EFFECTS OF BIM IN ENHANCING PREFABRICATED CONSTRUCTION

by

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Declaration of Authorship

I declare that this thesis is my own work and, to the best of my knowledge and belief, it does not contain material published or written by a third party, except where permission has been obtained and/or appropriately cited through full and accurate referencing.

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Dedication

To my father and mother who supported me during this period …

Abstract

The use of prefabricated construction is not new in the industry. However, recent advances in digital technology, predominantly Building Information Modelling (BIM), has created renewed momentum for extensive use of this method in construction. Prefabricated construction promotes efficiency in the delivery of building construction projects with respect to cost, time, quality, and safety. The main objective of this research study is to investigate the effect of advancements and innovations in the BIM technology and its features on implementation and enhancement of prefabricated construction. This study is aimed at projecting trends, outlook, and the directions in the construction industry as a result of the BIM technology and the prefabrication method of construction. As the extent of use of BIM continues to increase, its impacts on prefabricated construction and their significance in the industry should be investigated. In addition, the industry should be aware of existing issues, problems, and roadblocks in order to effectively use the BIM technology to improve and enhance the method of prefabricated construction. The study is an effort in that direction. It looks into the changes taking place in the global as well as in the UAE construction industry. In addition to the extensive literature survey conducted for this study, a questionnaire survey was conducted in the UAE. Furthermore, a selected group of the UAE construction industry professionals with BIM and prefabrication experience were interviewed for this research. The findings of the research study are presented in the form of guidelines and action steps for improving the effectiveness of prefabricated construction in the UAE as a result of BIM technology. The effectiveness is examined by the measures of major project parameters, namely cost, time, quality, and safety. The specific features of BIM in achieving improvements in cost, time, quality, and safety when prefabrication is used are identified. An actual case study of a recently undertaken construction project, the Dubai Museum of Future, is analyzed in this study to substantiate the main recommendations and illustrate the benefits of BIM in prefabrication projects.

Keywords: Building Information Modelling (BIM); Prefabricated Construction; Modular Construction.

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List of Abbreviations

BIM	Building Information Modelling
CAGR	Compound Annual Growth Rate
RFI	Request for Information
RII	Relative Importance Index
UAE	United Arab Emirates

Chapter 1. Introduction

1.1. Introduction

In this chapter, a brief overview of the construction industry in the UAE is presented, associated with some statistics. After that, the problem statement is investigated in this research, as well as the thesis contribution. Finally, the thesis' overall structure is presented.

1.2. Overview

The construction industry in the United Arab Emirates (UAE) has recently witnessed significant growth and development, especially after the declaration of the Dubai EXPO 2020 in November 2013. The construction industry output value in the UAE has been reported with a compound annual growth rate (CAGR) of 4.38% between 2012 and 2016 [1]. Furthermore, from 2015 to 2019, the UAE residential construction industry output value has increased at a CAGR of 6.7%, while the construction industry is expected to reach 6.2% in 2024 [2]. According to HSBC bank, the total budget of the Dubai EXPO 2020 project is 33 billion AED, while a 23 billion AED of this budget is allocated for infrastructure projects and urban development for EXPO 2020. This represents around 70% of the total EXPO 2020 budget [3]. Smart Cities in the UAE are another factor that has developed the construction industry, especially the infrastructure sector. The UAE government's vision is to implement this strategy in all the country, focusing on Dubai to be the world's smartest city by the year 2021.

While the time and the budget (cost) are the main critical factors in construction projects, it is common to find small and large projects exceeding the contractual time and budget in which causes delays, conflicts, and a poor work environment. According to a case study performed in 2006, around 50% of the UAE construction projects have experienced time and budget overrun [4]. Significant sources of delays that occur on-site in traditional construction projects are shortage of manpower, late delivery of materials on-site, shortage of equipment on-site and their allocation, and poor site management due to large number of tasks [4]. Delays are associated with a cost overrun since delays require the contractor to accelerate his work, requiring an additional cost. Time extensions awarded from owners to contractors increase the indirect cost of the project by having an increase in the project overhead. It may also cause an increase in the direct cost by increasing the material cost and labor wages due to inflation in the cost [5]. In 2001, the construction wastes such as cement, wood, and unused materials represented the most significant quantity of solid wastes in UAE, and it accounted for more than 3 million tons [6]. Hence, digital technology and offsite prefabricated construction have emerged as a proposed solution to reduce the project budget, time, and amount of wastes and energy generated by the traditional construction methods.

Prefabricated construction refers to the full or partial manufacturing of the structural components of a given structure and then assembling them onsite. Prefabricated elements could be beams, columns, wall panels, floor panels, slabs, roof trusses, staircases, volumetric units such as kitchens and bathrooms, and structural modules [7]. Building Information Modelling (BIM) is intelligent modelling that gives a 3D representation of the required structure. It provides the architecture, designer, and contractor with the opportunity to plan, design, construct, and manage buildings and infrastructures more efficiently [8]. BIM has become one of the leading digital technologies that has been intensively used recently. According to a recent survey in 2015 conducted by over 500 UAE professionals in the Architecture, Engineering, and Construction (AEC) industry, 87% of them have used BIM in their companies and organizations, and 62% have used BIM in more than one project in the UAE [9]. BIM plays an essential role in improving communication and teamwork, preparing cost estimates based on the project model, monitoring changes, visualizing the project in the planning stage, and detecting early design clashes [10]. In addition, it contributes to reducing the duration of a project by having fewer mistakes, adjustment work, and reiterations [10]. Moreover, the enhanced coordination reduces the risk cost calculated in the project tendering and insurance cost. Finally, BIM facilitates the generation of manufacturing diagrams and production processes [10].

In recent years, BIM has been implemented widely in several prefabrication construction projects. In fact, BIM has played a significant role in facilitating prefabrication construction projects for owners, consultants, contractors, and pre-fabricators. It enhances the collaboration between project key participants, allows for early clash detection, and contributes to efficiently achieving the objectives of prefabricated construction strategy [11].

1.3. Problem Statement

The construction industry, globally and in the UAE, is experiencing a surge in prefabricated construction as the method offers many significant advantages over traditional construction. However, the requirements of prefabricated construction are different and pose challenges that are not the same as in traditional construction. These may have contributed towards lower than expected use of prefabricated construction in the past. The relatively new and still evolving technology of BIM provides solutions to most of the requirements and challenges of prefabricated construction. By doing so, BIM contributes to the renewed acceptance of prefabricated construction methods. However, the role of BIM in enhancing prefabricated construction is still not well researched, and the specific links between the BIM features and the requirements of prefabrication are not well understood. This may be leading to missed opportunities by many companies as the benefits of BIM in prefabrication may not be realized to its fullest potential. Although the construction industry in UAE is not as large as in other industrialized countries, the growth rate in UAE is relatively high, as noted earlier. Thus, it is proposed in this study to examine the growth in prefabricated construction in the UAE and investigate whether BIM can motivate further growth and extent. The results and key findings of this research are used to help develop guidelines for an increase in the rate of implementation and enhancement of prefabrication construction in the UAE using BIM.

1.4. Thesis Objectives

The use of prefabricated construction is not new in the industry. However, recent advances in digital technology, such as BIM, have created renewed momentum in this construction method. Unique features of BIM such as 3D visualization with collaboration among project stakeholders, 4D scheduling, 5D cost modelling, early clash detection, and generation of detailed shop drawings for prefabricated components can enhance prefabricated construction. These features play a pivotal role in facilitating the use of prefabricated construction.

Prefabricated construction promotes efficiency in delivering construction projects with respect to cost, time, quality, and safety objectives in construction projects. The main objective of this research study is to investigate the effect of advanced development and innovations in BIM and its capabilities on the implementation and enhancement of prefabricated construction. Based on the findings, this research study aims to project trends, outlooks, and directions in the prefabrication construction industry. It is expected that this research study will help to develop guidelines for improvement in the rate of implementation and enhancement of prefabricated construction in the UAE.

The specific research objectives are to:

1) Determine the current status and trend of BIM and prefabricated construction in general, and in particular in the UAE.
2) Investigate the differences in the extent of use of prefabricated construction between UAE and selected advanced countries such as Sweden, China, and Australia.
3) Investigate the extent of use of BIM with prefabricated construction in the UAE.
4) Investigate the impact of BIM on prefabricated construction.
5) Analyze the role of BIM on prefabricated construction with respect to cost, time, quality, and safety objectives in construction projects.
6) Propose action steps for the industry to enhance the use of prefabricated construction in the UAE by using BIM.

1.5. Research Contribution

The contributions of this research work can be summarized as follows:

- Investigate the effect of BIM in enhancing prefabricated construction by identifying the BIM features and the associated prefabricated construction requirements. Furthermore, it investigates the effect of enhancing the prefabricated construction requirements on cost, time, quality, and safety.
- Propose action steps for the construction industry to enhance the use of prefabricated construction in the UAE by using BIM.

1.6. Thesis Organization

The following chapters are organized as follows: Chapter 2 provides a literature review about the types of offsite manufacturing, qualitative and quantitative advantages of prefabricated construction, prefabricated construction limitations, prefabrication requirements that BIM can enhance, and benefits of using BIM. Chapter 3 includes the detailed research methodology of this thesis. The global use of BIM with prefabrication is discussed in Chapter 4, along with findings from global case studies. Chapter 5 discusses the current BIM and prefabrication implementation status in the UAE through the survey results and interviews. It also includes verifying the defined prefabrication construction requirements and BIM features and investigating the effect of BIM in enhancing cost, time, quality, and safety objectives of prefabrication work. Furthermore, it includes the results obtained from the interviews with the UAE construction industry professionals to establish a relationship between BIM features and prefabrication requirements and determine their effect on cost, time, quality, and safety. A real case study is presented in Chapter 6, in which it presents an actual project in the UAE that used BIM with prefabrication work to demonstrate the effect of BIM in enhancing the cost, time, quality, and safety objectives of prefabrication work. The summary of findings of this research is outlined and discussed in Chapter 7. Lastly, Chapter 8 includes the conclusion and outlines the possible future work regarding this topic.

Chapter 2. Background and Literature Review

2.1. Offsite Construction

Offsite construction, or offsite manufacturing, is the creation of various parts of a structure in the factory before assembling them on the structure's actual site [2]. Offsite manufacturing is divided into four main categories, as shown in Table 2-1 [12]. The first category is the component manufacture and sub-assembly, which refers to the small-scale sub-assembly of construction project components and items (non-structural elements) that cannot be produced on-site, such as Doors and their furniture, windows, and light fittings. The second category is the non-volumetric pre-assembly which is the most common structural type in the construction industry. This type does not create usable space such as wall panels, precast beams and slabs, and structural steel sections. The third category is the volumetric pre-assembly which refers to the units that create usable space and are installed within or on to an independent structure frame such as Plantroom, toilet pods, and lift shafts. The last category is the Modular/complete building, which is like volumetric units, but it is the entire project with usable space in which it forms the actual structure such as retail outlets, offices, prisons, and multi-story residential units.

Table 2-1: Types of Off-site Construction [12]

Types	Definition	Examples
Component manufacture and sub-assembly	Small-scale subassembly of building project components and items that are never considered for on-site production	Windows, light fittings
Non-volumetric pre-assembly	Prior to final positioning, the product is factory assembled. Although it contains the project's key structural elements, it does not provide usable space.	Structural Sections, Wall panels, pipework assemblies
Volumetric preassembly	Within an independent structural frame, creates a closed unit.	Staircases, toilet pods, lift shafts
Modular/complete building	It's like volumetric units, but it's the full project that's usable.	Multi-story residential units, offices, prisons

2.2. Prefabricated Construction

Prefabricated construction refers to the full or partial manufacturing of the structural components of a given structure and then assembling them onsite. Prefabricated elements could be beams, columns, wall panels, floor panels, slabs, roof trusses, staircases, volumetric units such as kitchens and bathrooms, and structural modules [2]. Prefabricated construction can be illustrated as the non-volumetric pre-assembly, volumetric assembly, and modular building types, as mentioned in Table 2-1. Prefabricated components can be made of several materials such as concrete, steel, and wood [2]. Usually, prefabricated construction exists in the construction industry as the concrete precast, steel prefabrication, and modular construction.

2.2.1 Advantages of prefabricated construction

Several advantages of prefabricated construction over traditional on-site construction are listed in Table 2-2. Firstly, prefabricated construction reduces the required on-site workers and site activities, the direct labor cost, and the cost associated with on-site damages and wastes [13]. Secondly, prefabricated construction reduces the project duration by doing several activities simultaneously. To illustrate, in the construction phase, site preparation activities can be done simultaneously with the prefabrication work in the factory [14]. However, the sequence of site preparation and construction work is mandatory in traditional construction. Thirdly, prefabricated construction improves the quality of the produced structural work since they are produced in controlled factories and environments in which quality is produced according to standards with high consistency and less susceptibility to variations [13]. Fourthly, safety levels increase due to less work performed on the construction site [13]. This will result in a safer construction site in terms of human health. Fifthly, prefabricated construction simplifies the construction process compared to traditional construction in which a healthier work environment will be created by reducing the amount of tension that usually happens in the construction projects between contractors, subcontractors, and consultants [13]. This will happen because most of the work required to be done on-site will be prefabricated and ready for direct installation. Furthermore, it is environmentally friendly since it reduces the amount of material wastes used in the construction site, such as steel, concrete, concrete forms, tiles, paints, etc. [13].

Table 2-2: Qualitative Advantages of Prefabricated Construction [13]

Parameters	Qualitative Advantages of Prefabricated Construction
Cost	• Increased certainty-less risk in cost • Increased in added value • Lower project overhead • Less on-site damages and Less wastes • Less cost due to economy of scale principle for prefabricated elements • Offers better economic value
Time	• Less time spent on-site • Speed of delivery of product • Less time spent on commission • Guaranteed delivery- more certainty over the project schedule and reduced management time
Quality	• Products (building components) are tested in factory. • Greater consistency, product types are identical; more control of quality and compliance with standards
Safety	• Fewer people on-site hence reduced number of onsite accidents.
Productivity	• Less nagging • Less site disruption • Removal of difficult operations from on-site • Work being undertaken at the same time both on-site and off-site
Process	• Simplified construction process. • Systems can easily be measured and more accurately • Leads to quicker completion which in turn reduces site disruptions and hazards
Logistics and site operations	• Fewer trades on-site leading to better coordination • In remote areas where there is scarcity of trades and labors, prefabricated components can be transported from factory to site where the components are assembled • Prefabricated construction implies a reduction in site disruptions, excessive subcontracting, and spatial requirements
Waste	• Cleaner sites due to reduced number of on-site wet trades • Better management of site activities leading to reduction in waste

There are several reported quantitative advantages of prefabricated construction over traditional construction, as shown in Table 2-3. First, a reduction of capital and on-site labor costs can reach 10% and 50%, respectively [15],[16]. Second, prefabricated construction can reduce the required building time by 50% to 60% less than traditional construction [15]. Moreover, the project's construction time is considered faster than traditional construction, up to 50% [15]. Third, it has been reported that modular construction reduces on-site accidents by 80% compared to on-site construction [19]. A case study in China has revealed that a prefabricated constructed house has 6.61 % less on-site health damages than a traditionally constructed house [20]. Fourth, prefabricated construction reduces the number of on-site workers by 50% than traditional construction, making savings in the skilled manual labor on-site up to 50%, such as carpenters, steel fixers, and masonry [16],[21]. Furthermore, it has been reported that prefabricated construction uses about 30% less site manpower (in man-day) in general than in traditional construction. Fifth, regarding construction wastes, 84.7% of construction waste can be avoided by adopting prefabrication, while site waste can be reduced by 70% [22],[15]. It has been reported that prefabrication uses 35% less concrete, 25% less reinforcement, 40% less wastage of tiles than traditional construction [17]. Lastly, prefabricated construction contributes to environmental substantiality by having a 43% reduction in $CO2$ emissions using modular construction compared to traditional construction [24]. A reported case study has revealed that a sample of prefabricated residential building construction was more efficient, with a 20.49% reduction in total energy consumption, 35.82% reduction in resource depletion, 3.47% reduction in ecosystem damage compared to the sample traditional residential building [20].

