PROJECT SCHEDULE RISK MANAGEMENT THROUGH BUILDING INFORMATION MODELING

By

M. SAMI UR REHMAN

2015-NUST-MS-CE&M-07

A synopsis submitted in partial fulfillment of

the requirements for the degree of

Master of Science

in

Construction Engineering and Management

Department of Construction Engineering and Management

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST),

Islamabad, Pakistan

(September 2018)

PROJECT SCHEDULE RISK MANAGEMENT THROUGH BUILDING INFORMATION MODELING

Submitted by

M. SAMI UR REHMAN

(NUST2015MSCE&M0700000118824)

has been accepted towards the partial fulfillment
of the requirements for the degree of
Master of Science in Construction Engineering and Management

Dr. Muhammad Jamaluddin Thaheem

Supervisor,

Department of Construction Engineering and Management,

National University of Sciences and Technology (NUST), Islamabad

This thesis is dedicated to my parents, siblings and specially my wife for always being an unending source of love and encouragement.

ACKNOWLEDGMENT

First and foremost I would like to thank Almighty Allah Who always blessed me and guided me in the right direction throughout my life and also helped me to get through this master degree and associated research.

I would like to express my sincere gratitude and appreciation to my supervisor Dr. M. Jamaluddin Thaheem (HoD, CE&M) for his motivation, profound guidance and encouragement, to complete this challenging research work. I sincerely appreciate the valuable time and personal support bestowed by him. I am also extremely grateful to the committee members, Dr. M. Sohail Anwar Malik, Dr. Hamza Farooq Gabriel and Dr. Abdur Rehman Nasir for their sincere guidance to complete this research work. I owe my special thanks to the people of batch CEM-07 for their support, motivation and guidance throughout the course work and research work. I am very grateful to all respectable respondents for their valuable contribution to this research. And in the end I would like to pay my earnest and honest gratitude to my parents, my siblings and especially my wife for their unconditional love, patience, support, encouragement and prayers.

ABSTRACT

Construction projects are unique in nature resulting in an exclusive result at the end. Dynamic nature of these projects and involvement of large number of stakeholders exposes them to a variety of known and unknown risks. Cost and time are the two most important and interlinked project constraints that influence the currency of the project. Many a times, projects fail to keep up with the planned schedules and budgeted costs to meet their goals. Behind schedule delays lie many known and unknown risks, to cater to which many theories and models have been proposed. However, this aspect still demands much work in the face of consistent time failures in the projects. Building information modeling (BIM) has been introduced as a promising technology which aims to facilitate the planning and decision-making, and addresses a myriad of issues. But the effect of BIM on construction delays has not been sufficiently studied so far. This study focuses on project schedule risk management using the modern concept of BIM. In doing so, major risk factors affecting project schedule will be identified, along with the features of BIM which have effect in solving these risks. Based on the factor-feature matrix, the resolution capacity of identified risks due to BIM will be assessed and applied through a case study. The implications of this research involve value assessment of BIM in resolving duration related risk factors which will help stakeholders achieve project success and promote BIM adoption to its fullest.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CAD	Computer Aided Design
BIM	Building Information Modelling
AEC	Architecture, Engineering and Construction
LOB	Line of Balance
CPM	Critical Path Method
ICT	Information and Communication Technology
LEED	Leadership in Energy and Environmental Design
MEP	Mechanical, Electrical and Plumbing
HVAC	Heating, Ventilation and Air Conditioning
IT	Information Technology
LOD	Level of Development
4D-CAD	Four-Dimensional Computer-Aided Design
BOQ	Bill of Quantities

Chapter 1

INTRODUCTION

1.1 Preamble

Most projects experience extensive delays during execution and resulting a significant increase in initial time and cost estimates (Odeh and Battaineh, 2002). Timely completion of projects indicates its efficiency, but the construction process consists of many variables and uncertainties, which result from many sources. Performance of all project participants, availability of required resources, climatic conditions, interference by different parties and contractual relations are some of the resources which causes delays (Assaf and Al-Hejji, 2006). Delays can affect the project in negative ways such as increase in initial cost estimates, productivity losses and reduction in profits, litigation between clients and contracting firms and contract termination (Hisham and Yahya, 2016). Effective planning and efficient scheduling have been recognized as very important aspect in the success of the project, failure of these factors causes delays (Assaf and Al-Hejji, 2006). While working with only 2D drawings, the user could not perceive the complete spatial impression. To understand the entire plan human brain has to construct the complete 3D view mentally. This method cannot precisely reflect the planning logic which would otherwise increase the planning certainty to a higher level and increase the risks (Wang, 2007). Risks and challenges are always associated with innovation, but the risks related to implementation of BIM, as compared to CAD, in construction projects are much less (Smith and Tardif, 2009).

Risk management may be described as *"a systematic way of looking at areas of risk and consciously determining how each should be treated. It is a management tool that* *aims at identifying sources of risk and uncertainty, determining their impact, and developing appropriate management responses"* (Uher and Zantis, 2012). Process of classifying, identifying, analyzing and responding to risks is known as Risk management, where retention, reduction, transfer and avoidance are further four classes of risk response (Berkeley et al., 1991). An effective method for risk management is not only benefit in identification of risk but also guide towards managing these risks using various techniques throughout the life cycle of the project. Today risk management has been acknowledged as a necessity due to its ever increasing demand in almost all the industries in controlling the influences brought by various risks through its set of techniques (Schuyler, 2001, Baker and Reid, 2005).

Building information modeling (BIM), described as *"digital representation of physical and functional characteristics of a facility"*, has provided effective solution to many problems and challenges faced by the Architecture, Engineering, and Construction (AEC) industry because of its data storage ability relating to a facility, upon which BIM tool performs various analyses i.e. structural analysis and schedule planning analysis (Weygant, 2011), and enable information flow and making use of the available information between various computer software throughout the project lifecycle (Howard and Björk, 2008), which bring considerable improvements in efficiency and boosts effective coordination among project participants. Utilizations of BIM have thus earned much consideration within Architecture, Engineering, and Construction (AEC) in recent years. Scholars and industry experts have explored distinctive approaches to perform project planning using BIM. A substantial amount of research has been carried out for identifying the potential benefits of BIM in all aspects of the project. However, the reliance on old-fashioned drawings and practices for conducting its business still prevails among the AEC industry. All at once, AEC practitioners and participants are realizing the benefits of BIM for more effective and smart modeling (Azhar, 2011). In this regard, there are no such published data which serve the need of our construction industry in realizing the benefits of Building Information Modeling as a risk transformer for construction scheduling and its effective control throughout the lifecycle of the project. This absence creates decision problems for the owners of the Design firms and the Contractors, whether to adopt this Building Information Modeling tool or not. In response, this research aims to fill this gap and provide easy to use, guidelines for proper risk transformation using the Building Information Modeling tool.

1.2 Problem Statement

Meeting a set of goals, targets and objectives as stated in the initial project plan is the definition of project success (Frimpong et al., 2003). A successful project has to accomplish its technical performance, maintain its schedule, and remain within budget. Many projects exceed project initial time and preliminary cost estimates as they experience extensive delays (Odeh and Battaineh, 2002). Lack of detailed research and some strict planning guidelines, many projects experience construction delays and project team has to rely on their own judgment to keep the project on track. To overcome this problem, this study will identify the major problems and will suggest a solution using modern ICT tool i.e. Building Information Modelling (BIM). It will comprise of identification of key risk factors which causes project delays, identifying key features of BIM, Preparing the matrix which shows the relation between Key Risk Factors and the features of BIM, then comparing results from literature with field data.

1.3 Research Objectives

The following objectives are set forth for this study.

1. To identify key risk factors which affect the schedule performance during the whole construction process.
2. To identify BIM features and functions aimed at improving schedule related matters.
3. To map the factor-feature matrix which identifies potential relationship between them.
4. To validate the proposed matrix and quantify benefits of BIM using real case study project.

1.4 Advantages of Study

- Key Risk Factors will be identified which can be helpful for Project Management to implement BIM into their projects.
- After using BIM into real life projects, better understanding of its usefulness will be achieved.
- Established guidelines will help key management to implement BIM tool on their projects with much more confidence.
- Project Managers will have more control over the schedule tracking over the life cycle of the project.
- Study will contribute to existing body of knowledge and will divert attention towards an important but neglected area.

1.5 Thesis Organization

This thesis has been organized into five chapters.

Chapter 1 is 'Introduction.' It covers introduction to research, problem statement, research objectives and advantages of study. It provides a general insight about this research study.

Chapter 2 is ‘Literature Review.’ It explains the previous studies done concerning the research providing essential information regarding schedule related Key Risk Factors effecting the performance of project schedule and features of Building Information Modelling.

Chapter 3 is ‘Research Methodology.’ It explains the flow of research and a logical relation between various stages of this research in achieving the research objectives.

Chapter 4 is ‘Results and Discussion.’ It discusses the results obtained from online surveys, various analyses and opinions from the participants according to our research objectives. It also states the achievement of results using prescribed research methodology and how our collected data and modeling produces results which helps in attaining our research objectives.

Finally, Chapter 5 is ‘Conclusions and Recommendations.’ Final conclusions and recommendations have been discussed in this chapter.

Chapter 2

LITERATURE REVIEW

2.1 Background

This chapter discusses the past work done related to the research being carried out. It entails a discussion on construction project scheduling, techniques for efficient project scheduling, problems related to construction project scheduling which lead to construction delay and its possible solution using modern tools and techniques. Further, connecting the related literature for research, this chapter enhances the knowledge about building information modelling and use of this concept in assessing and resolving risks related to scheduling.

Construction delays have become an integral part of a project's lifecycle. Making matters more complicated are the complexity of construction process and a huge amount of project stakeholders involved in various stages of project lifecycle which include owners, consumers, architects, operators, constructors, suppliers, sub-contractors, consultants to name a few (Enshassi et al., 2006). Currently, in the presence of advanced ICT tools and techniques and comprehensive understanding of construction management techniques, construction industry still face construction delays and project completion dates gets disturbed (Stumpf, 2000). Construction delay has an adverse effect on owners, constructors and designers in terms of mistrust in their relationship, litigation, timely payment issues, poor inter party coordination and a general feeling of anger and revenge toward one another (Ahmed et al., 2003). Success of a project occurs when it achieve the prescribed objectives related to cost, time and quality successfully (Mahamid et al., 2011). However, it is very common to see construction projects fail to achieve its goals and objectives (Nega, 2008).

