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The implementation of building information modeling (BIM) towards sustainable construction industry in Egypt "The pre-construction phase"

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THE IMPLEMENTATION OF BUILDING INFORMATION MODELING (BIM) TOWARDS SUSTAINABLE CONSTRUCTION INDUSTRY IN EGYPT

"THE PRE-CONSTRUCTION PHASE"

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DEDICATION

This thesis is dedicated to everyone who believed in me and pushed me through the trials and frustrations I went through for creating this research. My parents, who offered endless love and support throughout this process and were always there for help. My sister, who always found a way to raise my spirits when I became overwhelmed during the hard times. Finally, my brothers who always encourage me.

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ABSTRACT

Global environmental changes, energy consumption, and the scarcity of water have all imposed the need to implement sustainable development strategies worldwide. The construction industry and its healthy practices are not exception, as it should take more strides to alleviate harmful impacts of unsustainable construction practices on the built environment. Sustainable construction has many aspects such as passive design, selection of the appropriate materials and construction techniques, energy efficient systems, and water conservation. In Egypt, current situation regarding energy consumption, accelerated urbanization, and high pollution rates are urging the Architecture, Engineering, and Construction (AEC) professionals to convert current conventional construction approaches into more sustainable ones. One of the useful in this regard is to capitalize on technological innovative means to narrow the gap and advance the sustainable green construction mission. Building Information Modeling (BIM) is a relatively recent technology within the construction industry that, when properly introduced, can help in providing adequate project quality, accurate time and quantity take-offs schedules, and project costs reduction. For instance, this tool can result in more efficient design practices, which contribute to reducing waste generation, energy consumption and promote passive design strategies.

This study aims at analyzing the impact of BIM implementation on the sustainable construction practices and assessing current BIM implementation trends during the design process phase in the AEC industry. In principle, the study tackles BIM adoption situation factors of influencing and the barriers, and opportunities confronting its implementation within the Egyptian consultancy firms. Building on the literature review, this study discusses the sustainable design and constructability concepts in the construction industry and the manner by which BIM can be effectively utilized the pre-construction phase. Furthermore, the study describes the BIM implementation obstacles, success factors, and the role of government and other stakeholders in adopting BIM for achieving sustainable construction industry. To meet this objective, interviews were conducted with BIM experts to investigate the BIM implementation situation in the Egyptian consultancy firms and needed actions for successful BIM adoption in the Egyptian construction market.

The academic knowledge with the interviews provide the researcher with the base to articulate the ideas and develops the discussion to figure out the critical issues regarding BIM adoption in Egypt. In this manner, the research provides some recommendations for successful BIM adoption in the Egyptian construction industry. In addition, the study recommended adopting BIM as the technological pillar towards sustainable construction industry in the country's 2030 sustainable development strategy. The research also encourages the collaboration between the construction industry stakeholders to set a roadmap for adopting BIM in the Egyptian construction industry. Finally, build on the literature and the experts' opinions, the research recommended practical actions for the industry players to ensure a successful transition towards BIM implementation.

Key words: Building Information Modeling, (BIM), BIM adoption, Sustainable Strategies, Benefits, Risks and Challenges.

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CHAPTER 1 : INTRODUCTION

1.1 Research background

A fact that cannot be denied, human activities have a substantial impact on climate change such as ice melting, increasing sea level, changing weather conditions, water scarcity, and the damages of the tropical forests causing the greenhouse effect and greenhouse gas emissions (Bampou, 2016). Moreover, with the rapid construction industry development, buildings are estimated to double by the year 2030 creating a greater energy demand. In addition, the International Energy Agency (IEA) forecasts the growth in energy demand 30% by the year 2030 which will cause an increase in the energy consumption rates, especially in the developing countries (Bampou, 2016).

The construction industry is a significant industry that contributes to the socio-economic growth, especially in the developing countries. Furthermore, the construction industry is the main contributor to the unsustainable development worldwide. For instance, the industry consumes 40% of the total energy production, 40% of all of the raw materials, and 25% of all the timber production worldwide. In addition, the construction industry is responsible for 16% of the total water consumption and 35% of the CO_2 emissions (Son, Kim, Chong, & Chou, 2011).

According to the "World population prospects" United Nation report, Egypt is ranked from the 15th most populous countries in the world with over than 90 million people (Nation, world population prospects, 2015) which means that Egypt has an extremely high urban population. This high population reflected on an increasing energy demand. For instance, 26% of the energy consumed in Egypt consumed in the built environment (Figure 1-1), 62% of the total electricity production consumed in residential, commercial, and public services buildings (Figure 1-2), and about 70% of the country CO_2 emissions come from urban areas (Raslan & Mavrogianni, 2013). Furthermore, the residential building is responsible for 23% of the energy consumption and 47% of the electricity consumption (Raslan & Mavrogianni, 2013). Recently, the demand for energy in the residential sector is increasing due to the rise in using electrical equipment which makes the residential buildings the highest electricity consumer in the Egyptian market (Hopkins & Mehanna, 2003).

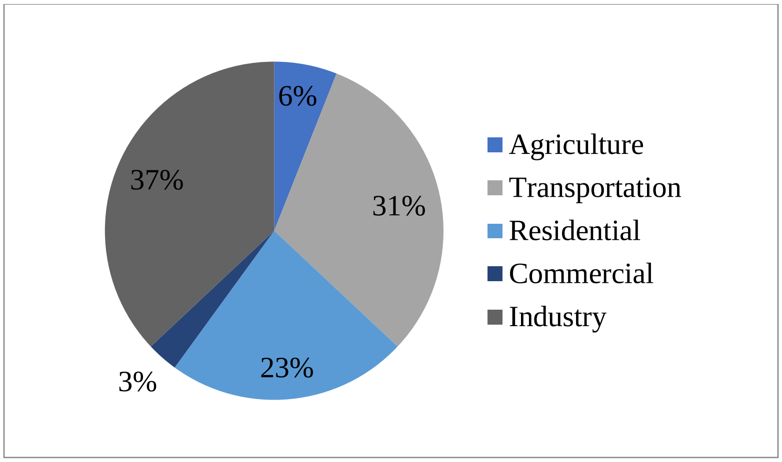


Figure 1-1: Energy consumption by sector in Egypt (Raslan & Mavrogianni, 2013)

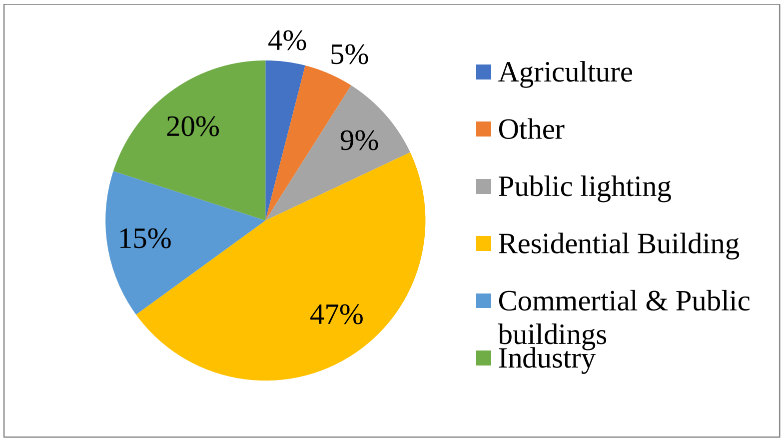


Figure 1-2: Electricity consumption by sector in Egypt (Raslan & Mavrogianni, 2013)

In addition, Egypt is suffering from serious environmental pollution problems like air pollution, solid and liquid waste, hazardous materials, high noise level, and harmful chemicals and pesticides. These problems cause diseases like schistosomiasis and microbiological diseases (Hopkins & Mehanna, 2003) that makes offering a safe and healthy environment for the people a vital issue that should be considered by the construction decision makers.

Globally, the construction sector forms a large part of the Gross National Product (GNP) and consumes 40% of the world's energy resources. In Egypt, the Egyptian construction sector constitutes to 25% of the GNP and 4.7% of the country Gross Domestic Product (GDP) at 2001 / 2002 (Hopkins & Mehanna, 2003).

There is an increasing recognition in the word that with the unsustainable consumption practices, the earth cannot keep absorbing the peoples' harmful impact on the environment for a long time. Since the construction industry has a significant economic, social, and environmental impact, the relationship between sustainable development and construction industry vital for saving the environment. As improving the construction practices become essential to minimize the construction industry detrimental effects on the natural environment (Sev, 2009).

Sustainability can be achieved only through the efforts of everyone involved in the construction industry. Furthermore, sustainability must be incorporated into the entire lifecycle of a construction project to make a significant impact starting from the concept phase up to the operation phase where different environmental, social, and economic considerations appear (Son, Kim, Chong, & Chou, 2011).

In 2004, the National Research Council (NRC) that focuses on providing the strategy for advancing the competitiveness, efficiency, and the productivity of the U.S. construction industry conducted a study to investigate the gap between the building industry and IT. This study found that the interoperable technology applications or Building Information Modeling (BIM) is not only a solution but also the most promising technology to improve the quality, timeliness, cost-effectiveness, and the sustainability of the construction projects. BIM is a process to improve and maintain an integrated digital representation of information through the different phases of the building lifecycle. In addition, BIM can create, document, coordinate, update, and manage information about each particular facility and components in the building through powerful data modeling capabilities forming a major change in the construction industry worldwide (Matarneh & Hamed, 2017).

1.2 Research motivation

Egypt is suffering from a rapid population growth, increasing demand on energy, water sacristy, high pollution rate, unsustainable economic growth, unbridled utilization of natural resources, industrialization, and unsustainable development. These problems led to environmental destructions and economic losses. Despite the importance of the construction industry for the Egyptian economy, most of the construction projects are mismanaged incurring much delay, cost escalation, and quality shortfall (Abu El-Matty & Akal, 2017). The main aspects of this study are the need for sustainable construction industry practices in Egypt, and the need for an innovative technology to eliminate the construction sector problems.

1.3 Research objectives

The main goal of the study is to investigate the situation of BIM implementation and the use of the technology towards sustainable construction industry in Egypt. Under this goal, the following objectives investigated.

1- The BIM sustainable practices within the AEC consultancy firms.
2- How BIM is implemented in the consultancy firms and used as a tool for sustainable practices in different countries.
3- BIM adoption situation and processes in Egyptian consultancy firms.
4- Figure the needed actions to organize and enhance the BIM adoption in the Egyptian construction sector.

1.4 Research methodology

The research followed the social science research technique. The literature review and interviews were found to be the most appropriate approach for the research nature. The inductive "down-up" approach is adopted for this research as the kind of the research is a learning process research that encourages the progress of the research from specific to general.

An extensive literature review of relevant articles was conducted to build a strong understanding of the history, development, practices, tools, barriers, challenges and future of sustainable construction design and BIM implementation.

The gathered data from the literature review used to develop qualitative interview questions for data collection from the field. The linear snowball sampling technique was used to reach the targeted population, as it was difficult to reach samples. The data was collected by over phone interviews with BIM and sustainable design experts from the Egyptian design consultancy firms to identify the BIM practices in their firms and the difficulties they faced in the implementation process. In addition to the benefits, they have gained from the implementation. These interviews added in-depth understanding of the current BIM implementation practices in Egypt and the future actions needed for a successful implementation and encourage the use of the BIM technology for achieving sustainable buildings. SWOT analysis was developed to identify strengths and weaknesses, as well as opportunities and threats regarding the BIM implementation situation in Egypt.

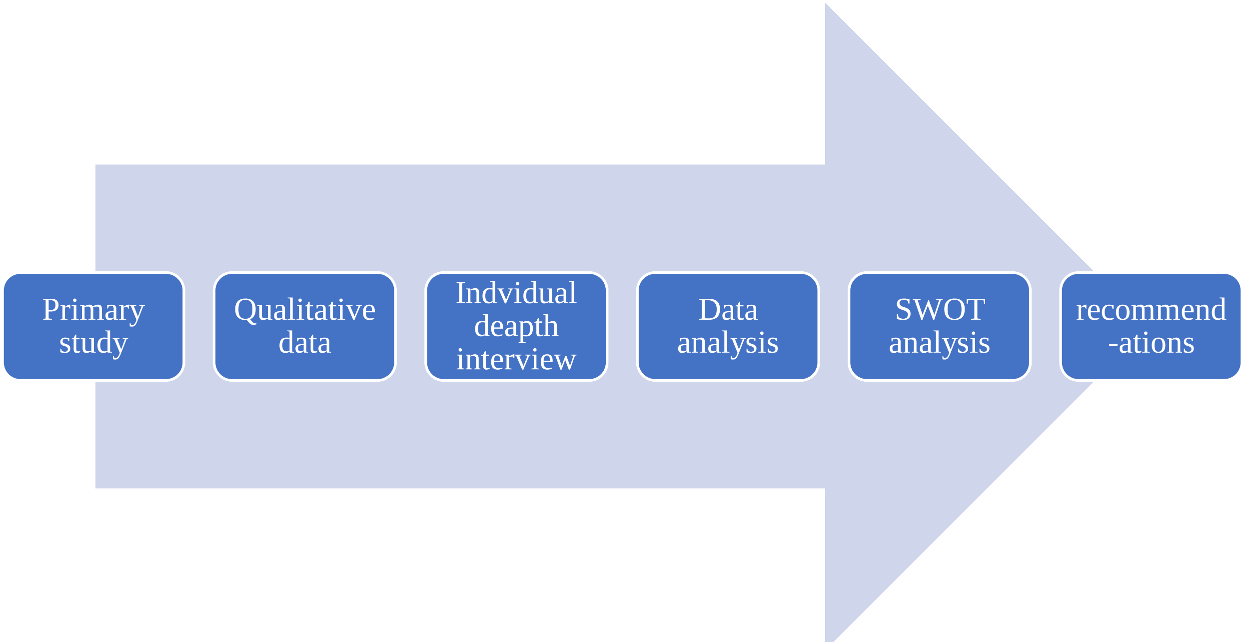


Figure 1-3: Methodology. Source: by the author

1.5 Research structure

The research is divided in to seven chapters; the structure of the chapters is as the following:

Chapter 1 entails the introduction to inform the reader by the research background, motivation, objectives, and methodology.

Chapter 2 provides a literature review on sustainable development and sustainability in construction.

Chapter 3 provides a literature review of BIM practices to form a deep understanding of the BIM concept and uses. Moreover, the chapter investigates the potential impact of BIM on sustainable construction.

Chapter 4 discusses the BIM adoption methods for organizations and countries, in addition to the BIM adoption global trends in different countries and its contribution to provide sustainable construction practices in these countries.

Chapter 5 represents the research methodology, data collection, analysis, and limitations. In addition, describes the interview questions that were conducted with BIM and sustainable buildings expertise from Egyptian consultancy firms varying in size, type, and structure.

Chapter 6 provides the overall analysis of the results stemming from the investigated data seen in the literature and interviews. The results found in this evaluation process provided answers to the research objectives.

Chapter 7 represents the research conclusion and recommendation to assist the Egyptian Government and other AEC players in a smooth switching to BIM for achieving sustainable buildings and to sustainable construction industry in Egypt. Finally, recommendations for further studies.

CHAPTER 2 : SUSTAINABLE CONSTRUCTION

2.1 Introduction

This part of the literature review discussed 1) the Sustainable development definitions and goals and the contribution that the construction industry can add to the Egyptian sustainable development strategy. 2) The sustainable construction and constructability concepts.

2.2 Sustainable development

Sustainability is a key concept in the countries' development strategies at all levels. Over the last two decades, the world began to act as a single system with common development goals that aim to accelerate the human development particularly in the poorest countries and to remove the development gross inequities with avoiding the depletion of the resources and biological systems (WCED, 1987). Sustainable development was described by the report of the World Commission on Environment and Development (WCED) as "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." The report showed that there are limits related to the ability of the biosphere to absorb the harmful effects of the human activities. Moreover, the report stated that poverty is no longer unavoidable and the technology and social parties can be managed to make a way for a new economic growth (WCED, 1987).

The sustainable development goals are aiming to maintain the social, economic, and ecological systems. These systems are linked to the people's needs for the services of the ecosystems for their wealth and security. For instance, the humanity receives many ecosystem services such as water, air, food, fuel, and others. Humans have the ability to transform the ecosystems conditions into more or less desirable ones. Unfortunately, the human actions can render the ecosystems that are unable to provide services with accepted consequences for human livelihoods, vulnerability, and security (Folke, et al., 2002).

The WCED, has given an international approval to a set of principles for sustainable development. The conference has claimed that the planet has reached a critical point of degradation in the three areas of sustainability. According to (WCED, 1987), the damage of the global soil base reduces the world's capacity for food production with the increasing populations' rates and the loss of the forests and wild lands leading to loss of biodiversity.

Although the environmental protection perspective is the origin of the sustainable development, sustainable development has moved beyond environment protection towards a broader framework to guide the human presence in the future. The three pillars: economic, social, and environmental objectives are now considered in the sustainable development (Affair, 2013). The Venn diagram shows the relation between the three pillars of sustainability Figure 2-1.

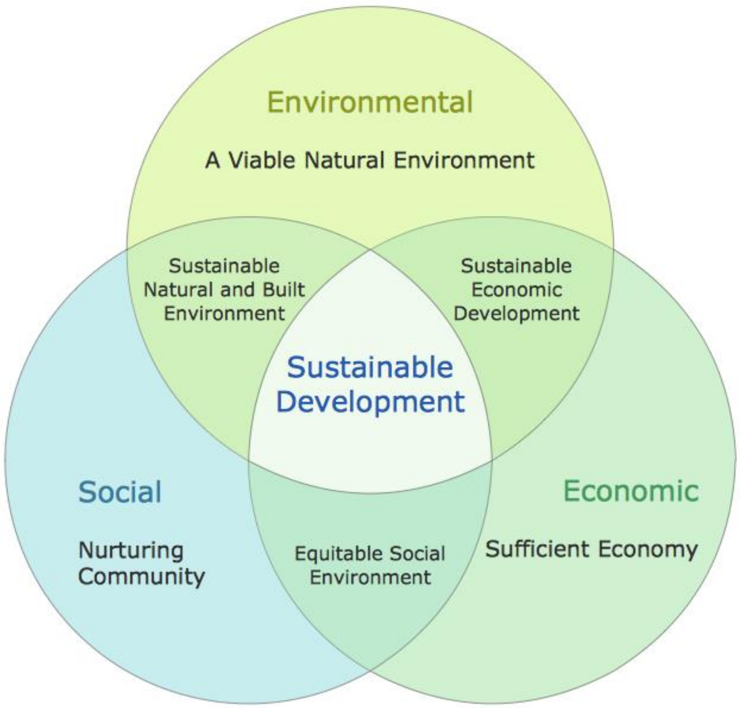


Figure 2-1: Sustainable development Venn diagram (http://www.conceptdraw.com/How-To-Guide/venn-diagram)

- **Economic sustainable development:** Sustainable development encourages the economic growth, as the environmental protection should not harm economic growth which is the foundation of national strength and social wealth. The sustainable development concerns about the quality and the quantity of the economic growth. In addition to emphasizing technology innovation, efficiency improvement, resource savings, and waste reduction (Zhang & London, 2013).

- **Environmental sustainable development:** Sustainable development states that the social and economic development should be coordinated with our the natural earth systems capacity, as neglecting the environmental aspects will eventually lead to resources depletion and hinder the development process (Zhang & London, 2013).
- **Social sustainable development:** Sustainable development is a mechanism to achieve the environmental protection and social equity. Deferent development strategies are adapted in various parts of the world aiming to achieve different goals. However, these development strategies should include the human life improvement and create a social environment that addresses equality, freedom, education, and human right.
- The sustainable development strategy settles the sustainable economic development as the base, sustainable environment development as a condition, and sustainable social development as the goal (Zhang & London, 2013).

2.2.1 Sustainable Development Goals (SDGs)

In the 2015 report "Transforming Our World," the United Nations (UN) announced a set of Sustainable Development Goals (SDGs) to guide the world development until 2030 (Nation, 2015). The SDGs are divided into 17 global goals which could eliminate poverty, inequalities, and climate change by 2030. The Sustainable Development Goals followed by the Millennium Development Goals (MDGs), each goal includes targets to explain the goals requirements and transform them into measurable and time-bound outcomes which would contribute directly to reach the goals (Nation, 2015) Figure 2-2.

Figure 2-2: Sustainable development goals (Nation, 2015)

The United Nations (UN) 2030 agenda represents an integrated approach towards sustainable development aiming to balance between the three dimensions economic, social, and environment; in addition to strengthening the connection between the goals and its targets. Accordingly, countries and the international organizations began to develop their development strategies and plans towards achieving the SDGs build on their national circumstances and the needs of each country (Gregersen, Mackie, & Torres, 2016).

2.2.2 The Egyptian sustainable development strategy 2030

Egypt has been engaged in the preparation for the 2030 agenda and will remain committed to the effective implementation of the agenda agreements. Egypt aims to end all forms of poverty, fight inequalities, and tackle climate change while ensuring that no one is left behind through applying the agenda “Egypt’s Vision 2030”. The Egyptian forward-looking strategy is span over the three dimensions of sustainable development (economic, social, and environmental). The strategy develops a framework for the broader values to guide Egypt in pursuing its developmental goals, Figure 2-3. The core of the Egyptian strategy is to possess a competitive, balanced, and diversified economy. The country plan is to depend on innovation and knowledge based on justice, social integrity, and participation to reach this aim. The needed actions should be under a balanced and diversified ecological collaboration system, investment in the creativity of places and human capital to achieve sustainable development and to improve the Egyptian citizens' life quality with the full participation of all the relevant stakeholders. The strategy also states that by 2030 Egypt will be one of the top thirty countries in the size of the economy market competitiveness, human development, quality of life, and anti-corruption areas (Ministry of Investment & International Cooperation, 2016) Figure 2-4).