Table 2-3: Quantitative Advantages of Prefabricated Construction [13]

Parameters	Quantitative Advantages of Prefabricated Construction	References
Cost	• The usage of prefabricated construction can reduce capital costs by up to 10%. • The usage of prefabricated construction can reduce onsite labor costs by up to 50%.	[15] [16]
Time	• The productive time can be enhanced by up to 12% • A normal modular house took 4 months to build, compared to 14 months for a similarly traditional or conventionally built house. (Case Study) • Construction times are typically 50–60% faster than regular onsite construction. • Faster construction times by up to 50%	[17] [18] [15] [15]
Safety	• When modular construction is employed instead of onsite construction, on-site reportable accidents can be decreased by up to 80%. • A sample prefabricated house in China has a 6.61% reduction in health damage when compared to a traditionally constructed house. (Case Study)	[19] [20]
Number of site workers	• There is 50% less onsite work, thus necessitating fewer trades. • Savings in on-site physical labor (up to 40%–50% of traditional construction), particularly in specialized professions like formwork, masonry, plastering, painting, and carpentry.	[16] [21]

	• Prefabrication utilizes around 30% fewer labor (in man-day) on the jobsite than traditional construction.	[17]
Waste	• Prefabrication can serve to reduce 84.7% of construction waste. • Precast construction can reduce construction, demolition, and excavation waste by up to 52%. • 70% reduction in site waste • In comparison to traditional construction, prefabrication utilizes 35% less concrete, 25% less reinforcement, and 40% less tile wastage	[22] [23] [15] [17]
Environmental sustainability	• When compared to onsite processes, modular processes result in a 43% reduction in $CO2$ emissions. • The energy usage of a modular home is 4.6% lower than that of a traditional home. • Compared to a traditional residential building, a sample prefabricated residential building construction was more efficient, with a 20.49% reduction in total energy consumption, 35.82% reduction in resource depletion, and 3.47% reduction in ecosystem damage. (Case Study)	[24] [25] [20]

2.2.2 Constraints of prefabricated construction

The implementation of prefabricated construction faces several limitations that impede its high level of implementation. According to research performed in Singapore, the highest constraint of prefabricated construction was the extensive coordination required prior to and during construction, as shown in Table 2-4. This is mainly because of the reduced flexibility for design changes in the future and the requirement of synchronization onsite and offsite schedules to maintain on-schedule site delivery for prefabricated components [26]. It can be seen in table 4 that prefabricated construction requires higher transportation and logistics considerations due to the large sizes of prefabricated components to be transported to the working site within the given rules and regulations of the transportation and roads authority in the country. Prefabrication construction is also known for higher initial cost, up-front cost, than traditional construction due to the cost associated with pre-fabricators at the beginning of the project, ranking this restriction as 5th according to their research [26]. Another study performed in China has revealed that one of the main constraints of prefabricated construction is the lack of awareness of prefabricated construction benefits among owners/developers and designers [27]. The lack of research and results about prefabricated construction to be shared among owners/developers and designers is critical, making the projects' decision-makers not aware of the benefits of prefabricated construction to put it as a valid option to use in their projects. The extensive need for high-quality and detailed shop drawings for prefabricated components for prefabrication and installation purposes is also considered a limitation of prefabricated construction, requiring additional design effort before construction [28].

Table 2-4: Constraints of Prefabricated Construction [26]

Rank	Constraints of Prefabricated Construction
1	Extensive coordination required in the design phase and construction phase
2	Additional project planning and design efforts are required
3	Higher transportation and logistics considerations
4	Requirement for early commitments
5	Higher initial cost than traditional construction method
6	Design limitations due to transportation restrictions (e.g., modules' size)
7	Reduced flexibility for future design changes
8	Transportation limitations due to rules and regulations
9	Restricted site layout (e.g., lack of storage space for prefabricated elements/lack of space to unload and move the elements)
10	Requirement of more communication among all stakeholders
11	Complex code compliance and inspection processes
12	Lack of awareness of prefabricated construction benefits among owners/developers and designers
13	Lack of prefabricated construction experiences in terms of design
14	Lack of prefabricated construction experiences in terms of installation
15	Unsupportive decisions made by engineers
16	Increased organizational requirements (e.g., increased complexity of procurement and contracting issues, changing roles of project participants)

2.3. Building Information Modelling (BIM)

2.3.1 Background

Building information modelling refers to the digital technology that uses the concept of 3D representation of the project structure to provide detailed information about any element in the structure throughout the construction lifecycle. BIM software has become one of the leading digital technologies that has been intensively used recently. According to a recent survey in 2015 conducted by over 500 UAE professionals in the Architecture, Engineering, and Construction (AEC) industry, 87% of them have used BIM in their companies and organizations, and 62% have used BIM in more than one project in the UAE [9].

2.3.2 Benefits of BIM

BIM has proved its role to be utilized in most construction projects due to several features. One of the main functional features of BIM is that it allows the owner and client to visualize the entire project in detail during the preconstruction phase [20]. This allows the owner to make changes before the actual construction process starts to avoid later changes during construction. In fact, having changes during construction results in delays and increased costs. In addition, BIM facilitates the work by improving communication and teamwork, allowing for sharing information among key participants [20]. Using the feature of cloud-based tools such as Autodesk's BIM 360 connects all the team members in different disciplines with data in real-time [20]. This Collaboration between key participants allows the contractor to be more comfortable in reducing the risk cost and insurance cost resulting in overall cost reduction in the project [20]. Furthermore, BIM allows for early clash detection due to sharing information between the different design disciplines [20]. This eases the work while it comes to the construction phase. Moreover, BIM provides a cost estimation model for the project in which it automates the time-consuming task of quantifying and applying costs to monitor the progress of the project [20]. BIM also provides an efficient way to improve the project schedule and keep it updated by continuously updating information according to the site condition [20]. Another feature of BIM is improving construction safety by pointing hazards and physical risks. This is attained by visualizing and planning the project's site logistics [20]. Further, the BIM information model contains valuable information about the structure in which it can be used for having more robust facility management after construction is over [20]. Finally, BIM enhances prefabrication construction by using the project's BIM data to generate shop drawings and production drawings for manufacturing purposes [20].

2.3.3 BIM software examples

A recent study categorized the different BIM software into ten categories according to their primary functions [29]. These categories are BIM execution planning software, BIM content management software, BIM modelling software, generative design software, BIM analysis software, BIM collaboration software, BIM checking software, preconstruction BIM 4D/5D software, construction BIM software, and facilities management BIM Software [29]. Autodesk Revit and Tekla are the most common BIM software used for 3D modelling, while Robot Structural Analysis and STAAD are used for structural analysis [29]. Autodesk Dynamo is used with Revit to create visual logic to explore parametric conceptual designs and automate tasks [29]. Navisworks is a BIM coordination tool that combines all the design and construction data in one model, identifies clashes and interference problems before construction, and captures material quantities [29]. The BIM software also includes Autodesk 3DS for 3D animation and PyroSim for fire simulation and energy analysis [29].

2.4. Barriers of BIM Implementation in the UAE

BIM has become one of the leading digital technologies that has been intensively used recently. A recent study was performed at the end of 2015 on 60 participants from the UAE construction industry, including contractors, sub-contractors, engineers, architects, project managers, government officials, facility managers, quantity surveyors, and the municipal administrative authorities [31]. The study revealed that the most BIM features used among the study participants are 3D Modelling, clash detection, and record-keeping purposes only, while all other benefits are yet to be realized among the project's stakeholders [31]. This indicates that the UAE construction industry participants lack awareness about the BIM benefits. The study has also revealed that the main perceived drivers toward BIM adoption are improving the design quality, saving time during the design process, improving communication and collaboration among stakeholders, improving overall project quality, and facilitating more offsite and prefabrication activities [31].

The same study has also viewed the main barriers against implementing BIM in the UAE, listed in Table 2-5. Most respondents agreed that the top four challenges are inadequate top management support, higher cost associated with the BIM implementation, inadequate statutory support, and lack of knowledge on BIM benefits to projects and organizations [31]. Moreover, the lack of BIM professionals and people's resistance to change and organizational change are other main challenges of BIM implementation in the UAE [31]. However, there are initiatives such as Dubai Municipality's mandate to adopt BIM for high capital projects, the adoption is still less in the projects, especially at the municipal level. Hence, the UAE municipalities play a critical role in facilitating the role of BIM in the UAE construction industry. Once the use of BIM becomes mandatory in all construction projects, contractors, consultants, and subcontractors will be required to follow the wave of BIM implementation in construction projects.

Table 2-5: Barriers of BIM Implementation in the UAE [31]

#	Barriers of BIM	Weighted Average (Out of 5)
1	Inadequate top management support on BIM adoption	4.09
2	High cost associated with BIM adoption	4.04
3	Inadequate statutory support to adopt BIM	4.02
4	Lack of knowledge on BIM benefits to projects and organizations	4.00
5	Lack of BIM Professionals	3.98
6	Lack of adequate information to the users about BIM	3.87
7	Lack of policies, road map, and role of BIM in the organization	3.87
8	People reluctance to learn new technology	3.84
9	Lack of adequate BIM training programs	3.78
10	People resistance to change and organizational change	3.78
11	More time to prepare, adopt and implement	3.76
12	Lack of appropriate data sharing/management and storing guidelines	3.71
13	Lack of well-defined BIM business process models	6.64
14	Lack of existence on BIM friendly contracts	3.42
15	The steep learning curve with those unfamiliar technologies	3.40
16	Legal issues around intellectual properties	3.36
17	Limitations of BIM use because of lack of library elements	3.27
18	Incompatibility of BIM other tools	3.07
19	Lack of responsibility sharing and guidelines	3.07
20	Clients' unawareness of BIM benefits	2.89

2.5. Use of BIM with Prefabrication Construction

2.5.1 Prefabricated construction requirements that can be enhanced by BIM

Using BIM with prefabrication work has been suggested to overcome some of the main prefabricated construction limitations. Firstly, BIM can facilitate the need for additional project planning and design efforts [26]. This helps produce an effective and accurate design with a high confidence level for low chances for changes in the future. It will also play a significant role in coordinating and synchronizing onsite and offsite schedules before the construction stage, considering the transportation limitations of prefabricated components to the working site. Secondly, BIM allows for better coordination before and during construction, allowing the project key participants to share and modify information in one single space [26]. Thirdly, using BIM with prefabrication work can reduce the high initial cost associated with prefabrication construction by having better planning and design trade-offs to reduce the prefabrication cost [26]. Fourthly, BIM can facilitate the automatic extraction of the shop drawings of the prefabricated components with a high level of precision and accuracy [18]. Hence, BIM with prefabrication work can significantly enhance the use and level of implementation of prefabrication construction. These distinct prefabrication requirements that can be enhanced by using BIM are listed in Table 2-6.

Table 2-6: Prefabricated Construction Requirements that Can be Enhanced by BIM

#	Requirement of Prefabricated Construction	References
1	Synchronizing On-site and Off-site schedules	[32]
2	Coordination during the design phase due to low flexibility for design changes later	[11],[26]
3	Extensive need of high quality shop drawings	[23]
4	High initial cost typically incurred in prefabricated construction	[26],[32]
5	Increased transportation and logistics considerations	[26]

2.5.2 BIM features used with prefabrication construction

Five main BIM features were mentioned intensively in several studies to be used with prefabricated construction, listed in Table 2-7.

Table 2-7: BIM Features Used in Prefabricated Construction

#	BIM Features Used in Prefabrication	References
1	3D Modelling “Structure Representation” for visualization, communication, and collaboration in data	[11],[32]
2	4D Modelling “Schedule Representation” to combine project schedule with BIM	[11],[32]
3	5D Modelling “Cost Modelling” to integrate quantity takeoff and cost estimates with BIM	[11],[32]
4	Identify clash detection in the project through early involvement of project’s key participants	[11]
5	Generation of shop drawings for prefabricated components	[11]

Firstly, 3D modelling, also called Structure Representation, is used for visualization, communication, and collaboration in data [11],[32]. Secondly, 4D modelling, refers to the schedule representation that combines the onsite and offsite project schedules with BIM [11],[32]. Thirdly, the 5D cost modelling feature integrates quantity take-off and cost estimates with BIM [11],[32]. Fourthly, the clash detection feature is usually used in the design stage among the project key participants to identify any interference or overlaps among the design elements or systems [11]. Lastly, the generation of shop drawing feature is used to produce detailed and accurate shop drawings for prefabricated components [11].

2.5.3 BIM software used in prefabricated construction

Defining the BIM software that fits each stage of the prefabricated construction project is considered an essential factor to smoothen the work in the project. A recent study has proposed a BIM software framework for prefabricated and modular construction projects [33]. Even though every project requires its software framework depending on its characteristics and requirements, the following framework can be used as a general software framework for commercial and residential prefabricated construction projects. The study has divided the project into three phases: design, construction, and operational [33].

Firstly, the design phase consists of 7 main divisions, as shown in Figure 2-1: virtual design, architectural design, sustainability analysis, structural design and analysis, MEP design and analysis, design coordination, and cost and quantities. The virtual design can be accomplished with Navisworks, software from Autodesk, which is usually used to improve BIM coordination. Architecture design could be done with Revit Architecture, while sustainability analysis could be obtained through IES and TRNSYS, commonly used for commercial building projects [33]. Also, FirstRate5, Revit, and Green Building Studio (GBS) are the most common sustainability analysis software used for residential buildings projects. Furthermore, Revit, Robot, and ETABS lead in structural analysis and design [35]. Revit MEP and simulation CFD are commonly utilized for thermal and flow analysis [33]. Moreover, PyroSim is used for fire simulation, while Ecotect and INSUL are used for acoustic analysis, which helps predict the sound insulation of walls, floors, ceilings, and windows [33]. Cost and quantities can be accomplished with several BIM software such as AutoCAD, Navisworks, and Revit. BIM integrates quantity take-off and cost estimates with the created 3D structural model. It provides the stakeholders with immediate estimates of quantities and costs at any phase of the project cycle. This tool is beneficial for material tracking and ordering.