2.2 Construction Scheduling and its Importance

Schedules, developed during the early planning stage, plays a key role in the successful execution of a project. Planning and scheduling yields a construction schedule which is a logical flow of a construction activities which helps in achieving project objectives thorough knowledge of construction methods, materials and practices. in the absence of a project schedule it is not possible to find a relation between various activities and to coordinate diverse activities of a construction project (Gould, 2005) since they are basis for management decisions (Castro-Lacouture et al., 2009). However, all the activities present in a project schedule contains risk of varying degree which needs to be addressed to keep the project on track (ISO, 2009, Nasir et al., 2003). Because of uncertainties, delays are common in various construction projects and cause considerable losses to project stakeholders (Kim et al., 2009). Many studies have been put forward to identify risk factors which delay the successful and timely completion of construction projects. It is evident that risk factors which causes delays must be identified for further analysis (Assaf and Al-Hejji, 2006, Abd El-Razek et al., 2008, Odeh and Battaineh, 2002).

2.3 Failures of Construction Schedules

In construction industry, delay could be defined as the project not completing within the completion date agreed upon for the delivery of the project by project stakeholders (Assaf and Al-Hejji, 2006). Many project experience extensive delays which causes the project to exceed its initial time and cost estimates (Odeh and Battaineh, 2002). Despite the construction management team's efforts and best practices CPM Schedules invariably become erroneous, each individual present in the team has to work up to the mark to pull their own weight. The major task of good schedule is to predict the future for the project, when the schedule has been made efficient enough that it will start predicting what is going to happen and when so that project team can get ready before hand. If the project is large and has multiple prime contractors, its schedule is even more susceptible to deprecation.

Many times, project management team knows that project is going to fail. Even so, it may seem inevitable. However, for the factors hindering success, there is a solution. Sometimes it's very hard to swallow but the team lead must have to take strict actions to bring back the schedule on track. It is up to the scheduler to do everything he can to maintain the integrity of the project schedule. The foregoing is intended to highlight the most challenging obstacles to schedule success and offer solutions.

2.3.1 Causes of Schedule Failures

Assaf and Al-Hejji (2006) conducted a study to examine large construction projects in Saudi Arabia and identified 73 delay causes, which indicated average time overrun is between 10% and 30% of the original duration. Chan and Kumaraswamy (1997) studied the construction projects going on in Hong Kong and conducted a survey to evaluate the relative importance of delay factors. Total of 83 potential delay factor were evaluated. Improper risk management and risk supervision, unanticipated site conditions, slow decision making among all stakeholders, design variations issued during project execution by client and necessary design variations were found and termed as primary and common factors. Hwang et al. (2013) conducted a study to find our critical factors which affect schedule performance. They found six most critical factors which includes site management, coordination among project stakeholders, design changes during construction by owner, and availability of labor, material and staff to manage projects. Iyer and Jha (2005) also identified seven factors which have a significant influence on schedule outcome. Various other studies have identified several delay factors which hinder the smooth execution of project schedule (Majid and

McCaffer, 1998, Faridi and El-Sayegh, 2006, Mahamid et al., 2011). It is evident from these studies that the focus has remained limited to identifying major risk factor and categorizing them.

2.4 Project Scheduling Risks

In current study, the risk factors were identified through extensive literature review in which a total of 30 studies published during years 1985-2013 were consulted to list down risk factors which affect schedule performance. Design changes during construction phase (Enshassi et al., 2009, Le-Hoai et al., 2008), availability of materials (Abd El-Razek et al., 2008, Aibinu and Odeyinka, 2006), speed of decision making of owner (Abdul Kadir et al., 2005, Sweis et al., 2008), coordination among parties (Sambasivan and Soon, 2007, Mahamid et al., 2011), weather (Lo et al., 2006, Koushki et al., 2005), availability of laborers on site (Frimpong et al., 2003, Alzahrani and Emsley, 2013), and preparation of schedules and updates (Mahamid et al., 2011, Enshassi et al., 2009) were found to be the most significant factors among others.

List of risk factors which affects schedule performance, identified from extensive literature review, are given in Table 2.1.

Table 2.1 List of Key Risk Factors

Sr. #	Factor	Description	References
1	Site management	Managing all aspects required to execute the construction activities successfully. Labor management, material management, equipment management are some of those aspects.	(Enshassi et al., 2009, Le-Hoai et al., 2008, Chan and Kumaraswamy, 1997, Lo et al., 2006, Sambasivan and Soon, 2007, Faridi and El-Sayegh, 2006, Chan and Kumaraswamy, 2002, Alaghbari et al., 2007)
2	Financing by contractors	Most important factor during the execution of the project is budget. Successful schedule relies on timely financing from contractor's end. Regular payments to labor, material suppliers and sub-contractors is vital for successful schedule performance.	(Enshassi et al., 2009, Le-Hoai et al., 2008, Hatush and Skitmore, 1997, Abd El-Razek et al., 2008, Aibinu and Odeyinka, 2006, Mezher and Tawil, 1998, Sweis et al., 2008, Ogunlana et al., 1996, Al-Momani, 2000, Lo et al., 2006, Al-Khalil and Al-Ghafly, 1999, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Mahamid et al., 2011, Arditi et al., 1985, Alaghbari et al., 2007, Alzahrani and Emsley, 2013)
3	Coordination among parties	Co-ordination among all key participants of the project must be proper. During the execution of the project many issues arises which needs input from client, consultants and contractors. Frequent co-ordination	(Enshassi et al., 2009, Le-Hoai et al., 2008, Abd El-Razek et al., 2008, Iyer and Jha, 2005, Abdul Kadir et al., 2005, Sweis et al., 2008, Ogunlana et al., 1996, Lo et al., 2006, Sambasivan and Soon, 2007, Al-

		among all parties throughout the project life is necessary.	Khalil and Al-Ghafly, 1999, Faridi and El-Sayegh, 2006, Mahamid et al., 2011, Walker and Vines, 2000, Majid and McCaffer, 1998)
4	Preparation of schedule plans and updates	Success of the schedule depends on its preparation. Preparation of schedule requires a skillful planner which has in-depth knowledge of construction. Similarly updating the schedule during the project lifecycle is also necessary.	(Enshassi et al., 2009, Aibinu and Odeyinka, 2006, Mezher and Tawil, 1998, Sweis et al., 2008, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Kaming et al., 1997, Mahamid et al., 2011, Majid and McCaffer, 1998)
5	Experience of contractors	Competence of the contractors to execute the specialized activities required by the project is very important for the success of the project.	(Hatush and Skitmore, 1997, Iyer and Jha, 2005, Lo et al., 2006, Sambasivan and Soon, 2007, Faridi and El-Sayegh, 2006, Chan and Kumaraswamy, 2002, Majid and McCaffer, 1998, Alzahrani and Emsley, 2013)
6	Construction methods	Construction methods are the procedures and techniques that are used during the construction process.	(Enshassi et al., 2009, Faridi and El-Sayegh, 2006, Le-Hoai et al., 2008, Mahamid et al., 2011, Majid and McCaffer, 1998, Sambasivan and Soon, 2007, Sweis et al., 2008)
7	Experience of consultants	Experienced consultant having sound expertise in design, drawings and execution control is very essential.	(Alaghbari et al., 2007, Al-Khalil and Al-Ghafly, 1999, Enshassi et al., 2009)

8	Foundation conditions	Detailed knowledge of ground conditions before design and execution plays the key role in successful execution of the project. It depends on detailed testing during preliminary stages of the project.	(Abdul Kadir et al., 2005, Al-Khalil and Al-Ghafly, 1999, Al-Momani, 2000, Chan and Kumaraswamy, 1997, Chan and Kumaraswamy, 2002, Enshassi et al., 2009, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Le-Hoai et al., 2008, Lo et al., 2006, Mahamid et al., 2011, Sambasivan and Soon, 2007, Mansfield et al., 1994, Sullivan and Harris, 1986)
9	Speed of decision making of owners	Issue arises in all construction projects, to resolve or address these issues all key participants of the project have to co-ordinate. Owner has the key role in timely addressing changes occurring during the life of the project. Speedy decision and valued inputs from client is essential for smooth running of project.	(Abd El-Razek et al., 2008, Abdul Kadir et al., 2005, Aibinu and Odeyinka, 2006, Alaghbari et al., 2007, Al-Khalil and Al-Ghafly, 1999, Assaf and Al-Hejji, 2006, Chan and Kumaraswamy, 1997, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Lo et al., 2006, Mahamid et al., 2011, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Sullivan and Harris, 1986, Sweis et al., 2008)
10	Financing by owners during construction	Financing the project is the key factor in the success of any project. Releasing timely payments by owner to suppliers, consultants, contractors and other agencies involved in the project results in	(Aibinu and Odeyinka, 2006, Alaghbari et al., 2007, Al-Khalil and Al-Ghafly, 1999, Al-Momani, 2000, Assaf and Al-Hejji, 2006, Frimpong et al., 2003, Koushki et al., 2005, Le-Hoai et al., 2008, Lo et al., 2006, Mahamid et al., 2011, Mezher and

		the timely completion of all project activities.	Tawil, 1998, Sambasivan and Soon, 2007, Sweis et al., 2008)
11	Design changes by owners during construction	Project having sound and detailed initial design has more chances of timely completion. However, client's demands have no ending, clients often initiates changes during the execution phase due to various reasons. Changes in design during the execution phase are the indicator of projects schedule failure. Most of the times design changes occur after the execution of certain activity which mostly end up in disputes.	(Abd El-Razek et al., 2008, Abdul Kadir et al., 2005, Aibinu and Odeyinka, 2006, Al-Khalil and Al-Ghafly, 1999, Al-Momani, 2000, Arditi et al., 1985, Chan and Kumaraswamy, 1997, Chan and Kumaraswamy, 2002, Enshassi et al., 2009, Faridi and El-Sayegh, 2006, Kaming et al., 1997, Koushki et al., 2005, Le-Hoai et al., 2008, Lo et al., 2006, Mahamid et al., 2011, Mansfield et al., 1994, Mezher and Tawil, 1998, Sambasivan and Soon, 2007, Sullivan and Harris, 1986, Sweis et al., 2008, Semple et al., 1994)
12	Experience of owners	Inexperienced owner of the project is also the cause of delayed project delivery.	(Abdul Kadir et al., 2005, Iyer and Jha, 2006, Koushki et al., 2005)
13	Availability of laborers on site	No matter what type of the project is, availability of skilled workers is always important factor in project success. Availability of skilled labor at site for all activities accordingly is vital for the project.	(Enshassi et al., 2009, Le-Hoai et al., 2008, Aibinu and Odeyinka, 2006, Sweis et al., 2008, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Al-Khalil and Al-Ghafly, 1999, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Alzahrani and Emsley, 2013, Assaf and