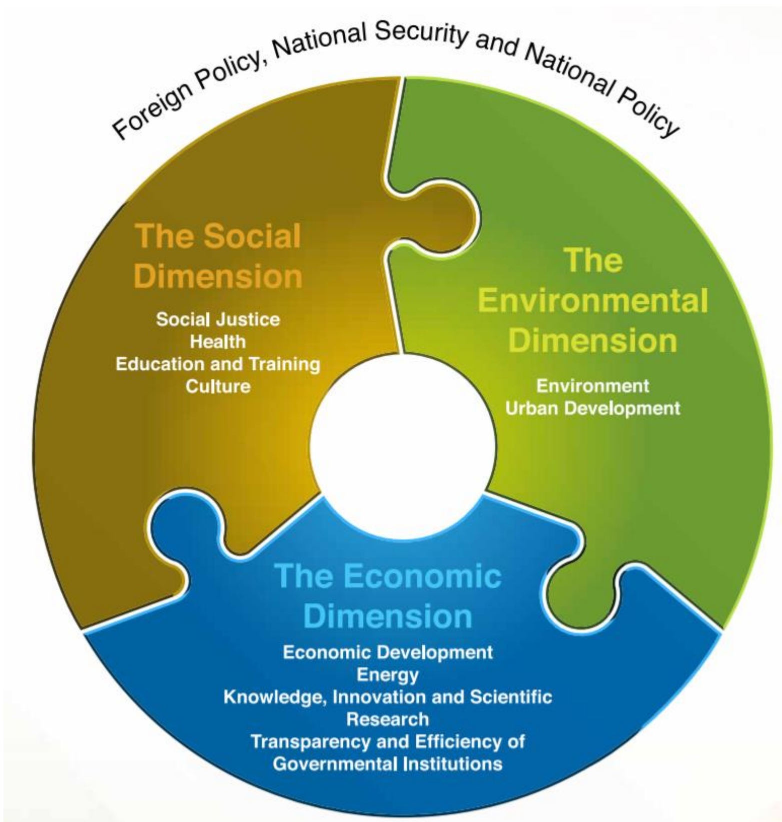


Figure 2-3: Pillars of the sustainable development strategy: Egypt Vision 2030. Source: (Ministry of Investment & International Cooperation, 2016)

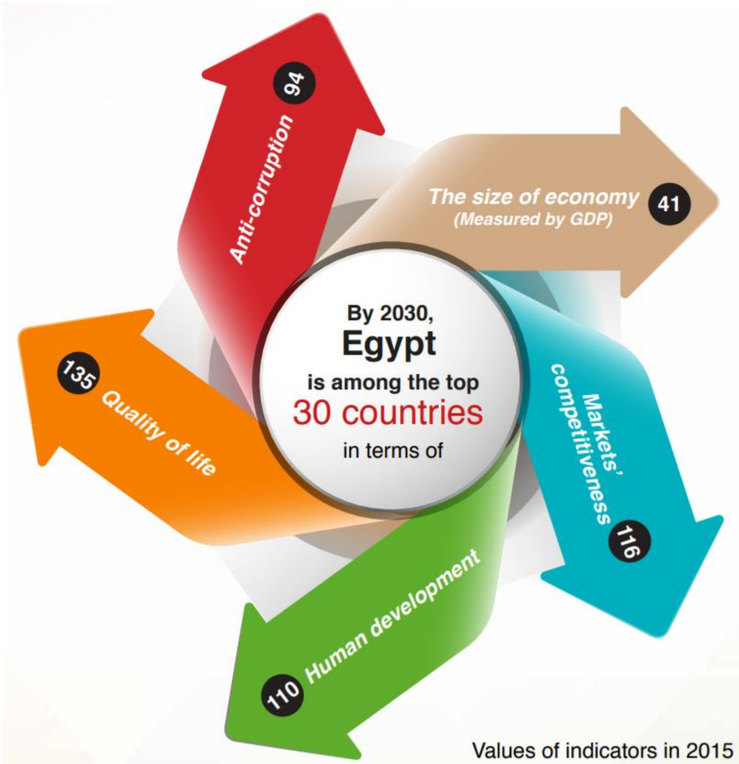


Figure 2-4: Main goals of sustainable development strategy: Egypt Vision 2030. Source: (Ministry of Investment & International Cooperation, 2016)

Nine goals out of the seventeen are matching with Egypt's sustainable development strategy in order to achieve social justice, promoting economic development, urban development, resilient infrastructure, and environmental sustainability. (Ministry of Investment & International Cooperation, 2016) Figure 2-5. The construction industry is directly contributing in five of the SDGs. The SDG 7 set environmental sustainable priority towards natural resources management, particularly on water resources where Egypt is under the global water poverty line and witnessed the reduction in the availability of renewable water. Moreover, Egypt witnessed a decrease in its air quality due to the increase in the CO_2 emissions, disintegrated application of policies and strategies, and geographical gaps. SDG 8 supports the growth of a competitive and diversified private-sector to lead an economy that is characterized by a stable macroeconomic environment, sustainable and inclusive growth, and generating decent and productive jobs. SDG 9 builds resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. SDG 11 proposes to make cities and human settlements inclusive, safe, resilient, and sustainable.

SDG 13 takes urgent actions to combat climate change and its impacts (Ministry of Investment & International Cooperation, 2016).

Figure 2-5: Nine SDGs goals that define the Egypt's sustainable development strategy. Source: (Ministry of Investment & International Cooperation, 2016)

2.3 The construction industry input

By 2056, the global economic activities will increase five times, the population will increase by over 50%, energy consumption will increase nearly three times, and manufacturing activities will increase at least three times. The construction industry is a multi-disciplinary industry that includes all of the built environment elements like infrastructure, workspaces, housing, utilities, and transportation. Also, the construction sector has a high economic impact and serious environmental and social concerns. Moreover, adding new construction to the built environment or maintaining the existing ones have numerous environmental, social, and economic impacts.

(Sev, 2009). Consequently, the construction sector is known as one of the most resource-intensive industries (Akadiri , Chinyio, & Olomolaiye, 2012).

Table 2-1 shows the impact of the construction industry on different aspects of nations' sustainable development. The table shows that the construction industry is responsible for the greenhouse gases emissions in many ways; for instance, the energy consumed for transportation, construction, material extraction, and buildings operation, maintenance, and demolition (Sorrell, 2003). Furthermore, the construction activities contribute to the loss of soil and agricultural land, this happens due to activities like the construction materials extraction and mining, the use of agriculture land for urban development, civil engineering projects, and the waste generated from the building process. In addition, construction projects contribute to wildlife and forest loss; for example, converting the land to urban land, the use of timber, bamboo, and other raw materials for the construction activities. Further, construction practices contribute in water pollution and the generation of polluted emissions like dust, fiber, particles, and toxic gases emissions from the site activities and building materials production (Spence & Mulligan, 1995). Also, the waste produced by the construction industry is between 15% to 50% of the country's waste depending on the region of construction project (Sev, 2009). Moreover, construction industry is a major consumer of the world's non-renewable energy (Spence & Mulligan, 1995). Finally, the industry is a heavy user of fusel fuel, metals, copper, and zinc and most of the energy is consumed by the construction sector is responsible for 50% of raw material consumption (Sev, 2009). It is clear that the continuous construction development in its current situation will increase the stress on environment which is already critical (Spence & Mulligan, 1995).

Sustainability is a broad concept that can reach and affect every aspect of the construction industry. The construction industry practices could adapt methods and techniques to reduce the harmful impact on the environment, economic, and social dimensions. The Kyoto Protocol in 1997 committed that developed countries have to lower their greenhouse gases emissions by 5.2% between 2008 and 2012. However, the experts believe that the greenhouse gases emissions are worse in the developing countries. Consequently, a high-performance construction with low environmental impacts is vital and the construction design firms should combine the sustainability principles at the beginning of any construction project (UNEP, 2003).

Table 2-1: Main impacts of construction industry and buildings (Sev, 2009)

	Environmental	Social	Economic
• Raw material extraction and consumption, related resource depletion	*		*
• Land use change, including clearing of existing flora	*	*	*
• Energy use and associated emissions of greenhouse gases	*		*
• Other indoor and outdoor emissions	*		*
• Aesthetic degradation		*	
• Water use and waste water generation	*		*
• Increased transport needs, depending on site	*	*	*
• Waste generation	*		*
• Opportunities for corruption		*	*
• Disruption of communities, including through inappropriate design and materials		*	*
• Health risks on worksites and for building occupants		*	*

2.4 Sustainability in construction industry

The term sustainable construction is used to define the sustainable development principles in the construction industry. In 1994, the Conseil International du Batiment (CIB) defined sustainable construction as "…creating and operating a healthy built environment based on resources efficient and ecological principles" (Al-Yami & Price , 2006). (Du Plessis, 2002) defines sustainable construction as "a holistic process aiming to restore and maintain harmony between the natural and built environments and create settlements that affirm human dignity and encourage economic equity". The framework for sustainable construction principles and strategies is shown in Figure 2-6. Since the construction industry generates environmental damages over the entire course of a project, sustainability measures should be undertaken throughout the whole construction process from the planning to the deconstruction phase and all the project's parties should be involved.

Sustainable construction can extend to four pillars: social, economic, biophysical and technical (Hill & Bowen, 1997). Sustainable construction principles that guide the decision makers throughout the whole lifecycle of a building process are resource consumption reduction, reuse resources, the use of recyclable materials, nature protection, toxins elimination, applying lifecycle costing, and emphasize quality. The sustainable construction industry aims to maintain the sustainable development principles while continuing the industry business growth (Al-Yami & Price , 2006).

As a result of the growing awareness of the importance of sustainable construction industry, buildings sustainable performance has become a vital issue for the construction professionals for multiple reasons. Some of these reasons are the growing awareness concerning the impact of construction on environmental deterioration which has also led to a number of measures such as building legislation and assessment; in addition to a number of national and regional drivers and targets (Zanni, Soetanto, & Ruikar, 2014). The most important factors about bringing sustainability are increasing the awareness of the impact of sustainable construction on the environment and the knowledge of how to deliver sustainability from the early design stage by the involvement and collaboration between all the project's stakeholders.

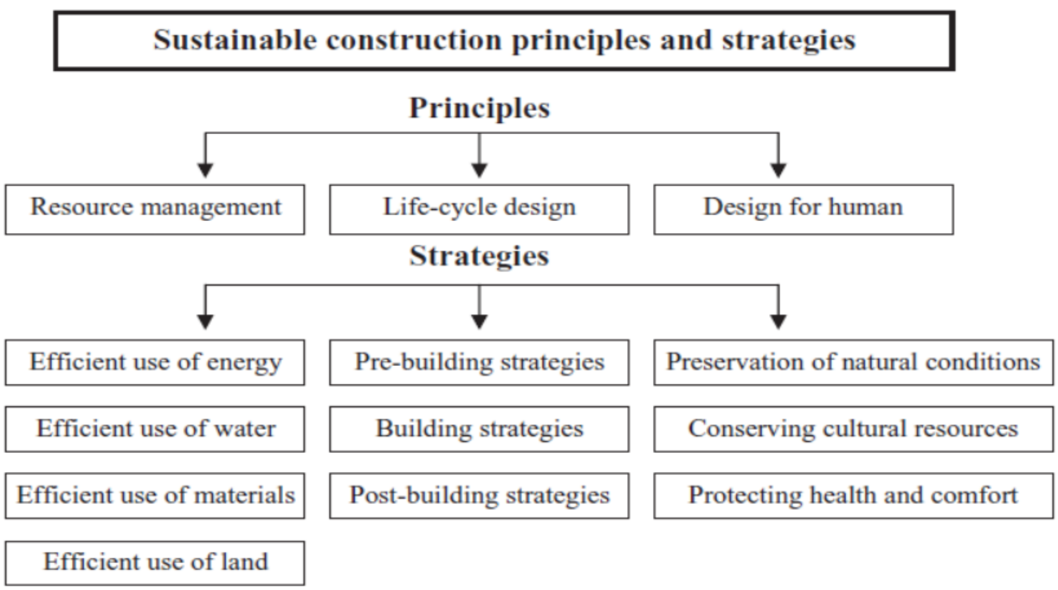


Figure 2-6: Sustainable construction concept and strategies (Sev, 2009)

Traditional design and construction focus on enhancing the cost, time, performance and quality of the construction project. The sustainable construction adds to these objectives, the minimization of resource depletion, environmental degradation, and creating a healthy built environment. (Hussin, Abdul Rahman, & Memon, 2013). Figure 2-7 shows the integration between the traditional construction objectives and the sustainable construction objective in global context.

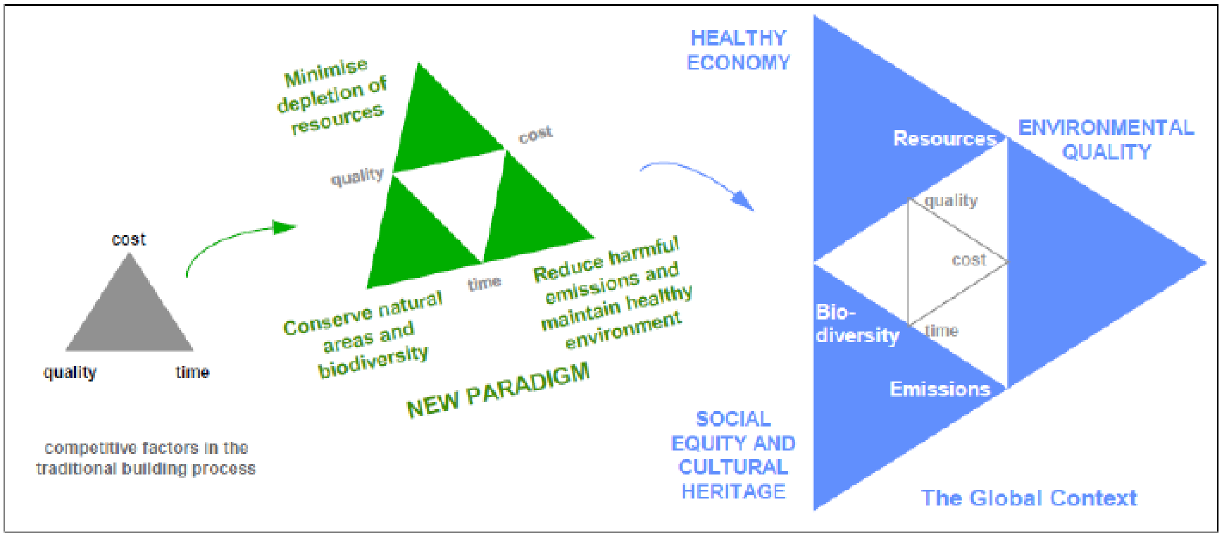


Figure 2-7: Sustainable construction in a global context (Hussin, Abdul Rahman, & Memon, 2013)

2.5 Construction project pre-construction stage

Nemours people involved in any construction project to fulfill the client's requirements where the project construction process can be divided into three main stages: pre-construction, construction, and post-construction (Kazi, 2005). Figure 2-8 shows the construction project process focusing on the research domain "per-construction stage"

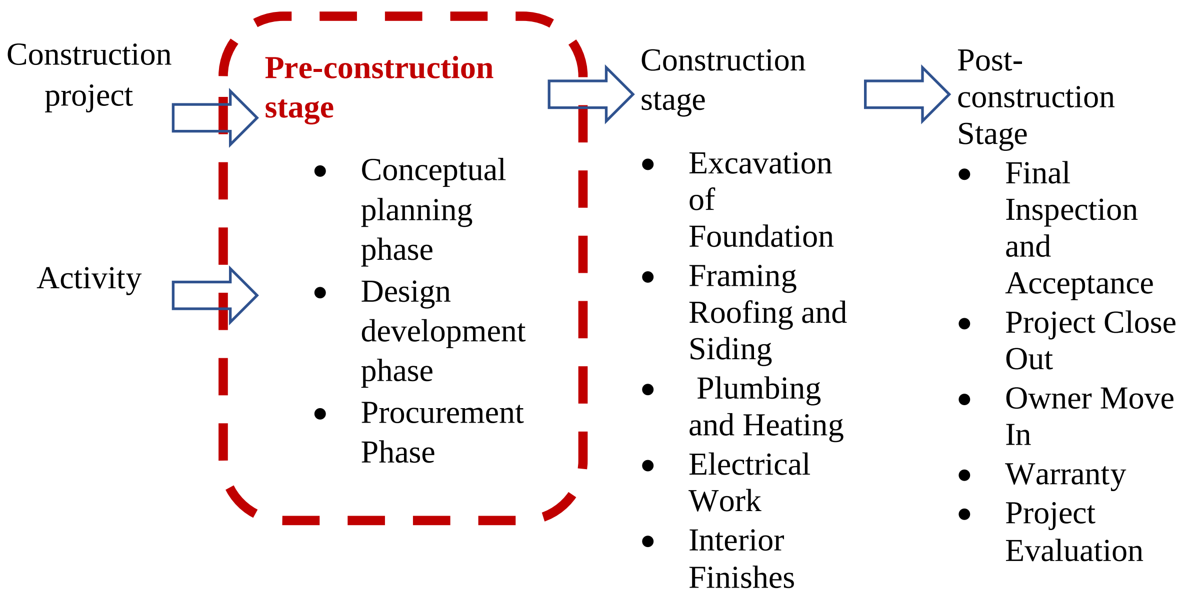


Figure 2-8: Construction Project Process (Kazi, 2005); (Thabet, 2000)

In the project’s pre-construction stage decisions related to the project's activities and performance are taken, the design process is divided into four phases pre-design and feasibility studies, conceptual design, design development, final design, and procurement (Thabet, 2000). Figure 2-9 shows the three main phases of the pre-construction stage.

The conceptual planning phase is the phase where the designers provide the owner with the information that assist him in taking important decisions related to the project’s feasibility. In this phase, the consultancy team develop a conceptual estimate, program, and plan for the project. **The design development phase:** the phase where the schematic designs developed by the design team to evaluate alternative design solutions, materials, and systems. The detailed design then prepared to evaluate, select, and finalize the major systems and components of the project. Finally, the consultancy team prepares the technical documents, specifications, general conditions, schedules, and budget. **The project procurement phase** is for the bidding and award process and final the project’s schedule and budget. The construction preparation starts after finishing the design process (Thabet, 2000).

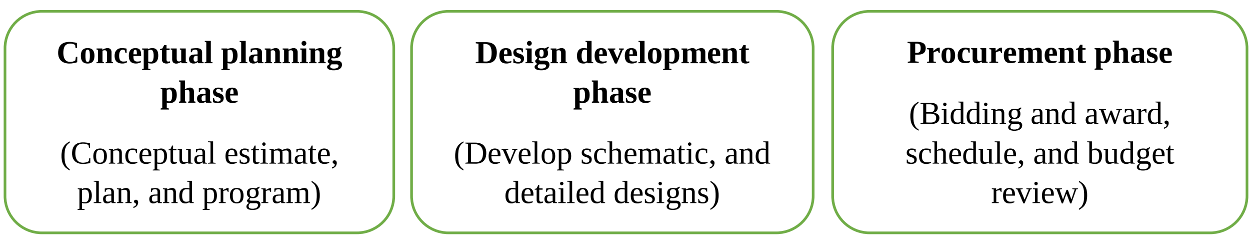


Figure 2-9: Pre-construction stage “Design Process” (Thabet, 2000)

Several stakeholders involved in managing the preconstruction stage (client, architect, structural engineer, MEP engineers, controls engineer, facilities manager, and the construction manager). They are also known as the design team (Laitinen, 1998). The cooperation between the stakeholders is essential to avoid the design problems like design changes, design clashes, poor design constructability, and poor 2D drawings that are the main factors that contribute in several construction problems like project delay, cost overrun, disputes, and low productivity. (Ahmed & Yusuff, 2016); (Kikwasi, 2012). Figure 2-10 shows the pre-construction problems effect on construction stage.

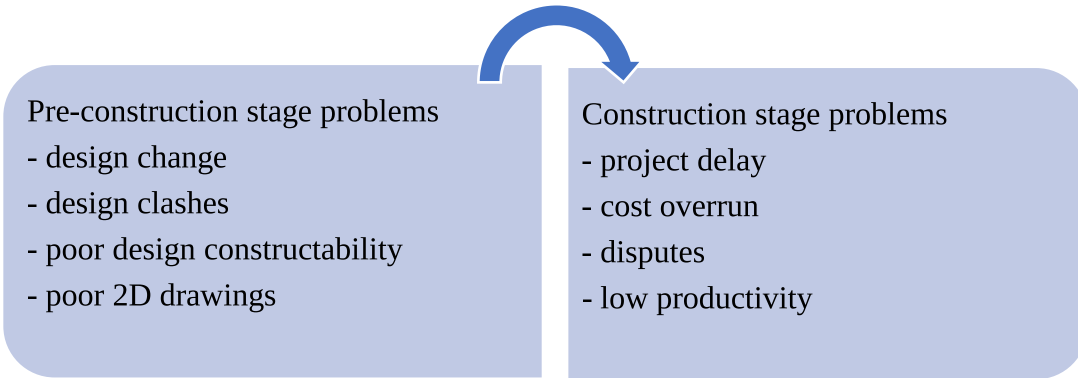


Figure 2-10: Pre-construction stage problems influence on construction stage. By the author

2.6 Sustainable building delivery process (pre-construction stage)

The building design process is a discrete and sequential set of activities where the designers put rules to create the design goals. If the proposed design does not meet the client's requirements, the designers redesign or update the project's design. This tedious trial and error approach continues until the design reaches the client's objectives and required performance (Attia, Gratia, Herde, & Hensen, 2013).

Enhancing the quality of life is the core of sustainable design. It aims to provide people a healthy living environment to improve their social, economic, and environmental conditions. Sustainable building should meet certain requirements like resources and energy efficient consumption, CO_2 and GHG emissions reduction, improve indoor air quality, noise mitigation, harmony with the environment, and pollution prevention. In addition, construction project should last for the end of its life cycle with modest maintenance and returns to the earth after demolition.