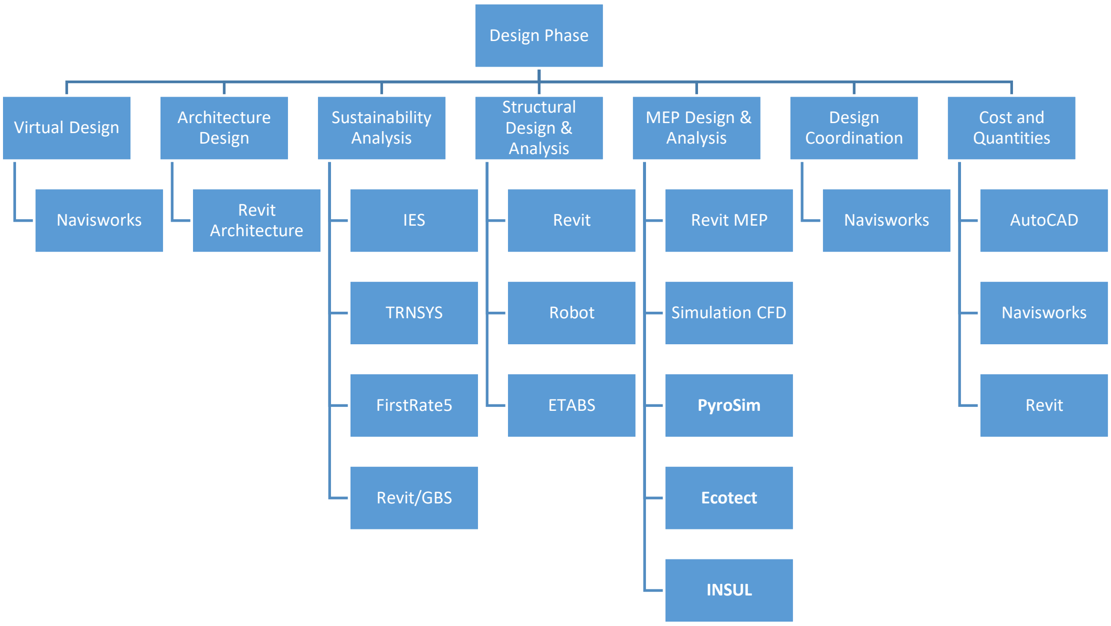


Figure 2-1: BIM Software Framework for Design Phase (Adapted from [33])

Secondly, the construction phase has five main components, which are 4D construction simulation, construction management, clash detection, prefabrication, and construction coordination which are presented in Figure 2-2. The 4D construction simulation, construction management, clash detection, and construction coordination can be all accomplished through Navisworks. In fact, Navisworks software is a BIM coordination tool that combines all the design and construction data in one model, identifies clashes and interference problems before construction, and captures material quantities [30]. For prefabrication, Autodesk Fabrication, SDS/2 Connect, and IDAT Precast are additional supporting tools for Revit to generate precise structural and MEP 3D models for fabrication at the factory [33]. Inventor software also can be used to generate precise structural and MEP 3D models for fabrication [33].

Thirdly, the operation phase consists of equipment management, construction management, and emergency management, which means the plan for quick and effective action in the cases of disastrous events [33]. Navisworks can be used for equipment management and construction management [33]. Navisworks is an efficient tool for coordination in the construction site since it works as a 5D model, including the time and cost components. For emergency management, the authors of the study propose using PyroSim and IES Virtual environment since they are energy analysis and performance modelling software [33]. These BIM software are presented in Figure 2-3.

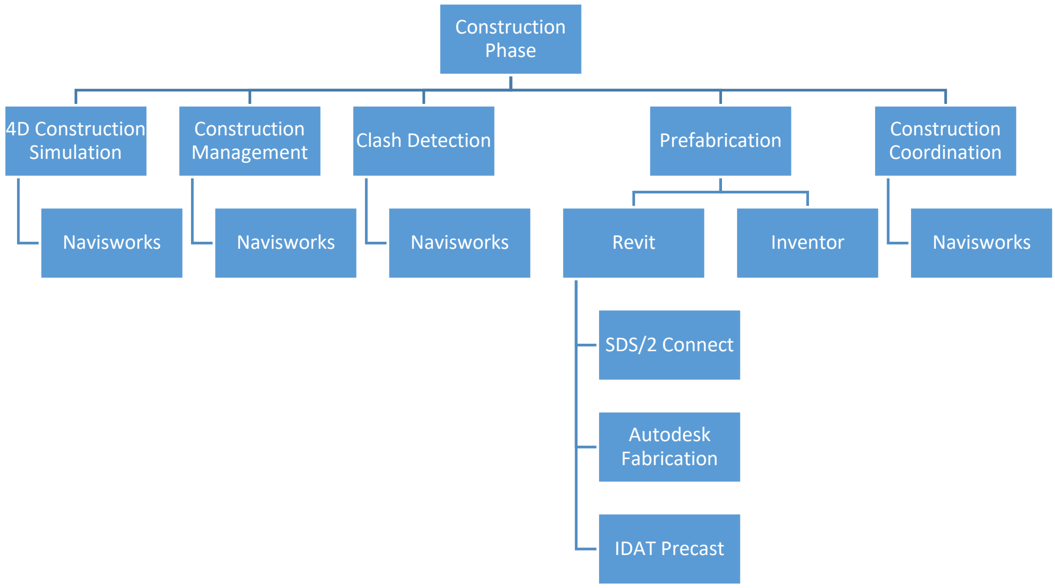


Figure 2-2: BIM Software Framework for Construction Phase (Adapted from [33])

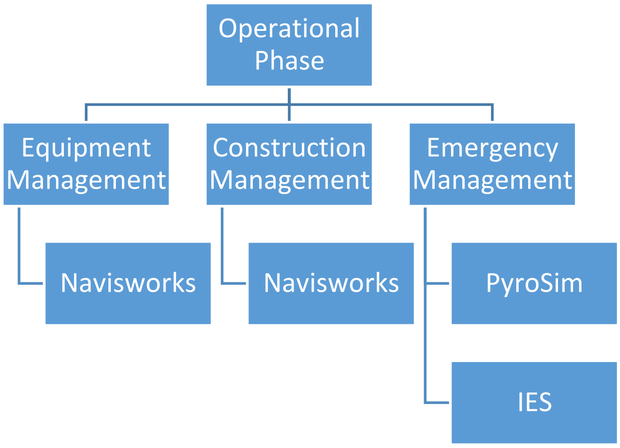


Figure 2-3: BIM Software Framework for Operational Phase (Adapted from [33])

Chapter 3. Methodology

In order to find the effect of BIM on prefabricated construction, the following steps are followed:

3.1. State of BIM in the UAE

It is essential to investigate the situation of BIM implementation in the UAE to perform the research objectives in the UAE. The previous work regarding the use of BIM in the UAE in the literature is investigated. Besides, a survey is distributed to some UAE construction professionals and participants such as contractors, consultants, and pre-fabricators. The results help to measure the level of implementation of BIM in the UAE and whether it has increased over the past five years.

3.2. Prefabrication in the UAE

In this research, it is vital to investigate the prefabrication industry in the UAE to know whether the prefabrication work is increasing or not and to understand the reasons behind choosing prefabrication in construction work. The BIM survey includes questions regarding the usage of prefabrication to understand the level of implementation of prefabrication in the UAE and whether it is increasing or not. The results obtained regarding the extent of use of prefabrication construction in the UAE is compared with other countries that rely heavily on prefabrication constructions.

3.3. Role of BIM in Prefabrication

One of the main results to obtain is the extent of BIM adoption in the prefabrication industry and whether it contributes to increasing the use of prefabrication construction. The BIM survey includes questions to inquire whether the survey's participants use BIM in their projects that have prefabrication work, the extent of BIM implementation in their projects that have prefabrication work, and whether the implementation of BIM has enhanced and increased their projects that have prefabrication work.

Lists of prefabrication requirements BIM features are developed according to the literature. Then, they are used in the survey using a five-point Likert scale of 1 to 5 to assess their significance. The results are analyzed using the Relative Importance Index (RII) analysis to determine the relative importance of each requirement and feature.

3.4. BIM Features - Prefabrication Requirements Relationships

In the “BIM features - Prefabrication Requirements” relationships, each BIM feature is linked to one or more of the prefabrication requirements that can be satisfied by BIM. These relationships are created with the aid of the survey and interviews with prefabrication and construction professionals in the UAE construction industry. These relationships are used to create a set of recommendations for the industry to enhance prefabricated construction in the UAE using BIM.

3.5. Success Criteria

The main output of this research is to investigate the effect of using BIM with prefabrication on four main success criteria of construction projects: cost, time, quality, and safety. Qualitative responses are obtained through the survey. Effects of enhancing each prefabrication requirement on cost, time, quality, and safety are obtained from the interviews with the prefabrication and construction professionals in the UAE construction industry.

3.6. Case Studies

Even though obtaining detailed information to support the created relationships is considered a challenge due to confidentiality issues, companies in this field are targeted to obtain case studies to support the research idea and objectives. Moreover, case studies available online are used and illustrated to support the research idea and objectives.

3.7. Summary

In this research, literature, questioner survey, interviews, and case studies were used to accomplish the objectives of this research. Table 3-1 illustrates the main outputs of each instrument of this research. The literature was used to obtain a list of proposed prefabrication requirements that can be enhanced by BIM and a list of BIM features that can be effectively used in prefabrication work. It was also used to obtain a review of the global use of BIM and prefabrication. A survey consisting of 3 sections was distributed to the UAE construction companies and industry professionals, resulting in 52 responses. The first section of the survey includes general information about the respondents, while the second section addresses the BIM and prefabrication situation in the UAE. The third section addresses the combined use of BIM with prefabrication, verification of prefabrication requirements, and verification of BIM features. Also, it asses the effect of using BIM in prefabrication qualitatively on cost, time, quality, and safety objectives of prefabricated construction. After that, interviews with ten industry professionals who implemented BIM with prefabrication previously were conducted to establish relationships between BIM features and prefabrication requirements. They were also asked to indicate the effect of enhancing the selected prefabricated requirements on prefabricated construction's cost, time, quality, and safety objectives. This helped develop recommended action steps to increase prefabrication work in the UAE. Lastly, a real case study was obtained from the project director of the Dubai Future Museum project in Dubai to show and verify the effect of using BIM in prefabrication work.

Table 2-8: Summary of Methodology

Literature	**Survey**	**Interviews**	**Case Study**
List of proposed prefabrication requirements that can be enhanced by BIM	BIM implementation trend in UAE	Establish relations between BIM features and prefabrication requirements that can be enhanced by BIM	Verification of the BIM features used in the prefabrication project
List of BIM features that can be effectively used in prefabrication work	Prefabrication implementation Trend in UAE	Identify the effect of enhancing the specified prefabrication requirements in terms of Cost, Time, Quality, and Safety	Verification of the prefabrication requirement that got enhanced by BIM in the prefabrication project
BIM implementation trend in several developed construction industries	Level of BIM implementation in prefabrication work in UAE	General observations about use of BIM with prefabrication work	BIM software used
Prefabrication implementation status in several developed construction industries	Level of agreement with prefabrication requirement list that can be enhanced by BIM	How BIM can enhance Cost, Time, Quality, and Safety success criteria	Effects of using BIM in prefabrication project in terms of Cost, Time, Quality, and Safety objectives of prefabrication projects

Reported results about effect of using BIM on prefabrication in terms of Cost, Time, Quality, and Safety objectives of prefabrication projects	Level of effectiveness of BIM features when used in prefabrication	
	Qualitative results about "Effect of BIM on prefabrication in terms of Cost, Time, Quality, and Safety"	

Chapter 4. BIM and Prefabrication: A Review of Global Use

4.1. BIM Implementation in Several Developed Construction Industries

The BIM implementation has been increasing drastically in several developed construction industries such as in the United Kingdom (UK), United States of American (USA), China, Singapore, and South Korea. For instance, the UK is considered the global leader in BIM adoption [34]. Since 2012, the UK government has made BIM implementation mandatory in all construction projects [34]. In the USA, according to a survey developed by the American Institute of Architects in 2020, 100% of prominent architecture firms are using Building Information Modeling for billable work, while over a third of small firms use BIM, too [34]. Furthermore, according to a survey developed by McGraw-Hill Construction in the USA, the BIM users in 2007 was 17%, while in 2009 and 2017, it reached 49% and 81%, respectively [35]. Another study has revealed that the top 5 leading countries with BIM adoption are the UK, USA, France, Scandinavian region, and Singapore, while the United Arab Emirates are the leading country in the Middle East [36].

4.2. Prefabrication Implementation in Several Developed Construction Industries

The prefabrication construction technique has significantly increased in several developed construction industries, such as Sweden, the UK, the USA, China, Singapore, and South Korea. In fact, Sweden is considered the highest country in implementing prefabrication construction in the housing sector [37]. Sweden's percentage of prefabricated detached houses is around 85% [37]. Prefabricated construction in China has been experiencing a massive improvement in the last decade. The prefabrication work in China in 2020 has increased 50% more than the previous year [38]. The Chinese government plans to increase the percentage of newly added prefabricated buildings to 30% in the next ten years [39]. In the USA, the number of construction projects with prefabrication work has increased from 13% in 2010 to 35% in 2016, almost three times increase for six years [40]. Moreover, according to a survey conducted in the USA construction industry, 26% of the respondents indicated having 20% of their projects as prefabrication projects, while in 2016, 55% indicated having 20% of their projects as prefabrication projects [40]. A study performed on the UK construction industry revealed that the Compound Annual Growth Rate (CAGR) in implementing prefabrication construction is found to be approximately 4.5% between 2016 and 2021 and is expected to continue to 2026 [41]. Furthermore, out of 200,000 homes in the UK, 15,000 homes are prefabricated [41].

4.3. Findings from Global Case Studies

The utilization of a prefabricated construction system has generated the need to have additional tools to overcome the main challenges and limitations of implementing prefabricated construction, such as the required design and construction coordination between the structural, electrical, and plumbing systems [11]. Using the outstanding features of BIM, the prefabricated construction technique has become more applicable, understandable, and facilitated to be implemented. BIM enables sufficient visualization of the project by having a 3D representation of the building's prefabricated components geometry, location, systems, and final product, including the finishes, to the owners, designers, and contractors [11]. It also allows for code compliance reviews using the 3D model generated with related data for code compliance reviews [11]. Moreover, it facilitates the fabrication process by utilizing the ability of BIM to generate detailed shop drawings for the prefabricated components [11]. Furthermore, BIM enhances the coordination and collaboration among the design team, contractors, fabricators, and clients of the prefabrication project by simultaneously creating construction documents, product imagery and prototypes, exterior envelopes, interior finishing, and MEP fixtures of all the building modules [11]. Another main advantage of using BIM with prefabricated construction is the concept of early clash detection. The design of prefabricated construction requires efficient collaboration between the design disciplines in which the use of BIM detects interference in the designed building. For instance, it can detect the physical interference of an air distribution duct for the HVAC system with a concrete beam [11]. Early clash detection smoothens the work during construction, reduces conflicts, and protects the project duration from being delayed. Further, BIM facilitates prefabricated construction by providing detailed cost estimation by performing material quantification and pricing [11]. This cost estimation can be automatically generated and modified whenever changes are applied for each prefabricated component. Lastly, BIM generates a construction schedule for material ordering, fabrication process, delivery of prefabricated components, and onsite installation of each prefabricated component to provide an efficient sequence of activities [11].

A case study is a Healthcare Expansion Project in Charlotte, North Carolina, USA [11]. The BIM model was produced for the architectural design, structural design, and Mechanical, Electrical, and Plumbing (MEP) design. The model was developed through collaboration among the different design teams. The model was used intensively in cost engineering, subcontractor buyout, MEP coordination, and clash detection between all the design disciplines. The results of using BIM technology in this project are the clearly defined work scope for subcontractors, the automatic quantity extraction of structural steel and major MEP systems, the easy extraction of shop drawing of structural steel and MEP systems, and 560 early clash detection cases between the MEP systems and the structural systems prior to the fabrication process.