			Al-Hejji, 2006, Mahamid et al., 2011, Majid and McCaffer, 1998)
14	Availability of staff to manage projects	Successful project is the project which has been managed properly during its lifecycle. To manage a project there must be a trained staff to manage the project. Whether it is owner's side or contractor's, trained staff is essential for management.	(Abdul Kadir et al., 2005, Al-Khalil and Al-Ghafly, 1999, Alzahrani and Emsley, 2013, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Hatush and Skitmore, 1997, Mahamid et al., 2011, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Sweis et al., 2008)
15	Availability of equipment	Good management in construction must pursue the availability and efficient utilization of equipment. Many construction activities requires modernized equipment, timely completion and keeping up with the schedule requires proper management of equipment.	(Abdul Kadir et al., 2005, Aibinu and Odeyinka, 2006, Al-Khalil and Al-Ghafly, 1999, Alzahrani and Emsley, 2013, Enshassi et al., 2009, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Hatush and Skitmore, 1997, Mahamid et al., 2011, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Sweis et al., 2008)
16	Availability of material	Availability of material is a very important aspect in successful project execution. Productivity of labor and equipment relies heavily on availability of materials. Hence, material management is very vital throughout the life of the project. Lack of	(Enshassi et al., 2009, Le-Hoai et al., 2008, Abd El-Razek et al., 2008, Aibinu and Odeyinka, 2006, Abdul Kadir et al., 2005, Sweis et al., 2008, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Al-Khalil and Al-Ghafly, 1999, Koushki et al., 2005, Mansfield et al., 1994, Faridi

		which affect overall time, quality and budget.	and El-Sayegh, 2006, Frimpong et al., 2003, Kaming et al., 1997, Alaghbari et al., 2007, Majid and McCaffer, 1998)
17	Availability of site	Construction site having no disputes with government, locals and environment agencies plays vital role in timely completion of the project.	(Semple et al., 1994)
18	Weather	Bad weather can affect the schedule performance. Many times it only halts the construction activities for some time, on the other hand it may damage the material, equipment and already constructed structures as well.	(Le-Hoai et al., 2008, Aibinu and Odeyinka, 2006, Iyer and Jha, 2005, Abdul Kadir et al., 2005, Lo et al., 2006, Sambasivan and Soon, 2007, Al-Khalil and Al-Ghafly, 1999, Koushki et al., 2005, Sullivan and Harris, 1986, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Mahamid et al., 2011, Kaming et al., 1997, Semple et al., 1994)
19	Sub-contractors	Sub-contractors helps the prime contractors to do various jobs during the project. Their thorough management is vital for timely project completion.	(Le-Hoai et al., 2008, Aibinu and Odeyinka, 2006, Abdul Kadir et al., 2005, Lo et al., 2006, Sambasivan and Soon, 2007, Mansfield et al., 1994, Faridi and El-Sayegh, 2006, Majid and McCaffer, 1998)
20	Design delays	Design delays can hinder the initial start of the project and design delays during construction can derail the project.	(Aibinu and Odeyinka, 2006, Arditi et al., 1985, Faridi and El-Sayegh, 2006)

21	Political scenarios	Political situation of the area plays an important role. Although chances of their occurrence is low but it can cause serious project delays.	(Abdul Kadir et al., 2005, Aibinu and Odeyinka, 2006, Enshassi et al., 2009, Mahamid et al., 2011, Majid and McCaffer, 1998)
22	Construction management practices	To successfully execute the project and to meet the expected level of quality and contract terms, key participants must follow best construction management practices.	(Enshassi et al., 2009, Le-Hoai et al., 2008, Abd El-Razek et al., 2008, Abdul Kadir et al., 2005, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Mansfield et al., 1994, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Arditi et al., 1985, Assaf and Al-Hejji, 2006, Walker and Vines, 2000, Majid and McCaffer, 1998)
23	Delayed payments by owner	Timely payments to contractors is the key for its effective performance. Delays in timey payment to contractors by owner has impacted negatively on the performance of the contractor and hence affecting the overall project delivery time.	(Enshassi et al., 2009, Le-Hoai et al., 2008, Abd El-Razek et al., 2008, Abdul Kadir et al., 2005, Sweis et al., 2008, Sambasivan and Soon, 2007, Al-Khalil and Al-Ghafly, 1999, Mansfield et al., 1994, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Mahamid et al., 2011)
24	Government/permits	Apart from designs, construction methods and contracts, permits are also essential part of the project. To start a project at certain locality team must have to get permits from various legal agencies.	(Enshassi et al., 2009, Le-Hoai et al., 2008, Aibinu and Odeyinka, 2006, Abdul Kadir et al., 2005, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Al-Khalil

			and Al-Ghafly, 1999, Faridi and El-Sayegh, 2006)
25	Unrealistic duration by owner	Reasonable duration from owner and contractor as well is vital. Sometimes due to various reasons client/owner sets very unrealistic durations which effects the project.	(Enshassi et al., 2009, Abdul Kadir et al., 2005, Lo et al., 2006, Sambasivan and Soon, 2007, Al-Khalil and Al-Ghafly, 1999, Faridi and El-Sayegh, 2006)
26	Owners interference	Owner appoints a team of consultants or in-house management team to supervise the project. However some owners starts interfering with projects matters which effects the project in a negative way.	(Enshassi et al., 2009)
27	Site safety	Construction is full of hazardous activities. All parties involved in the construction must take care of the safety of workers and equipment as well.	(Enshassi et al., 2009, Hatush and Skitmore, 1997, Sweis et al., 2008, Al-Khalil and Al-Ghafly, 1999, Alzahrani and Emsley, 2013)
28	Inaccurate estimates	All management techniques relies on estimates. Inaccurate estimates leads to faulty planning and hence cause delays and financial losses.	(Enshassi et al., 2009, Le-Hoai et al., 2008, Mansfield et al., 1994, Faridi and El-Sayegh, 2006, Frimpong et al., 2003, Kaming et al., 1997)
29	Preparation of shop drawings and approvals	Preparation, submission and approvals of shop drawings is a demanding process. Many contractors and architects don't have capability to prepare and access shop drawings properly.	(Abd El-Razek et al., 2008, Abdul Kadir et al., 2005, Aibinu and Odeyinka, 2006, Al-Momani, 2000, Faridi and El-Sayegh, 2006, Ogunlana et al., 1996, Sambasivan and Soon, 2007, Sweis et al., 2008)

2.5 Building Information Modeling (BIM)

Building Information Modeling (BIM) is an Information Technology (IT) enabled approach that involves in devising a policy and generating a methodology to manage essential building design and project data in a digital representation for different phases of the project lifecycle in the form of a data repository (Gu and London, 2010). In recent years, there has been a shift from CAD to BIM in the AEC industry owing to its benefits and savings in resources being used during design, planning and construction phases (Bryde et al., 2013, Eastman et al., 2011). Using BIM, design phase has experience a significant improvement due to rigorous analysis, simulations and validity of design alternatives (Azhar, 2011). Effective implementation of BIM is beneficial during project planning (Ma et al., 2005), scheduling (Dawood et al., 2003, Jongeling and Olofsson, 2007) and control phase (Feng et al., 2010, Yabuki and Shitani, 2005). Implementing BIM in construction promises to improve the communication and collaboration between participants through high interoperability of data (Hardin and McCool, 2015). BIM generates information and procedures which are vital for facility's lifecycle management (Succar et al., 2007). Literature suggests that all the phases of a construction project have been positively affected by the proper implementation of BIM.

BIM was implemented in the construction of Aquarium Hilton Garden Inn, Atlanta, Georgia with an objective to quantify its benefits. Over $200,000 was saved through clash detection and the schedule benefited by 1,143 hours (Azhar, 2011). A comprehensive study, conducted by gathering the data of 32 major projects at Stanford University's Center for Integrated Facilities Engineering, shows that BIM achieved up to 40% elimination of un-budgeted variations, up to 80% reduction in time for preparation of detailed cost estimates, up to 10% savings of the contract value through clash detection and 7% reduction in project time (CIFE, 2007).

2.5.1 BIM as a Tool for Risks Risk Management

"*A detailed BIM model is a risk mitigation tool*" (Eastman et al., 2011). BIM consider risk in a positive way and its modern tools bring various opportunities, reducing uncertainty in design and coordination among project stakeholders (Deutsch, 2011). Integration of BIM and safety outlined framework for automatic identification of safety related risk and corresponding mitigation methods can be applied in an automated approach (Zhang et al., 2013). Various features of BIM can improve visualization which reduces risks related to design interpretation among project participants and better understanding of construction schedule (Chantawit et al., 2005). However, published data on the integration of BIM and risk is limited (Zou et al., 2017, Araszkiewicz, 2016).

Ahmad et al. (2018) conducted a detailed study to identify and quantify the implementation of BIM in risk management to justify if implementation cost of BIM can be traded off with potential gains due to better risk management. They concluded that highest ranked risks were either eliminated or significantly addressed reducing their impact considerably and the value proposition of BIM implementation was higher due to its benefits hence justifying investing in BIM. It can be seen that this study was done to identify implementation of BIM and quantifying its effects on all aspects of project. However, the effect of BIM implementation on project schedule and quantification of its benefits is not reported in literature. Since it may be argued that BIM can reduce the effect of risks on schedule, but the actual benefits of BIM on project schedule performance need to be quantified.

2.6 List of Identified BIM Features

In current study, features of BIM which positively affect the project factors were identified through extensive literature review. It is found that BIM features such as 3D Modelling (Azhar, 2011, Zhang et al., 2013), project planning and analysis (Chantawit et al., 2005, Chau et al., 2004), cost estimation (Barlish and Sullivan, 2012, Wang et al., 2014), safety analysis (Wang et al., 2015, Zhang et al., 2015), data sharing and coordination among parties (Sacks et al., 2010, Stadel et al., 2011), site utilization planning (Kim and Cho, 2015, Succar, 2009), clash detection (Hajian and Becerik-Gerber, 2009, Wong and Fan, 2013) and risk management (Bryde et al., 2013, Hartmann et al., 2012) significantly influence the schedule performance throughout project's lifecycle.

