantly from BIM include: “slowness in decision making by client” (DF4) which derives six benefits and indicating that BIM has the potential to speed up the decision-making process by clients; “Ineffective planning and scheduling of construction projects” has five benefits as does “poor communication and coordination between construction parties”.

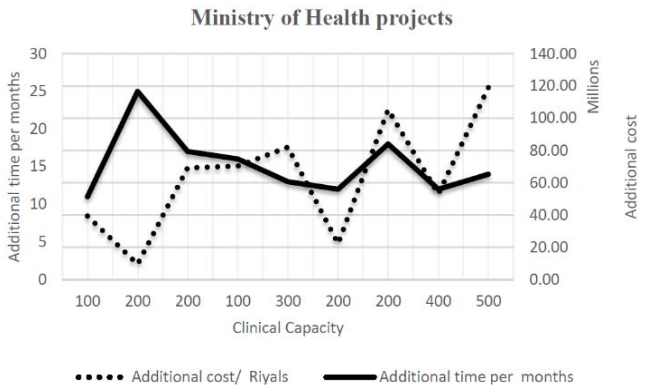

Fig. 1 Variations in additional cost, additional time and clinical capacity in the nine case study hospitals

TABLE VI
A Case Study of Nine Hospital Projects Commissioned by the Ministry of Health (MOH) in KSA

	Project name	Region	Clinical Capacity (beds)	project cost (SR)	Start Date	contract period (months)	Finish date	Additional time (months)	Additional cost (SR)	Client-related causes of delay*
1	Abqaiq General Hospital	East region	100	134,128,792	04/02/2012	36	01/01/2015	11	39,259,323.15	1, 2, 3
2	Aljmom General Hospital	Makkah	100	225,410,765	16/06/2012	24	25/05/2014	16	70,307,463.45	2, 3, 4
3	Maternity & Children's Hospital	Hail	200	392,000,000	09/06/2012	36	01/05/2015	25	9,485,951.00	1,3, 4,5
4	Maternity & Children's Hospital	Tabuk	200	390,000,000	18/06/2012	36	16/05/2015	17	69,264,402.54	1, 2, 3, 4,5
5	Miqat General hospital	Medina	300	416,292,960	17/06/2012	24	26/05/2014	13	82,030,685.40	1, 2, 3, 5
6	Tower Medicine in Iman hospital	Riyadh	200	222,766,616	25/06/2012	36	23/05/2015	12	22,276,660.75	1,3, 4,5,6
7	Emergency tower at King Salman Hospital	Riyadh	200	157,280,793	22/06/2012	24	31/05/2014	18	105,367,247.44	1, 2, 3, 4
8	Medical Tower for childbirth and children	Jeddah	400	378,652,682	09/09/2012	36	07/08/2015	12	53,030,068.10	1, 2, 3, 4
9	Al Takhassusi Hospital	Jazan	500	719,028,164	10/09/2012	36	08/08/2015	14	119,068,840.37	1, 2, 3, 4,5,6

*1 = Errors in design; 2 = Delay in progress payment; 3 = Change order and delay in approving it; 4 = Lack of finance to complete the work by client; 5= Soil condition issues 6= Poor communication between the project parties.

The benefits of BIM that are applicable to specific delay factors: It is found that one specific benefits which is *improving communication i.e. information exchange among stakeholders (B10) has influence on* mitigating four out of five identified types of delays which are: 1) insufficient planning and scheduling (DF1); changes during construction by clients (DF3); slowness in decision-making by clients (DF4) and poor coordination between construction parties (DF5). Therefore, this study establishes that improving communication while adopting BIM in construction projects is a highly important benefit that would help to mitigate several types of construction delays. Other notable benefits of BIM that can affect up to three out of five delay factors include *‘accurate sequencing of construction activities’* (B6), which can help to mitigate ineffective planning and scheduling (DF1); slowness in decision-making (DF4); and lack of coordination between construction parties (DF5);‘*improved visualisation of design construction details’ (B7)* helps to mitigate changes during construction by clients (DF3); slowness in decision-making (DF4); and lack of coordination between construction parties

(DF5); and finally '*more accurate scheduling and cost estimation' (B12)* helps to mitigate Ineffective planning and scheduling of construction projects (DF1); Delay in progress payment by client (DF2) and Slowness in decision-making by client (DF4). Based on these mapping of benefits to delay factors, we can therefore theorise that BIM can help to mitigate all five critical factors of delays in construction in four main ways as follows:

1 Improving communication and coordination between all parties (B10);
2 Effective and accurate sequencing of construction activities and ensuring that reliable data on project duration is efficiently fed into the BIM process (B6);
3 Accurate visualisation of the design being constructed in detail is produced in ways that can assist clients to make informed decisions (B7);
4 Production of accurate schedules and cost estimates (B12).

Other benefits given in Table V, however, can also have an impact (perhaps in synergy with the four primary benefits above) in mitigating such delays in construction.

IX. Conclusion

This study investigated the CDF in construction with respect to the benefits that can be obtained from using BIM in Saudi Arabia. Based on extensive literature review and established theory, it was postulated that client related factors and optimism bias contribute to delays with associated cost overruns. The delay factors were mapped to benefits and data from a case study seemed to support the idea that optimism bias is one of the leading causes of project delays in Saudi Arabia. However, the various projects investigated in the case study require further scrutiny to establish if other hidden causes are responsible for the observed and significant differences in delay periods and additional cost. Further investigations through in-depth interviews with three categories of stakeholders (i.e. client representatives, consultants and contractors) are planned supported by more case studies of the Ministry of Education (MOE) and Ministry of Transportation (MOT).

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