The building industry stakeholders began to pay attention to the environmental damages resulting from the building activities and start to take serious actions towards avoiding them. The design team can reduce the construction project's damaging impacts on the environment through implementing the sustainability objectives to the project design. (Akadiri , Chinyio, & Olomolaiye, 2012). Other principals and objectives of sustainable building are collected and illustrated in Table 2-2.

Table 2-2: Sustainable design principals and objectives (Akadiri , Chinyio, & Olomolaiye, 2012)

Title	Key Theme	Principal & objectives
Economic sustainability	Maintenance of high and stable levels of local economic growth and employment: • Improve project delivery • Increase profitability & productivity	Improve productivity; Consistent profit growth; Employee satisfaction; Supplier satisfaction; Client satisfaction. Minimizing defects; Shorter and more predictable completion time; Lower cost projects with increased cost predictability; Delivering services that provide best value to clients and focus on developing client business.
Environmental sustainability	Prudent use of natural resources • Improve energy efficiency • Efficient use of resources	Energy efficient at depots and sites; Reduce energy consumption in business activities; Design for whole-life costs; Use of local supplies and materials with low embodied energy; Lean design and construction avoiding waste; Use of recycled/sustainability sourced products Water and Waste minimization and management.
Social sustainability	Social progress which recognizes the needs of everyone • Respect for staff • Working with local communities and road users	Provision of effective training and appraisals; Equitable terms and conditions; Provision of equal opportunities; Health, safety and conducive working environment; Maintaining morale and employee satisfaction; Participation in decision-making; Minimizing local nuisance and disruption; Minimizing traffic disruptions and delays; Building effective channels of communication; Contributing to the local economy through local employment and procurement; Delivering services that enhance the local

	environment; Building long-term relationships with clients; Building long-term relationships with local suppliers; Corporate citizenship; Delivering services that provide best value to clients and focus on developing client business.

To reach the sustainable design aims many international organizations and countries have develop rating systems to assess sustainable construction practices (Azhar, Carlton, Olsen, & Ahmad, 2011).

The sustainable building rating systems; as going to be shown, create a set of design criteria to improve the building performance and its contribution to the built environment. Each rating system requires different performance goals. However, all of the systems are working with similar sustainable criteria which are energy consumption, material use, water efficiency, indoor visual, and thermal comfort.

2.6.1 Green building rating systems

At the early stage of the planning and design phase, most of the work regarding improving the building's performance is done. In order to accomplish the environmental goals, many international and local rating systems were developed (Elattar, 2014).

Building Research Establishment Environmental Assessment Method (BREEAM) was the first rating system worldwide, it was established in the UK in 1990 (Bernardi , Carlucci , Cornaro , & Bohne, 2017). After BREEAM, other methodologies such as Green Star from Australia, the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) from Japan, the Leadership in Energy and Environmental Design (LEED) From the United States, Excellence in Design for Great Efficiencies (EDGE) from the world bank, Pearl Rating System (PRS) from UAE, and Green Pyramid Rating System (GPRS) and TARSHEED from Egypt (Elattar, 2014); (Bernardi , Carlucci , Cornaro , & Bohne, 2017); (Assaf & Nour, 2015). The main goal of all the up mentioned rating systems and other ones is to reach the highest building performance covering all the environmental aspects related to the building lifecycle. These aspects are the efficient use of energy and water, the use of renewable and recyclable construction materials and resources, and minimizing the GHG and CO_2 emissions. These targets can be achieved through efficient engineering, design, planning, construction, effective operation and demolition plan. (Assaf & Nour, 2015); (Elattar, 2014). High building performance can be achieved through the following categories: (Elattar, 2014)

- **Site Design Sustainability:** Sustainable site selection and design.
- **Water Efficiency:** High-efficiency system for drinking water, Rainwater, gray water, black water, and garden irrigation.
- **Energy Efficiency:** an efficient system for heating and cooling, use of renewable energy systems whenever possible.
- **Quality of the Indoor Environment:** A building and site that explicitly support a healthy work and Lifestyle, interaction and innovation, controlled air supply system, and reduces the CO_2 emissions.
- **Usage and sources of Materials and Resources:** sufficient use of materials, the use of the recycled and reused materials and locally sourced materials.

2.6.2 Barriers and drivers of sustainable buildings

(Ayarkwa, Acheampong, Wiafe, & Boateng, 2017), (Rostami & Thomson, 2017), and (Häkkinen & Belloni, 2011) maintained different drives and barriers to achieve sustainable buildings. The barriers are the high investment costs and the lack of client demand and awareness, incentives, building codes and regulations, stockholders cooperation, technology and knowledge on sustainable practices, and sustainable design practices by architects. On the other hand, the drivers are summarized in the client demand and awareness, financial intensives, availability of integrated method, stakeholder's participation, planned policies and regulations, and increasing the awareness regarding the environmental, social, and economic impacts of implementing environmental building system. Table 2-3 summarize the barriers and drivers towards sustainable buildings (SB).

Table 2-3: Sustainable buildings barriers and drivers adopted from (Ayarkwa, Acheampong, Wiafe, & Boateng, 2017), (Rostami & Thomson, 2017), and (Häkkinen & Belloni, 2011)

	Barriers	Drivers
Financial investment	Higher investment costs for SB compared with traditional building	Energy-efficient buildings can offer major cost savings during operation
Incentives	the developer or investor don't fell that cost saving, the impact goes to the last	financial incentives and innovative fiscal arrangements, reduced

	user	volumes of waste, being able to anticipate forthcoming legislation, access to investment capital, and improve brand and reputation
Knowledge on sustainable practices	Ignorance or a lack of common understanding about sustainability makes it difficult to assess the profitability impacts of SB. Lack of knowledge for designers about SB, reduce their confidence in their ability to develop construction design that can integrate sustainability into building design	Efficient use of all information and the effective cooperation of team members for methods that enable the management and sharing of information. Overcome the obstacles of capturing and managing the knowledge needed by project teams.
Stakeholders collaboration		Availability of integrated method. SB requires good cooperation and effective communication between the project team. SB requires close interaction of suppliers, professionals and users
Client demand and awareness	Lack of demand and awareness to the benefits of SB	Governmental and local authority organizations can develop public buildings with the SB methodology may affect significantly the development of SB
Policies and regulations		

2.7 Constructability

(Jergeas & Put, 2001) define constructability as a project management technique that examine the construction processes from design to demolition during the pre-construction phase. The technique is about developing an elaborated study for the model design, construction drawings, specifications, and construction procedures. This process must take place before the project's bids and construction phase to identify the obstacles before starting work on site. The benefits of constructability are to overcome the delays, errors, and cost overruns.

The concept of Constructability was first arisen in the United Kingdom and the United States of America during the late 1970s in order to maximize the efficiency, productivity, cost-effectiveness, and quality in the construction industry. To achieve the benefits of Constructability, contractors should be involved from the very beginning of the project (Othman, 2011).

- Constructability Concepts have been developed to enhance and facilitate the adoption and application of the constructability philosophy through the different phases of the construction project. (Othman, 2011), illustrated the constructability concept in the following tables: Table 2-4, Table 2-5, and Table 2-6.

In addition, the ability to influence project cost is more effective when applying constructability from the early stage of design and keep applying it on all the project's phases (Othman, 2011). Figure 2-11 shows the other benefits of constructability to the construction projects. From the rank, the most aspects influenced by the constructability concepts are better design, improve site management, enhance project quality, and efficient waste management. Also, applying constructability concepts in building designs have reduced the capital estimated cost from 1% to 14% (Zhang, Zayed, Hijazi, & Alkass, 2016).

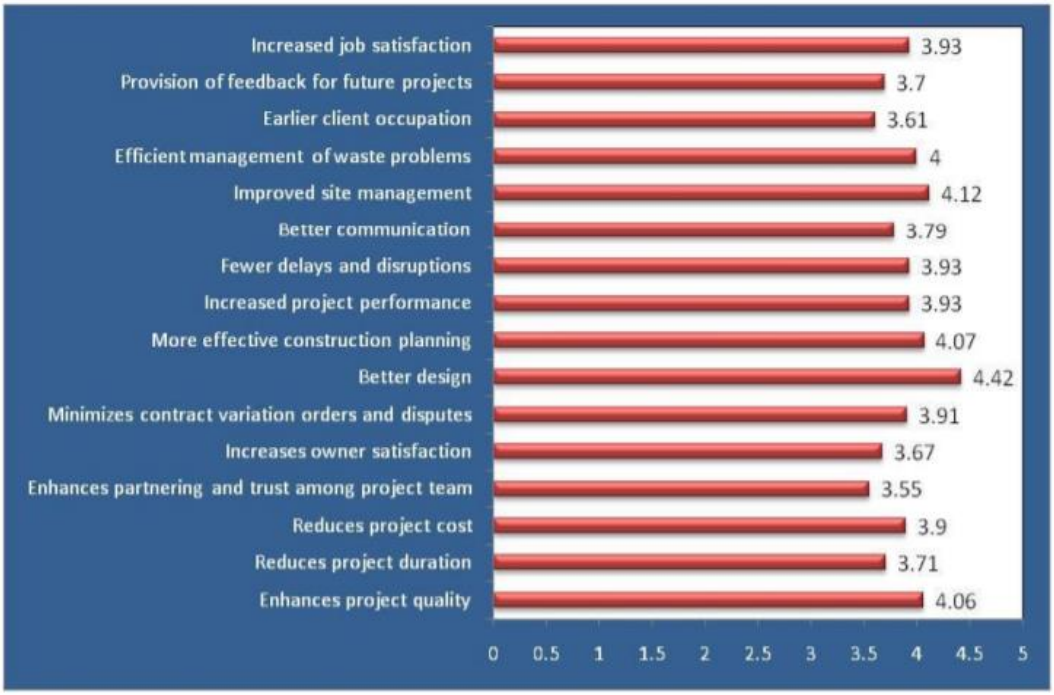


Figure 2-11: Benefits of implementing constructability (Othman, 2011)

Table 2-4:Constructability enhancement concepts during conceptual planning phase. Source: (Othman, 2011)

Concept C1	The project constructability program should be discussed and documented within the project execution plan, through the participation of all project team members.
Concept C2	A project team that includes representatives of the owner, engineer and contractor should be formulated and maintained to take the constructability issue into consideration from the outset of the project and through all of its phases.
Concept C3	Individuals with current construction knowledge and experience should achieve the early project planning so that interference between design and construction can be avoided.
Concept C4	The construction methods should be taken into consideration when choosing the type and the number of contracts required for executing the project.
Concept C5	The master project schedule and the construction completion date should be construction sensitive and should be assigned as early as possible.
Concept C6	In order to accomplish the field operations easily and efficiently, major construction methods should be discussed and analyzed in-depth as early as possible to direct the design according to these methods. This could include recovery and recycling

	methods as well as sustainable and final disposal planning.
Concept C7	Site layout should be studied carefully so that construction, operation and maintenance can be performed efficiently, and to avoid interference between the activities performed during these phases.

Table 2-5: Constructability enhancement concepts during design and procurement phases. Source: (Othman, 2011)

Concept C8	Design and procurement schedules should be dictated by construction sequence. Thus, the construction schedule must be discussed and developed prior to the design development and procurement schedule.
Concept C9	Advanced information technologies are important to any field including the construction industry. Therefore, the use of those technologies will overcome the problem of fragmentation into specialized roles in this field and enhance constructability.
Concept C10	Designs, through design simplification by designers and design review by qualified construction personnel, must be configured to enable efficient construction. This will help minimize material waste, recycling and cost-effectiveness.
Concept C11	Project elements should be standardized to an extent that will never affect the project cost negatively.
Concept C12	The project technical specifications should be simplified and configured to achieve efficient construction without sacrificing the level or the efficiency of the project performance.
Concept C13	The implementation of modularization and preassembly for project elements should be taken into consideration and studied carefully. Modularization and preassembly design should be prepared to facilitate fabrication, transportation and installation.
Concept C14	Project design should take into consideration the accessibility of construction personnel, materials and equipment to the required position inside the site.
Concept C15	Design should facilitate construction during adverse weather conditions. Efforts should be made to plan for the construction of the project under suitable weather conditions; otherwise, the designer must increase the project elements that could be

	prefabricated in workshops.

Table 2-6: Constructability enhancement concepts during field operations phases. Source: (Othman, 2011)

Concept C16	Field tasks sequencing should be configured in order to minimize damages or rework of some project elements, minimize scaffolding needs, formwork used, or congestion of construction personnel, material and equipment.
Concept C17	Innovation in temporary construction materials/systems or implementing innovative ways of using available temporary construction materials/systems that have not been defined or limited by the design drawings and technical specifications will contribute positively to the enhancement of constructability.
Concept C18	Incorporating innovation of new methods in using off-the-shelf hand tools, or modification of the available tools, or introduction of a new hand tools that reduce labor intensity.
Concept C19	Introduction of innovative methods for using the available equipment or modification of the available equipment to increase their productivity will lead to a better constructability.
Concept C20	In order to increase the productivity, reduce the need for scaffolding, or improve the project constructability under adverse weather conditions, constructors should be encouraged to use any optional preassembly.
Concept C21	Constructability will be enhanced by encouraging the constructor to carry out innovation of temporary facilities.
Concept C22	Good contractors, based on quality and time, should be documented, so that contracts for future construction works would not be awarded based on low bids only, but by considering other project attributes, i.e. quality and time.
Concept C23	Evaluation, documentation and feedback of the issues of the constructability concepts should be maintained throughout the project to be used in later projects as lessons learned.

2.8 Constructability method and SB

The need for sustainable buildings in the architecture/engineering/construction (AEC) industry is growing where sustainable design proved its ability to reduce the energy and water consumption, minimize the impacts of the construction projects on the environment, and encourage the use of environment friendly materials. However, the process of delivering sustainable buildings is difficult than the process of delivering traditional buildings. As the sustainable building design needs more players' involvement and interaction in the design process, complicated simulation and analysis programs, advanced construction standards, site precautions, and encouragement to the use of renewable materials. In addition, managing the sustainable building design with conventional project management style can create inefficient design and construction process.

In order to accelerate the capabilities of construction professionals in designing sustainable buildings, methods are needed to capture the sustainable buildings knowledge. Constructability with its ability to improve the construction through the design phase by reducing the waste materials, improving the site safety, reducing field labor cost, and streamline construction addresses sustainability from the early stage of design. Constructability and sustainable design are complementary concepts where the both concepts focus on reducing the unnecessary construction efforts to improve the construction industry practices and eliminate the construction projects harmful impacts on the environment, but the sustainability concept is adding more care for the environmental aspects than the constructability one. (Pulaski, Horman, & Riley, 2006).

Decision made for the sustainable building at the pre-construction phase is beneficial for the owners, developers, designers, and other stakeholders to calculate the cost associated with the construction process. For example, designers tend to examine and analyses different design criteria at the conceptual stage of projects (e.g. materials, technologies, spaces) that are directly affect the principles, measures, and cost of the Sustainable Universal Design (SUD) (Bryde, Broquetas , & Volm, 2013). The construction industry in general lacks to an advanced tool to assess in implementing the sustainability and constructability in design.

To manage a construction project, many overlapped practices should be controlled like the funds, scope of work, effective project scheduling, avoiding changes, disputes, and delays, and materials procurement. Information is a big and complicated aspect in the construction industry. Traditionally, the human factor is the controller of the information coordination where a lot of meetings, reports, work schedules, and blue papers are used to coordinate the work progress. IT developments would asset in managing this information by providing accurate, visual, and updated model data that can allow managers to monitor the design and construction process. Project computerization improves the speed and accuracy of the project's deliverables. In addition, the IT systems are used today to collaborate between all the construction disciplines to describe and document a role for each member of the project team. Building Information Modeling (BIM) is the most recent IT technology in the construction industry. BIM is the process in which a digital representation of the physical and functional characteristics of a facility is built, analyzed, documented, and assessed virtually then revised to create the optimal building design. BIM is not only a 3D project model but also a complete database with significant information packages for the project practices such as estimating, scheduling, change orders, etc... BIM provides a realistic simulation for the project before the construction phase starts (Yalcinkaya & Arditi, 2013).

BIM also is defined as an innovative approach that allows designers to control the project cost from the early stage of design. It helps designers to visualize their designs, associated materials, and technologies before the building physically exists (Bryde, Broquetas , & Volm, 2013).

2.9 Chapter summary

This chapter discuss the UN SDGs and Egypt vision 2030 and the input of the construction sector on the sustainable development. In this context, the chapter identify the sustainable construction principals and strategies through the two concepts of the sustainable construction, which are sustainable design and constructability. Finally, the chapter highlighted the need for innovation technology like BIM to manage the overlapped and complicated construction practices.

CHAPTER 3 : BIM AND SUSTAINABLE CONSTRUCTION

3.1 Introduction

In the last decades, there is a dramatic improvement in the use of the IT tools to enhance the quality of the construction documents and facilitate the workflow between the construction project disciplines. Nowadays, all the projects are developed using software tools in many different formats. The construction documents (2D and 3D drawings, schedules in different formats, various diagrams, charts, tables, and etc.) are used to present the project's information in the progress meetings where the project engineers take most of the decisions related to the project constructability, see Figure 3-1. For coordination, engineers need to share their information with each other to revise the construction methods, detailed design, cost, and schedules. Every engineer gives an image for the current and future situation based on his own interpretations of the documents away from the other engineers' opinions. Since most of these discussions and decisions require the input of all the engineers from several disciplines, IT supports the multidisciplinary planning and coordination of the construction projects. Computerizing the design process aims to integrate and coordinate information across disciplines and throughout the different project phases (Fischer & Kunz, 2004).

Figure 3-1: Project multidesplines constructability review meeting (Fischer & Kunz, 2004)

The idea of the integrated approach for construction information was discussed at the 90's, where the project information is defined as a set of IT methods, tools, and standards for the development and implementation of applications for managing, exchange, and sharing the product data. In Figure 3-2, the difference between the traditional data sharing approach and the integrated approach is shown. In the shared building product, the data shared once to reach all the project stakeholders and they can add or revise data directly and at the same time (Laitinen,

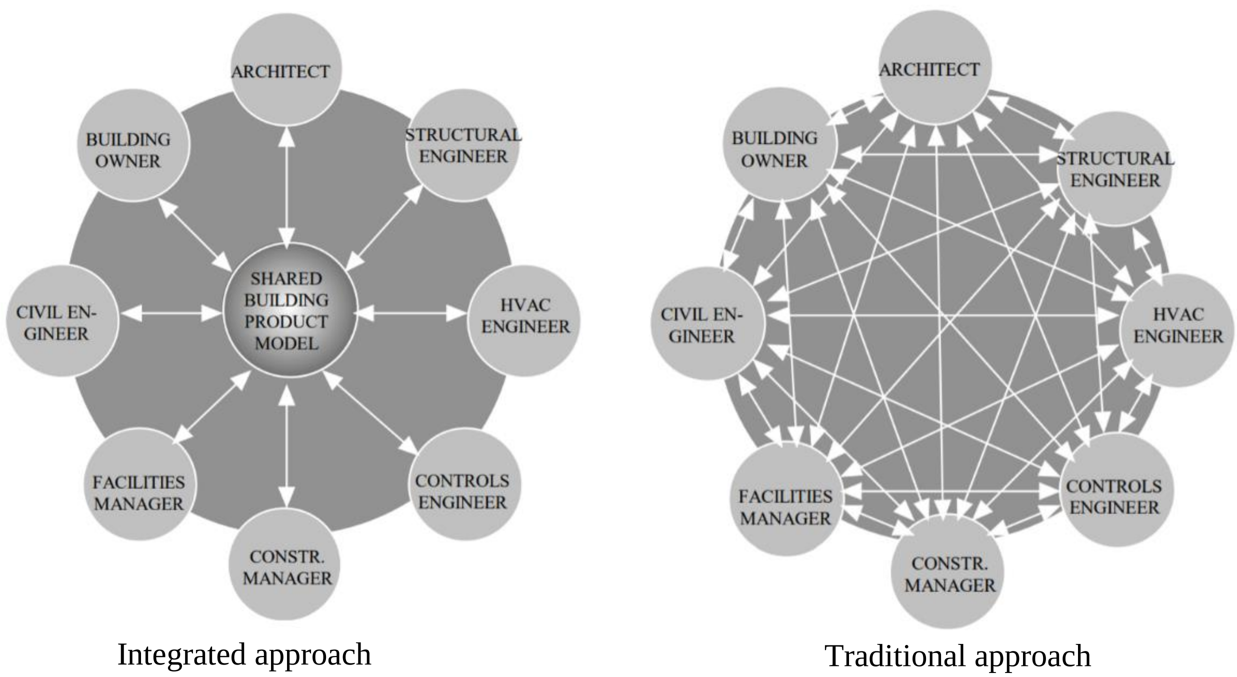


Figure 3-2: Difference between the coordination and correlation process in the traditional and integrated approach (Laitinen, 1998).

3.2 Building information modeling (BIM)

Computerization has improved the speed and accuracy in the construction industry. BIM is the process where a digital representation of the construction elements is built, analyzed, documented, evaluated virtually, and developed until the final model documented. BIM is a giant database for the project that contains all the information for construction management like cost estimation, schedules, change orders, and construction documents before the construction stage (Yalcinkaya & Arditi, 2013).