Extensive literature review has been carried out to identify features of building information modelling (BIM). Table 2.2 contains the identified BIM features;

Table 2.2 List of BIM Features

Sr. #	Factor	Description	References
1	3D modelling	3D-Modelling facilitates the engineers, architects and the construction team in seeing the complete facility in a better way. It relieves them from thinking the 3rd dimension in their minds for clear understanding. Design becomes more vivid and key participants having less technical knowledge have an easy access to understanding the facility being constructed.	(Azhar, 2011, Zhang et al., 2013, Hartmann et al., 2012, Chantawit et al., 2005, Bynum et al., 2012, Chau et al., 2004, Koo and Fischer, 2000, Barlish and Sullivan, 2012, Wang et al., 2014, Jan et al., 2013, Sacks et al., 2010, Stadel et al., 2011, Eastman et al., 2011, Hajian and Becerik-Gerber, 2009, Campbell, 2007, Becerik-Gerber et al., 2011, Gu and London, 2010, Gursel et al., 2009, Wang et al., 2015, Zhang et al., 2015, Succar, 2009, Jung and Joo, 2011, Azhar et al., 2011, Kim and Teizer, 2014, Kim and Cho, 2015, Steel et al., 2012, Wong and Fan, 2013, Melzner et al., 2013)
2	Quantity takeoff/ cost estimation	Quantity take-offs (QTO) are a comprehensive estimation of materials required to efficiently complete a construction project without much wastage. These estimated are prepared by an experienced estimator before start of construction phase.	(Hartmann et al., 2012, Chau et al., 2004, Barlish and Sullivan, 2012, Wang et al., 2014, Bryde et al., 2013, Eastman et al., 2011, Campbell, 2007, Gu and London, 2010, Melzner et al., 2013, Steel et al., 2012, Succar, 2009, Wong and Fan, 2013)

3	Clash detection	Clash detection is a very useful feature in BIM modeling tool. It finds clashes in the amalgam of structural, architectural and MEP Models.	(Azhar, 2011, Barlish and Sullivan, 2012, Eastman et al., 2011, Hajian and Becerik-Gerber, 2009, Koo and Fischer, 2000, Sacks et al., 2010, Wong and Fan, 2013)
4	Analysis and planning	Integration of fourth dimension i.e. time, is known as 4D-BIM which allows you to discover and estimate a project's execution sequence, visualize construction processes through 4D simulation, identify clashes of any sort, manage an effective coordination between project participants throughout the design and construction process, and better predict, manage and communicate project outcomes.	(Azhar, 2011, Barlish and Sullivan, 2012, Bryde et al., 2013, Campbell, 2007, Chantawit et al., 2005, Chau et al., 2004, Eastman et al., 2011, Gursel et al., 2009, Hajian and Becerik-Gerber, 2009, Jung and Joo, 2011, Kim and Cho, 2015, Kim and Teizer, 2014, Koo and Fischer, 2000, Melzner et al., 2013, Steel et al., 2012, Succar, 2009, Wang et al., 2014, Wong and Fan, 2013, Zhang et al., 2013)
5	Energy modelling/sustainability	Energy analyses or sustainability analyses are usually known as Building Energy Modeling (BEM). BEM is an efficient tool to calculate energy consumptions for a facility for design purposes, code reviews, retrofit designs, LEED certifications and planning and design of various systems.	(Bynum et al., 2012, Stadel et al., 2011, Eastman et al., 2011, Becerik-Gerber et al., 2011, Jung and Joo, 2011, Azhar et al., 2011, Steel et al., 2012, Wong and Fan, 2013)

6	Structural analysis	Various structural analysis software utilizes BIM models to analyze the state and behavior of a structure under nominated loads. Upon analysis it will help you to redesign, analyze and document your project efficiently.	(Bynum et al., 2012, Succar, 2009, Jung and Joo, 2011, Kim and Teizer, 2014)
7	Data sharing/co-ordination	Building information modeling (BIM) has the ability to facilitate and enhance coordination between the various parties working on complex projects.	(Hartmann et al., 2012, Barlish and Sullivan, 2012, Bryde et al., 2013, Sacks et al., 2010, Stadel et al., 2011, Campbell, 2007, Steel et al., 2012, Succar, 2009)
8	Design reviews	Stakeholders view the 3D model and according to their contractual role and capabilities they access the design and provide their feedback to validate multiple aspects of the design.	(Barlish and Sullivan, 2012, Jung and Joo, 2011, Koo and Fischer, 2000, Sacks et al., 2010, Steel et al., 2012, Succar, 2009, Wong and Fan, 2013)
9	LEED validation	BIM models and analysis helps in evaluating the facility for LEED validation.	(Azhar et al., 2011, Stadel et al., 2011)
10	Lighting analysis	Lighting analysis can help you in designing energy efficient buildings by using daylighting and knowing precise lighting requirement through rendering software.	(Azhar et al., 2011, Bynum et al., 2012, Wong and Fan, 2013)
11	Site utilization planning	Graphical representation of temporary and permanent facilities on site using BIM. This helps in organizing various	(Azhar, 2011, Becerik-Gerber et al., 2011, Bynum et al., 2012, Chau et al., 2004, Gu and London, 2010, Kim and

		site activities during multiple phases of the project.	Cho, 2015, Kim and Teizer, 2014, Succar, 2009)
12	Building system analysis	Building system analysis measures the efficiency of various mechanical and HVAC systems being used in the building. This also compares the design values to actual building performance. This helps in managing energy use in the building.	(Dossick and Neff, 2009)
13	Maintenance scheduling	Maintenance throughout the lifecycle of the facility is done to ensure the soundness of the structure elements and functionality of various equipment installed in the building as well.	(Becerik-Gerber et al., 2011, Gursel et al., 2009, Jung and Joo, 2011, Sacks et al., 2010, Succar, 2009)
14	Life cycle analysis	A facility uses energy from construction phase to its demolition, using BIM designers are now more confident in finding those critical values with more precision than ever.	(Bynum et al., 2012, Becerik-Gerber et al., 2011, Gursel et al., 2009, Sacks et al., 2010, Stadel et al., 2011, Succar, 2009)
15	Safety analysis	Safety analysis or hazard analysis is a practical method for identifying, evaluating and controlling safety related risks in construction. BIM	(Zhang et al., 2013, Chantawit et al., 2005, Koo and Fischer, 2000, Barlish and Sullivan, 2012, Wang et al., 2015, Zhang et al., 2015, Jung and Joo,

		helps safety analysis by visualizing various site scenarios.	2011, Kim and Teizer, 2014, Melzner et al., 2013)
16	Code reviews	Designs are done by consulting various codes which includes structures, size, HVAC, type of construction, sustainability etc. BIM provides platform which checks building design against code requirements.	(Azhar, 2011, Jung and Joo, 2011, Kim and Teizer, 2014, Koo and Fischer, 2000, Sacks et al., 2010, Stadel et al., 2011, Steel et al., 2012, Wong and Fan, 2013)
17	Forensic analysis	Investigation of building or its components which fails or do not work properly.	(Azhar, 2011)
18	Facility management	BIM is an information management tool which stores loads of data related to building while modeling. It creates many manuals which helps in maintaining and operating the facility during its lifecycle.	(Azhar, 2011, Becerik-Gerber et al., 2011, Bynum et al., 2012, Eastman et al., 2011, Hajian and Becerik-Gerber, 2009, Wong and Fan, 2013)
19	Risk management	BIM helps in risk management by elimination of manual extraction of drawings, reducing the design deficiency and integrating design with construction.	(Bryde et al., 2013, Gu and London, 2010, Hartmann et al., 2012, Kim and Teizer, 2014, Zhang et al., 2015)

20	MEP	BIM software offers tool to design, detail estimate, fabricate and install MEP systems.	(Azhar, 2011, Bynum et al., 2012, Dossick and Neff, 2009, Koo and Fischer, 2000)
21	Acoustic	BIM helps in accessing the acoustics of the building and helps in modification of acoustics of the facility.	(Azhar et al., 2011, Bynum et al., 2012, Steel et al., 2012, Wong and Fan, 2013)
22	Thermal/HVAC	Software simulations helps the designer understand heating and cooling loads.	(Azhar et al., 2011, Bynum et al., 2012, Eastman et al., 2011, Steel et al., 2012, Wong and Fan, 2013)

2.7 Matrix between Key Risk Factors and Features of BIM

As discussed in the objectives of this research, first objective of this research is to find key risk factors which effects the performance of construction schedule through extensive literature review. Second objective is to identify the features of BIM through the literature review. After achieving both the objectives next step is to make a factor-feature matrix. The main purpose of factor-feature matrix is to identify the key risk factors which can be resolved using adequate feature of BIM. After listing down all key risk factors along Y-axis and features of BIM along X-axis, we can now be able to visualize that which feature of BIM affects which key risk factor. After this assessment we have now been able to go ahead with the verification of this matrix through the interviews or questionnaire by the BIM experts and project managers which are engaged in such projects where BIM is already implemented.

Table 2.3 Bibliometrics Details of Reviewed Papers

Sr. #	Source	Research Focus	Number Cited
1	International Journal of Project Management	Critical factors which effects the construction project success also some techniques to address these factors.	13
2	Journal of Construction Engineering and Management	Causes of construction delays and use of latest ICT tools suggesting possible solutions.	12
3	Automation in Construction	Major focus of these studies indicates the importance of Building Information Modelling in gaining the desired project milestones.	10
4	Construction Management and Economics	Causes of delays in construction projects: critical factors, solutions using present project management techniques.	7
5	Journal of Management in Engineering	Causes of delays and its effect on major attributes of the project i.e. Cost and Time.	2
6	Advanced Engineering Informatics	Assuring project success using advanced and modern ICT tools.	2
7	Journal of Financial Management of Property and Construction	Discussing the cost attribute of the project and discrepancies in it due to delays in construction projects.	2
8	Engineering, Construction and Architectural Management	Discussing the construction project delay factors in various parts of the world.	2
9	International Journal of Operations and Production Management	Major focus of this study is to highlight the delays in construction projects due to various factors.	1
10	KSCE Journal of Civil Engineering	Construction Project delays and cost over runs.	1
11	Structural Survey	Factors affecting the labor related delay factors.	1
12	Others	These studies discusses variety of topics ranging from the	22

		major delay factors which effect the success of construction projects. Also mentioning the remedial strategies using modern ICT tool i.e. Building Information Modelling, to minimize the effect of critical factors.	

Chapter 3

METHODOLOGY

3.1 Introduction

This chapter will explain the intended approach to achieve the objectives of this research as stated in Chapter 1. Techniques like literature review, expert interviews, surveys and case study will be used in this research.

3.2 Research Design

Research design is the integration of multiple techniques in a logical way to achieve predefined research objectives. The current study was conducted through five distinctive phases that include literature review, validation of factor-feature matrix, case study having pre-BIM risk register its initial output, BIM modeling and post-BIM risk register, and results, analysis and discussions. The technique used in each phase is

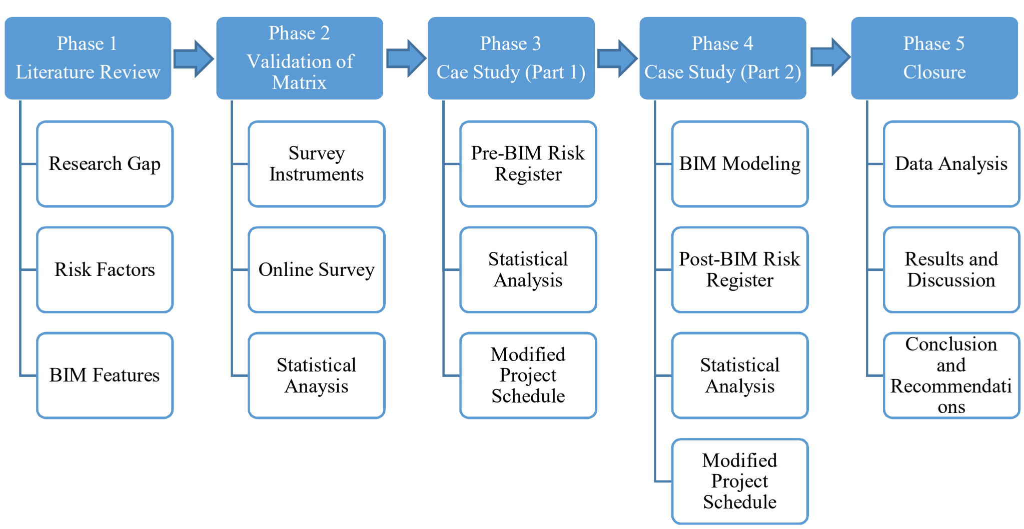

Figure 3.1 Research Methodology Flowchart

explained below. Figure 3.1 shows the schematic representation of working methodology for this research.