A second case study is a High School Project in Gastonia, North Carolina, USA [11]. The project is a modular construction project that consists of modular prefabricated classrooms equipped with rough MEP installation. A BIM model was created, including the architectural design, structural design, and MEP design, as presented in Figure 4-1. The BIM model was determined to be beneficial in this project for having effective design coordination, defining subcontractor work scope, providing cost engineering, and providing MEP coordination and project sequencing. Also, 258 conflicts were detected and eliminated during the design phase. Figure 4-2 shows design clash detection between the structural elements and MEP ductwork.

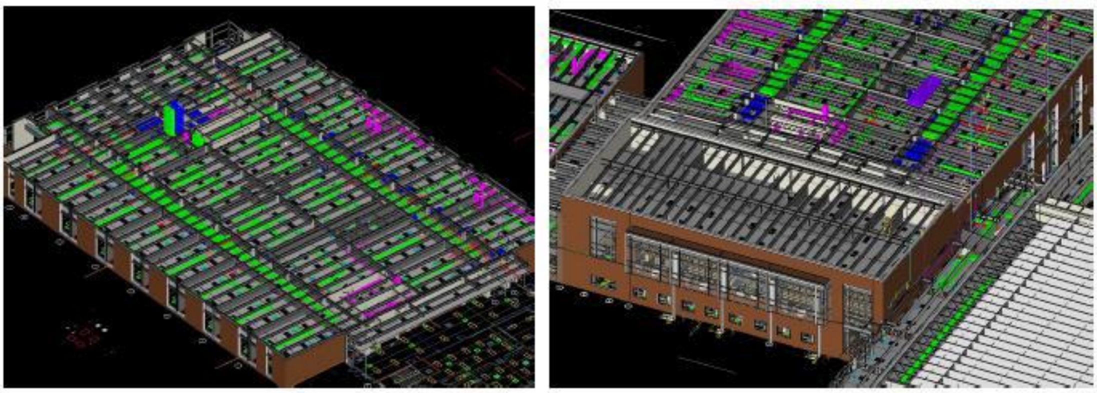


Figure 4-1: BIM Model for High School Project (Source [11])

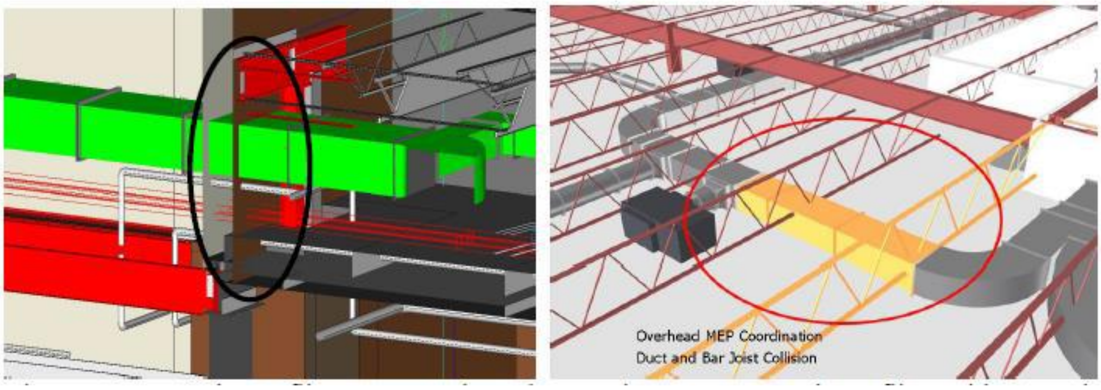


Figure 4-2: Clash Detection between Structural Elements and MEP Ductwork (Source [11])

The third case study is neighborhood residence facilities construction in Gyeonggi-do Namyangju-si, South Korea, a prefabricated steel frame construction project [42]. Table 4-1 shows the main tasks involved in steel frame construction and how BIM can serve these tasks. From the BIM model, the details regarding the number of bolts, welding length, cutting parts, grouting, and surface treatment related to the steel joints can be easily obtained and visualized as presented in Figure 4-3. Furthermore, according to this data, the steel members' type, quantity, grade, area, weight, and unit weight can be automatically calculated and generated through the BIM model as presented in Figure 4-4.

Table 4-1: Main Tasks Involved in Steel Frame Construction with BIM [42]

Phase	**Task**	**Location**	**BIM Use**
Preconstruction	Drawing and specification review	On-site	-
	Construction planning	On-site	Visualization, 4D simulation
	Shop drawing	On-site	Creation of 2D shop drawings
	Cross check	On-site	Visualization, clash check
Prefabrication	Bringing steel framing members and reviewing the quantity	Off-site	Quantity calculation
	Steel frame cutting	Off-site	Creation of 2D drawings (cutting plan)
	Steel frame mounting	Off-site	-
	Steel frame assembly and welding	Off-site	Quantity calculation
	Painting steel frame members	Off-site	Quantity calculation
	Marking	Off-site	3D BIM authoring

	Precision inspection	Off-site	Visualization (e.g., laser scanning)
	Carrying steel frame on and of the site	Off-site	Quantity calculation
Construction	Review of quantity brought to a laydown area	On-site	Quantity calculation
	Building and installing steel frame columns	On-site	Visualization, temporary works, and construction management
	Steel girder, beam lifting, and installation	On-site	Temporary works and construction management
	Vertical and horizontal inspection of the steel	On-site	Visualization (e.g., laser scanning)
	Bolting and welding of the steel	On-site	Quantity calculation
	Fireproof coating spray on steel	On-site	Quantity calculation
	Steel frame installation finish (fastening)	On-site	Quantity calculation

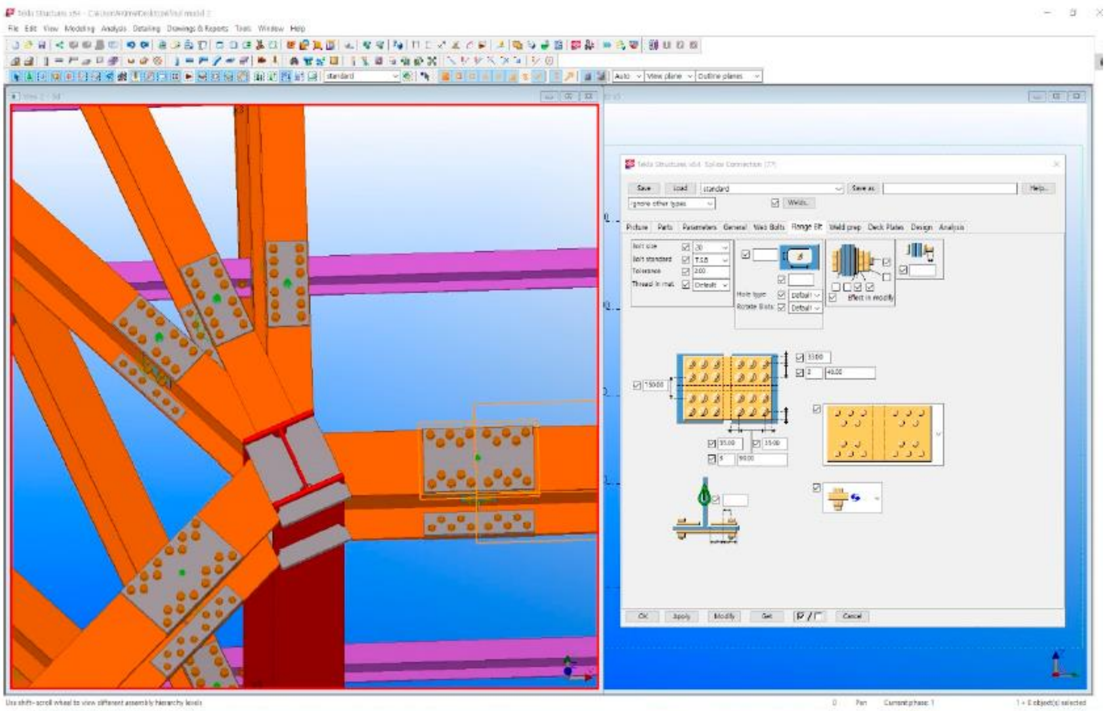
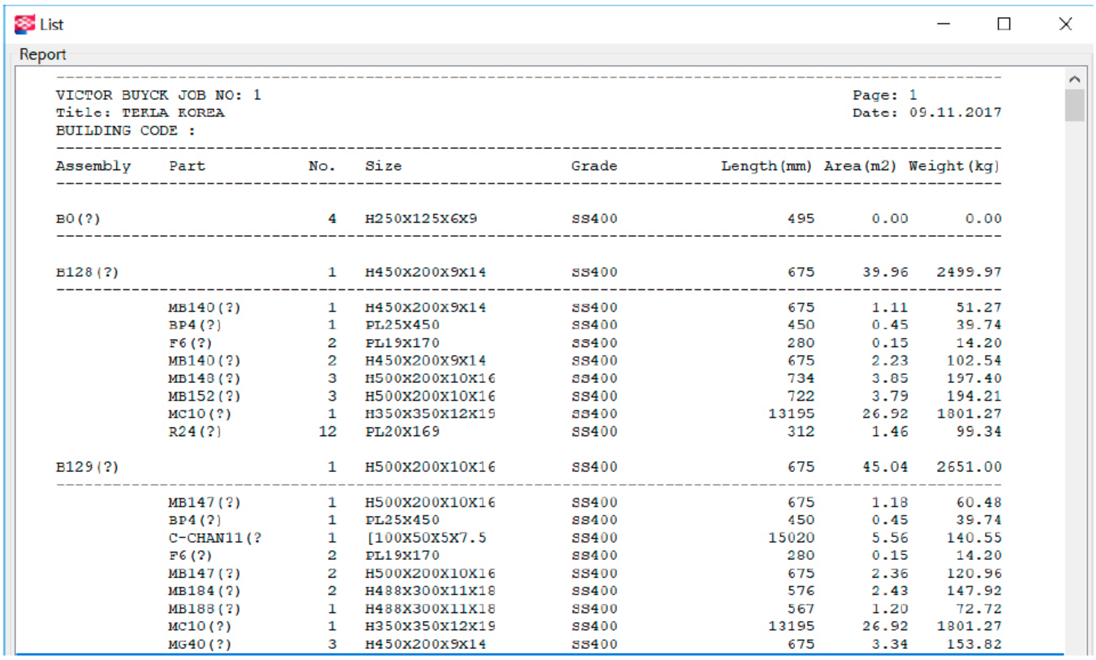


Figure 4-3: Detailed Information Regarding the Joints of the Steel Frame Members (Source [42])



List

Report

VICTOR BUYCK JOB NO: 1 Page: 1
Title: TEKLA KOREA Date: 09.11.2017
BUILDING CODE :

Assembly	Part	No.	Size	Grade	Length(mm)	Area(m2)	Weight(kg)
B0(?)		4	H250X125X6X9	SS400	495	0.00	0.00
B128(?)		1	H450X200X9X14	SS400	675	39.96	2499.97
	MB140(?)	1	H450X200X9X14	SS400	675	1.11	51.27
	BP4(?)	1	PL25X450	SS400	450	0.45	39.74
	F6(?)	2	PL19X170	SS400	280	0.15	14.20
	MB140(?)	2	H450X200X9X14	SS400	675	2.23	102.54
	MB148(?)	3	H500X200X10X16	SS400	734	3.85	197.40
	MB152(?)	3	H500X200X10X16	SS400	722	3.79	194.21
	MC10(?)	1	H350X350X12X19	SS400	13195	26.92	1801.27
	R24(?)	12	PL20X169	SS400	312	1.46	99.34
B129(?)		1	H500X200X10X16	SS400	675	45.04	2651.00
	MB147(?)	1	H500X200X10X16	SS400	675	1.18	60.48
	BP4(?)	1	PL25X450	SS400	450	0.45	39.74
	C-CHAN11(?	1	[100X50X5X7.5	SS400	15020	5.56	140.55
	F6(?)	2	PL19X170	SS400	280	0.15	14.20
	MB147(?)	2	H500X200X10X16	SS400	675	2.36	120.96
	MB184(?)	2	H488X300X11X18	SS400	576	2.43	147.92
	MB188(?)	1	H488X300X11X18	SS400	567	1.20	72.72
	MC10(?)	1	H350X350X12X19	SS400	13195	26.92	1801.27
	MG40(?)	3	H450X200X9X14	SS400	675	3.34	153.82

Figure 4-4: Quantities Information of the Steel Frame Members (Source [42])

BIM helped produce shop drawings that show detailed information about planes, elevations, welded parts, anchor bolts and plates, and assembly drawings. In addition, the BIM model helped to identify 39 clashes in the design phase, which mainly happened between the steel frame members and bolted plates which can be shown in Figure 4-5.

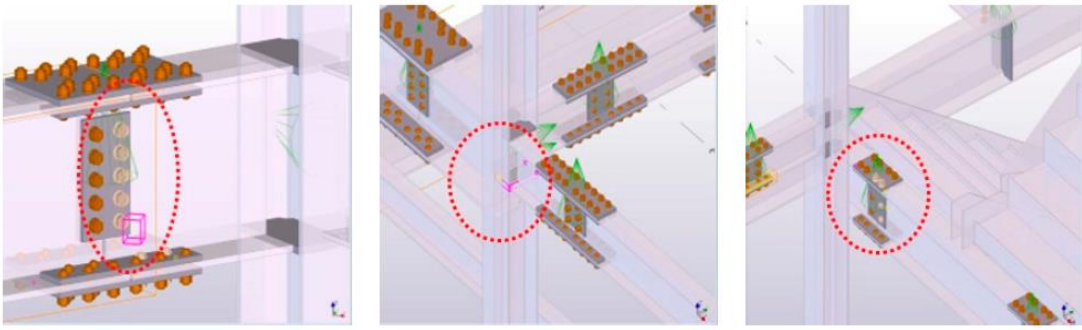


Figure 4-5: Detected Clashes in the Prefabricated Steel Structure (Source [42])

Finally, BIM in prefabricated steel frame construction projects can assist the owner, contractor, and subcontractor/pre-fabricator according to their role perspective, presented in Table 4-2. For instance, BIM can assist the client decision-making based on quantitative cost data obtained from the BIM model. Furthermore, the use of BIM in prefabricated steel frame construction projects for contractors facilitates placing orders for steel frame members using shop drawings extracted from the BIM model. For pre-fabricators, BIM with a prefabricated steel framework ensures the quality of shop drawings through clash detection review of members in the preconstruction stage, which creates higher accuracy and confidence during the production stage.