3.2 BIM history

BIM roots returned back to the parametric modeling research conducted in the USA in the early 1970s, the concept first practiced on the projects of Professor Charles Eastman at the Georgia Tech School of Architecture. Building Description System (BDS) was the first software developed with individual library elements from the database of Program Data Processor (PDP) computer before the personal computers appear. Later in the 1980s, like information systems were developed in the UK. With the development of the personal computer, wider uses and applications following the same concept were possible. In 1984, ArchiCAD software was developed by Graphisoft Company and integrated the idea of virtual building. The new software power came from its ability to built-in programming environment from its parametric library component using Geometric Description Language (GDL). The AEC industry practically started to implement BIM in projects from the mid-2000s, where a company has developed the Revit program which was written in C++ and utilized a parametric engine which was a revolutionary step. Later in 2002, Autodesk purchased the Revit program and heavily invested in developing the program which provided a transitional approach to BIM (Dobelis, 2015). The developed software gives the industry an enhanced control over time, cost, and quality. Despite that a fragmented management way still existed as each member of the team is working separately form the other members that makes a collaborative visual building model like the BIM model is required to fill in the gap of the virtual design concept Figure 3-3.

During the last seven years, the term BIM has gone from being a buzzword to the centerpiece of the AEC technology (Azhar, Khalfan, & Maqsood, 2012).

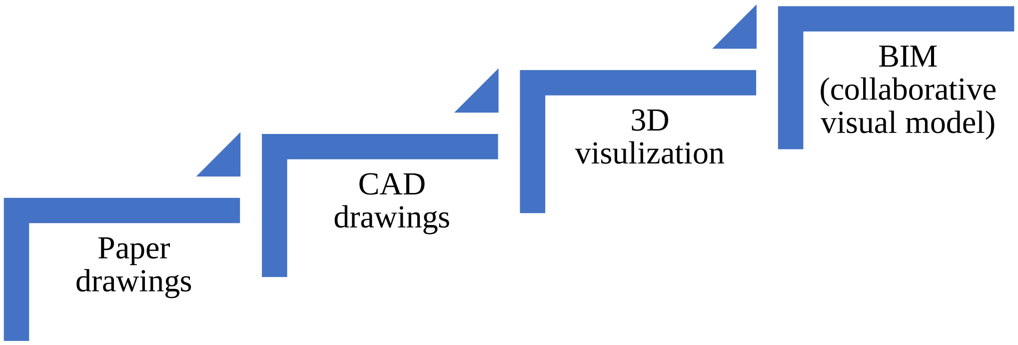


Figure 3-3: Evolution of technology within AEC industry. By the author

3.2.1 BIM definition

BIM is widely used nowadays in the construction industry because of its ability to enhance and facilitate the collaboration between the construction sector disciplines.

There are several definitions for BIM that are different according to the user's background and point of view (Abbasnejad & Moud, 2013).

- **Design perspective:** BIM is defined as the digital representation of the physical and functional characteristics of a project which refers to the technological process used to develop a BIM model.
- **Construction perspective:** BIM is the use of a computer modeling software to develop and simulate the construction and operation abilities.
- **Facility managers' perspective:** BIM provides all the necessary data to operate the construction project after occupancy and until the demolition.

BIM also have other definitions from the organizational and institutional perspective. For example, The National Institute of Building Sciences (NIBS) defines BIM as "Building Information Model or BIM utilizes cutting-edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information, and it is intended to be a repository of information for the facility owner/operator to use and maintain throughout the life-cycle of a facility." Other definitions are mentioned in (Table 3-1) (Abbasnejad & Moud, 2013).

Table 3-1: Different definitions of BIM (Abbasnejad & Moud, 2013)

Scholars / organizations	Definition
Van Nederveen	Comprises complete and sufficient information to support all lifecycle processes and which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components, and comprises information about properties such as function, shape, material and processes for the building life cycle.
NIBS	Provide parametric based model to reflect insertion, extraction, updating or altering physical, functional characteristics of building at each step as needed throughout the processes to support cooperation among related parties
Cheol and Shik	Comprehensively manage and use information on all steps from planning to expiry through exchanging and sharing information according to projects, processes focusing on interoperation of information through the entire lifecycle of construction.
GSA	Refers to the entire processes of exchanging, reusing, controlling information generated during the lifecycle of building through object oriented artificial intelligent information model.
Gang	Comprehensively control all information and organization, duties and processes needed from the stage of planning for construction to its cycle of design, construction, maintenance and demolition

However, some users thought that BIM is an advanced Computer Aided Design (CAD), while BIM is a process that is completely different from the CAD system. BIM provides more advanced services over CAD as the BIM model is not just a 3D model, it manages and controls the information to eliminate data redundancy and conflicts due to the miscommunication between the project's team. The capabilities of BIM are (Popov, Mikalauskas , Migilinskas, & Vainiūnas, 2006):

- Manage and integrate informational data flows in a graphical interface and process description.

- Transform the decentralized tools to complex solutions.
- Develop an earlier strategy for the building design, construction, and facility management.
- Provide more effective lifecycle operation for the building in a shorter and lower cost process.

The way CAD defines structural elements and the way BIM do show the obvious differences between them. While CAD deals with the construction elements as 2D geometries, BIM builds each element as an intelligent object with all its information in a 3D model form. Moreover, BIM keeps the relation between objects in the project in a way that makes these objects affected by the change in any of them. (Succar, 2009) has summarized the common BIM terms in the following Figure 3-4.

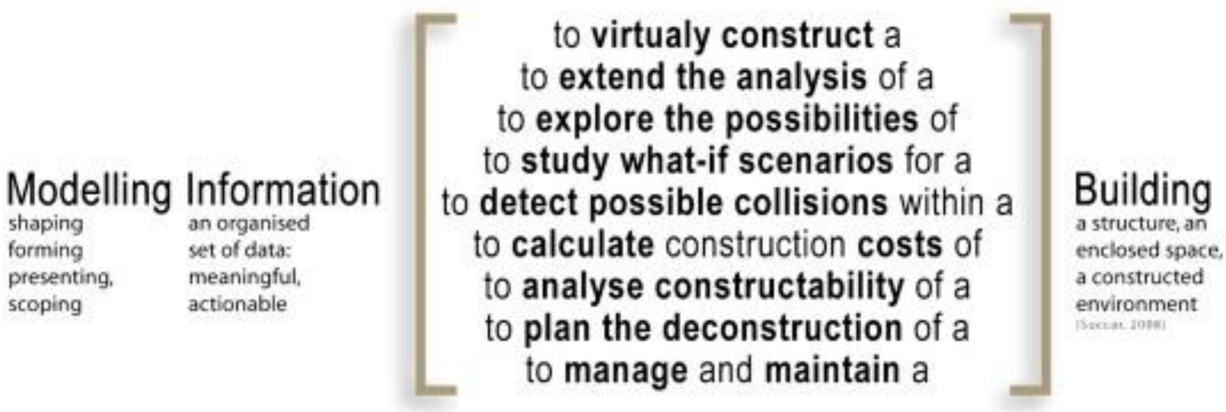


Figure 3-4: Common BIM terms (Succar, 2009)

3.3 BIM benefits for construction industry

According to (Azhar, Behringer, Sattineni, & Maqsood, 2012), BIM benefits the construction industry through the project's phases; programming, preconstruction, construction, and post-construction phases saving time and cost, improve quality, and increase efficiency. The collaboration between the project's team is one of the biggest benefits of BIM where they are involved together in the project from the early stage what leads to a better understanding of the project and reduces the tasks time, save resources, and increase the efficiency.

In addition, the accuracy of the BIM model contributes to a better design, faster and more effective process, control the whole life costs and environmental data, automated assembly, better customer service, and lifecycle data (Azhar, 2011).

The benefits of BIM for the construction industry stakeholders are numerous, according to (Azhar, Khalfan, & Maqsood, 2012) and (Barlish & Sullivan, 2012). These benefits are outlined in the following Table 3-2.

Table 3-2: BIM benefits according to Project Stakeholders, adapted from (Azhar, Khalfan, & Maqsood, 2012)

Owner	
	1. Ensure that project requirements are met from the early design assessment. 2. Evaluate building performance and maintainability. 3. Low financial risk because of reliable cost estimates and reduced number of change orders. 4. Better marketing of project by making effective use of 3D renderings and walk-though animation. 5. Complete information about building and its systems in a single file.
Designer	
	1. Better design by rigorously analyzing digital models and visual simulations and receiving more valuable input from project owners. 2. Early incorporation of sustainability features in building design to predicts its environmental performance. 3. Better code compliance via visual and analytical checks. 4. Early forensic analysis to graphically assess potential failures, leaks, evacuation plans and so forth. 5. Quick production of shop or fabrication drawings,
Contractor	

	1. Quantity takeoff and cost estimation. 2. Early identification of design errors through clash detections. 3. Construction planning and constructability analysis. 4. Onsite verification, guidance and tracking of construction activities. 5. Offsite prefabrication and modularization. 6. Site safety planning. 7. Value engineering and implementation of lean construction concepts. 8. Better communication with project owner, designer, subcontractors and workers on site. 9. High profitability. 10. Better customer service. 11. Cost and schedule compression. 12. Better production. 13. More informed decision making. 14. Better safety planning and management.
Facility managers	1. The same critical information is present in a single electronic file. 2. The facility managers do not have to shift through the piles of information to gather data, as the BIM database offers any information about any equipment in the project in just one-click.

3.4 BIM applications and tools in the preconstruction stage

BIM applications as a lifecycle evaluation tools provide integrated processes throughout the entire lifecycle of a construction project. Figure 3-5 shows how BIM facilitates the project stakeholder's coordination and communication throughout the project's lifecycle by providing different facilities (Arayici, Egbu, & Coates, 2012).

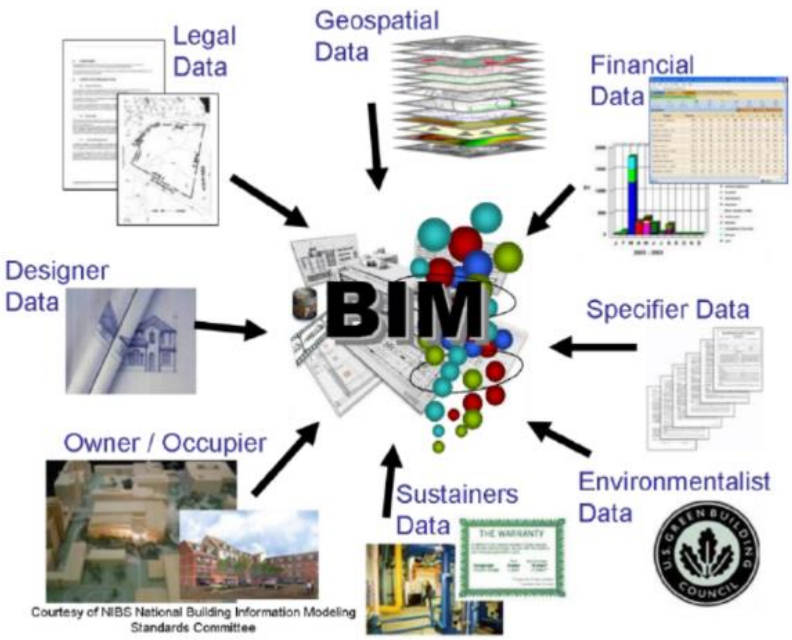


Figure 3-5: Communication, collaboration and visualization with BIM model. Source: (Arayici, Egbu, & Coates, 2012)

As discussed in chapter 2, the pre-construction stage is the stage where most of the main project's decisions take place. The pre-construction stage is divided into conceptual planning, design development, and project procurement phases. The BIM implementation at this stage provides a professional management for the construction project using different applications. These applications can be illustrated in the following Table 3-3

Table 3-3: BIM applications in the preconstruction stage. Source: (Ashcraft, 2008) (Azhar, Khalfan, & Maqsood, 2012)

Conceptual planning	Design development	Project procurement
Options Analysis (to compare multiple design options)	3D exterior and interior models (visualization)	4D phasing and scheduling (e.g. clash detections)
Photo Montage (to integrate	Walk-through and fly-	Building systems analysis, ex:

photo realistic images of project with its existing conditions)	through animations	Energy, lighting, structural, and full design analysis
Cost estimation and financing	Building performance analyses (e.g. energy modeling)	Shop or fabrication drawings
Feasibility outline	Full design coordination	

BIM facilities and application aids the project's stakeholders in improving communication, decreasing construction time and cost, and eventually reducing risk. Inevitably, BIM changes the way that the owners, designers, and contractors communicate to construct the project; however, the core responsibilities of the project's members do not change. Table 3-4 demonstrates the stakeholders' benefits of BIM applications in the pre-construction stage (Al Awad, 2015).

Table 3-4: BIM applications for stackholders. Source: (Al Awad, 2015)

	Owner	Designer	Constructors
Visualization	*	*	*
Option analysis	*	*	*
Sustainability analysis	*	*	
Quantity survey		*	*
Cost estimation	*	*	*
Phasing and 4D scheduling		*	*
Constructability analysis		*	*
Building performance analysis	*	*	*

3.4.1 BIM software

BIM applications have different computer programs to support reaching the production of an accurate, efficient, and constructible building model. The BIM software must be able to import and export data smoothly to allow an intelligent data sharing. The following Table 3-5 represents the BIM tools, discipline uses, and the company of manufacturing.

Table 3-5: BIM programs by discipline & manufacture. By the author

Discipline	Program	Manufacture
Architecture	Revit Architecture	Autodesk
	AutoCAD Architecture	
	ArchiCAD	Graphisoft
	Vectorworks Designer	Nemetschek
	Allplan arcitecture	
	Affinity	Trelligence
	Digital Project	Gehry technologies
	Architecture	Bentley systems
	Site Planning and Design	
	Architectural Design	4MSA IDE (IntelliCAD)
	Envisioneer	CADSoft
	RhinoBIM	Rhino
	Spirit	Softtech
Structure	Revit structure	Autodesk
	Autocad civil	
	Robot Structural Analysis	
	Structural Modeler	Bentley
	RAM, STAAD and ProSteel	
	Tekla Structures (Structure-centric Model Schedule driven link)	Tekla

	CypeCAD	CypeCAD
	Advance Design	Graytec
	Metal Wood Framer	StructureSoft
	Scia	Nemetschek
	Strad and Steel	4MSA
MEP	Revit MEP (3D Detailed MEP Modeling)	Autodesk
	Hevacomp Mechanical Designer (3D Detailed MEP Modeling)	Bentley
	FineHVAC + FineLIFT + FineELEC + FineSANI (3D Detailed MEP Modeling)	4MSA
	Digital Project MEP Systems Routing(3D Detailed MEP Modeling)	Gehry Technologies
	(CADduct / CADmech) (3D Detailed MEP Modeling)	CADMEP
Sustainability	Ecotect Analysis	Autodesk
	Green Building Studio	
	Visera	
	EcoDesigner	Graphisoft
	Virtual Environment VE-Pro	IES Solutions
	Tas Simulator	Bentley
	Hevacomp	
	DesignBuilder	DesignBuilder
Construction (simulation-estimation-construction analysis)	Naviswork Manage (clash detection – scheduling)	Autodesk
	Project Collaboration	Bentley
	ConstrucSim (clash detection – scheduling)	
	Solibri Model Checker (Spatial Coordination)	Solibri
	Office Suite (Coordinate Scheduling Estimating)	Vico
	Field BIM	Vela systems
	BIMSight	Tekla
	Glue	Horizontal Systems

	Synchro Professional (Planning & Scheduling)	Synchro software
	Virtual simulation (Scheduling)	Innovaya
	Digital Project Designer (Model Coordination)	Gehry Technologies

As there are many BIM software platforms, a domain or a hub where all the BIM software can be fully integrated was needed. The Industry Foundation Classes (IFC), which is an object-oriented file format, was developed by the International Alliance for Interoperability (IAI) to facilitate interoperability in the building industry (Malsane , Matthews , Lockley, Love, & Greenwood, 2015). (Hijazi, Alkass, Eng., & Zayed , 2009) define the IFC as a data model with a neutral and open specification that is not controlled by a single vendor or group of vendors. Also, the IFC defined as an open online format that focuses on the interoperability between the software and is a commonly used format for BIM. The IFC data model is an international standard which was registered by the International Organization for Standardization (ISO) as ISO/IS 16739. The IFC data files export the model objects' hierarchy, properties, and behavior from a BIM tool to deferent BIM tools for further analysis and usage (Malsane , Matthews , Lockley, Love, & Greenwood, 2015). Figure 3-6 illustrates the IFC exchange programs.

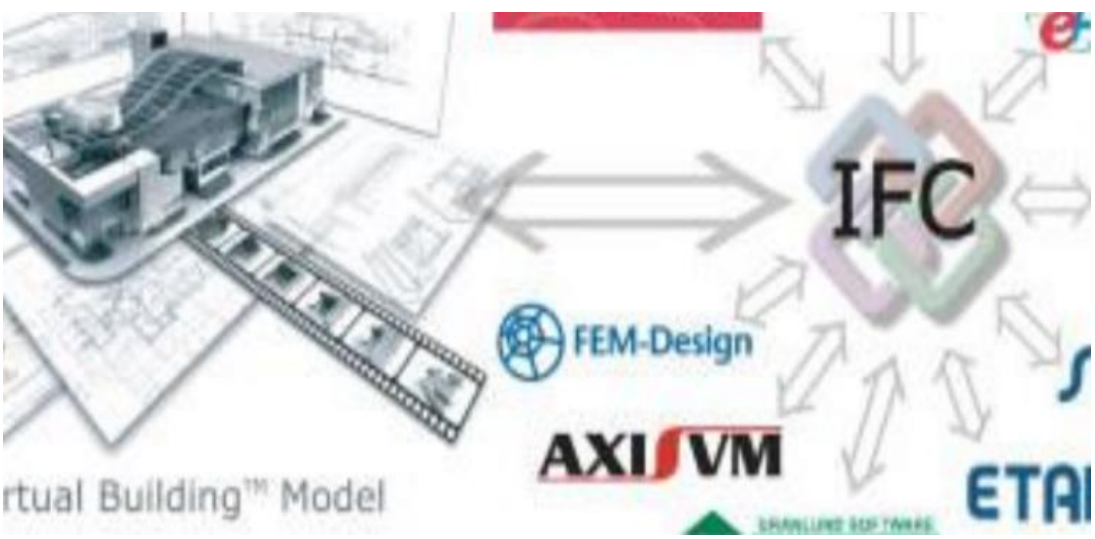


Figure 3-6: IFC programs exchange and outputs. Source: (Svennevig, 2015)

Another interoperability tool is the gbXML (Green Building eXtensible Markup Language) which is an open data scheme to transfer the building data from CAD or BIM applications to environmental analysis software (especially energy software). The main scope of the schem is to provide the data for operational energy consumption analysis like the thermal properties of the building materials and the HVAC installations in the project (Adamus, 2013). See Figure 3-7.

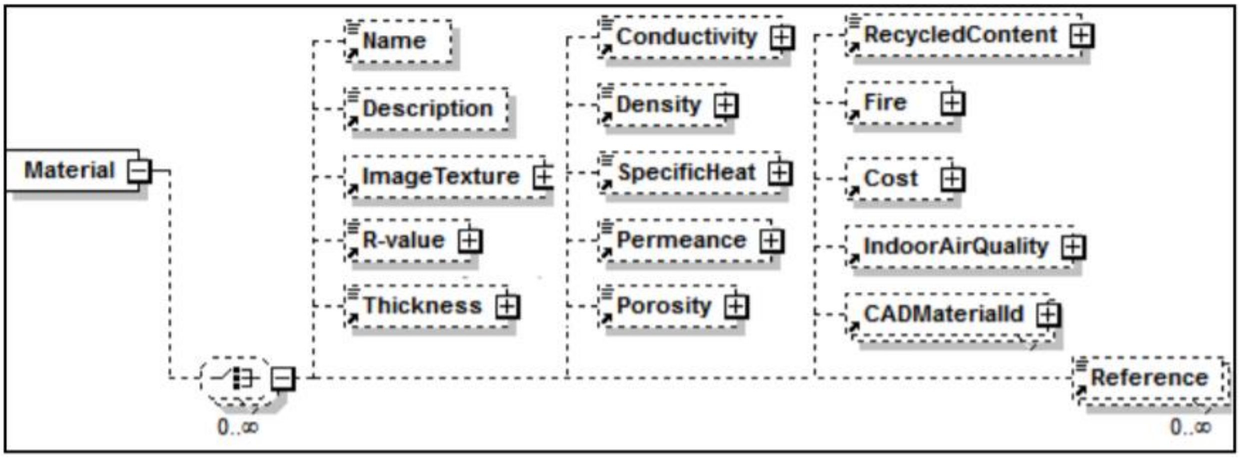


Figure 3-7: gbXML material properties scheme. Source: (Adamus, 2013)

3.4.2 BIM Collaboration method

Collaboration means working together as one team where all individuals have one goal to accomplish. BIM implementation in the construction industry has a lot of optimistic outcomes like saving the time and cost, in addition to increasing productivity and efficiency. Construction project needs a vital collaborative relationship to develop a collaborative interaction system between the cross professions. This interaction system is essential according to the construction experts to solve the poor productivity and fragmentation problems in the construction industry practices (Lu, Zhang, & Rowlinson, 2013). Successful collaboration has three determinates: collaborative team, environment characteristics, and collaborative processes. The collaborative team should have relevant skills, knowledge, and attitude to work with each other; the collaborative environment needs organizational and technical supports; while the collaborative processes are related to the effective communication that can solve any conflicts (Lu, Zhang, & Rowlinson, 2013) see Table 3-6. This collaborative concept where adapted in the construction industry and has been used in the BIM collaboration process (Lu, Zhang, & Rowlinson, 2013).

Table 3-6: Collaboration determinates and outcomes. Source: (Lu, Zhang, & Rowlinson, 2013)

Determination of collaborative success	**Collaboration outcomes**

Collaborative team characteristics: • Professional-relevant skill and knowledge • Collaboration skill • Attitude and motivation	Firm level: • Productivity • Financial profitability
Collaborative environment characteristics: Institutional support	Individual and team level • Goal achievement • Effective functioning • Individual benefit
Collaborative process: • Communication • Initial clarity • Effective use of members capabilities • Conflict resolution process	

BIM is not only about using technologies, but it is also a collaboration tool between the project team. BIM allows the project team to communicate about the design requirements and coordinate the data across different levels of the project lifecycle earlier before the construction phase. This communication and collaboration increase the efficiency and effectiveness of the project (Keung, 2018). The successful BIM project is known by its ability to provide an effective collaboration between the project shareholders (Lu, Zhang, & Rowlinson, 2013).