To successfully achieve the objectives of this study and to cover the identified gap in the current research, an ample research methodology comprising of five distinctive phases was adopted. In the first phase, critical risk factors which cause schedule delays and features of BIM which affect various phases of project were identified. For this purpose, extensive literature review was conducted in which databases of ASCE, Elsevier, Taylor & Francis, Emerald, Scopus and Google Scholar were used. Further, keywords such as 'project schedule delays', 'construction delays' and 'construction schedule risks' were used to identify schedule risk factors. Similarly, keywords such as 'building information modeling', 'features of BIM' and 'tools of BIM' were used to identify various features of BIM. In total 30 research papers were consulted to obtain critical risk factors which hinder the successful execution of construction schedule and 29 risk factors were identified as a result. Also, 30 research papers were consulted to obtain features of BIM and 22 features were identified. After the identification of risk factors and BIM features, a factor-feature matrix was developed by placing risk factors on vertical axis and BIM features on horizontal axis. The matrix reflects effect of a BIM feature on a particular risk factor. This matrix defines the relationship between various risk factors and BIM features which is the key for this study as all future analysis, surveys and case studies depends on this. It was developed by consulting the literature on BIM, which at first identifies the feature and later explains its effectiveness. This factor-feature matrix is the basis of this study. For further studies, grouping was done for various identical risk factors. "*Design delays*" contain "*design delays*" and "*design changes by owner during construction*". Similarly, *"decision making"* contains *"speed of decision making of owner", "preparation of drawing and schedules"* contains "*preparation of drawings and approvals*" and *"preparation of schedules plans and updates",* "*site management*" contains "*site safety*" and "*site management*", "*estimation*" contains "*inaccurate estimates*", "*coordination among parties*" contains "*coordination among parties*" and "*duration by owner contains*" contains "*unrealistic duration by owner*". Grouping was done on the basis of similarity in nature of these risk factors and similar features effecting various risk factors.

In the second phase, a web-based international survey was conducted to validate the factor-feature matrix. The respondents were BIM experts and practitioners with hand-on experience. To obtain accurate and logical data, careful evaluation of potential respondent's profile was done through LinkedIn® which is an online professional platform. In this regard, respondents experience, current job position and previous job history were analyzed. As a result, over 400 BIM practitioners from around the world were selected for the survey. A formal request was initiated and after a positive response, a link to a web-based questionnaire developed in Google Docs® was forwarded. This survey was conducted between the months of March-June 2018 and 59 responses were collected, giving a response rate of 14.75%. Two distinctive parts comprise the survey questionnaire; part one contained the demographics of the respondents. Part two contained the questions about particular features of BIM affecting certain risk factor on a 5-point Likert scale (1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree). Statistical tests were performed including Cronbach's alpha for data reliability.

After assessing schedule risks and BIM features, it was necessary to investigate and quantify the effect of BIM on schedule performance through an actual on-going project. For this purpose, pre-BIM and post-BIM risk registers of the project were required. Since BIM has not been contractually implemented on any project in Pakistan, such a building had to be selected which is in the early phases of construction and for which all the design documentation can be made available to develop a BIM model. In this regard, a case study of an under-construction building, which is a student hostel block at the National University of Sciences and Technology, Islamabad, Pakistan, having a covered area of 78,528.50 Sq. Ft., was selected. This is a government funded project managed by a publicly owned subsidiary acting as client/PM consultant. The data was obtained from the concerned institution containing architectural, structural and MEP drawings, a baseline construction schedule and project contract and specifications. A layout plan of the building is shown in Figure 3.2.

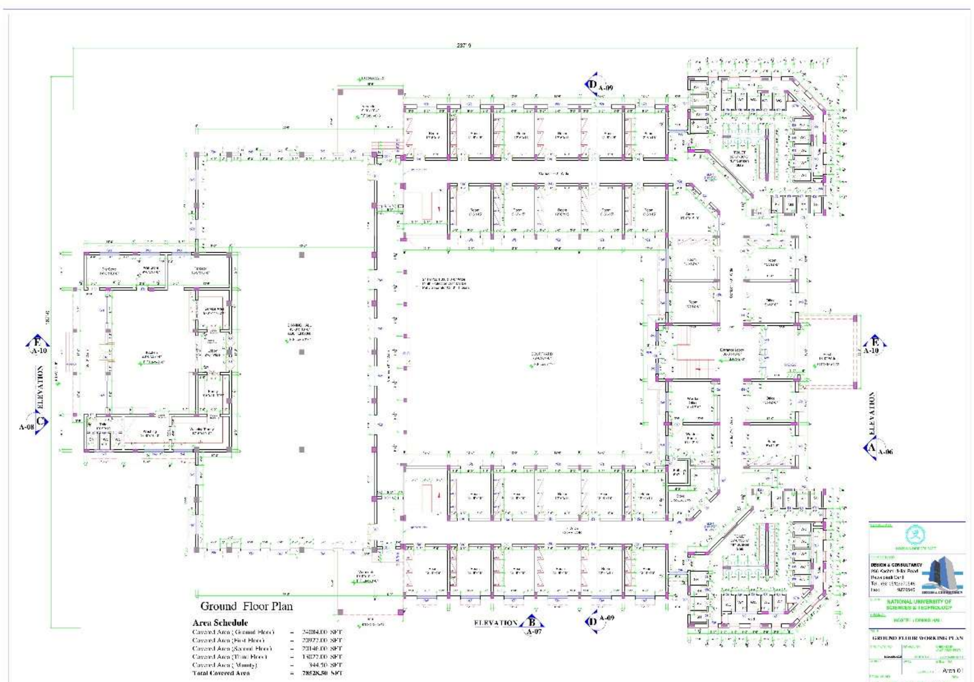

Figure 3.2 Layout plan of case study building

In the third phase, a pre-BIM risk register was made using the baseline project schedule provided by the client which contractor has submitted at the time of project start. All activities were considered in making of pre-BIM risk register and durations were taken as stated in the project schedule. A total of five respondents, one from designer, two from contractor and two from client/PM consultant, were engaged to gather data on the probability (P) and impact (I) of risks effecting project schedule. After collection of data, averages and percentages were calculated to analyze the data.

In the fourth phase, construction drawings were used to develop a BIM model which was used for developing a post-BIM risk register. Architectural, structural and MEP models were developed in Autodesk Revit® at the level of development (LOD) of 300. These models were then imported to Autodesk Navisworks ® for analyzing any clashes. In making of post-BIM risk register, construction schedule which was submitted by the contractor at the time of project start and used in pre-BIM risk register as well, was used. After complete modeling, various walkthroughs, screenshots and reports were generated and shared with the same respondents for post-BIM risk register. This was done in the form of a complete presentation separately given to designer, contractor and client/PM consultant representatives. After giving detailed information, respondents were asked to provide probability (P) and impact (I) values against all the schedule risks effecting project activities. The respondents could ask questions and clarifications in the light of BIM generated information. After collection of data, averages and percentages were calculated to further analyze the results. In fifth phase, after detailed data collection and preparation, the overall analysis was carried out. On the basis of which, results and analysis are presented, discussion is made and conclusion and recommendations are drawn.

Chapter 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter covers the analysis carried out on the collected data. Results are drawn and detailed discussion is done over various findings in subsequent sections.

4.2 Identification of risk factors and BIM features

In the first phase, 29 schedule risk factors were identified from 30 research papers. All these risks have adverse effect on construction schedule and may hinder the smooth execution of project. Some of the top risks are discussed below.

The top risk, reported in 21 papers, is "*design changes by owner during construction*". Studies show that the client has a major role in triggering this factor by issuing design changes during construction phase due to many known and unknown drivers. This delays the project and incurs additional cost (Mahamid et al., 2011, Chan and Kumaraswamy, 2002, Sambasivan and Soon, 2007). The second most frequent factor, reported in 17 studies, is "*financing by contractors*". Both small and large contracting firms face this risk which affects all phases of construction project (Alzahrani and Emsley, 2013, Alaghbari et al., 2007, Mahamid et al., 2011). Third in the list, with 16 mentions, is "*availability of material*". Suppliers, transporters and the contractor contribute to this delay cause. Price hike is one of the main reasons behind material shortage. Contracting firms stop their procurement activities during hike and wait for prices to go down. This causes considerable delays during project execution (Sambasivan and Soon, 2007, Enshassi et al., 2009).

After the identification of risk factors, BIM features were gathered. In doing so, a total of 22 BIM features were gathered from 30 research papers. In the identified BIM features, "*3D modeling*" topped the list with 28 mentions. Visualization through 3D models provides *What You See Is What You Get (WYSIWYG)* benefits. It relieves from making a mental model by looking at a 2D plan which is a tedious task and prone to errors (Chantawit et al., 2005). The second most frequent BIM feature, reported in 18 papers, is "*planning and analysis*". The idea of integrating 3D modeling and time was first suggested by (Koo and Fischer, 2000) and it was named as Four-Dimensional Computer-Aided Design (4D-CAD). Third in the list, with 12 mentions, is "*quantity takeoff/cost estimation*". Similarly, other features were also identified which have a significant effect on various aspects of a project. "*Safety analysis*", ranked at number 4, has a significant impact on the health and safety aspect of a project. "*Clash detection*", ranked at number 7, also has an impact on design, estimation, planning and decision making at various stages of a project. All these factors affect various phases of project and their proper redressal can ensure successful project execution.