Table 4-2: BIM Uses/Effect According to Stakeholders' Perspective [42]

Perspective	**BIM Effects**
Client	Decision making based on quantitative cost data
	Communication through visualization
	Execution of the built structures based on construction progress
	Confirmation of construction quality via surveying
General Contractor	Deciding construction orders by presenting quantitative construction estimate data
	Placing orders for steel frame members using shop drawings extracted from BIM model
	Conducting simulations to carry the steel members to the site and confirm the location of the laydown area
	Executing volume management based on daily progress
Subcontractor/Prefabricator	Ensuring quality of shop drawings through clash detection review of members in the preconstruction stage
	Implementing prefabrication and processing of steel frame members using shop drawings
	Implementing construction shop drawings

4.4. Effects of BIM in Enhancing Prefabricated Construction Requirements on Cost, Time, Quality, and Safety objectives of Prefabricated Construction

Using BIM with prefabrication has a considerable impact on prefabricated construction's cost, time, quality, and safety objectives. The information obtained from the literature has shown some of these impacts, as illustrated in Table 4-3. Table 4-3 includes results of real projects on enhancing cost, time, quality, and safety objectives of prefabricated construction due to the use of BIM in these prefabrication projects. For instance, the use of BIM in a healthcare project in Northern California, USA, which consists of 100% prefabrication work, has led to a $9 million savings in the overall project cost of 96.6 million [48]. Furthermore, the use of BIM in this project has led to a six-month saving in the project's duration with only one recorded injury during the project duration [48]. Moreover, the use of BIM in a small tilt-wall project, a three-story assisted living facility project, and a midrise commercial condominium project has led to 34%, 68%, and 43% reduction in the numbers of requests of information

(RFIs) respectively, which indicate the improvement in the quality of design due to the use of BIM in the design stages [53].

Table 4-3: Global Examples of Effect of Using BIM with Prefabrication [13]

Parameters	Effect of Using BIM with Prefabrication	References
Cost	• The **capital cost** of a typical sized kitchen was decreased by about 5%.	[43]
	• A 4% saving in **total building costs** for a 57-unit apartment block project in Stockholm.	[44]
	• A **construction cost** saving of between 8% and 10% for Royal Opera House and Portcullis House.	[45]
	• 20% **cost** saving, Cookham Wood project in UK.	[46]
	• Cost savings of 9.8% on **project cost** and 18% in **cost of drawing production** for a four-story office building consisting of preconstructed units at Stansted.	[47]
	• $9 M savings in **overall project cost** for a $96.6 million healthcare project in Northern California, USA.	[48]
	• $220,000 **cost** savings in a modular healthcare facility in Charlotte, North Carolina.	[49]
	• 6.92% **cost** saving in a public housing project in Hong Kong.	[50]
	• Overall **cost benefit** of over $200,000 in Aquarium Hilton Garden Inn project in Atlanta, Georgia.	[51]
	• 45% increase in **profit margins** in housing projects in Finland.	[52]
Time	• 40% reduction in the **number of change orders** in a tilt-wall project, 48% on a three-story assisted living facility, and 37% on a midrise commercial condominium project.	[53]
	• 6 months' **savings on the schedule** in a $96.6 million healthcare project in Northern California, USA.	[48]
	• 20 days less in **project duration** in the construction of an apartment block project of 57 units in Stockholm.	[44]
	• 65.6 days as a **time saving** from clash detection in a high school project, Gastonia, North Carolina.	[49]
Quality	• 34% reduction in the total **number of RFIs** in a small tilt-wall project, 68% on a three-story assisted living facility, and 43% on a midrise commercial condominium project.	[53]
Safety	• Only one **recorded injury** throughout the installation of MEP systems over a 250,000 square feet project area in a $96.6 million healthcare project in Northern California of 100% pre-fabrication.	[48]
	• 5% reduction in **on-site accidents** in housing projects in Finland.	[52]
	• Generally, using BIM, 40% of **potential fatalities** in construction projects can be identified.	[52]
	• Generally, using BIM, 71% of **safety incidents** can be prevented using BIM at design.	[54],[55]

Chapter 5. BIM and Prefabrication Implementation in the UAE

5.1. Survey

5.1.1 Profile respondents

In this research, a survey is designed to determine implementation and BIM trends in the UAE. The respondents' profile is shown in Table 5-1. There were 52 responses obtained from civil engineering professionals in the UAE construction industry. Most respondents were contractors and consultants with percentages of 48.1% and 36.5% accordingly. The survey targeted local and international companies in the UAE to obtain vital information. Respondents with years of experience 11 to 20 years and more than 20 years were the highest among the survey participants. These two categories represent 77% of the survey respondents, reflecting the high-level effectiveness of the survey data obtained. The building sector was the highest sector of the survey respondents with 65.4% of the total respondents, followed by the infrastructure sector with 26.9%. Lastly, the number of projects in a typical year for the survey respondents is found to be 40.4% for larger than 20 projects per year and 42.3% for 11 to 20 projects per year, which are the highest categories among the respondents.

Table 5-1: Survey Respondents' Profile

General Information	Respondent	Number of Responses	Percentage
Type of Company	Owner/Government	2	3.8%
	Contractor	25	48.1%
	Consultant	19	36.5%
	Prefabricator	0	0%
	Construction Management Firm	3	5.8%
	Other	3	5.8%
Business Location	Local (Main Office in UAE)	37	71.2%
	International (Main office outside UAE)	15	28.8%
Years of Experience	<5	4	7.7%
	5 to 10	8	15.4%
	11 to 20	20	38.5%
	>25	20	38.5%
Industry Sector	Buildings	34	65.4%
	Infrastructure	14	26.9%
	Industrial	2	3.8%
	Other	2	3.8%
Size of Projects	<50M AED	2	3.8%
	50M to 200M AED	13	25%

	200M to 500M AED	23	44.2%
	>500M	14	26.9%
Number of Projects in a Typical Year	<5	1	1.9%
	5 to 10	8	15.4%
	11 to 20	22	42.3%
	>20	21	40.4%

5.1.2 BIM implementation trend in the UAE

According to the survey, 7.7% percent of the respondents' companies used BIM for the first time in the period of 2000 to 2005, while 28.8% used it from 2006 to 2010, with a percentage increase of 21% between the two periods. In 2011-2015, the percentage of respondents who declared that the first time their companies used BIM was 38.5%, resulting in the highest period where companies started using BIM for the first time, as shown in Figure 5-1. The percentage increase between the period of 2011-2015 and 2006-2010 is 9.7% which is less than the percentage increase in the periods 2000-2005 and 2006-2010 that has a percentage increase of 21%. Overall, this indicates that BIM implementation in the UAE construction projects has increased from 2000 to now.

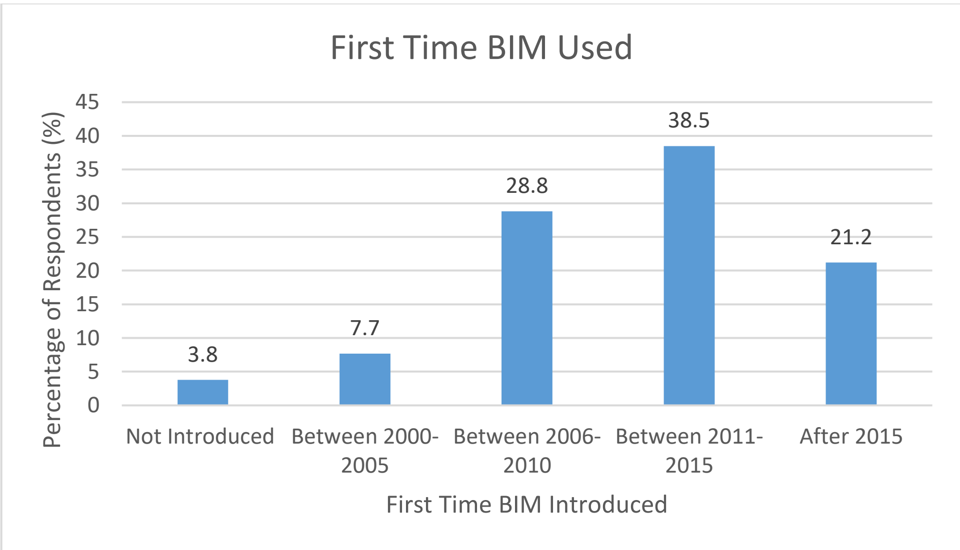


Figure 5-1: First Time BIM Used

Furthermore, it is found that 57.7% of the respondents have declared that they use BIM when required contractually only, while 19.5% of the respondents use BIM in all their projects, as shown in Figure 5-2. On the other hand, 19.2% of the respondents only use BIM in large projects, while 3.8% only do not use BIM in their projects. Even though no one has indicated the option of using BIM in prefabricated projects only, this means they are using BIM but not exclusively for prefabrication work. This reflects that the BIM implementation in the UAE is usually due to the stated requirement in the contract to use BIM. It could be a requirement from the municipality, as is the case in the Dubai Municipality, or a requirement from the owner or the designer to ensure efficient and smooth work and tractability.

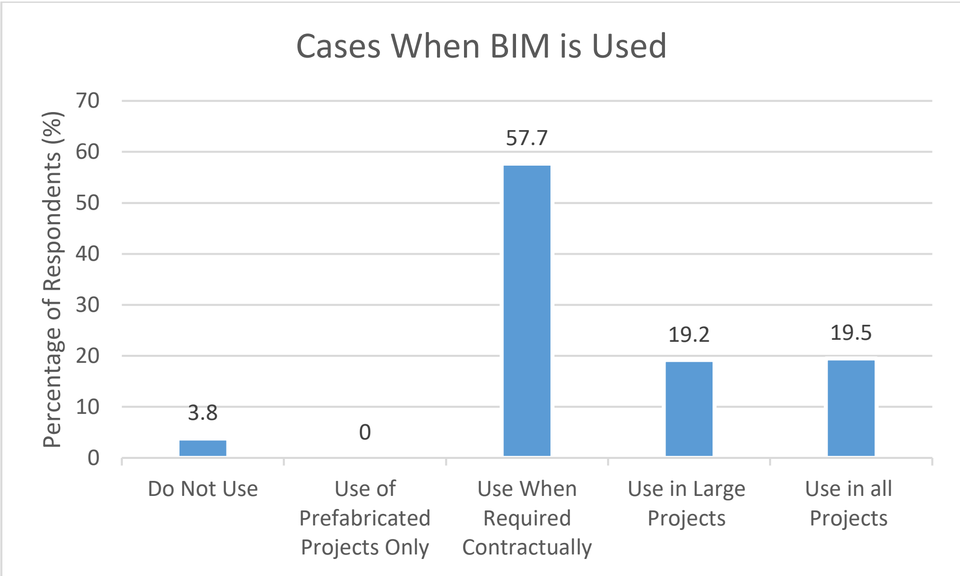


Figure 5-2: Cases When BIM is Used in UAE

The survey respondents were asked to indicate the extent of BIM implementation in their companies' projects, as shown in Figure 5-3. 37% of the respondents indicated that 51% to 75% of their projects use BIM, while 31% indicated that more than 75% of their projects are using BIM. Only 4% of the respondents indicated no implementation of BIM in their projects. A lower boundary percentage and an upper boundary percentage were calculated for each group of the five groups of the responses. For instance, for the range of 25% to 50%, the lower boundary result assumes that the percentage of respondents who chose this range implements BIM in 25% of their current projects, while the upper boundary assumes 50% implementation in their projects. The percentage of respondents, 23%, is multiplied by the boundaries, 25% and 50%. The same procedure is applied to the other ranges. Then the sum is calculated for each boundary, as mentioned in Table 5-2. Hence, the level of implementation of BIM in the respondents' current projects is concluded to be at least 48%, but not more than 72%. This range of BIM implementation indicates that the UAE construction industry is currently experiencing a good level of BIM implementation.

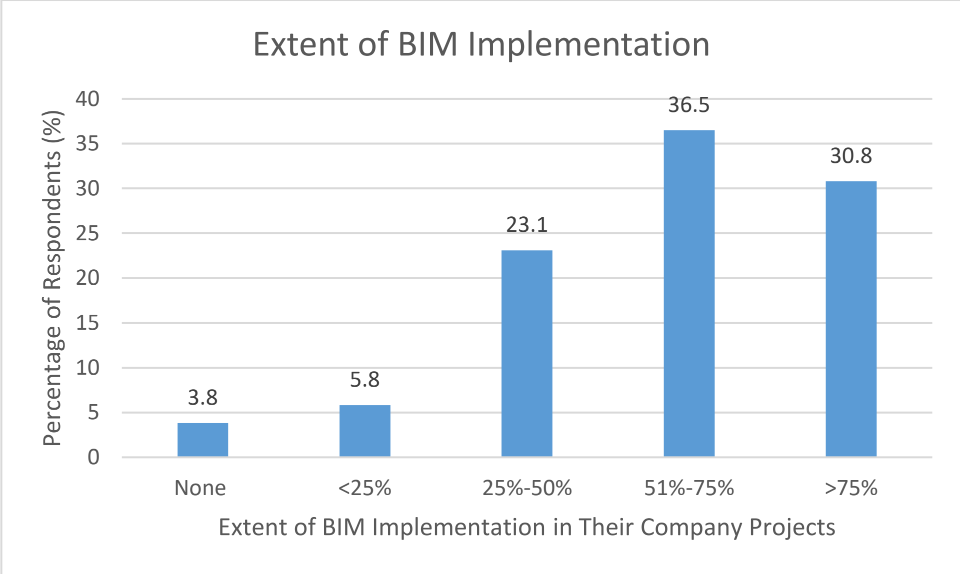


Figure 5-3: Extent of BIM Implementation

Table 5-2: Lower and Upper Boundary of BIM Extent of Implementation

	%	L.B (%)	U.B (%)
None	3.8	0	0
<25%	5.8	0.058	1.392
25%-50%	23.1	5.775	11.550
51%-75%	36.5	18.615	27.375
>75%	30.8	23.408	30.800
SUM	100	47.856	71.117

The survey has also revealed the percentage increase of BIM use in the last five years, presented in Figure 5-4. More than half of the respondents have indicated a percentage increase of more than 50% implementation. To illustrate, 33% of the respondents have indicated a 51% to 75% increase in BIM implementation in the past 5 years, while 28.8% indicated a more than 75% increase in the implementation. A lower boundary percentage and an upper boundary percentage were calculated for each group of the five groups of the responses. Then the sum is calculated for each boundary, as mentioned in Table 5-3. Hence, the percentage increase of BIM implementation over the past five years is at least 45%, but not more than 67%. This indicates that the BIM implementation in increased over the last five years.