Integrated Project Delivery (IPD) is a vital project delivery method for construction projects that enhance collaboration and accelerate the communication effectiveness objective (Lu, Zhang, & Rowlinson, 2013).

The IPD is defined by the American Institute of Architecture (AIA 2007) as a collaborative approach to engage people, technology, practices, and business structure in a collaborative process. The IPD enables all the project participants to maximize the project's value, reduce waste, and improve efficiency throughout the project's lifecycle. The new delivery approach is different from the traditional one in the following characteristics: 1- early parties' involvement, 2- collaborative decision-making, 3- risk and rewards sharing, 4- multi-party contact, and 5- equal project development goals (Ghassemi & Becerik-Gerber, 2011).

The IPD challenge is to create the collaborative atmosphere needed for an inclusive use of BIM by aligning the goals of all the project stakeholders and encourage them to work together throughout the project lifecycle (Kent & Gerber, 2010). Coupling BIM with IPD for collaboration not only improve efficiency and reduce errors, but also allows the evaluation of alternative approaches and market expansions opportunities (Kent & Gerber, 2010). Moreover, the engagement between the IPD approach and BIM has changed the traditional delivery approach where the project team (constructor, installers, suppliers, fabricators, and designers) used to work in unison to overcome the construction phase problems like unpredicted risks, and buildability issues earlier in the design phase. In addition to the ability to simulate and model the project accurately using the BIM tools. Furthermore, the early investment in money and time during the pre-construction phase leads to more robust construction time and cost schedule. This integration also assists in the facility management process. All of the above means that to deliver a project that is well defined and coordinated provides a higher level of efficiency and effectiveness to the project before starting the documentation phase (Stirton & Tree, 2015). Figure 3-8 shows how the IPD approach adjusts the traditional approach in the term of stakeholders' involvement earlier in the project according to the AIA (AIA, 2007).

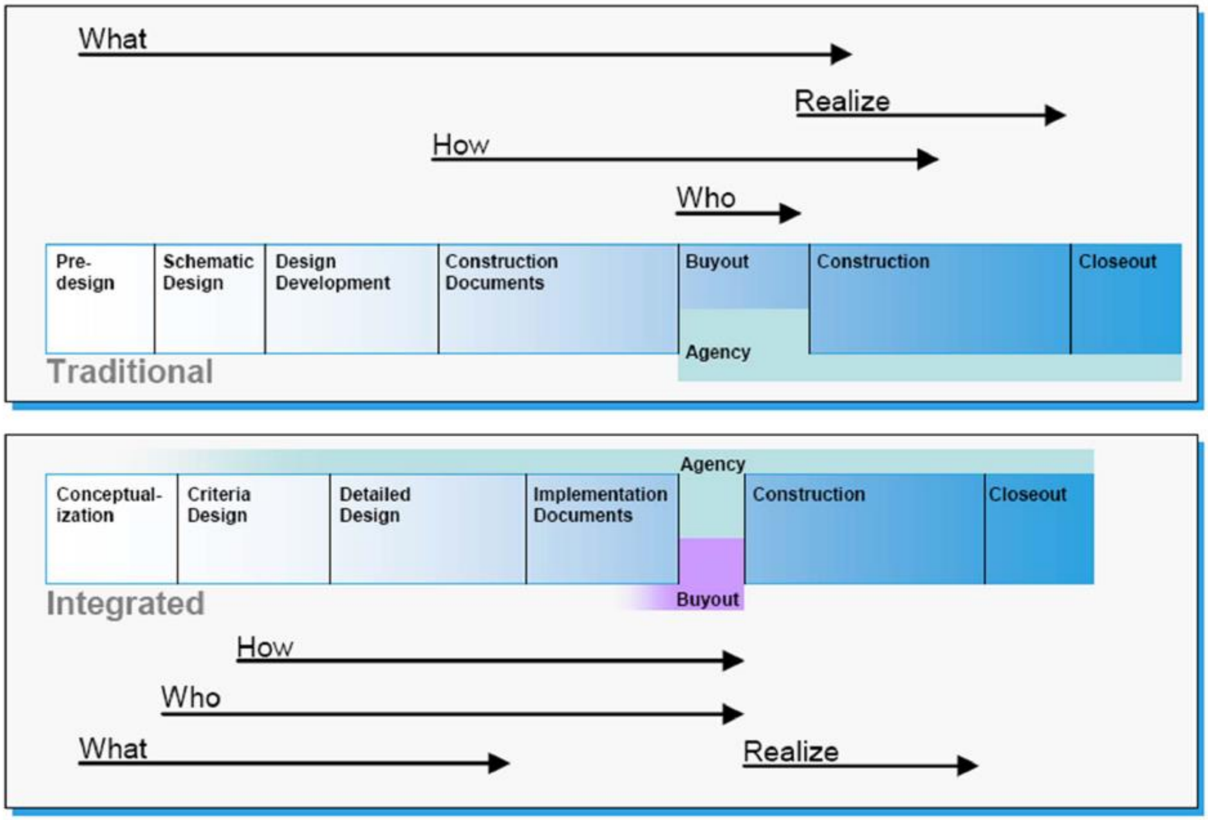


Figure 3-8: Traditional project phases are adjusted by IPD. Source: (AIA, 2007)

Figure 3-9 illustrates the principle of discovering any errors or clashes in the project in the early design phase quickly and at the lowest cost. Line 1 indicates the ability of BIM to influence the construction industry by inverting the time spends in construction to the pre-construction phase and its ability to lower the overall project cost. Line 2 shows how the cost of design increases as the project is moving forward with the traditional approach. Line 3 illustrates how the work effort increases late in the traditional process when the time and cost line meet together. Line 4 shows how the IDP using BIM moves the majority of design effort to the pre-design phase to provide a smooth construction process with the lowest possible cost (Smith & Tardif, 2009).

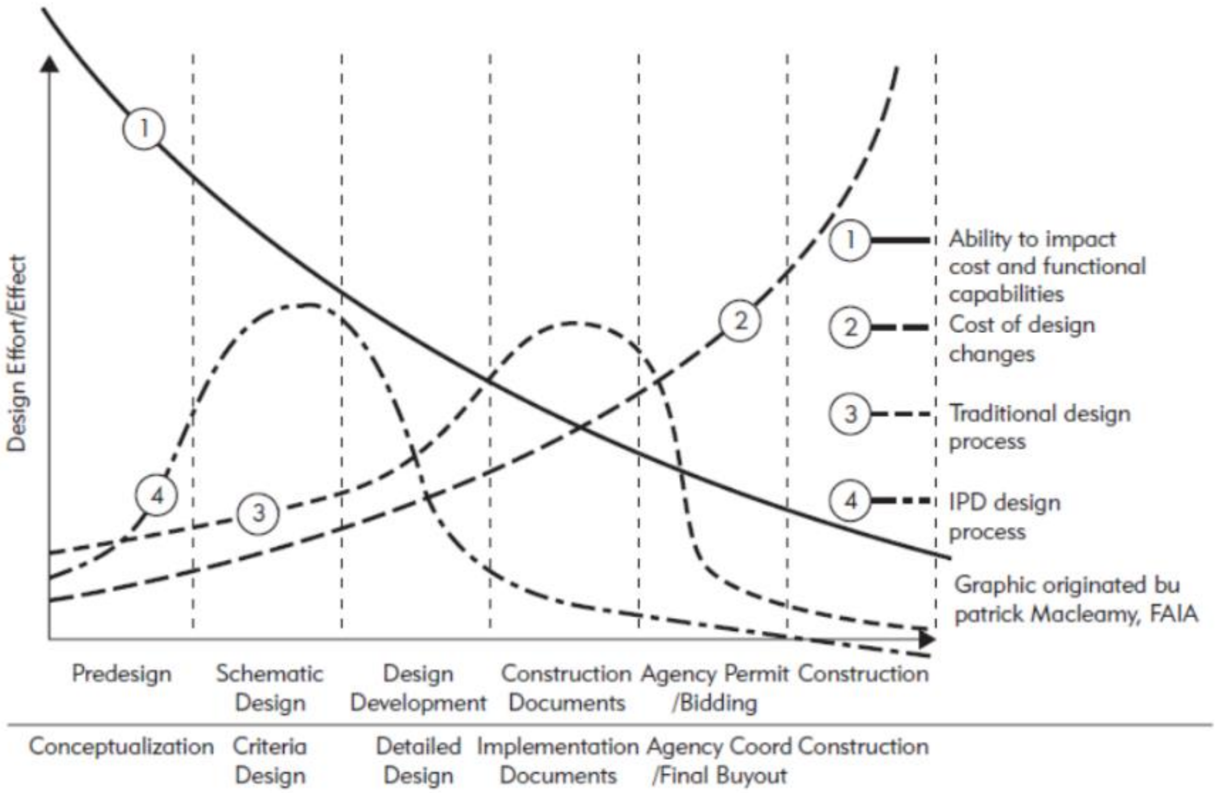


Figure 3-9: BIM work flow- design effort and the cost of change. Source: (Smith & Tardif, 2009)

To sum up, the integration between IDP and BIM are highly recommended for the construction industry where the collaboration success factors are illustrated in five success factors (POWER) according to (Sebastian, 2011):

(1) Product information sharing (P).

(2) Organizational roles synergy (O).

(3) Work processes coordination (W).

(4) Environment for teamwork (E).

(5) Reference data consolidation (R).

3.5 BIM benefits in the pre-construction phase

BIM provides reliable information about the project lifecycle from the concept phase to the demolition phase. This process allows professionals to identify the project characteristics and help in better decision making. The BIM model includes data about the project like specifications, energy analysis and materials take-off; in addition to the coordinated data between the cross-functional project team in an intelligent model in order to produce a better design, planning, construction, and management Figure 3-10 (Wei & Md, 2017).

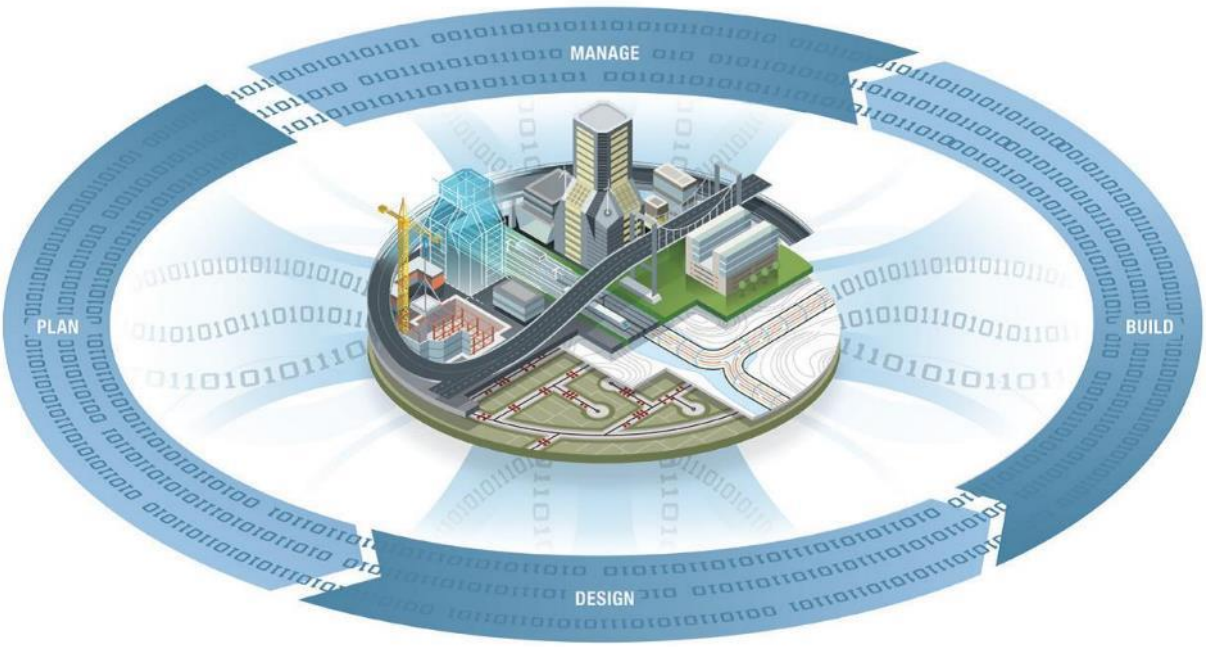


Figure 3-10: Cross-functional project teams share intelligent models to better design, planning, build, and building management. Source: (Wei & Md, 2017)

(Sun, Jiang, Skibniewski, Man, & Shen, 2017) & (Azhar, 2011) summarized the BM benefits from many articles in the following points:

- Accurate geometry.
- Faster and effective process.
- Control cost throughout the project life cycle.
- Better design options.
- Better production quality.
- Better customer services and lifecycle data.
- Automated assembly.
- 8-15% time saving in new projects.
- Up to 35% time saving in the repeated data between projects due to reusing of information easily, this leads to better decision-making and early phase analysis.

- Reduce cost and improve accuracy and speed of cost estimation.
- Reduce time up to 7% in project time.
- Avoid clashes that leads to up to 10% of contract value saved.
- Facilitates construction coordination.
- Eliminate up to 40% of unbudgeted changes due to the reduction of requests for information and changing orders.
- Ensure lower cost through the project lifecycle through sustainable design.
- Facilitate simulation and visualization of the construction project.
- Facilitate construction documents generation.
- Cost estimation accuracy within 3%.
- Up to 80% reduction in the time taken to generate cost estimation.

3.6 BIM and constructability

The constructability idea is to minimize the gap between what designers design at offices and what contractor build on site. According to some case studies, applying constructability principles in projects have saved 10.2 % of the project's time and 7.2% of the cost (Hijazi, Alkass, Eng., & Zayed , 2009). The virtual construction process during the design development stage facilitates reviewing the building design, analyze, and criticize different scenarios for the construction options and alternatives. BIM enables automated rule-based approach for constructability checking that will assist in a better decision-making process (Thabet, 2000), see Figure 3-11.

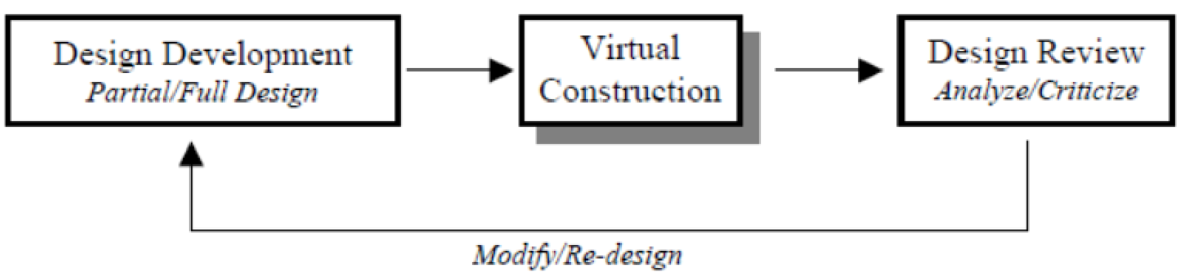


Figure 3-11: Design / construction integration. Source: (Thabet, 2000)

The rule-based approach for constructability is applied during the pre-construction phase and is divided into four stages shown in Figure 3-12,1- Schematic Design “SD” / 2- Design Development “DD” / 3- Construction Drawings “CD” / 4- Pre-Construction drawings “Pre-Con.” Each stage has a level of details in the BIM process. Constructability feedback is automatically generated and reviewed by the project team to help in the decision-making process (Jiang & Leicht, 2014).

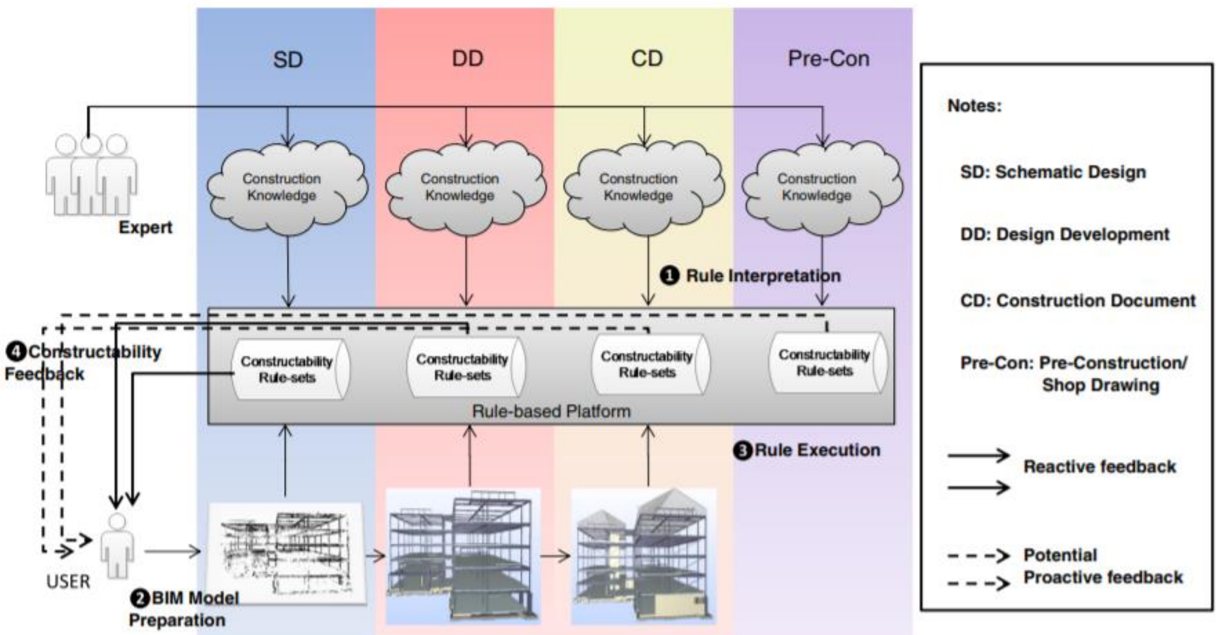


Figure 3-12: Rule-based constructability checking. Source: (Jiang & Leicht, 2014)

For example, the 2D and 3D CAD programs are not suitable for representing a space in its physical state. But the BIM model provides information about spaces and the relation between walls, ceilings, and floors which used in the constructability performance analysis (Hijazi, Alkass, Eng., & Zayed , 2009), see Figure 3-13.

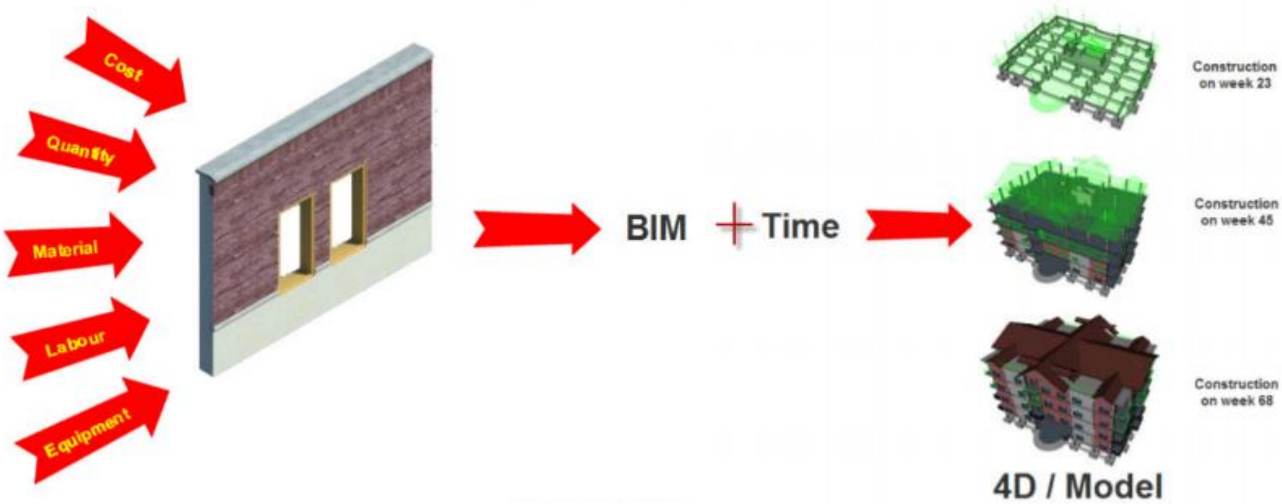


Figure 3-13: Building data and 4D simulation. Source: (Hijazi, Alkass, Eng., & Zayed , 2009)

BIM has the capability to manage the project time (4D) and cost (5D), building team collaboration and communication, and the procurement issues. In addition, the design changes are directly reflected in the project outcomes (Tiwari, 2017). (Tiwari) compared differences between developing a project using the conventional modeling process and the BIM modeling process in the following case study, Table 3-7.

Table 3-7: Conventional VS. BIM case study analysis. Source: (Tiwari, 2017)

A G+4 proposed building of 24 flats and of 4 shops is taken for case study location is in Ravet, PUNE under PCMC for plot size 6800 sq. feet	
Program used	AutoDesk Revit / Navis Work
Area of comparison	4D and 5D influence on scheduling, quantity, and cost
Finding	• Total of 39 days can be saved in total for tasks like scheduling, planning, and monitoring in BIM process. • Cost was saved by 25-30% due to the coordination and reduction in man power. However, the cost of material will remain same.