4.3 Risk factor-BIM feature matrix

4.3.1 Formation of factor-feature matrix

After the identification of risk factors and BIM features, a factor-feature matrix was developed, as shown in Table 4.1. Looking at this matrix from vertically downward, the feature "*3D modeling*" affects 10 risk factors, which is by far the maximum effect. The factors include "*site safety*"; this feature displays the 3D object which represents the physical condition of a project hence giving safety engineers information for analyzing and utilizing what safety measures are needed? When the required measures should be taken? Where it is necessary to follow safety protocols? And why particular area requires certain safety precautions and measures? (Chantawit et al., 2005). Further,

Table 4.1 Factor-Feature Matrix

Risk Factors \ BIM Features	3D Modeling	Quantity Takeoff/Cost Est.	Clash Detection	Analysis and Planning	Energy Modeling and Simulation	Structural Analysis	Data Sharing and Coordination	Design Reviews	Site Utilization Planning	Safety Analysis	Code Reviews	Risk Management	MEP	Acoustic Analysis	Thermal/HVAC	LEED Validation	Lighting Analysis	Building System Analysis	Maintenance Scheduling	Lifecycle Analysis	Forensic Analysis	Facility Management	Frequency
Speed of decision making of owners	1	1	1	1	1	1	1	1			1	1		1	1								12
Design delays	1	1	1		1	1	1	1			1	1	1	1	1								12
Design changes by owners during construction	1	1	1		1	1	1	1				1	1	1	1								11
Preparation of shop drawings and approvals	1	1	1			1	1	1			1	1	1		1								10
Site safety	1	1	1	1		1	1		1	1		1											9
Preparation of schedule plans and updates	1	1	1	1			1																5
Unrealistic duration by owner	1	1	1	1								1											5
Inaccurate estimates	1	1						1				1											4
Site management	1								1	1													3
Coordination among parties	1						1					1											3
Financing by contractors																							0
Experience of contractors																							0
Construction methods																							0
Experience of consultants																							0
Foundation conditions																							0
Financing by owner during construction																							0
Experience of owners																							0
Availability of laborers on site																							0
Availability of staff to manage projects																							0
Availability of equipment																							0
Availability of materials																							0
Availability of site																							0
Weather																							0
Subcontractors																							0
Political scenarios																							0
Construction management practices																							0
Delayed payment by owner																							0
Government permits																							0
Owners interference																							0

this feature affects risk factor "*design delays*" as design proposals in 3D can be rigorously analyzed, various simulations can be performed quickly hence enabling improved and quick designs (Azhar, 2011). Also, the factor "*coordination among parties*" is affected as 3D models and illustrations allow project managers and jobsite engineers to increase their knowledge about the project and share their experience and knowledge regarding possible problems and their solutions (Jan et al., 2013). Further, the BIM features "*quantity takeoff/cost estimation*" and "*risk management*" both ranked at number two as they affect eight risk factors each. Finally, "*clash detection*" and "*data sharing and coordination*", ranked at number 3, affect seven risk factors each.

Looking at this matrix from horizontally rightward, risk factors "*speed of decision making of owners*" and "*design delays*" are affected by 12 BIM features. "*Design changes by owner during construction*" is affected by 11 features and 10 features affect "*preparation of shop drawings and approvals*". There are some factors which are not affected by any of the identified BIM features like "*financing by contractors*", "*delayed payment by owners*", *availability of material*", *availability of labors*", "*weather*" and "*political scenarios*". Adoption of BIM will make no difference to these risks. Similarly, there are some BIM features which do not directly affect any of the identified risk factors like "*facility management*", "*LEED validation*", "*building system analysis*" and "*forensic analysis*". These features have their value addition but in case of project schedule management, their role is negligible.

4.3.2 Endorsement of factor-feature matrix

Though the factor-feature matrix synthesizes and represents the state of literature, it was still deemed necessary to include the expert opinion on the impact of BIM features on identified risk factors towards addressing project schedule problem. For this purpose, an international survey was conducted in which data from 59 respondents was collected to verify the findings of the literature review and effectiveness of factor-feature matrix. Figure 4.1 shows the type of organization of the respondents with 40.7% participation of consultants and 35% of contractors. This enhances the reliability of results as consulting firms with architecture and design capabilities are considered the maximum of BIM users (Construction, 2008).

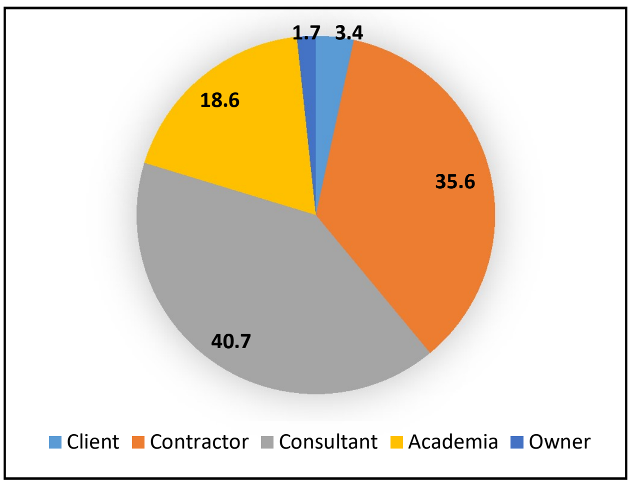

Figure 4.1 Type of organization

Further, the reliability of results demands an adequate knowledge of BIM, level of understanding of BIM was also asked from the respondents and the results are shown in Figure 4.2. It is evident that 61% respondents were either experts or proficient with BIM and only 8.5% respondents were beginners making these responses highly suitable for this study. However, to ensure the reliability of data for further analysis, Cronbach's alpha test was performed resulting an alpha (α) value of 0.954619 making the data highly reliable.

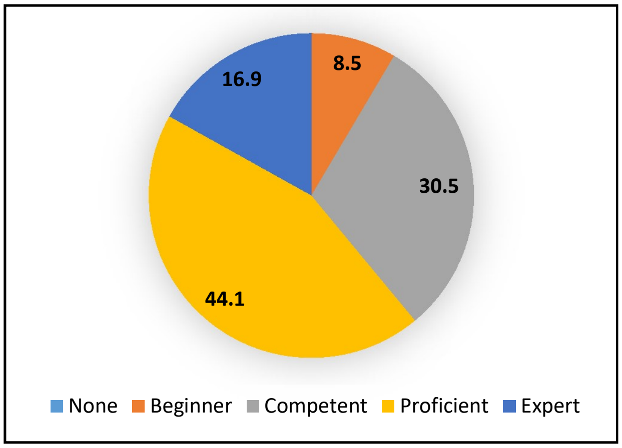

Figure 4.2 Level of understanding of BIM

The analysis suggests that majority of the respondents strongly agreed on effectiveness of some features of BIM in addressing various risk factors. In total, 50% of respondents strongly agreed that "*design delays*" can be affected by BIM feature "*clash detection*". Almost 50% respondents also strongly agreed that "*quantity takeoff/cost estimation*" can positively address "*inaccurate estimates*". Similarly, "*3-D modeling*" and "*data sharing and coordination*" gets 47% and 60% strong agreement for affecting "*coordination among parties*". More than 70% respondents either agreed or strongly agreed with all the questions listed in the questionnaire. This authenticates the synthesis of literature and makes the factor-feature matrix a reliable tool for mapping the benefits of BIM. It also provides a handy set of strategies for addressing various schedule related risks by exploiting different features of BIM. Thus, this matrix is fit for further study and analysis.

4.4 Pre-BIM risk register

In the third phase of this study, a pre-BIM risk register was developed. For this purpose, bid documents submitted by the contractor were utilized. There were a total 55 activities in the submitted schedule, all of which were considered in the pre-BIM risk register. However, since all activities did not involve risk, using insight from project participants, probability (P) and impact (I) of only the risks influencing activities were collected.

It is found that client/PM marks the impact of "*design delays*", "*decision making*", "*preparation of drawings/schedules*" and "*site management*" as low, "*duration by owner*" as moderate, "*estimation*" as high, and "*coordination among parties*" as very high. But when asked from contractor, the impact of "*decision making*" and "*preparation drawing/schedules*" was reported as low, "*design delays*", "*site management*", "*estimation*" and "*coordination among parties*" as moderate, and "*duration by owner*" as high. The contractor did not mark any risk with a very high impact. Further, designer stated a very low impact on time for risk factor "*preparation of drawings/schedules*", a low impact for "*design delays*" and "*site management*", and a moderate impact for "*decision making*", "*estimation*", "*duration by owner*" and "*coordination among parties*".

It is interesting to note that different stakeholders perceive the impact of risk factors differently. This difference of opinion, quantified in the form of Δ, is mainly based on the professional strengths, capacity and contractual obligations of the project participants (Ahmad et al., 2018). Such as the designer perceived design related risk with low impact and moderate for contractor and client/PM related risks. Similarly, contractor and client/PM also marked a low impact for risks related to their respective organizations. All responses were almost identical with $\Delta < 9\%$ having no significant deviation except for risk factor *"coordination among parties"* where difference in responses from contractor and client/PM was significant having $\Delta = 15\%$ for structure related activities, $\Delta = 16.25\%$ in architectural related activities, and $\Delta = 17.5\%$ in electrical and plumbing related activities.

Concerns on coordination among parties were raised by the client/PM as a contractor usually hides the schedule related information whether to take advantage of the situation and later claim for monetary benefits or to hide his mistakes so that upon revelation on later stages, client/PM has no other option but to ignore it. Client/PM also suggested that if a contractor ensured proper coordination, many managerial, technical and administrative issues can be resolved early in the project with no losses of time and cost.

After estimating activity durations and updating using information from risk registers, a project schedule was developed in Primavera® preserving the activity precedence. Initially, the project duration was 302 days, and increased to 530 days after analysis from pre-BIM risk registers. It is pertinent to note that the project with almost 28% actual physical progress against planned progress of 45%, has already faced delays of over 4 months. Thus, a standard ex post facto risk assessment validates the quality of analysis.

4.5 BIM modeling and post-BIM risk register

In the fourth phase of this study, post-BIM risk register was developed. But since BIM was not already implemented in this project, initially a BIM model was developed for the case study, as shown in Figure 4.3 and 4.4. The model was used to provide information about BIM, its implementation and benefits to the project stakeholders. In doing so, a comprehensive presentation was separately given to different project stakeholders highlighting major features of model and the respective benefits of BIM. Major focus of these presentations was to familiarize all the stakeholders with benefits of BIM with respect to the identified risks. The participants could raise questions and ask for clarifications in order to fully understand the state of project risk after BIM implementation. At the end of each presentation, probability (P) and impact (I) of each risk on project activities was gathered and organized into a post-BIM risk register.