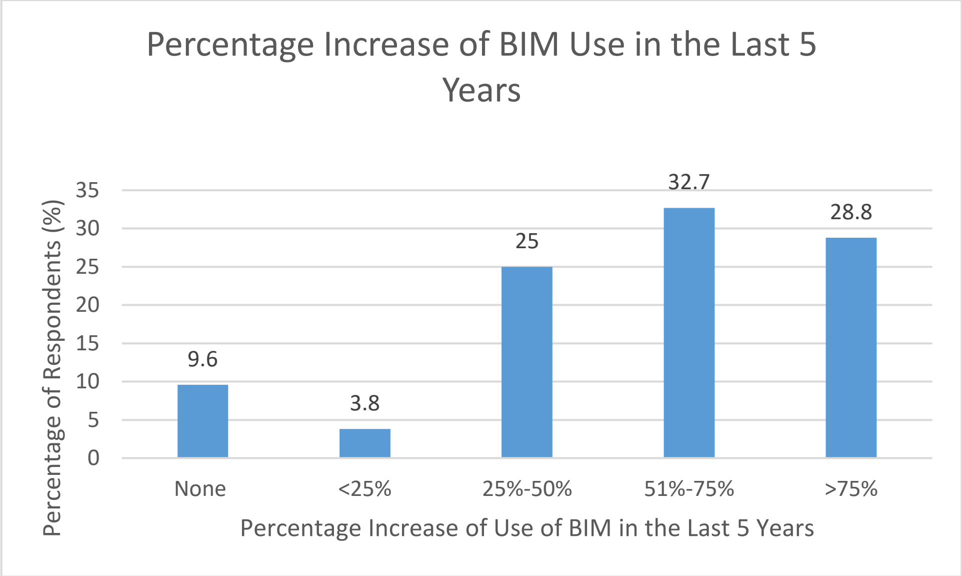


Figure 5-4: Percentage Increase of BIM Use in the Last 5 Years

Table 5-3: Lower and Upper Boundary of the Percentage Increase of BIM Use in the Last 5 Years

	%	**L.B (%)**	**U.B (%)**
None	9.6	0	0
<25%	3.8	0.038	0.912
25%-50%	25	6.250	12.500
51%-75%	32.7	16.677	24.525
>75%	28.8	21.888	28.800
SUM	100	44.853	66.737

5.1.3 Prefabrication implementation in the UAE

The UAE construction industry has recently witnessed an increase in the implementation of prefabricated construction. According to the survey respondents, 73% indicated the range of 25% to 50% of their current projects implements prefabrication. This was found to be the highest range of implementation indicated by the survey respondents, followed by 33% respondents for less than 25% of prefabrication work to their total projects. However, only 6% of the respondents have indicated a current percentage of prefabrication work larger than 75%, which is considered very small, as shown in Figure 5-5. A lower boundary percentage and an upper boundary percentage were calculated for each group of the five groups of the responses. Then the sum is calculated for each boundary, as mentioned in Table 5-4. According to the survey results, the level of implementation of prefabrication in the respondents' current projects is at least 23%, but not more than 45%. This percentage is not considered high, indicating that the level of implementation of prefabricated construction in the UAE requires more enhancement than in other countries like Sweden.

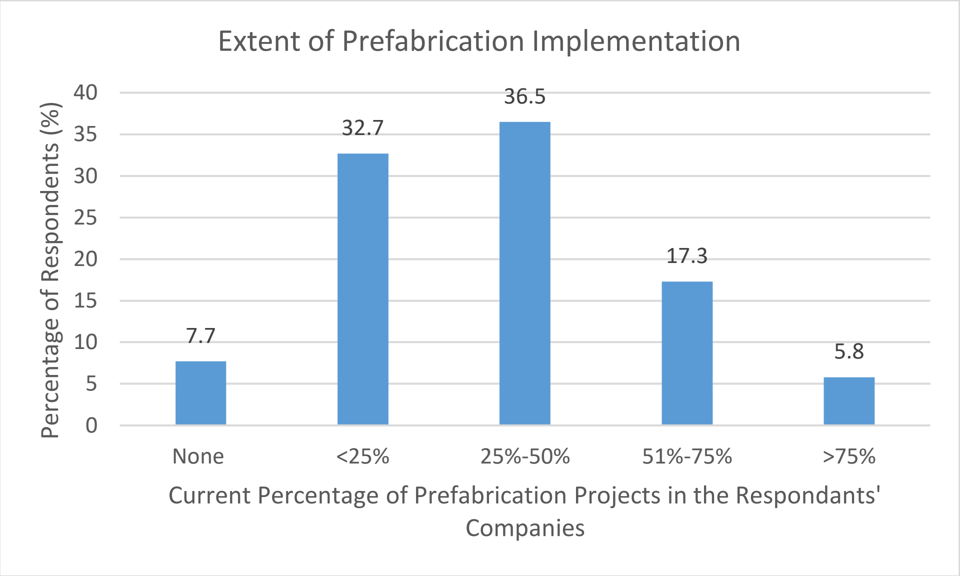


Figure 5-5: Extent of Prefabrication Implementation

Table 5-4: Lower and Upper Boundary of Prefabrication Implementation

	%	**L.B (%)**	**U.B (%)**
None	7.7	0	0
<25%	32.7	0.327	7.848
25%-50%	36.5	9.125	18.25
51%-75%	17.3	8.823	12.975
>75%	5.8	4.408	5.8
SUM	100	22.683	44.873

The respondents were also asked to indicate the percentage increase of prefabrication work in their companies over the past five years. The results are presented in Figure 5-

6. The highest percentage increase found is less than 25%, according to 37% of the respondents. This was followed by a 25% to 50% percent increase according to 26.9%. However, only 6% of the respondents experience more than 75% increase in their prefabrication work. This strongly indicates that the level of increase of prefabrication work in the UAE is still not high enough.

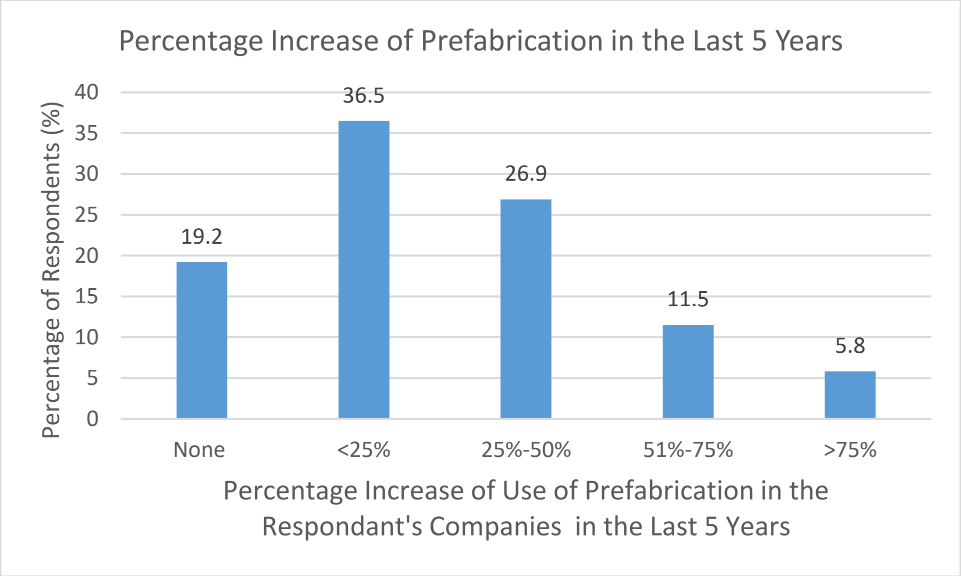


Figure 5-6: Percentage Increase of Prefabrication in the Last 5 Years

5.1.4 Use of BIM with prefabrication work in the UAE

According to this research survey, only 27% of the respondents always use BIM with their prefabrication work, and 25% of them indicated that they often use BIM with their prefabrication work. However, half of the respondents sometimes, rarely, and never use BIM with prefabrication work, clearly seen in Figure 5-7. This indicates insufficient implementation of BIM with prefabrication work in the UAE construction industry. The respondents were also asked to indicate whether using BIM with their prefabrication work has enhanced/increased their prefabrication work, and the results are presented in Figure 5-8. 31% of the respondents strongly agree that using BIM with their prefabrication work has enhanced/increased their prefabrication work, while 48% of the respondents agree. Hence, around 80% of the respondents agree and prove that using BIM with prefabrication has enhanced/increased their prefabrication work. This qualitative result can play a major role in convincing the UAE construction industry professionals regarding the benefits of using BIM with prefabrication.

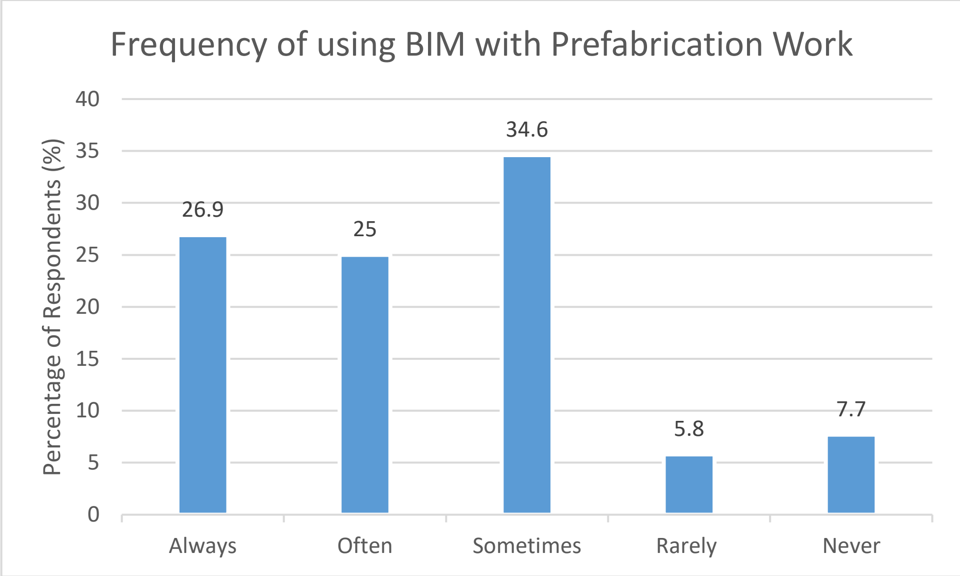


Figure 5-7: Frequency of Using BIM with Prefabrication Work

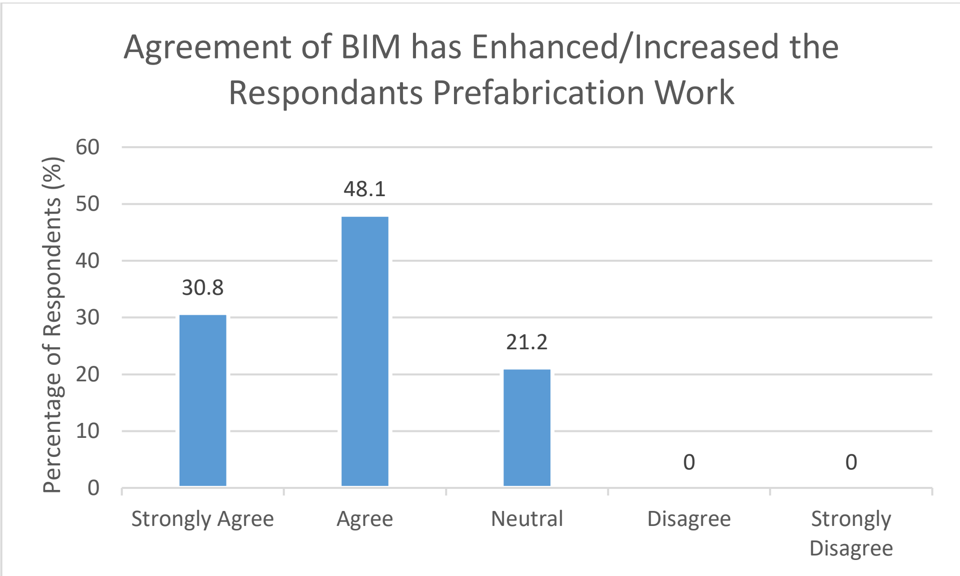


Figure 5-8: BIM Enhanced/Increased the Respondents' Prefabrication Work

5.1.5 Requirements of prefabricated construction

According to the literature, five primary requirements of prefabricated construction that BIM can enhance were identified. Then, their levels of importance were verified through the survey. The responses of the 52 survey participants are shown in Table 5-5. The survey verification questions used a five-point Likert scale of 1 to 5 to assess the significance of each of the factors. The meaning of each point scale is as follows:

1 = Strongly Disagree

2 = Disagree

3 = Neutral

4 = Agree

5 = Strongly Agree

- Relative Importance Index (RII) = $\frac{5n5+4n4+3n3+2n2+1n1}{5N}$ (1)

  where: n5 refers to the number respondents of Strongly Agree

  n4 refers to the number respondents of Agree

  n3 refers to the number respondents of Neutral

  n2 refers to the number respondents of Disagree

  n1 refers to the number respondents Strongly Disagree

  N refers to the total number respondents

Table 5-5: Prefabrication Requirement Results

Prefabrication Requirements	Rating				
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Coordinating onsite and offsite schedules	32	18	1	1	0
Coordination during the design phase due to low flexibility for design changes later	26	18	8	0	0
Extensive need of high quality shop drawings	23	20	9	0	0
High initial cost typically incurred in prefabricated construction	12	32	7	1	0
Increased transportation and logistics requirements	12	31	7	2	0

The results obtained from the RII analysis of the survey results, presented in Table 5-6, rank the prefabricated construction requirements according to their importance. The RII number of the five prefabrication requirements ranges between 0.8 and 0.91, close to 1. This indicates high relative importance for the five prefabrication requirements.

Table 5-6: Ranked Prefabricated Construction Requirements

Prefabrication Requirements	Total Respondents (N)	Weighted Total	RII	Rank
Coordinating onsite and offsite schedules	52	237	0.91	1
Coordination during the design phase due to low flexibility for design changes later	52	226	0.87	2

Extensive need of high quality shop drawings	52	222	0.85	3
High initial cost typically incurred in prefabricated construction	52	211	0.81	4
Increased transportation and logistics requirements	52	209	0.80	5

5.1.6 BIM features used in prefabricated construction

According to the literature, five main BIM features used in prefabrication were identified. The questionnaire was adopted by applying a five-point Likert scale of 1 to 5 to assess the effectiveness of each BIM feature. Then, their levels of effectiveness were verified through the survey. The responses of the 52 survey participants are shown in Table 5-7.

Table 5-7: BIM Features Results

BIM Features	**Rating**				
	Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
3D Modelling "Structure Representation" for visualization and communication	27	18	7	0	0
4D Modelling "Schedule Representation" to combine project schedule with BIM	20	24	8	0	0
5D Modelling "Cost Modelling" to integrate quantity takeoff and cost estimates with BIM	14	29	9	0	0
Identify clash detection in the project through early involvement of project's key participants	32	14	6	0	0
Generation of shop drawings for prefabricated components	31	16	5	0	0

The results obtained from the RII analysis of the survey results are presented in Table 5-8, which ranks the BIM features used in prefabricated construction according to their effectiveness. The RII number of the 5 BIM features ranges between 0.82 and 0.90, close to 1. This indicates a high level of effectiveness for the 5 BIM features.

Table 5-8: Ranked BIM Features

BIM Features	Total Respondents (N)	Weighted Total	RII	Rank
3D Modelling “Structure Representation” for visualization and communication	52	228	0.88	2
4D Modelling “Schedule Representation” to combine project schedule with BIM	52	220	0.85	3
5D Modelling “Cost Modelling” to integrate quantity takeoff and cost estimates with BIM	52	213	0.82	4
Identify clash detection in the project through early involvement of project’s key participants	52	234	0.90	1
Generation of shop drawings for prefabricated components	52	234	0.90	1

5.1.7 Effect of using BIM in prefabricated construction on cost, time, quality, and safety objectives of prefabricated construction

This research is screening the effect of using BIM with prefabricated construction on prefabricated construction cost, time, quality, and safety objectives. In this research survey, the 52 respondents were asked to indicate the effect of using BIM in prefabricated construction qualitatively on cost, time, quality, and safety objectives of prefabricated construction. The survey results are presented in Table 5-9.

Table 5-9: Prefabrication Construction Objectives Results

Objectives of Prefabricated Construction	Rating				
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Cost	18	25	7	2	0
Time	28	16	7	1	0
Quality	25	16	11	0	0
Safety	14	29	9	0	0

The results obtained from the survey results' RII analysis are presented in Table 5-10. It ranks the objectives of prefabricated construction according to the level of being affected by using BIM qualitatively. The RII number of the four success factors ranges between 0.82 and 0.87, close to 1. This indicates that the four success factors of prefabrication are highly affected using BIM. According to this survey, time is the most affected factor when using BIM, followed by quality, cost, and safety.