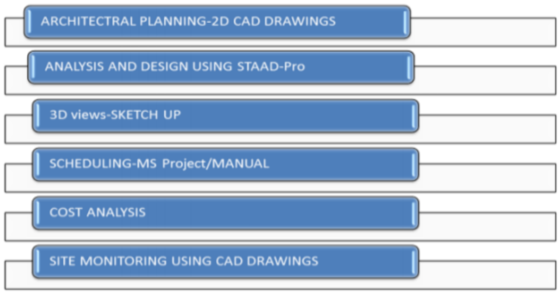
<table>
<tr><th></th><th>Conventional model</th><th>BIM Model</th></tr>
<tr><td>Workflow</td><td>

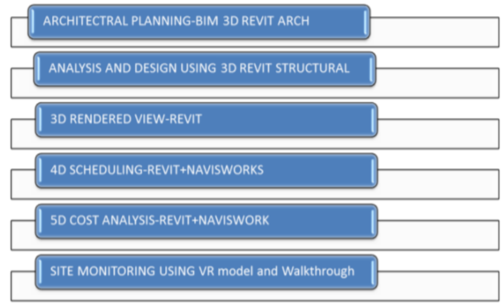
Figure 3-14: CAD workflow. Source: (Tiwari, 2017)</td><td>

Figure 3-15: BIM workflow. Source: (Tiwari, 2017)</td></tr>
<tr><td>Modeling</td><td>

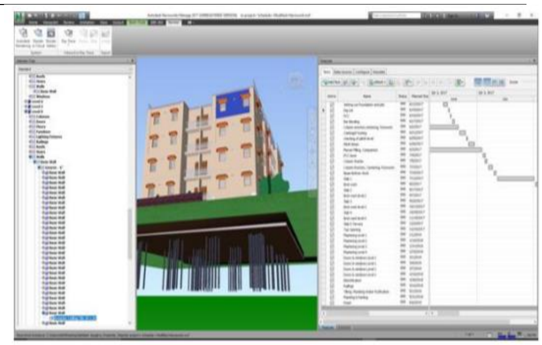
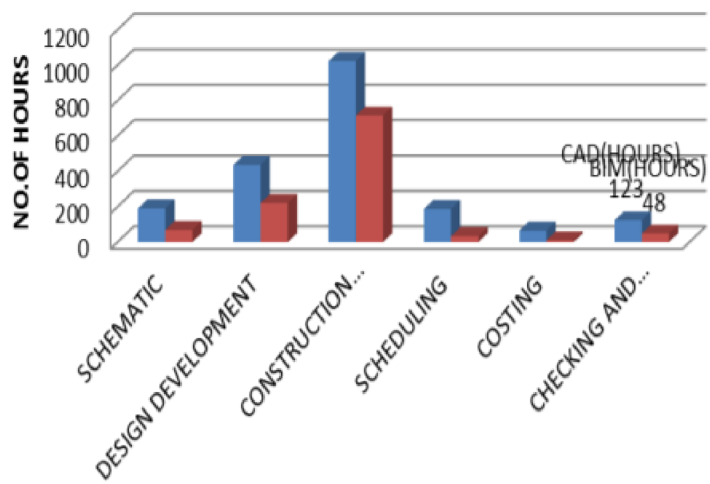
Figure 3-16: 2D cad drawings. Source: (Tiwari, 2017)</td><td>
Figure 3-17: BIM model. Source: (Tiwari, 2017)</td></tr>
<tr><td>Pre-construction phase</td><td colspan="2">

Figure 3-18: Conventional vs. BIM. Source: (Tiwari, 2017)</td></tr>
</table>

No. of days

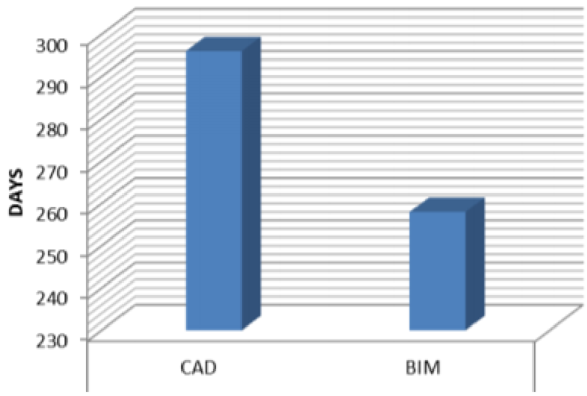


Figure 3-19: Number of days. Source: (Tiwari, 2017)

Cost of activities

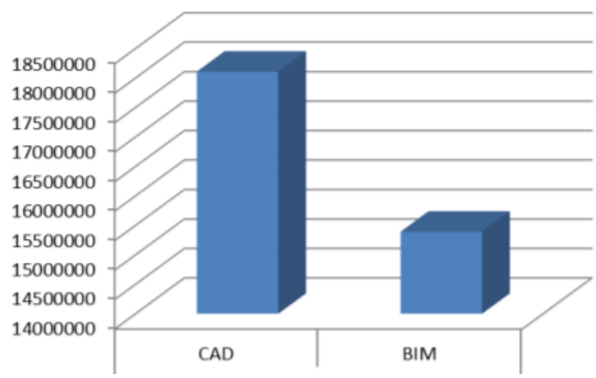


Figure 3-20: Cost of activity. Source: (Tiwari, 2017)

Cost of materials

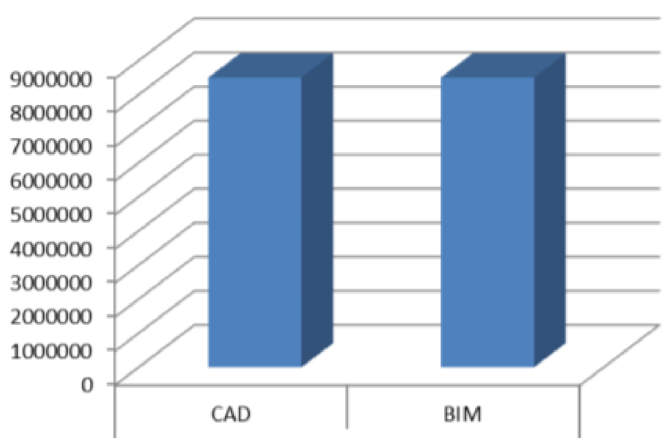


Figure 3-21: Cost of material. Source: (Tiwari, 2017)

Another case study by (Azhar, 2011), the designers use BIM for planning and value analysis to select the most economical and workable building layout Table 3-8.

Table 3-8: Savannah State academic building case study. Sourse: (Azhar, 2011)

Project information	Higher education facility, Savannah State University, Savannah, Georgia • Cost: $12 million • BIM cost to project: $5,000
Process	BIM based cost estimation for three scenarios generated with different cost (budgeted, midrange, and high range)
Findings	• The owner was able to walk through the virtual model to select the best alterative according to his requirements. • 3D collaboration process took place for viewing the different scenarios which improved communication and trust between the project's stakeholders and facilitate decision making in an early stage. • The whole process took only 2 weeks. • The owner achieved about $1,995,000 cost saving at the predesign stage. • BIM helped the owner in making a quick, effective, and well-informed decision.

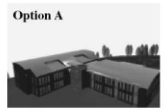
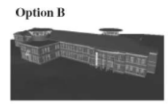
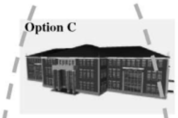
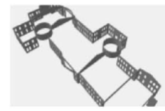
Option/Aspect	Specifications	Option A	Option B	Option C
Front Elevation				
Plan				
Stories	Not specified	2	2	3
Construction Funding	$11,000,000			
Max. Cost/GSF	$147.74			
Area (GSF)	74,459	87,296	83,018	73,852
Net Area	46,537	49,125	50,612	43,338
Net to Gross Ratio	63%	56%	61%	59%
Cost Scenarios				
Budget: $147.74/sf	$11,000,000	$12,897,111	$12,270,919	$10,910,894
Mid-Range: $175.00/sf	$13,030,325	$15,276,800	$14,535,140	$12,924,100
High-Range: $200.00/sf	$14,891,800	$17,459,200	$16,611,600	$14,770,400
Building Skin				
Primary Materials	Brick/Precast/Glass	Brick/Precast/Glass	Brick/Precast/Glass	Brick/Precast/Glass
Skin Articulation	Articulated, Trim	Articulated, Trim	Articulated, Trim	Articulated, Trim
Floor to Floor Height	n/a	14' @1; 14'@ Upper	14' @1; 14'@ Upper	14' @1; 14'@2; 12' @ Upper
Skin to Floor Ratio	n/a	58%	50%	39%
% Glass, % Brick	n/a	20% Glass, 80% Brick	28% Glass, 72% Brick	36% Glass, 64% Brick

Figure 3-22: Savannah state academic building: GSF = gross square foot; sf = square foot (Courtesy of Holder Construction Company, Atlanta, GA). Source: (Azhar, 2011)

To sum up, as mentioned the constructability concepts that were discussed in chapter 2, Table 2-5, C9 concerns about using advanced information technologies in any construction project to overcome fragmentation problems and enhance constructability. From the above literature, BIM has a significant influence on all the constructability concepts that were mentioned in Table 2-4, Table 2-5, and Table 2-6. BIM provides collaboration between the project's team members, and a full integration between all the construction phases. Moreover, applying BIM in the early stage of the project assists in efficient design review for different scenarios analysis, this facilitates the decision for the selection of the best construction method, elements prefabrication, generating schedules, and providing drawing with free errors for construction. This input of BIM in the construction industry leads to cost and time reduction and high quality deliverables which are the three main objectives of the construction industry. In addition, using BIM contributes in the reduction of materials waste, and effective construction management throughout the project lifecycle. Figure 3-23, illustrates the benefits of BIM for construction industry.

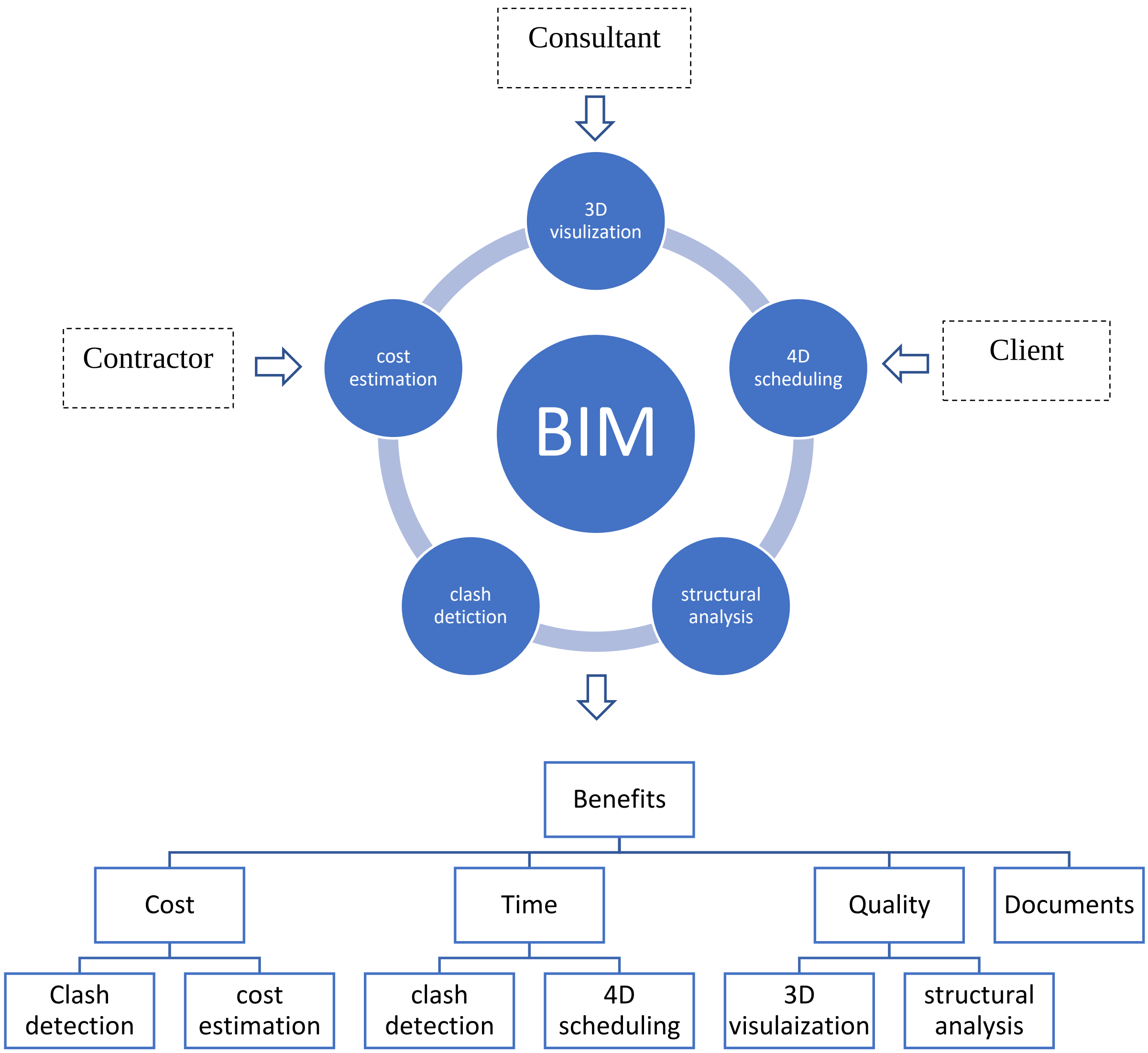


Figure 3-23: BIM benefits for construction industry. By the author

3.7 BIM and sustainable design

One of the barriers to sustainable construction is the notoriously low rate of Information Communication Technology (ICT) adoption. As the most of the adopted information systems are single entry oriented where the software is used for a specific activity in the building and not supporting the collaboration between the AEC players. In addition, most of the software lacked working interoperability. For example, Cad and any project management software work with geometries, quantities, time management, and budget management but none of them can read information directly from the other and updates the project data. The proper use of ICT in the construction industry during the design and pre-construction phases can significantly facilities the sustainable construction process through enabling applications interoperability, information access, intelligent documents, and integrated data exchange (Matar, Georgy, & Abou-Zeid, 2010). BIM can contribute in providing sustainable construction. As a technology, BIM simulates building projects in its virtual environment and integrates all associated data include geometry, geographic information, quantities, relationships, and all the buildings elements properties. In addition, it provides simulation for the building performance in different fields helping the designers to select the optimal proposal for construction (Oduyemi & Okoroh, 2016). Figure 3-24 illustrates the difference between the CAD model and the information interoperability model through BIM.

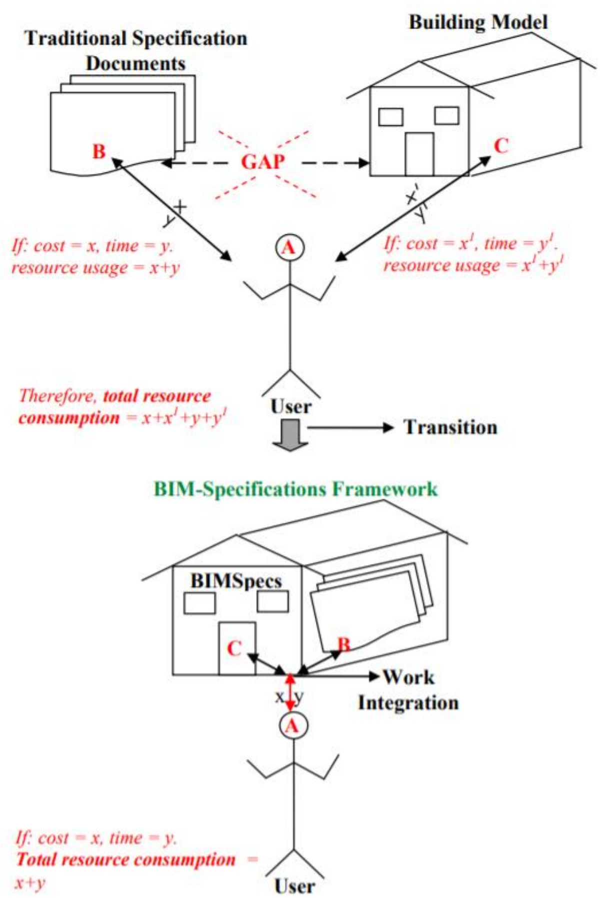


Figure 3-24: BIM interoperability framework vs. traditional framework (Utiome, Drogemuller, & Docherty, 2014)

3.7.1 BIM for sustainable design

BIM can assist in providing sustainable design by (Wong & Zhou, 2015), (Jrade & Jalaei , 2013), (Dowsett & Harty, 2013).

1- Analyzing the building orientation (selecting the best building orientation that can reduce the energy cost).
2- Controlling the indoor ventilation temperature.
3- Analyzing the structural integrity.
4- Daylighting analysis.
5- Water harvesting (reducing water needs in the buildings during construction or operation).
6- Energy modeling (analyze and reduce energy needs, renewable energy options, and reducing energy cost).
7- Analyze the building masses (optimize the building envelope and analyze the form).
8- Materials selection (sustainable materials selection).
9- Site analysis and logistics management (minimize the carbon footprint and construction waste).

(Lu, Wu, Chang, & Li, 2017) have developed the green BIM triangle "BIM green building nexus" to show the interaction between BIM and green buildings and how BIM supports green buildings in different phases throughout the whole building lifecycle, see Figure 3-25. The triangle has divided the green building into three main dimensions, the "project phase", "green attributes", and "BIM attributes". The project phase dimension includes the perspective of the project lifecycle (project design, construction, maintenance and operation, and demolition). The project attributes dimension includes sustainability considerations such as energy saving, thermal comfort, water saving, material selection, waste materials, day lighting, natural ventilation and acoustics analysis. The BIM attributes dimension presents how BIM software contributes to the two green building dimensions by visualization, analysis and simulation, document management, and interaction database. Thought the nexus it was found that BIM could support green building in: 1- the lifecycle of the green buildings analysis, 2- analysis and assessment of green projects.

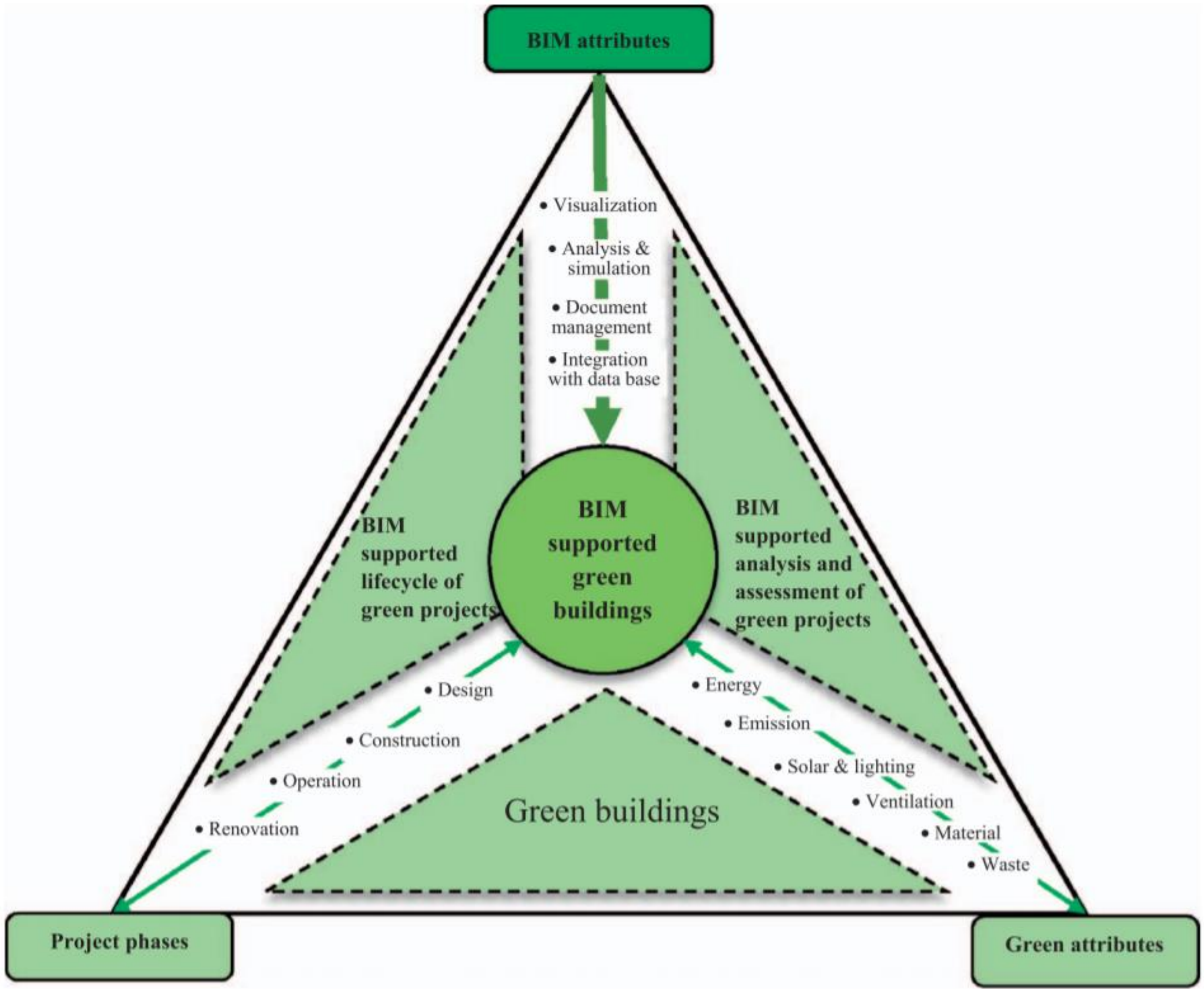


Figure 3-25: Green BIM Triangle taxonomy. Source: (Lu, Wu, Chang, & Li, 2017)

BIM applications have been developed to cover sustainability aspects during the design process. Most of the BIM green applications designed to analyze the building performance; these applications assist the designers by providing an integrated visualized model for the building performance in the early phase of design (Lu, Wu, Chang, & Li, 2017). In Figure 3-26, (Jalaei & Jrade, 2014) illustrates the process of developing sustainable design through BIM interoperability software. The input data like MasterFormat WBS, families and keynotes about the materials and suppliers, the required rating system for sustainability analysis, and the project site orientation and data translated to a BIM model with its financial, environmental, function, and technical information. By applying an exchange interface tool like IFC and the gbXML, the integration between the BIM model and the environmental analysis software used to analyze the sustainability performance. For instance, Figure 3-27 shows the interoperability between BIM authoring tools and dynamic simulation accredited software (Zanni, Soetanto, & Ruikar, 2017). The integrated model should assist the designers in selecting the appropriate building materials, building orientation, and energy model. In addition to sustainability and cost evaluation, the output will be a visualized in a 3D model that includes the selected sustainable materials, energy and daylighting simulation, and the building environmental impact.