All the respondents were convinced that proper implementation of BIM not only mitigates the risks but also creates various opportunities. Hence client/PM marked the impact of BIM features on "*estimation*" and "*coordination among parties*" as high, on "*decision making*", "*site management*" and "*preparation of drawings/schedule*" as moderate, on "*design delays*" as low, and impact of BIM features on "*duration by owner*" as very low. Similarly, the contractor stated the impact of BIM features on risk factor "*preparation of drawings/schedule*", "*site management*" and "*estimation*" as

Figure 4.3 BIM model for case study building

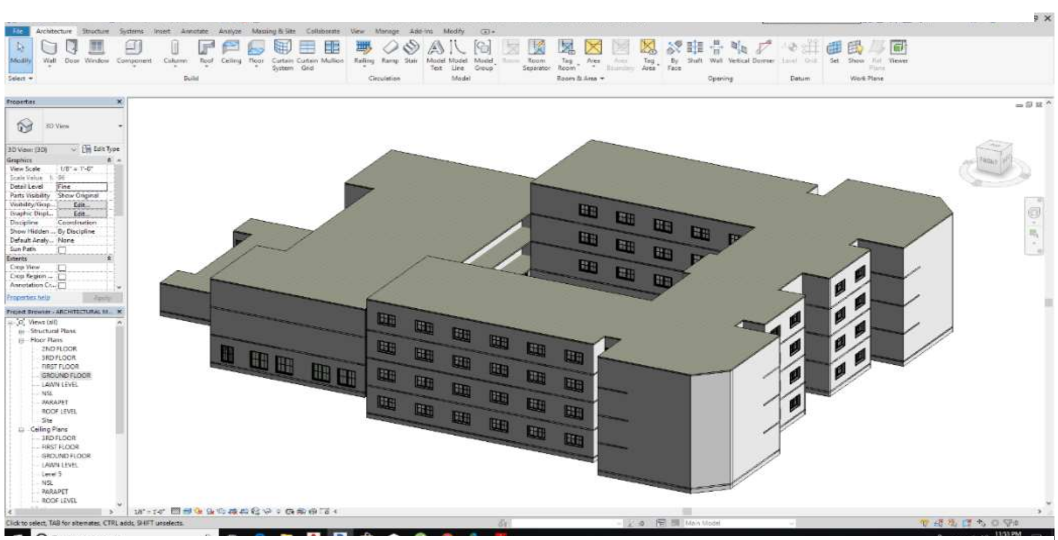

Figure 4.4 Revit modeling for case study building

moderate, and on "*decision making*", "*design delays*", "*duration by owner*" and "*preparation of drawings/schedules*" as low. Finally, designer stated the impact on risk factors "*decision making*", "*preparation of drawings/schedules*", "*estimation*" and "*coordination among parties*" as moderate, on "*design delays*" and "*site management*" as low, and impact on "*duration by owner*" as very low. All responses were identical having $\Delta < 7\%$.

After estimating project schedule, new activity durations were obtained and an updated construction schedule was made on Primavera® using same activity relations as present in the original schedule. As a result of proactive risk management through BIM, the project duration drops down to 251 days with 16.88% decrease from 302 days as stated in the original schedule provided by the contractor at project initiation. Thus, implementation of BIM not only reduces delays but also reduces the project completion time to a significant extent. The same is substantiated through literature. Azhar (2011) conducted a research to measure benefits of BIM and schedule benefits were reported in number of hours saved but the study was limited and did not reflect actual benefits as the project was not initially designed using BIM and it was later used by the general contractor. Barlish and Sullivan (2012) identified that without BIM, schedule was 15% behind standard schedule and with the implementation of BIM. It reduces to only 5% behind the standard schedule. But the case study was carried out with no additional BIM cost to the project and project was not competitively bided, hence it cannot portray the actual benefit of BIM for schedule.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter concludes the research by stating and summarizing the inferences, findings and recommendations for future research. The insight will help the reader to understand the crux of the study and parting ways for future endeavors related to this area of research.

5.2 Conclusions

Substantial research has targeted the identification, categorization and mitigation of risk factors which cause schedule delays, but construction projects still face delays, resulting into schedule failure and time overruns. Many attempts have been made using modern ICT tools to control delays causing factors; recently BIM has revolutionized the way ICT tools affect various attributes of construction project. It is established in the published research that BIM has a significant impact in resolving schedule related delays but research has yet to quantify its benefits. Building upon this, the current study was conducted to identify risk factors, BIM features and finding relationship between them. To measure the effectiveness of BIM in schedule risk management, pre-BIM and post-BIM risk registers were used to quantify the effect of BIM on risk factors.

It is observed that many of the schedule delaying risk factors are directly addressed by BIM features. After involving project stakeholders and conducting risk management it has been found that BIM not only mitigates the delays caused by risk factors but also has the capacity to bring opportunities for the project by reducing its initial duration.

5.3 Recommendations

Time related benefits were evident, however cost factor related to BIM implementation and quantification of monetary benefits due to BIM is beyond the scope of this study and is recommended for future studies. As BIM is neither implemented in the case study project form the start nor it was the requirement from the client/PM, hence it was not easy to quantify these benefits. Calculation of monetary benefits required for the BIM modeling to be the part of contractual bill of quantitates (BOQ) results in the seriousness of all participants of project.

REFERENCES

ABD EL-RAZEK, M., BASSIONI, H. & MOBARAK, A. 2008. Causes of delay in building construction projects in Egypt. *Journal of construction engineering and management,* 134**,** 831-841.

ABDUL KADIR, M., LEE, W., JAAFAR, M., SAPUAN, S. & ALI, A. 2005. Factors affecting construction labour productivity for Malaysian residential projects. *Structural survey,* 23**,** 42-54.

AHMAD, Z., THAHEEM, M. J. & MAQSOOM, A. 2018. Building information modeling as a risk transformer: An evolutionary insight into the project uncertainty. *Automation in Construction,* 92**,** 103-119.

AHMED, S. M., AZHAR, S., KAPPAGNTULA, P. & GOLLAPUDIL, D. Delays in construction: a brief study of the Florida construction industry. Proceedings of the 39th Annual ASC Conference, Clemson University, Clemson, SC, 2003. 66.

AIBINU, A. A. & ODEYINKA, H. A. 2006. Construction delays and their causative factors in Nigeria. *Journal of construction engineering and management,* 132**,** 667-677.

AL-KHALIL, M. I. & AL-GHAFLY, M. A. 1999. Important causes of delay in public utility projects in Saudi Arabia. *Construction Management & Economics,* 17**,** 647-655.

AL-MOMANI, A. H. 2000. Construction delay: a quantitative analysis. *International journal of project management,* 18**,** 51-59.

ALAGHBARI, W. E., RAZALI A. KADIR, M., SALIM, A. & ERNAWATI 2007. The significant factors causing delay of building construction projects in Malaysia. *Engineering, Construction and Architectural Management,* 14**,** 192-206.

ALZAHRANI, J. I. & EMSLEY, M. W. 2013. The impact of contractors' attributes on construction project success: A post construction evaluation. *International Journal of Project Management,* 31**,** 313-322.

ARASZKIEWICZ, K. 2016. Building Information Modelling: an Innovative Way to Manage Risk in Construction Projects. *International Journal of Contemporary Management,* 14**,** 23-40.

ARDITI, D., AKAN, G. T. & GURDAMAR, S. 1985. Reasons for delays in public projects in Turkey. *Construction management and economics,* 3**,** 171-181.

ASSAF, S. A. & AL-HEJJI, S. 2006. Causes of delay in large construction projects. *International journal of project management,* 24**,** 349-357.

AZHAR, S. 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering,* 11**,** 241-252.

AZHAR, S., CARLTON, W. A., OLSEN, D. & AHMAD, I. 2011. Building information modeling for sustainable design and LEED® rating analysis. *Automation in construction,* 20**,** 217-224.

BAKER, W. & REID, H. 2005. *Identifying and managing risk*, Pearson Education.

BARLISH, K. & SULLIVAN, K. 2012. How to measure the benefits of BIM—A case study approach. *Automation in construction,* 24**,** 149-159.

BECERIK-GERBER, B., JAZIZADEH, F., LI, N. & CALIS, G. 2011. Application areas and data requirements for BIM-enabled facilities management. *Journal of construction engineering and management,* 138**,** 431-442.

BERKELEY, D., HUMPHREYS, P. & THOMAS, R. 1991. Project risk action management. *Construction Management and Economics,* 9**,** 3-17.

BRYDE, D., BROQUETAS, M. & VOLM, J. M. 2013. The project benefits of building information modelling (BIM). *International journal of project management,* 31**,** 971-980.

BYNUM, P., ISSA, R. R. & OLBINA, S. 2012. Building information modeling in support of sustainable design and construction. *Journal of Construction Engineering and Management,* 139**,** 24-34.

CAMPBELL, D. A. Building information modeling: the Web3D application for AEC. Proceedings of the twelfth international conference on 3D web technology, 2007. ACM, 173-176.
CASTRO-LACOUTURE, D., SÜER, G. A., GONZALEZ-JOAQUI, J. & YATES, J. 2009. Construction project scheduling with time, cost, and material restrictions using fuzzy mathematical models and critical path method. *Journal of Construction Engineering and Management,* 135**,** 1096-1104.
CHAN, D. W. & KUMARASWAMY, M. M. 1997. A comparative study of causes of time overruns in Hong Kong construction projects. *International Journal of project management,* 15**,** 55-63.
CHAN, D. W. & KUMARASWAMY, M. M. 2002. Compressing construction durations: lessons learned from Hong Kong building projects. *International journal of project management,* 20**,** 23-35.
CHANTAWIT, D., HADIKUSUMO, B. H., CHAROENNGAM, C. & ROWLINSON, S. 2005. 4DCAD-Safety: visualizing project scheduling and safety planning. *Construction Innovation,* 5**,** 99-114.
CHAU, K., ANSON, M. & ZHANG, J. 2004. Four-dimensional visualization of construction scheduling and site utilization. *Journal of construction engineering and management,* 130**,** 598-606.
CIFE 2007. Technical Report 2007. *http://cife.stanford.edu/Publications/index.html*. Stanford University Center for Integrated Facility Engineering
CONSTRUCTION, M.-H. 2008. Building Information Modeling Trends SmartMarket Report. *New York*.
DAWOOD, N., SRIPRASERT, E., MALLASI, Z. & HOBBS, B. 2003. Development of an integrated information resource base for 4D/VR construction processes simulation. *Automation in construction,* 12**,** 123-131.
DEUTSCH, R. 2011. *BIM and integrated design: strategies for architectural practice*, John Wiley & Sons.
DOSSICK, C. S. & NEFF, G. 2009. Organizational divisions in BIM-enabled commercial construction. *Journal of construction engineering and management,* 136**,** 459-467.
EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*, John Wiley & Sons.
ENSHASSI, A., AL-HALLAQ, K. & MOHAMED, S. 2006. Causes of contractor's business failure in developing countries: the case of Palestine. *Journal of construction in developing countries,* 11**,** 1-14.
ENSHASSI, A., AL-NAJJAR, J. & KUMARASWAMY, M. 2009. Delays and cost overruns in the construction projects in the Gaza Strip. *Journal of Financial Management of Property and Construction,* 14**,** 126-151.
FARIDI, A. S. & EL-SAYEGH, S. M. 2006. Significant factors causing delay in the UAE construction industry. *Construction Management and Economics,* 24**,** 1167-1176.
FENG, C.-W., CHEN, Y.-J. & HUANG, J.-R. 2010. Using the MD CAD model to develop the time–cost integrated schedule for construction projects. *Automation in Construction,* 19**,** 347-356.
FRIMPONG, Y., OLUWOYE, J. & CRAWFORD, L. 2003. Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. *International Journal of project management,* 21**,** 321-326.
GOULD, F. E. 2005. *Managing the construction process*, Pearson Education India.
GU, N. & LONDON, K. 2010. Understanding and facilitating BIM adoption in the AEC industry. *Automation in construction,* 19**,** 988-999.
GURSEL, I., SARIYILDIZ, S., AKIN, Ö. & STOUFFS, R. 2009. Modeling and visualization of lifecycle building performance assessment. *Advanced Engineering Informatics,* 23**,** 396-417.