Table 5-10: Ranked Prefabrication Construction Objectives

Objectives of Prefabricated Construction	Total Respondents (N)	Weighted Total	RII	Rank
Cost	52	215	0.83	3
Time	52	227	0.87	1
Quality	52	222	0.85	2
Safety	52	213	0.82	4

5.2. Interviews

5.2.1 BIM features – prefabrication requirements relationships

After obtaining the approval of the Institutional Review Board (IRB) at AUS, ten experienced civil engineering industry professionals in the UAE who have previously implemented BIM in their prefabrication work have been interviewed. The interviews were used to establish relationships between the verified BIM features and the prefabrication requirement. The profile of the interviewees is presented in Table 5-11. The average years of experience of the interviewees is 25 years, and the sample standard deviation is 5.6 years. In fact, finding experienced people in the UAE construction field who have implemented BIM in their prefabrication work and are willing to participate in the research interviews was considered challenging. It resulted in having only 10 participants who met the interview requirements and were willing to participate.

Table 5-11: Interviewee List Profile

Interviewee #	Company Type	Years of Experience
Interviewee 1	Contractor	25
Interviewee 2	Consultant	18
Interviewee 3	Consultant	30
Interviewee 4	Contractor	20
Interviewee 5	Contractor	28
Interviewee 6	Consultant	30
Interviewee 7	Contractor	30
Interviewee 8	Consultant	25
Interviewee 9	Contractor	30
Interviewee 10	Consultant	15

- Average years of Experience = $\frac{25+18+30+20+28+30+30+25+30+15}{10}$ = 25.1 years
- Sample Standard Deviation = $\sqrt{\frac{\sum(xi-\mu)^2}{n-1}}$ (2)
    - where: xi is the years of experience of interviewee i

μ is the mean (average)

n is the total number of interviewees

$$\text{Sample Standard Deviation} = \sqrt{\frac{\sum(25-25.1)^2+\cdots+(15-25.1)^2}{10-1}} = 5.6 \text{ years}$$

The ten interviewees were asked each of the 5 BIM features separately in which whether it could enhance each prefabrication requirement or not. Then, the aggregated responses were calculated for each prefabrication requirement according to each BIM feature. The results are:

1- The BIM feature: 3D Modelling “Structure Representation” for visualization, communication and collaboration in data can enhance:

Table 5-12: 3D Modelling-Prefabrication Requirement

Prefabrication Requirement	Yes Responses	Percentage Agreement
Coordinating onsite and offsite schedules	4/10	40%
Coordination during the design phase due to low flexibility for design changes later	10/10	100%
Extensive need of high quality shop drawings	2/10	20%
High initial cost typically incurred in prefabricated construction	1/10	10%
Increased transportation and logistics requirements	7/10	70%

2- The BIM feature: 4D Modelling “Schedule Representation” to combine project schedule with BIM can enhance:

Table 5-13: 4D Modelling-Prefabrication Requirement

Prefabrication Requirement	Yes Responses	Percentage Agreement
Coordinating onsite and offsite schedules	10/10	100%
Coordination during the design phase due to low flexibility for design changes later	1/10	10%
Extensive need of high quality shop drawings	0/10	0%
High initial cost typically incurred in prefabricated construction	2/10	20%
Increased transportation and logistics requirements	9/10	90%

3- The BIM feature: 5D “Cost Modelling” to integrate quantity takeoff and cost estimates with BIM can enhance:

Table 5-14: 5D Modelling-Prefabrication Requirement

Prefabrication Requirement	Yes Responses	Percentage Agreement
Coordinating onsite and offsite schedules	0/10	0%
Coordination during the design phase due to low flexibility for design changes later	7/10	50%
Extensive need of high quality shop drawings	0/10	0%
High initial cost typically incurred in prefabricated construction	8/10	80%
Increased transportation and logistics requirements	7/10	70%

4- The BIM feature: Identify clash detection in the project through early involvement of project’s key participants can enhance:

Table 5-15: Clash Detection-Prefabrication Requirement

Prefabrication Requirement	Yes Responses	Percentage Agreement
Coordinating onsite and offsite schedules	0/10	0%
Coordination during the design phase due to low flexibility for design changes later	10/10	100%
Extensive need of high quality shop drawings	1/10	10%
High initial cost typically incurred in prefabricated construction	2/10	20%
Increased transportation and logistics requirements	0/10	0%

5- The BIM feature: Generation of shop drawings for prefabricated components can enhance:

Table 5-16: Generation of Shop Drawings-Prefabrication Requirement

Prefabrication Requirement	Yes Responses	Percentage Agreement
Coordinating onsite and offsite schedules	0/10	0%
Coordination during the design phase due to low flexibility for design changes later	3/10	30%

Extensive need of high quality shop drawings	10/10	100%
High initial cost typically incurred in prefabricated construction	7/10	70%
Increased transportation and logistics requirements	1/10	10%

Then, the BIM feature-Prefabrication Requirement relationships that have obtained a percentage agreement of 70% and above were considered effective relationships. This is because they have a high percentage agreement among the ten experienced industry professionals who previously implemented BIM with their prefabrication work. Hence, the final BIM feature-Prefabrication Requirement relationships are presented in Table 5-17. These relationships are used to create proposed action steps for the UAE industry professionals to increase the level of implementation of prefabricated construction in the UAE according to cost, time, quality, and safety objectives.

Table 5-17: BIM Features – Prefabricated Construction Relationships

#	BIM Features	Prefabrication Requirements
1	The use of 3D Modelling "Structure Representation" feature for visualization, communication, and collaboration in data	Coordination during the design phase due to low flexibility for design changes later
		Increased transportation and logistics requirements
2	The use of 4D Modelling "Schedule Representation" feature to combine project schedule with BIM	Coordinating onsite and offsite schedules
		Increased transportation and logistics requirements
3	The use of 5D Modelling "Cost Modelling" feature to integrate quantity takeoff and cost estimates with BIM	High initial cost typically incurred in prefabricated construction
		Increased transportation and logistics requirements
4	The use of early clash detection feature in the project design phase	Coordination during the design phase due to low flexibility for design changes later
5	The use of generation of shop drawings feature for prefabricated components	Extensive need of high quality shop drawings
		High initial cost typically incurred in prefabricated construction

5.2.2 Effects of BIM in enhancing prefabricated construction requirements on cost, time, quality, and safety objectives of prefabricated construction.

The interviewees were also asked to determine the effect of enhancing each of the five prefabrication requirements on prefabricated construction's cost, time, quality, and safety objectives. Then, the aggregated responses were calculated for each success criteria according to each of the five prefabrication requirements. The results are:

Table 5-18: Agreement with "Yes"

Prefabrication Requirement	Success Criteria			
	Cost	**Time**	**Quality**	**Safety**
Coordinating onsite and offsite schedules	10/10	10/10	1/10	7/10
Coordination during the design phase due to low flexibility for design changes later	10/10	9/10	9/10	0/10
Extensive need of high quality shop drawings	8/10	9/10	10/10	1/10
High initial cost typically incurred in prefabricated construction	10/10	1/10	0/10	0/10
Increased transportation and logistics requirements	9/10	10/10	0/10	8/10

Table 5-19: Percentage Agreement with "Yes"

Prefabrication Requirement	Success Criteria			
	Cost	**Time**	**Quality**	**Safety**
Coordinating onsite and offsite schedules	100%	100%	10%	70%
Coordination during the design phase due to low flexibility for design changes later	100%	90%	90%	0%
Extensive need of high quality shop drawings	80%	90%	100%	10%
High initial cost typically incurred in prefabricated construction	100%	10%	0%	0%
Increased transportation and logistics requirements	90%	100%	0%	80%

Then, the impacts that obtained a 70% agreement and above were considered valid. This is because they have a high percentage agreement among the ten experienced industry professionals who previously implemented BIM with their prefabrication work. Hence, the final effect of enhancing each of the five prefabrication requirements on cost, time, quality, and safety objectives of prefabricated construction is presented in Table 5-20.

Table 5-20: Effects of Enhancing Prefabricated Construction Requirements on Cost, Time, Quality, and Safety Objectives of Prefabricated Construction

Prefabrication Requirement	**Success Criteria**			
	Cost	**Time**	**Quality**	**Safety**
Coordinating onsite and offsite schedules	✓	✓		✓
Coordination during the design phase due to low flexibility for design changes later	✓	✓	✓	
Extensive need of high quality shop drawings	✓	✓	✓	
High initial cost typically incurred in prefabricated construction	✓			
Increased transportation and logistics requirements	✓	✓		✓

5.2.3 General observations about Use of BIM with prefabrication work

The interviewees were asked general questions to obtain an overview about the use of BIM with prefabrication work in which the aggregated responses are mentioned below:

5.2.3.1. Uses of BIM with prefabrication

BIM is usually used in complicated projects in which simple 2D CAD is not enough to present the overlapping details, such as for connections of different elements. The use of BIM requires the consultant and contractors to be aware of BIM and use it professionally and fluently.

5.2.3.2. Benefits of using BIM in all prefabrication projects

The effect of BIM becomes more tangible in prefabricated construction when the amount of prefabricated work in the project increases. When multiple elements or systems of prefabricated work are used in the project, it requires more design work and coordination in the design phase to ensure workflow. It also requires additional planning on the production timing of the several elements and their exact timing to reach the project site. The precision of installation becomes an essential issue for connecting these elements, which associate more risk for time and cost of the project. Safety of workers and site accidents become more critical when multiple operations work on site. Cranes' work interference becomes another issue when multiple prefabricated elements require proper site operation planning.

5.2.3.3. Percentage improvement for using BIM with prefabrication on cost, time, quality, and safety

The effect of BIM on prefabrication in terms of cost, time, quality, and safety cannot be unified as a percentage, and they vary from one project to another due to several aspects:

- Percentage of prefabrication work in the project.
- Project Conditions.
- Level of personal knowledge of BIM for all project key participants, which is different.
- Some features like distance of factory to site.
- Number of stakeholders associated with the project.
- Outside events like shortage of funding, weather conditions, and change orders from the owner.

Moreover, giving estimates to the parameters of cost, time, quality, and safety cannot be estimated for each requirement or BIM feature. The parameters' results are integrated with the whole project and cannot be evaluated separately. Moreover, these parameters are usually estimated at the end of the project for the entire project, including parts that are not prefabricated.

5.2.3.4. Obstacles against the use of BIM with prefabrication

The obstacles are not regarding the use of BIM with prefab. It is about the use of BIM in general in all projects:

- High learning cost for the staff for BIM.
- Require all project team from both consultants and contractors to have powerful knowledge about how to use BIM fluently (ex: as same as AutoCAD).
- Not cost-effective for small projects.
- Lack of knowledge of BIM for other stakeholders, which make communication harder and complex.
- Resistance to change from some project stakeholders if not specified in the contract.

- Lack of awareness of BIM benefits.

5.2.3.5. *Prefabrication work increase due to more investment in BIM*

- It will allow for having more complex prefabrication work. For instance, it will allow several prefabrication systems to incorporate together in the same project without worrying about the design complexities, complex site planning of work and sequencing, and communication with pre-fabricators and their issues.
- It will reduce the risk associated with exceeding the project schedule and budget due to the complexity of the prefabrication work.
- It will allow for more prefabrication, which means more benefits for construction than traditional construction. This means reduced project duration and cost, higher quality of work fabricated in the factories, and fewer safety issues in the construction site.

5.2.3.6. *Effects of BIM on prefabrication time*

- Increase in productivity:
    - Easier design process.
    - Easier installation process and site coordination.
    - Easier Prefabrication process.
    - On-time delivery of prefabricated components.
    - Less site inspection process.
- Reduction of rework:
    - Precise sizes of prefabrication component with less incorrect geometry produced and fewer rejections of elements on site.
    - Precise sizes of prefabrication component with less incorrect geometry produced and fewer rejections of elements on the prefabrication factory.
- Reduction in change orders:
    - High-quality design with fewer design errors which means fewer change orders.
- Early clash detection in the design phase:

    - Less construction work interruption that is due to interference between systems and elements such as structural elements with MEP systems.
- Reduction of risk associated with project delay due to work complexity:
    - This is through having the complex work being done and executed as scheduled, without activities interference or interruption, and according to the required sequence.

5.2.3.7. Effects of BIM on prefabrication cost

- Cost saved from increasing productivity.
- Cost saved from the reduction of rework.
- Cost saved from the reduction in change orders.
- Waste reduction cost:
    - Material tracking due to special coordination prior construction.
- Cost saved from the automatic shop drawing production for prefabricated components:
    - Due to saving in time of preparing the shop drawing of prefabricated components.
    - Due to fewer error encountered with manual creation of prefabrication shop drawings.
- Cost saved from having a more economical and optimized design:
    - Easier creation of multiple designs for prefabricated components with different design parameters such as strength, length, and weight.
    - More suitable prefabrication design for the transportation limitations available means fewer extra action steps to transport prefabrication components.

5.2.3.8. Effects of BIM on prefabrication quality

- Early Clash Detection in the Design Phase:
    - Less construction work interruption that is due to interference between systems and elements such as structural elements with MEP systems.

- Reduction in the number of RFI during construction and manufacturing from contractors, subcontractors, and pre-fabricators:
    - Higher quality of design with design fewer errors and interference between systems.
    - Detailed 3D model available to view the details of the structure.
    - High-quality shop drawings for prefabrication components with accurate detailing.

5.2.3.9. Effects of BIM on prefabrication safety

- Reduce reported labor injuries onsite:
    - Having health and safety planning with animation through BIM, which can provide visualization, simulation, virtual prototyping, and validation.
    - BIM allows previewing a series of potential scenarios of site operation before the construction phase in which helps the design and planning team to mitigate any risk of accidents it may happen.
- Reduce reported accidents without injuries:
    - BIM allows previewing a series of potential scenarios of site operation before the construction phase in which helps the design and planning team to mitigate any risk of accidents it may happen.

5.2.3.10. Interviews with pre-fabricators

Pre-fabricators were not involved primarily in this research since the decision to use BIM in a prefabrication project is for the consultant and the contractor. Contractors and consultants are the main key participants of the project where they do the entire project design, planning, and execution. Also, they bear the entire responsibility and risk of the project. However, the pre-fabricators receive the quantity, sizes, and specifications of prefabrication components for production. According to 6 interviews with well-known concrete and steel pre-fabricators in the UAE, the following information where obtained:

- They usually do not use BIM
- They use 2D AutoCAD drawings for simplicity because most precast manufacturing products are simple such as simple beams, columns, and wall panels.

- BIM is used when the precast components to be manufactured are complicated. For instance, BIM is used when having complicated connections to be produced and having multiple unique elements to be produced and connected. In this case, they use TEKLA or Revit.
- They are usually provided with the BIM files by the main contractor for their design review and production actions.
- It is considered expensive in terms of cost and time to implement BIM in simple prefabrication work that can be accomplished with regular 2D AutoCAD drawings except for complicated prefabrication work.

Chapter 6. Case Study

6.1. Dubai Future Museum

The Dubai Future Museum case study is a project with extensive prefabrication work, and BIM was implemented heavily throughout all the project stages, especially for the prefabrication work. The case study information was obtained with the aid of the project director from the consultant firm Buro Happold whose name is Engineer Tobias Bauly.