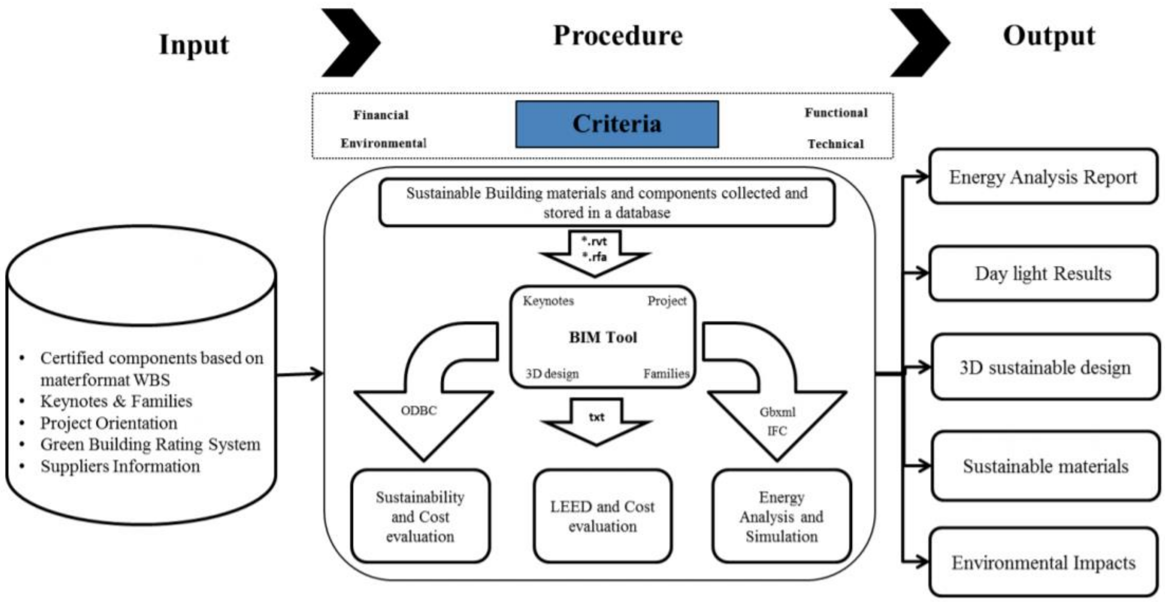


Figure 3-26: Sustainable design process with BIM software interoperability. Source: (Jalaei & Jrade, 2014)

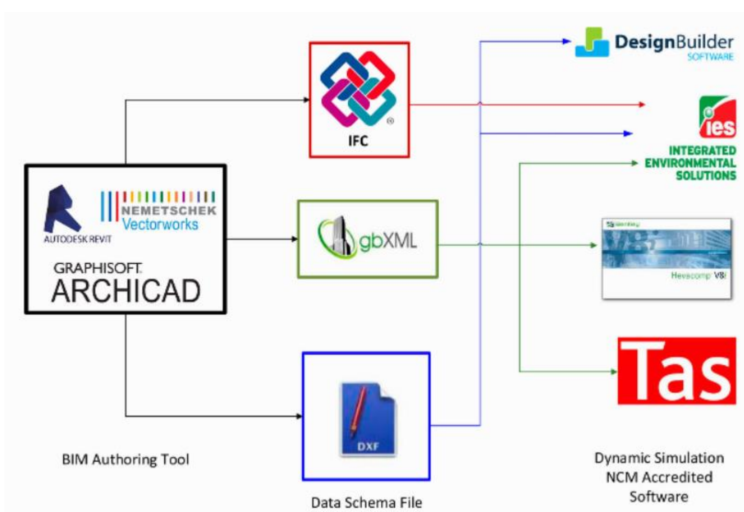
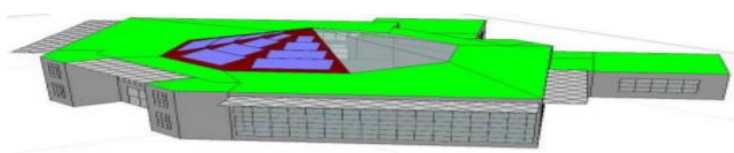
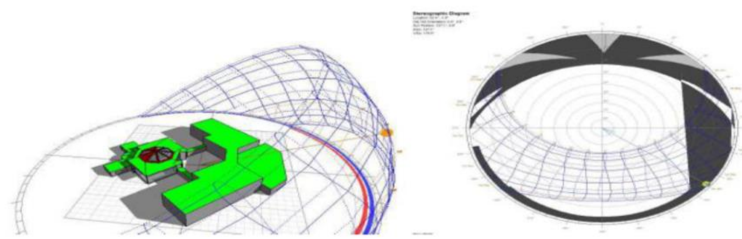
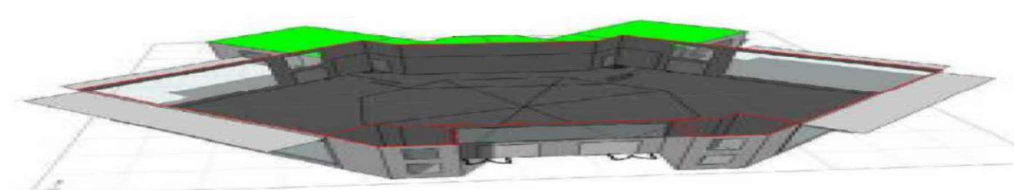


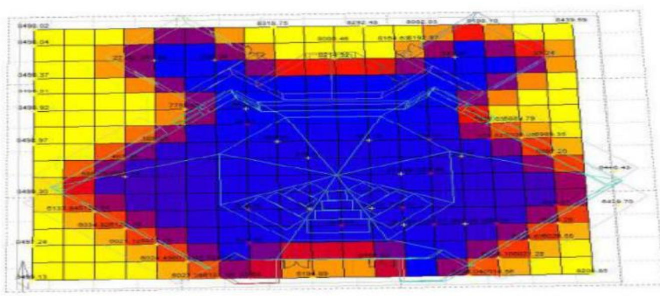
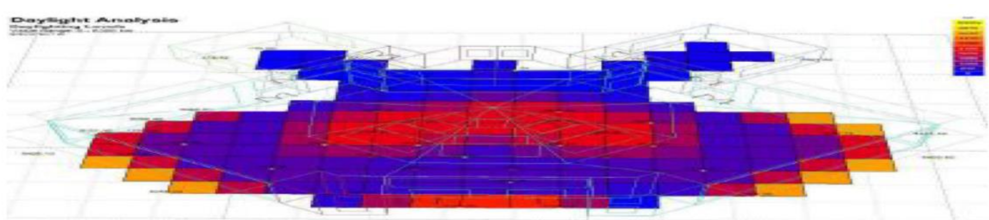
Figure 3-27: Interoperability between BIM authoring tools and dynamic simulation accredited software. Source: (Zanni, Soetanto, & Ruikar, 2017)

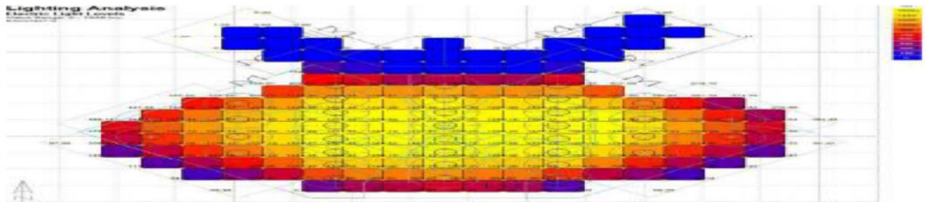
As an example for the benefits of integrating BIM and IPD to develop sustainable building design, (Fajana, 2017) uses a BIM framework to get (sun cast shadow studies, internal sun penetration, shading design, day lighting analysis, artificial day lighting analysis, visual impact studies, environmental cost impact analysis, and energy use analysis). Table 3-9 includes the building data and analysis from the BIM model. The limit of the study was mentioned by (Fajana, 2017) as he did not use an interoperability interface platform. The study has demonstrated that BIM integration tools can enormously assist the designers in achieving decent sensitive analysis for various building design scenarios. In addition, the evaluation of different design proposals in the early design stage eliminates the cost of change in the future. Consequently, BIM provides accurate environmental analysis and reduces the project running cost, lifecycle cost, and GHG emissions.

Table 3-9: Water front multi-use building. Source: adopted from (Fajana, 2017)

Water front multi-use building, consists of self-surviving conference and multi-purpose hall  **Figure 3-28: Water front multi-use building. Source: (Fajana, 2017)**	
Site	Derby North riverside, northern part of the city and bounded by St. Alkmund's Way (inner ringroad), the River Derwent, Exeter Place and Darwin Place, a total area of 2.31 ha (5.7 acres). The area is meant to be redeveloped and integrated back into the city center as the redevelopment of the site area of the city center is one of the priority projects within the Derby Cityscape Master plan.  **Figure 3-29: Site analysis. Source: (Fajana, 2017)**

software	Autodesk ECOTECT “insight recently”, Autodesk Green Building Studio (GBS) and Integrated Environmental Solutions (IES), and Virtual Environment (VE).
Building sun cast shadow analysis and overshadow	The overshadowing and sun path analysis are carried out to determine to what extent the conference room would be overshadowed, especially during the two solstices (December 21st and June 21st) when there is a high tendency of overshadowing.  **Figure 3-30: Sun cast shadow analysis and overshadow. Source: (Fajana, 2017)** An adequate spacing between the hotel tower and the conference hall is required so that the hall will not be overshadowed throughout the year and without putting unnecessary spacing between the buildings.
Internal sun penetration and shading design	Solar design in this study is purposely meant for the summer period while internal blinding would serve as a means of preventing solar penetration (at the wish of occupants) during other months of the year.  **Figure 3-31: Internal sin penetration and shading design. Source: (Fajana, 2017)** Sun shading devices purposely optimized to prevent excessive solar gain in summer. Different shading devises were examined to select the optimized shading device with an athletic quality for the building design. The selected device was to be self- controlled to suit the required shading in the summer and winter time.

Day lighting study	The desired day lighting level for the conference hall ranged from 300 to 500lux and for the multi-purpose hall, so the required day lighting not to be less than 500lux. So, the lux level required to not be less than 500, especially at the podium. Clerestory windows are introduced at the upper part of the adjoining spaces of the podium to throw light into the hall, the door type changed from wooden to glazed door where the lighting analysis shows low lux level with 32lux. This change in the door type increases the lux level but still inadequate.  **Figure 3-32: Day lighting before adding skylight. Source: (Fajana, 2017)** A skylight was introduced to maximize the day lighting level; accordingly, the lux level becomes over 500lux. This change reduces the lighting energy during the day. To avoid the expected losing heat because of the skylight, a proper glazing/translucent material was selected to save the energy gained through the artificial lighting.  **Figure 3-33: Day lighting after adding skylight. Source: (Fajana, 2017)**
Artificial lighting analysis	For the multipurpose halls, the uses are indispensable, especially during night periods where it gets dark as early as 4 pm. Therefore, artificial lighting is also evaluated to ensure that there would be adequate lighting level during the night. Energy efficient bulbs were used with overall lux level from 500 to 1400lux to

	satisfy the lighting needs at night without negative impact on the cost of the project.  **Figure 3-34: Artificial lighting analysis. Source: (Fajana, 2017)**
Visual impact studies	A visibility study was conducted to simulate the outdoor space of the conference hall, the study aimed to ensure that a good view is achieved from any part in the inner spaces by preventing any bad view in the outer space. According to the study, the hotel tower which is part of the project was preventing the river view. In addition, the courtyard view is more than $80m^2$ distance from the eastern and western parts of the site and is bounded by a ring road. From the previous analysis, in order to achieve a good view, proper landscaping should be done in the courtyard, as it is visible from the eastern and western building openings. Also, the northern part should be landscaped. The “earthbound” landscape technique is used to achieve a good view from the inner spaces, prevent noise pollution from the on-going vehicles, and serves as a flood mitigation strategy.
Cost analysis	The cost was assigned to various materials used in the building to evaluate the baseline cost of the less thermal efficient design, as a basis for the comparison. The rough cost estimate was obtained from a guide available at www.homebuilding.co.uk. Initial embodied energy and CO_2 footprint of the materials are also assigned using information from CES, GreenSpec guide and "ecology of building materials." The result shows that the improved glazing panels and the increased insulation thickness resulted in increasing the initial cost of the embodied energy and reduces the building CO_2 emissions. Moreover, the later design achieved adequate daylighting with fewer energy needs for maintenance. Hence, the energy efficient design would consider as the cheapest choice, as it lowers the

	running cost of the energy needs compared to its higher initial cost and embodied energy.
Green building studio analysis (energy use pattern)	The design was exported to GBS in order to evaluate the environmental performance and the lifecycle cost of the final design that was made by the Ecotect analysis software. Various alternatives were explored to calculate the annual energy cost, life cycle cost, and CO_2 emissions. The base design recorded an annual energy cost of £15,786 at current energy cost and a total of £215,007 over the 30years lifecycle. The CO_2 emission is recorded at a total of 53.4Mg CO_2 per year, equivalent to 5.4SUVs/year with the potential of reducing the emission level to 0.3SUV/year, which is equivalent to 3.1Mg CO_2 per annum.

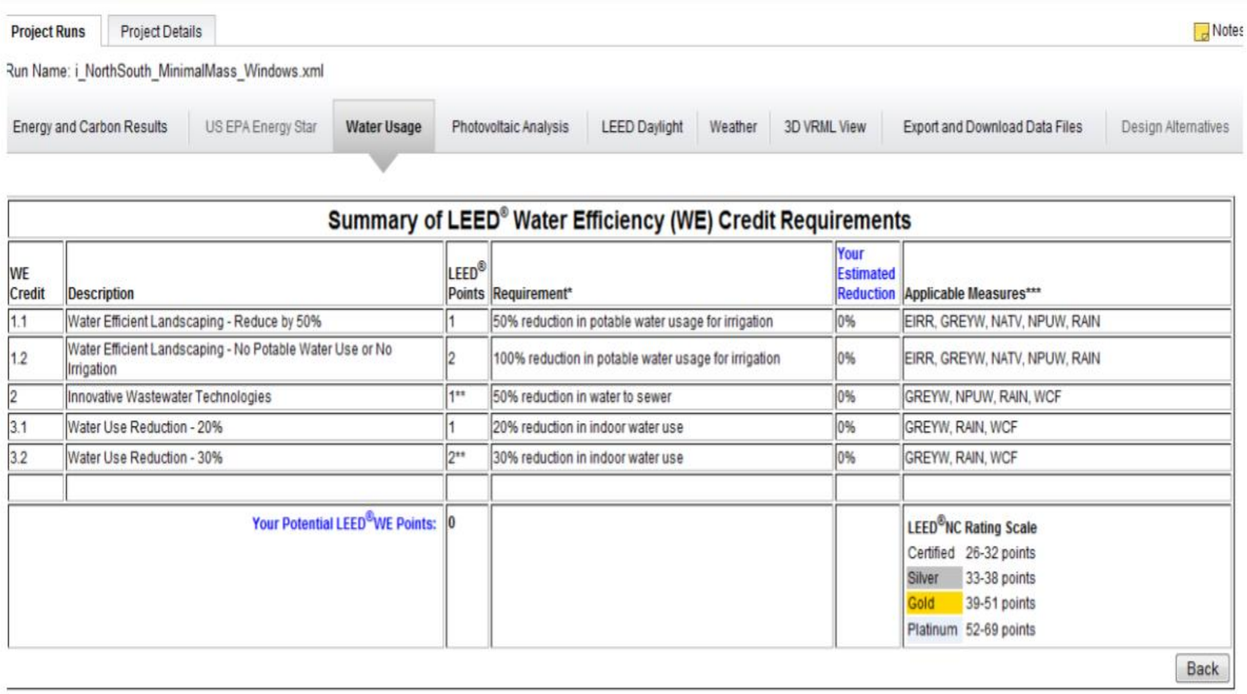
3.7.2 BIM and rating systems

The design concepts that guide a project towards sustainable outcome are (building orientation, energy modeling, daylighting analysis, building mass studies, sustainable materials, water harvesting, and renewable energy) (Solla, Hakim, & Yunus, 2016). As cleared in the previous discussion, BIM has proved its ability in supporting sustainable building design through its different software and platforms. This factor drives many countries to implement BIM in the construction projects (Solla, Hakim, & Yunus, 2016). BIM software can contribute in calculating rating system credits through the model objects information (Solla, Hakim, & Yunus, 2016). For instance, Table 3-10 illustrates the points that can be scored directly from applying BIM for the LEED rating system. LEED silver certification can directly achieve from the information provided in the BIM model, as the BIM software can calculate 38 credits out of the 69 required credits for getting the golden certification. The other 31 credits that are not supported by BIM software can be indirectly achieved using some key information from the BIM model (Solla, Hakim, & Yunus, 2016).

Table 3-10: BIM achievement in LEED rating system. Source: (Solla, Hakim, & Yunus, 2016)

Criteria	Maximum points	Weighting %	BIM points	BIM weighting %
Sustainable sites	14	20.3%	6	8.7%
Water efficiency	5	7.2%	5	7.2%
Energy & atmosphere	17	24.6%	10	14.5%
Materials & resources	13	18.9%	9	13.1%
Indoor Environmental quality	15	21.8%	4	5.8%
Innovation & design process	5	7.2%	4	5.7%
Total	69	100%	38	55%

For example, the Green Building Studio (GBS) "BIM online platform" measures the indoor and outdoor water usage and its cost according to the project location, selected fixture, and occupancy type. The GBS then generates the water calculations required for the LEED water efficiency category (WU, 2010). Figure 3-35 shows the LEED water credit calculated by GBS.



Summary of LEED® Water Efficiency (WE) Credit Requirements

WE Credit	Description	LEED® Points	Requirement*	Your Estimated Reduction	Applicable Measures***
1.1	Water Efficient Landscaping - Reduce by 50%	1	50% reduction in potable water usage for irrigation	0%	EIRR, GREYW, NATV, NPUW, RAIN
1.2	Water Efficient Landscaping - No Potable Water Use or No Irrigation	2	100% reduction in potable water usage for irrigation	0%	EIRR, GREYW, NATV, NPUW, RAIN
2	Innovative Wastewater Technologies	1**	50% reduction in water to sewer	0%	GREYW, NPUW, RAIN, WCF
3.1	Water Use Reduction - 20%	1	20% reduction in indoor water use	0%	GREYW, RAIN, WCF
3.2	Water Use Reduction - 30%	2**	30% reduction in indoor water use	0%	GREYW, RAIN, WCF
	Your Potential LEED® WE Points:	0			LEED® NC Rating Scale Certified 26-32 points Silver 33-38 points Gold 39-51 points Platinum 52-69 points

Figure 3-35: LEED water credit by GBS. Source: (WU, 2010)

3.7.3 BIM and the sustainability pillars and indicators

The need for developing sustainable buildings is increasing daily. Recently, there is a move to ensure that the impact of the built environment on economic, social, and environmental capitals is decreasing rapidly. The most effective sustainability decisions for the construction project are taken in the early design stage. As BIM can analyze multi-disciplinary data within one model, BIM can be an essential part of the sustainability analysis and simulation and can contribute to sustainable construction from the early design stage to the demolition stage. BIM assists buildings sustainability by improving the economic, social, and environmental dimensions in an integrated way (Soltani, 2016), (Ahmad, Aibinu, & Thaheem, 2017).

The following Table 3-11 shows the use of BIM analysis in the three sustainable development aspects and the way that BIM influences each of them. The table identifies the factors that belong to each aspect and the capabilities of implementing BIM in achieving the sustainable building design.

Table 3-11: BIM influence on sustainability dimensions. Source: (Soltani, 2016), (Dutta, Chong, Wang, & Zekavat, 2016)

Sustainability Dimensions	Sustainability factors	BIM implementation	Remarks
Environmental	Site and Land Use Materials Energy Water Air	Orientation Shadow Light Path Heating and Cooling Load Analysis	• Improved energy management; energy saving & reduction • Effective waste management (improve material reuse & resource management • Water Harvesting/Management • Reduced greenhouse gases, carbon emissions & pollution • Use of sustainable, green, & environmental friendly materials
Economic	Long-term Resources Productivity Low running Costs Operating Cost Maintenance Cost Revenue	Cost Estimation Quantity Surveying	• Improved quality management • Better scheduling of construction activities; improved project management • Improved economic results through timely design validation; reduced risks of losses from project failures; on time project completion; effective resource management (including right quantity of materials)
Social	Health Well-being Comfort Social and		• Reduced accidents and onsite hazards; occupant behavior, improved employee productivity; better working conditions; improved

Cultural Values Human Design Community	quality of life and occupant health; social equity; more job opportunities; better quality of service to users/customers • Improved collaboration & coordination between project parties; more bottom-up strategies; better leadership to promote sustainability; improved building management; Effective information-sharing and communication; reduced liability

- **Environmental sustainability:** BIM capability to produce, store, and share all type of building information data make taking the decision towards providing environmental building performance more easier. Thus, minimizing the environmental impact in areas related to water and energy consumption, sustainable materials use, materials recycling and reuse, waste management, LCA, and carbon footprint become easier and possible for the construction industry experts (Soltani, 2016), (Ahmad, Aibinu, & Thaheem, 2017), (Dutta, Chong, Wang, & Zekavat, 2016), (Reizgevicius, Ustinovičius, Cibulskiene, Kutut, & Nazarko, 2018).
- **Economic sustainability:** Many researchers discuss the economic benefits of BIM for investors, consultants, and contractors where it assures economic viability, reduces waste, and enhance productivity. As implementing the BIM technology leads to early clash detection, efficient logistics, and accurate cost calculation throughout the building lifecycle, effective resource management, and better decisions regarding selecting the building systems and materials (Soltani, 2016), (Ahmad, Aibinu, & Thaheem, 2017), (Dutta, Chong, Wang, & Zekavat, 2016), (Reizgevicius, Ustinovičius, Cibulskiene, Kutut, & Nazarko, 2018).
- **Social sustainability:** BIM contributes to creating healthy and livable communities by providing the data and analysis tools to improve the indoor air quality, waste management,

safe site, and construction. In addition to maintaining activities plans, reduce noise pollution, and decrease disturbing operations on municipal infrastructure. Moreover, BIM provides better communication between project's stockholders through the better analysis and decision making tools, and easier access to information provides by BIM software (Soltani, 2016), (Ahmad, Aibinu, & Thaheem, 2017), (Dutta, Chong, Wang, & Zekavat, 2016), (Reizgevicius, Ustinovičius, Cibulskiene, Kutut, & Nazarko, 2018).