HAJIAN, H. & BECERIK-GERBER, B. 2009. A research outlook for real-time project information management by integrating advanced field data acquisition systems and building information modeling. *Computing in Civil Engineering (2009).*

HARDIN, B. & MCCOOL, D. 2015. *BIM and construction management: proven tools, methods, and workflows*, John Wiley & Sons.

HARTMANN, T., VAN MEERVELD, H., VOSSEBELD, N. & ADRIAANSE, A. 2012. Aligning building information model tools and construction management methods. *Automation in construction,* 22**,** 605-613.

HATUSH, Z. & SKITMORE, M. 1997. Assessment and evaluation of contractor data against client goals using PERT approach. *Construction Management & Economics,* 15**,** 327-340.

HISHAM, N. & YAHYA, K. 2016. Causes and Effects of Delays in Construction Industry. Universiti Teknologi Malaysia, Faculty of Civil Engineering. Available from http://civil. utm. my/wp-content/uploads/2016/12/Causes-and-Effects-of-Delays-in-Construction-Industry. pdf.

HOWARD, R. & BJÖRK, B.-C. 2008. Building information modelling–Experts' views on standardisation and industry deployment. *Advanced Engineering Informatics,* 22**,** 271-280.

HWANG, B.-G., ZHAO, X. & NG, S. Y. 2013. Identifying the critical factors affecting schedule performance of public housing projects. *Habitat International,* 38**,** 214-221.

ISO, I. 2009. 31010: Risk management–Risk assessment techniques. *Event (London). Geneva,* 552.

IYER, K. & JHA, K. 2005. Factors affecting cost performance: evidence from Indian construction projects. *International journal of project management,* 23**,** 283-295.

IYER, K. & JHA, K. 2006. Critical factors affecting schedule performance: Evidence from Indian construction projects. *Journal of construction engineering and management,* 132**,** 871-881.

JAN, S.-H., HO, S.-P. & TSERNG, H.-P. 2013. Applications of building information modeling (BIM) in knowledge sharing and management in construction. *International Journal of Civil, Structural, Construction and Architectural Engineering,* 7.

JONGELING, R. & OLOFSSON, T. 2007. A method for planning of work-flow by combined use of location-based scheduling and 4D CAD. *Automation in construction,* 16**,** 189-198.

JUNG, Y. & JOO, M. 2011. Building information modelling (BIM) framework for practical implementation. *Automation in construction,* 20**,** 126-133.

KAMING, P. F., OLOMOLAIYE, P. O., HOLT, G. D. & HARRIS, F. C. 1997. Factors influencing construction time and cost overruns on high-rise projects in Indonesia. *Construction Management & Economics,* 15**,** 83-94.

KIM, K. & CHO, Y. K. 2015. Construction-specific spatial information reasoning in Building Information Models. *Advanced Engineering Informatics,* 29**,** 1013-1027.

KIM, K. & TEIZER, J. 2014. Automatic design and planning of scaffolding systems using building information modeling. *Advanced Engineering Informatics,* 28**,** 66-80.

KIM, S.-Y., VAN TUAN, N. & OGUNLANA, S. O. 2009. Quantifying schedule risk in construction projects using Bayesian belief networks. *International Journal of Project Management,* 27**,** 39-50.

KOO, B. & FISCHER, M. 2000. Feasibility study of 4D CAD in commercial construction. *Journal of construction engineering and management,* 126**,** 251-260.

KOUSHKI, P., AL-RASHID, K. & KARTAM, N. 2005. Delays and cost increases in the construction of private residential projects in Kuwait. *Construction Management and Economics,* 23**,** 285-294.

LE-HOAI, L., DAI LEE, Y. & LEE, J. Y. 2008. Delay and cost overruns in Vietnam large construction projects: A comparison with other selected countries. *KSCE journal of civil engineering,* 12**,** 367-377.

LO, T. Y., FUNG, I. W. & TUNG, K. C. 2006. Construction delays in Hong Kong civil engineering projects. *Journal of construction engineering and management,* 132**,** 636-649.

MA, Z., SHEN, Q. & ZHANG, J. 2005. Application of 4D for dynamic site layout and management of construction projects. *Automation in construction,* 14**,** 369-381.

MAHAMID, I., BRULAND, A. & DMAIDI, N. 2011. Causes of delay in road construction projects. *Journal of Management in Engineering,* 28**,** 300-310.

MAJID, M. A. & MCCAFFER, R. 1998. Factors of non-excusable delays that influence contractors' performance. *Journal of management in engineering,* 14**,** 42-49.

MANSFIELD, N. R., UGWU, O. & DORAN, T. 1994. Causes of delay and cost overruns in Nigerian construction projects. *International journal of project Management,* 12**,** 254-260.

MELZNER, J., ZHANG, S., TEIZER, J. & BARGSTÄDT, H.-J. 2013. A case study on automated safety compliance checking to assist fall protection design and planning in building information models. *Construction Management and Economics,* 31**,** 661-674.

MEZHER, T. M. & TAWIL, W. 1998. Causes of delays in the construction industry in Lebanon. *Engineering, Construction and Architectural Management,* 5**,** 252-260.

NASIR, D., MCCABE, B. & HARTONO, L. 2003. Evaluating risk in construction–schedule model (ERIC–S): construction schedule risk model. *Journal of construction engineering and management,* 129**,** 518-527.

NEGA, F. 2008. Causes and effects of cost overrun on public building construction projects in Ethiopia. *Unpublished doctoral dissertation, Addis Ababa University, Ethiopia*.

ODEH, A. M. & BATTAINEH, H. T. 2002. Causes of construction delay: traditional contracts. *International journal of project management,* 20**,** 67-73.

OGUNLANA, S. O., PROMKUNTONG, K. & JEARKJIRM, V. 1996. Construction delays in a fast-growing economy: comparing Thailand with other economies. *International journal of project Management,* 14**,** 37-45.

SACKS, R., KOSKELA, L., DAVE, B. A. & OWEN, R. 2010. Interaction of lean and building information modeling in construction. *Journal of construction engineering and management,* 136**,** 968-980.

SAMBASIVAN, M. & SOON, Y. W. 2007. Causes and effects of delays in Malaysian construction industry. *International Journal of project management,* 25**,** 517-526.

SCHUYLER, J. R. 2001. *Risk and decision analysis in projects*, Project Management Inst.

SEMPLE, C., HARTMAN, F. T. & JERGEAS, G. 1994. Construction claims and disputes: causes and cost/time overruns. *Journal of construction engineering and management,* 120**,** 785-795.

SMITH, D. K. & TARDIF, M. 2009. *Building information modeling: a strategic implementation guide for architects, engineers, constructors, and real estate asset managers*, John Wiley & Sons.

STADEL, A., EBOLI, J., RYBERG, A., MITCHELL, J. & SPATARI, S. 2011. Intelligent sustainable design: Integration of carbon accounting and building information modeling. *Journal of professional issues in engineering education and practice,* 137**,** 51-54.

STEEL, J., DROGEMULLER, R. & TOTH, B. 2012. Model interoperability in building information modelling. *Software & Systems Modeling,* 11**,** 99-109.

STUMPF, G. R. 2000. Schedule delay analysis. *Cost Engineering,* 42**,** 32.

SUCCAR, B. 2009. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in construction,* 18**,** 357-375.

SUCCAR, B., SHER, W., ARANDA-MENA, G. & WILLIAMS, T. A proposed framework to investigate building information modelling through knowledge elicitation and visual models. Conference Proceedings Of The Australasian Universities Building Education Association, Melbourne, July, 2007. 4-5.

SULLIVAN, A. & HARRIS, F. 1986. Delays on large construction projects. *International journal of operations & production management,* 6**,** 25-33.

SWEIS, G., SWEIS, R., HAMMAD, A. A. & SHBOUL, A. 2008. Delays in construction projects: The case of Jordan. *International Journal of Project Management,* 26**,** 665-674.

UHER, T. & ZANTIS, A. S. 2012. *Programming and scheduling techniques*, Routledge.

WALKER, D. H. & VINES, M. W. 2000. Australian multi-unit residential project construction time performance factors. *Engineering, Construction and Architectural Management,* 7**,** 278-284.

WANG, J., ZHANG, S. & TEIZER, J. 2015. Geotechnical and safety protective equipment planning using range point cloud data and rule checking in building information modeling. *Automation in Construction,* 49**,** 250-261.

WANG, W.-C., WENG, S.-W., WANG, S.-H. & CHEN, C.-Y. 2014. Integrating building information models with construction process simulations for project scheduling support. *Automation in construction,* 37**,** 68-80.

WANG, X. 2007. Using augmented reality to plan virtual construction worksite. *International Journal of Advanced Robotic Systems,* 4**,** 42.

WEYGANT, R. S. 2011. *BIM content development: standards, strategies, and best practices*, John Wiley & Sons.

WONG, K.-D. & FAN, Q. 2013. Building information modelling (BIM) for sustainable building design. *Facilities,* 31**,** 138-157.

YABUKI, N. & SHITANI, T. 2005. A management system for cut and fill earthworks based on 4D CAD and EVMS. *Computing in Civil Engineering (2005).*

ZHANG, S., SULANKIVI, K., KIVINIEMI, M., ROMO, I., EASTMAN, C. M. & TEIZER, J. 2015. BIM-based fall hazard identification and prevention in construction safety planning. *Safety science,* 72**,** 31-45.

ZHANG, S., TEIZER, J., LEE, J.-K., EASTMAN, C. M. & VENUGOPAL, M. 2013. Building information modeling (BIM) and safety: Automatic safety checking of construction models and schedules. *Automation in Construction,* 29**,** 183-195.

ZOU, Y., KIVINIEMI, A. & JONES, S. W. 2017. A review of risk management through BIM and BIM-related technologies. *Safety science,* 97**,** 88-98.