6.1.1 Project Description

- Location: Dubai's Trade Centre on Sheikh Zayed Road
- Architecture design: Killa Designs (Engineer Sean Keila)
- Principal Consultant: Buro Happold Engineering Consultancy
- Principal Contractor: BAM International
- Steel Fabricator: Eversendai L.L.C
- Total Project Cost: $ 136 Million
- Total Project Duration: 6 Years approximately
- General Information:
  - Pillar-less Building.
  - 7 Story, 77m height and 30000 m^2 area, Facade area is 17600 m^2 consist of 1024 robot made pieces.
  - Has 14000 m^2 of lightening calligraphy.
  - The structure is a concrete structure from the basement to the top that supports a steel diagrid structure up to Level 7, with composite concrete floor slabs.
  - 2400 diagonally intersecting steel members used to develop the steel diagrid.

6.1.2 Objectives of the Project

- The primary inspiration of this project is to create a form that represents the client's vision of the future - dynamic and innovative, where the torus shape of the building captures the perpetual energy of the city.
- It will be an active space for innovations and an exhibition space showcasing futuristic concepts, services, and products for the cities, health care, and transportation.

Figure 6-1: Dubai Future Museum [56]

Figure 6-2: Dubai Future Museum under Construction [57]

6.1.3 Why BIM is Used in the Project

- Complex structure geometry.

- Precise interface requirements with various trade-off processes of prefabricated work such as structural steel elements, façade systems, and MEP systems.
- Maintain all required work with available budget and time according to the quality and safety standards.

6.1.4 BIM software Used

Table 6-1: BIM Software Used in Dubai Future Museum Project

#	BIM Software	Uses
1	Autodesk Revit	Coordinate all data inputs such as 2D CAD and produce unified project deliverables
2	Autodesk Dynamo Studio	Create visual logic to explore parametric conceptual designs and automate tasks
3	Autodesk Navisworks	For 5D project scheduling
4	Autodesk Robot Structural Analysis Professional	For structural analysis and code compliance
5	Autodesk 3DS Max	For 3D animation
6	Tekla BIM Sight	For 3D model and data collaboration

6.1.5 BIM Features Used

1- 3D Modeling “Structure Representation” for visualization and communication.

- Used to support coordination and collaboration in the design and construction phases.
  - Structural design.
  - MEP design.
  - Façade systems.
  - Logistics work.
  - Health and safety planning with animation.
  - Decision making through rendering and walkthrough.
- Used to compare as-built drawings with the 3D model.
- Used for visualization to have efficient engineering and construction process.

2- 4D Modeling “Schedule Representation” to combine project schedule with BIM.

- Used to schedule the supply of prefabrication work (steel structure elements and facade panels) according to their sequence of erection.
- Used to manage and plan transportation and site restrictions.

- Used for quality control inspections routines.

3- 5D "Cost Modeling" to integrate quantity takeoff and cost estimates with BIM.
   - Used for decision-making in the design phase for the tradeoff process of the structural steel element sizes to reduce the prefabrication cost.

4- Identify clash detection in the project through early involvement of project's key participants.
   - Used with the 3D model, it allowed the design team to work in one single space to work through the challenges and conflicts resulting from the clash detection feature.
     - Check element by element for the interference of the steel structure members, facade system, and MEP system due to low flexibility for design changes later.
     - This pushed the creation of parametric scripts for steel structure members system, facade system, and MEP system.

5- Generation of shop drawings for prefabricated components
   - Used for better coordination for pre-fabricators
   - Used for steel connections design
   - Used to generate workshop fabrication drawings for the fabrication process of the structural steel elements and facade panels.
   - Used for erection and installation engineering studies

To verify the BIM features and prefabrication requirements obtained in this research, the BIM features and their corresponding prefabrication requirements used in this project are matched with the five prefabrication requirements of this research. For instance, Table 6-2 shows that the project stakeholders used the 4D modelling feature to schedule the supply of prefabrication work, manage and plan transportation and site restrictions, and plan quality control inspections routines. These three prefabrication requirements refer to the coordinating onsite and offsite schedules requirement and the increased transportation and logistics requirements, which were the only two prefabrication requirements identified in the relationships table for the 4D modelling feature.

Table 6-2: Verification of BIM Features-Prefabrication Requirements Relationships

BIM Features used in the Project	Prefabrication Uses in the Project	Prefabrication Requirements
3D Modelling	Used for coordination in Structural design, MEP design, Façade systems, Logistics work, health, and safety planning with animation	Coordination during the design Phase/Increased transportation and logistics requirements
	Used to compare as-built drawings with the 3D model.	Coordination during the design Phase
	Used for visualization to have efficient engineering and construction process.	Coordination during the design Phase
4D Modelling	Used to schedule the supply of prefabrication work (steel structure elements and facade panels) according to their sequence of erection.	Coordinating onsite and offsite schedules
	Used to manage and plan transportation and site restrictions.	Increased transportation and logistics requirements
	Used for planning quality control inspections routines.	Coordinating onsite and offsite schedules
5D Modelling	Used for decision-making in the design phase for the structural steel element sizes trade-off process to reduce the prefabrication cost.	High initial cost typically incurred in prefabricated construction/Increased transportation and logistics requirements
Clash Detection	The 3D model allowed the design team to work in one single space to work through the challenges and conflicts resulting from the clash detection feature.	Coordination during the design phase
Generation of shop drawings	Used for better coordination for prefabricators	Extensive need of high quality shop drawings
	Used for steel connections design	Extensive need of high quality shop drawings
	Used to generate workshop fabrication drawings for fabrication process of the structural steel elements and facade panels.	Extensive need of high quality shop drawings/ High initial cost typically incurred in prefabricated construction
	Used for erection and installation engineering studies	Extensive need of high quality shop drawings

6.1.6 BIM Effect on Time, Cost, Quality, and Safety Objectives of Prefabrication Construction

The percentages obtained below for the four objectives of prefabricated construction are with respect to another project that roughly has the exact size of this project, quantity and complexity of prefabrication work, project limitations, and geographical location. However, the implementation of BIM in the compared project was minimal and negligible. Hence, the difference between the two projects is considered the use of BIM.

1- Time:

- Increase in productivity: **50%**
- Reduction in site rework: **65%**
- Reduction in clash detection: **70% to 80%** in clashes that occur on site within MEP installation and Structure elements.
- Reduction in change orders: **50%**
- Reduction in project schedule: **10%,** however it significantly reduced the risk of the program extending.

2- Cost:

- Cost Saved from increasing productivity.
- Cost Saved from reduction of rework.
- Cost saved from reduction in change orders.
- Cost saved waste reduction:
    - Steelwork waste reduction: **50%**
    - MEP work waste reduction: **25%**
    - Concrete work: **Not significant**
- Reduction in shop drawing production Cost: **25%**
- Reduction in total construction cost: **10% to 20%**
- Cost saved from having more economical and optimized design.

3- Quality:

- For Diagrid steelwork, digital working and computational engineering avoided any required change in element sizing during the fabrication stage, and hence there were no rejections of elements on-site and no incorrect geometry produced.
- Reduction in RFI: **50%**

4- Safety:

- Reduction in Reported Injuries and Accidents (Human): **25%**
- Reduction in Reported Accidents and Defects without injuries: **25%**

Chapter 7. Summary of Findings

7.1. BIM and Prefabrication Implementation in the UAE

The UAE construction industry is witnessing an increase in BIM implementation in its projects. According to this research survey, the percentage increase in BIM use in the last five years among the UAE professional industry participants is roughly estimated to be between 45% and 67%. Furthermore, the percentage of their projects that currently use BIM can be roughly estimated to be between 48% and 71%. However, prefabrication in the UAE is not witnessing a high-level implementation in the UAE projects. According to the same survey results, the current percentage of prefabrication work in the UAE is roughly estimated to be between 23% and 45%. Also, more than half of the survey respondents are experiencing increased prefabrication work less than 25% over the past five years. Moreover, more than half of the survey respondents have indicated that they sometimes, rarely, or never use BIM with prefabrication work which is a key indicator of the low implementation of BIM with prefabrication work in the UAE. Hence, the UAE construction industry requires further actions to increase its prefabrication work, which can be attained using BIM.

7.2. Effect of BIM on Prefabrication Success Criteria

The use of BIM with prefabrication has considerable impacts on the cost, time, quality, and safety objectives of prefabricated construction. The survey results proved that the use of BIM with prefabrication enhances these four success criteria of prefabricated construction with a percentage agreement of more than 80%, according to the UAE construction industry professionals who participated in the survey. Furthermore, according to the global case studies obtained from literature, BIM can lead to cost savings in prefabricated construction up to 20% of the prefabrication work cost and quality improvement up to 50% through the reduction in numbers of RFI. From the obtained UAE Dubai Future Museum case study, the use of BIM with prefabrication can lead to time savings of up to 10% of the project schedule. This is in addition to the significant impact on reducing the risk of the program extending of prefabrication projects that are usually prone to this issue. Moreover, the case study has proved that using BIM with prefabrication can increase the safety levels up to 25% in terms of reported injuries and accidents without injuries.

According to the interview results, relationships between, BIM features, prefabrication requirements, and success criteria are created in Table 7-1.

Table 7-1: BIM Features-Prefabrication Requirements-Success Criteria Framework

#	**BIM Features**	**Prefabrication Requirements**	**Success Criteria**			
			Cost	**Time**	**Quality**	**Safety**
1	The use of 3D Modelling “Structure Representation” feature for visualization, communication, and collaboration in data	Coordination during the design phase due to low flexibility for design changes later	✓	✓	✓	
		Increased transportation and logistics requirements	✓	✓		✓
2	The use of 4D Modelling “Schedule Representation” feature to combine project schedule with BIM	Coordinating onsite and offsite schedules	✓	✓		✓
		Increased transportation and logistics requirements	✓	✓		✓
3	The use of 5D Modelling “Cost Modelling” feature to integrate quantity takeoff and cost estimates with BIM	High initial cost typically incurred in prefabricated construction	✓			
		Increased transportation and logistics requirements	✓	✓		✓
4	The use of early clash detection feature in the project design phase	Coordination during the design phase due to low flexibility for design changes later	✓	✓	✓	
5	The use of generation of shop drawings feature for prefabricated components	Extensive need of high quality shop drawings	✓	✓	✓	
		High initial cost typically incurred in prefabricated construction	✓			

7.3. Proposed Action Steps

According to the results obtained in table 34, the following action steps are proposed to the UAE construction industry to increase the level of implementation of prefabricated construction:

1- In order to enhance the **cost** associated with prefabricated construction, the construction stakeholders should concentrate and invest more in the following BIM features:

- Use 3D Modelling "Structure Representation" feature for visualization, communication, and collaboration in data for better coordination during the design phase.
- Use 3D Modelling "Structure Representation" feature for visualization, communication, and collaboration in data for dealing with transportation and logistics requirements.
- Use 4D Modelling "Schedule Representation" feature to coordinate onsite and offsite schedules.
- Use 4D Modelling "Schedule Representation" feature to combine project schedule with BIM for better planning of transportation and logistics requirements.
- Use 5D Modelling "Cost Modelling" feature to integrate quantity takeoff and cost estimates with BIM to reduce the high initial cost incurred in prefabricated construction.
- Use 5D Modelling "Cost Modelling" feature to integrate quantity takeoff and cost estimates with BIM for dealing with transportation and logistics requirements.
- Use early clash detection feature in the project design phase for better coordination during the design phase.
- Use generation of shop drawings feature for prefabricated components to produce high quality shop drawings.
- Use generation of shop drawings feature for prefabricated components to reduce the high initial cost incurred in prefabricated construction, shop drawing cost.

2- In order to enhance the **time** associated with prefabricated construction, the following stakeholders should concentrate and invest more on the following BIM features:

- Use 3D Modelling “Structure Representation” feature for visualization, communication, and collaboration in data for better coordination during the design phase.
- Use 3D Modelling “Structure Representation” feature for visualization, communication, and collaboration in data for dealing with transportation and logistics requirements.
- Use 4D Modelling “Schedule Representation” feature to coordinate onsite and offsite schedules.
- Use 4D Modelling “Schedule Representation” feature to combine project schedule with BIM for better planning of transportation and logistics requirements.
- Use 5D Modelling “Cost Modelling” feature to integrate quantity takeoff and cost estimates with BIM for dealing with transportation and logistics requirements.
- Use early clash detection feature in the project design phase for better coordination during the design phase.
- Use generation of shop drawings feature for prefabricated components to produce high quality shop drawings.

3- In order to enhance the **quality** associated with prefabricated construction, the following stakeholders should concentrate and invest more on the following BIM features:

- Use 3D Modelling “Structure Representation” feature for visualization, communication, and collaboration in data for better coordination during the design phase.
- Use early clash detection feature in the project design phase for better coordination during the design phase.
- Use generation of shop drawings feature for prefabricated components to produce high quality shop drawings.

4- In order to enhance the **safety** associated with prefabricated construction, the following stakeholders should concentrate and invest more on the following BIM features:

- Use 3D Modelling “Structure Representation” feature for visualization, communication, and collaboration in data for dealing with transportation and logistics requirements.
- Use 4D Modelling “Schedule Representation” feature to coordinate onsite and offsite schedules.
- Use 4D Modelling “Schedule Representation” feature to combine project schedule with BIM for better planning of transportation and logistics requirements.
- Use 5D Modelling “Cost Modelling” feature to integrate quantity takeoff and cost estimates with BIM for dealing with transportation and logistics requirements.

Chapter 8. Conclusion and Future Work

In conclusion, the increase in using BIM in construction projects, especially in prefabrication projects, has enhanced prefabrication work by reducing some of its barriers and constraints of implementation in large-scale work. It also enhanced the cost, time, quality, and safety objectives of prefabrication construction. The use of BIM in construction projects in the UAE is increasing nowadays, but it is slower than in other countries such as Sweden and UK. This can be due to the inadequate top management support on BIM adoption, high cost associated with BIM adoption, and lack of knowledge on BIM benefits to projects and organizations. However, the implementation of prefabricated construction in the UAE is not high as it should be. Half of the survey participants of the UAE construction industry professionals have indicated sometimes, rarely, and never use BIM with prefabrication work, and only 27% of them use BIM in all their prefabrication work. Hence, if the UAE construction industry professionals implement BIM in their prefabrication work, considering the BIM features/prefabrication requirements relationships obtained in this research, the number of prefabrication projects will also increase. Finally, this research is intended to increase the knowledge of the UAE construction industry about the benefits of prefabrication, BIM role in enhancing major requirements and barriers of the prefabrication construction with an actual UAE construction case study, and propose action steps for the UAE construction industry to enhance and increase the implementation of prefabricated construction. This research also is considered a starting point for the researchers to show the effect of BIM in prefabrication through establishing valid relations between BIM features and prefabrication requirements.

As future work, the BIM Feature-Prefabrication requirement relationships could be distributed to UAE construction professionals who have implemented BIM with prefabrication work to verify whether the created relationships have helped them enhance or increase their prefabrication work. Furthermore, future research shall include the effect of project delivery methods on BIM in prefabrication work since the effect will differ from one type to another. Moreover, the impact of using BIM in prefabricated construction can be addressed from a sustainability perspective since suitability is a critical and essential success factor nowadays in construction projects. Finally, after having a high level of implementation of prefabricated construction in the

UAE, analysis of using BIM in prefabricated construction can be categorized according to the project stakeholders’ background such as owner, consultant, and contractor.

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Vita

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