3.8 Chapter summary

Building on the two sustainable construction concepts mentioned in chapter 2: sustainable design and constructability, this chapter shows the benefits of BIM towards achieving sustainable construction industry during the design process phase. These benefits can be summarized in improving the efficiency and the productivity of the design process, increasing the quality of the construction drawings, facilitating building systems performance simulation and analysis, assisting in calculating the green rating certificates credits, enhancing the collaboration and communication between the project's stakeholders, and significant cost and time reduction.

CHAPTER 4 : BIM ADOPTION

Adoption is the decision to use an innovative idea or technology using the available actions in a certain context. The decision making for adopting innovation requires knowledge, persuasion, implementation, and confirmation. BIM is an innovative technology that aims to raise the efficiency and effectiveness of the construction industry outputs. However, BIM adoption process is a challenge for the professionals in the construction industry (Hore, McAuley, West, Kassem, & Kuang, 2017).

Recently, the BIM technology shift in the construction industry introduced as a promising tool and process to benefit the AEC stakeholders. The AEC stakeholder can envision the project in detail and get information about its element and performance before construction; this visual model helps the designers and engineers in prober design, planning, construction, and other potential issues for the construction projects (Hidayat, 2018). As discussed in the previous chapter BIM capabilities and benefits for the construction industry are numerous and can assist in enhancing the industry performance and sustainability. This digital transformation not only improves the productivity but also helps in better understanding of the buildings elements and city data paving the way for improving communication in the construction sector and people interaction in the built environment. With these benefits, the AEC industry in many countries like the United States of America (USA), United Kingdom (UK), Singapore, and others decided to adopt BIM in their construction industry.

4.1 BIM framework for implementation

BIM framework is a delivery foundation for the AEC players to understand the BIM implementation requirements. The framework represents the concepts and relationships between different fields and its players to reduce complexity and provide adequate knowledge and validation for the BIM implementation process (Succar, 2009), (Jung & Joo, 2011).

4.1.1 BIM activity fields

There are three BIM activity fields: Technology, People, and Process (TPP) (see

Figure 4-1), each field contain two subfields: deliverables and players (Succar, 2009). These fields illustrated by (Succar, 2009) with presenting the interaction and overlap between them in the following points:

4.1.1.1 Process

The process field can be divided into groups of players who design, manufacture, procure, use, manage, and maintain structures. These groups include architects, engineers, owners, contractors, facility managers, and all the other AEC industry stakeholders who are involved in the construction project delivery, ownership, and operation (Succar, 2009).

4.1.1.2 Policy

The policy players do not involve in delivering any construction product documents. They represent specialized organizations like research centers, insurance companies, educational institutes, and regulatory bodies. They are working as regulators and preparatory for the contractual part related to the design, construction, and the operation processes. Policies here are written principles and roles to guide in the decision making process (Succar, 2009).

4.1.1.3 Technology

This field joins a group of software, hardware, networking systems, and equipment specialists and developers who assist in increasing the productivity, efficiency, and profitability of the AEC industry. This field includes software solution companies, and equipment organizations who are direct or indirect affect the design, construction, and facility management processes (Succar, 2009).

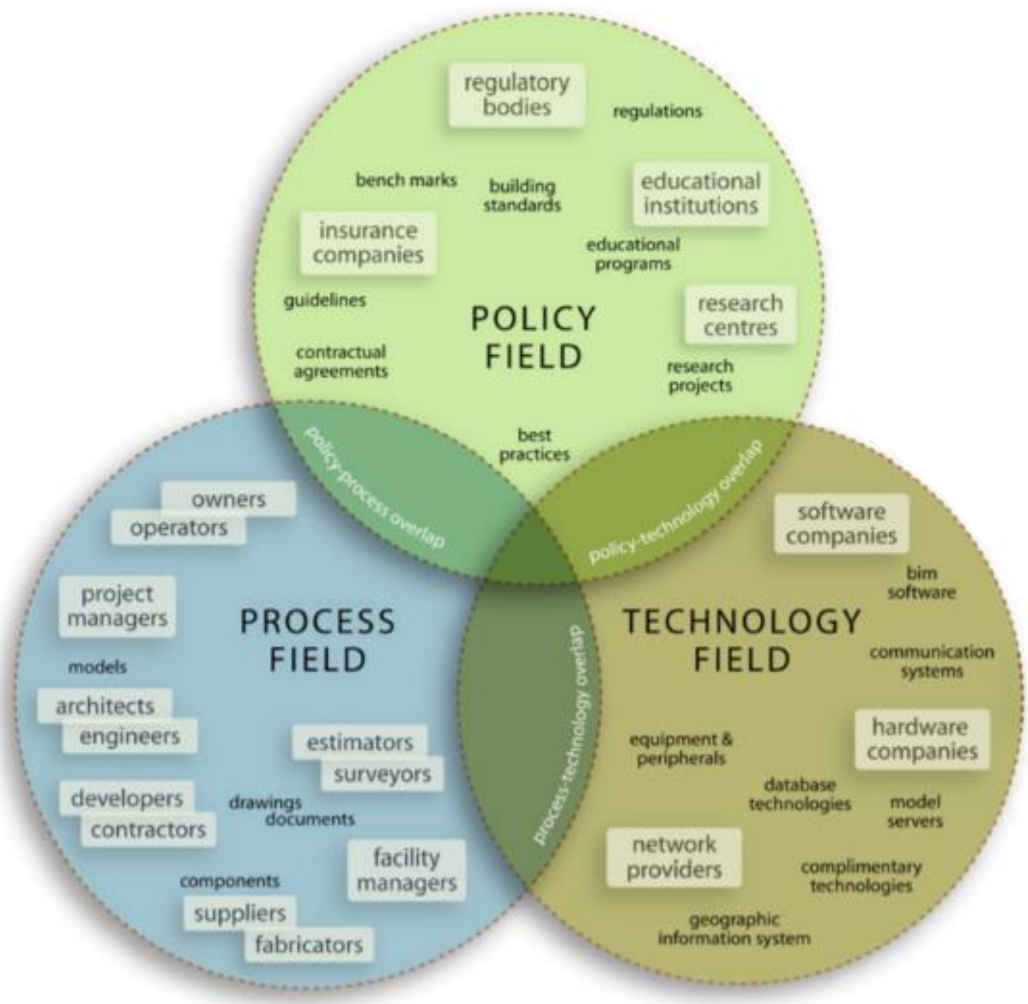


Figure 4-1: Three interlocking fields of BIM activity — venn diagram.mSource: (Succar, 2009)

4.1.1.4 Fields interaction

The interaction between the TPP fields is happened under a pushing and pulling mechanisms between the fields and its sub-fields (see Figure 4-2). The pushing mechanism is a process of transferring knowledge from field to another field /sub-field. The pulling mechanism is the process of requesting knowledge from field to another field / sub-field. The transferred data could be data about the contracts, team dynamics, or technical data. These interactions between the TTP fields are an important component of the work deliverables outputs framework. Table 4-1 illustrates the BIM fields and the interaction between them (Succar, 2009).

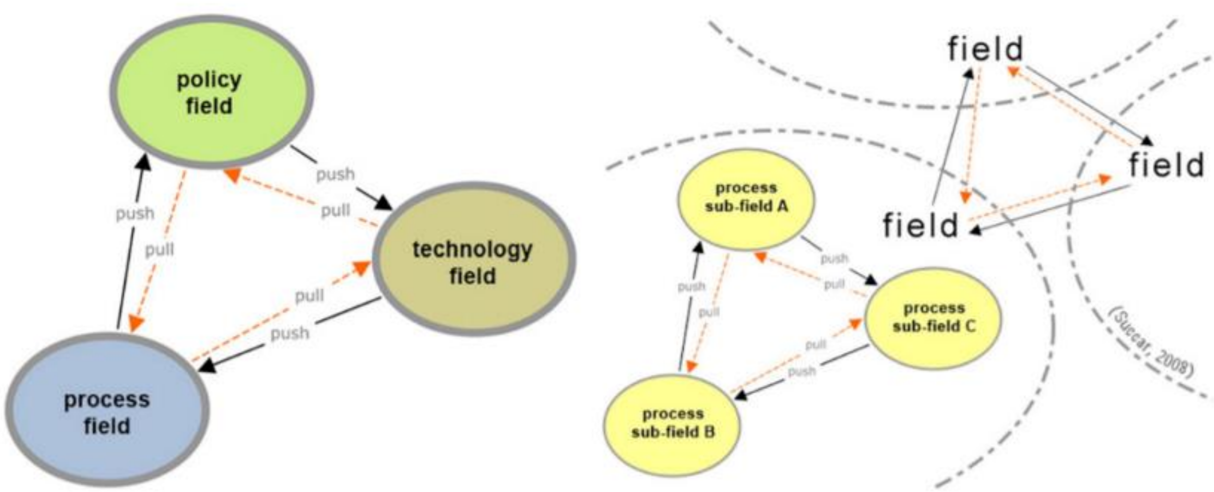


Figure 4-2: BIM interactions between and within fields. Source: (Succar, 2009)

Table 4-1: BIM fields and interaction. Source: (Succar, 2009)

	process field	Policy field	Technology field
Definition	Process is “a specific	Policies are “written	Technology is “the

		ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action"	principles or rules to guide decision-making"	application of scientific knowledge for practical purposes"
Extended field definition		The field of interaction between design, construction and operational requirements for the purpose of generating and maintaining structures and facilities	The field of interaction generating research, talents, standards and best practices for the purpose of safeguarding benefits and minimizing contestation between AEC stakeholders	The field of interaction between software, hardware, equipment and networking systems for the purpose of enabling or supporting the design, construction and operations of structures and facilities
Players (sub-field)		Owners, operators, architects, engineers, estimators, surveyors, developers, contractors, sub-contractors suppliers, fabricators, facility managers, …	Governments, researchers, educational institutions insurance companies and regulatory bodies, …	Software, hardware, network and equipment companies plus their development and sales channels
Deliverables (sub-field)		Construction products and services including drawings, documents, virtual models/components, physical components, structures and facilities	Regulations, guidelines, standards, best practices, bench marks, contractual agreements, educational programs	Software, hardware, peripherals, network solutions, and office/ site equipment
Sample interaction between fields and sub-fields	Push into other fields	-Case studies into Policy -Feedback to Technology	- Skilled graduates, standards, guidance into Process - Concepts, mathematical solutions into Technology	Innovative solutions and new equipment into Policy and Process
	Pull from other fields	-Development of solutions from Technology - Standards, guidelines and graduates from	- Subject matter experts from Process - Interoperability from Technology	-Standardization efforts from Policy - Requirements and experiences from Process

	Push–pull within the same field	Policy Architect's Instructions (AI-push) and Request Further Information (RFI-pull)	Interchanges between research, education and accreditation boards	Hardware capabilities (push) and software requirements (pull)

4.1.1.5 Fields overlap

The three fields are sharing deliverables and players which form an overlap between them. This overlap happened when: 1- players from different fields responsible for one deliverable. For example, using an integrated technological tool like IFC needs cooperation between the researchers and technology developers (policy & technology fields). 2- Players in a field develop a deliverable that will take place in another field. For example, architects (process field) develop best practice guidelines (policy field) (Succar, Building information modelling framework: A research and delivery foundation for industry stakeholders, 2009). See Figure 4-3

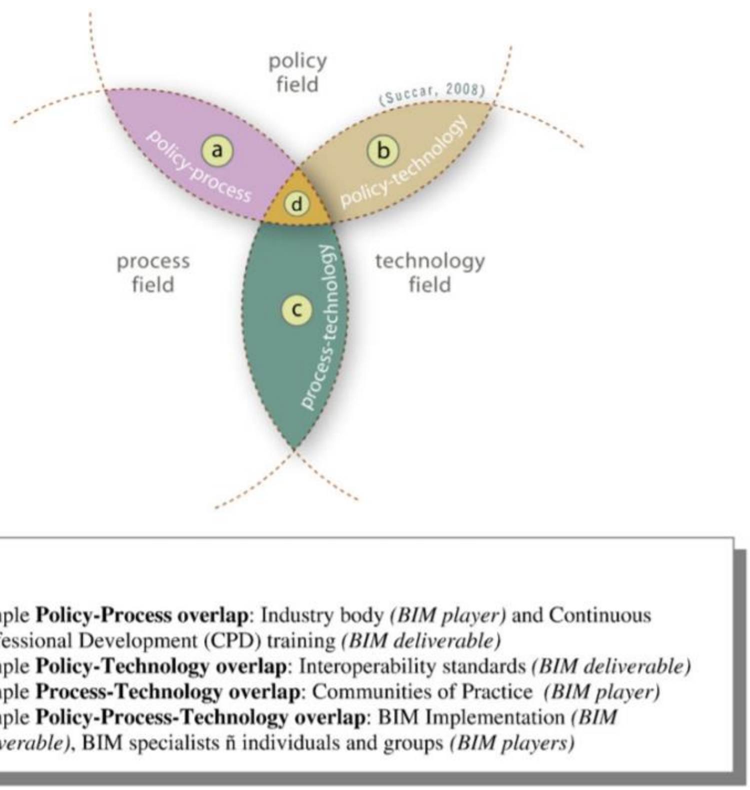


Figure 4-3: BIM fields overlap. Source: (Succar, 2009)

4.1.2 BIM maturity level

With the continuous BIM development, BIM adopters need to manage the process of BIM implementation within their organizations (Porwal & Hewage, 2013). Accordingly, (Succar, 2009) developed three fixed BIM stages to delineate the implementation maturity level (object-modeling-based collaboration – network-based integration). The BIM maturity levels include the TPP activities fields and divide them into the three maturity stages according to the level of proficiency (Succar, 2009).

Figure 4-4: BIM maturity stages. Sourse: (Succar, 2009)

In order to measure the BIM maturity level and facilitate the implementation process, (Succar, 2009) divided the three main phases of the construction project lifecycle into three sub-phases Where the whole project's lifecycle activities are managed before the construction process. Table 4-2.

Table 4-2: Project's life cycle phases and sub-phases. Source: (Succar, 2009)

Design phase (D)		Construction phase (C)		Operation phase (O)	
D1	Conceptualization, programming and cost planning	C1	Construction planning and construction detailing	O1	Occupancy and operations
D2	Architectural, structural and systems design	C2	Construction, manufacturing and procurement	O2	Asset management and facility maintenance
D3	Analysis, detailing, coordination and specification	C3	Commissioning, as-built and handover	O3	Decommissioning and major re-programming

4.1.2.1 BIM stage 1: object-based modeling (Succar, Building information modelling framework: A research and delivery foundation for industry stakeholders, 2009)

In this stage, each discipline generates its own 3D model for the different phases (a model for the design phase, a model for the construction phase, and a model for the operation phase). The data extracted from these models are used in preparing 2D documents and 3D visual models for the construction systems. Only minor changes occurred at this stage where each model is a stand-alone model and the data exchanged between the project stakeholders is unidirectional and the communication is still divided. However, all the project's systems become visualized and can be used in the coordination process for clash detection, schedules generating, and in encouraging the project's fast-tracking. For example, the project team can accurately manage the change requests when there is an overlapping between the design and construction phase. The positive results from this stage are expected to contribute to the upgrading for the next stage. See Figure 4-5.

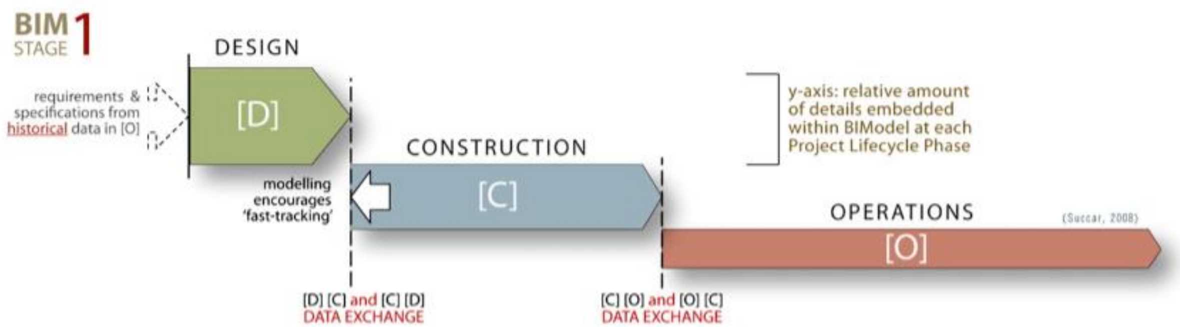


Figure 4-5: Maturity level - stage 1: object-based. Source: (Succar, 2009)

4.1.2.2 BIM stage 2: model-based collaboration (Succar, 2009)

In this stage, the disciplines players can collaborate with each other where the collaboration between two project phases can occur and the communication began to improve although it still in its primary stage. However, the separation between the project stages began to fade. For example, it becomes possible to interchange between the architectural and structural models. See Figure 4-6 .

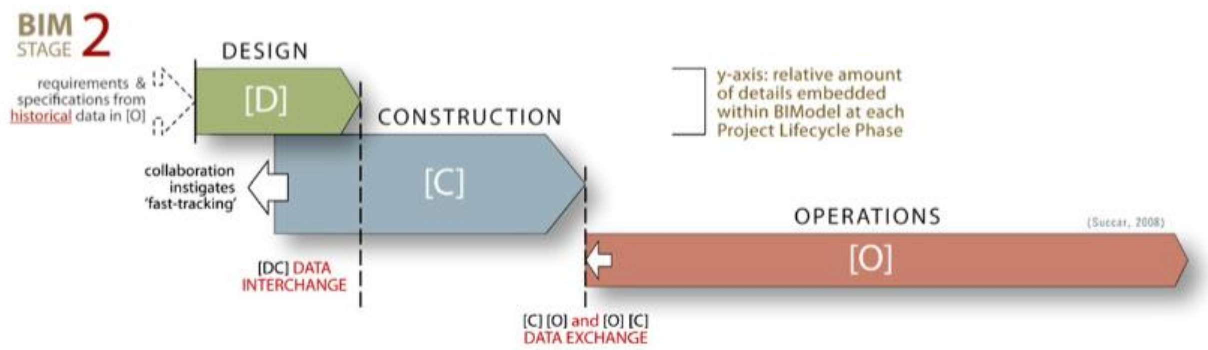


Figure 4-6: Maturity level - stage 2: model-based collaboration. Source: (Succar, 2009)

4.1.2.3 BIM stage 3: network-based integration (Succar, 2009)

The project reaches the integrated model where all the systems are integrated, developed, shared, and maintain collaboration between project's lifecycle. BIM stage 3 model is an interdisciplinary model that allows complex analysis like green policies, life cycle costs, lean construction, and business intelligence at the early stage of project design. See Figure 4-7.

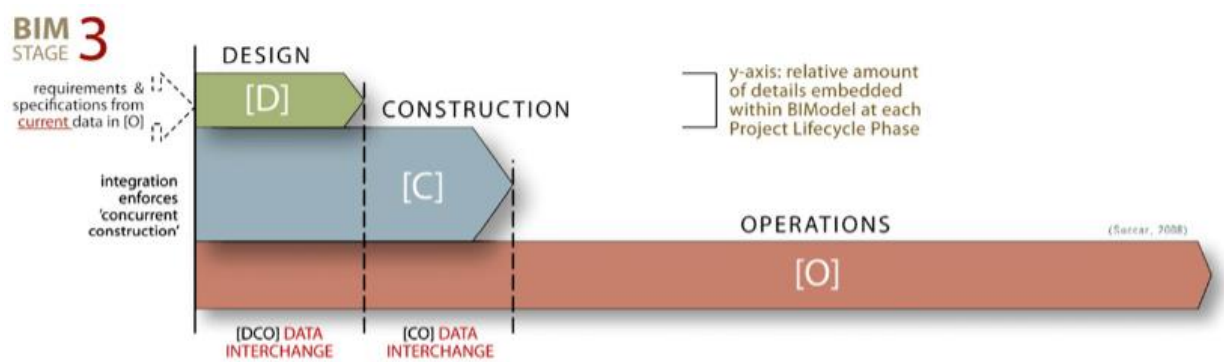


Figure 4-7: Maturity level - stage 3: Network-based integration. Source: (Succar, 2009)

Figure 4-8 illustrates the steps taken to upgrade from one maturity level to another including the TPP activity fields that are used to identify the required technology, policies, and processes needed to step up for the next level (Succar, 2009). An example for the TTP activity fields that should be included in the steps for upgrading is shown in Figure 4-8.

Figure 4-8: Steps leading from maturity level to another with TTP. (Succar, 2009)

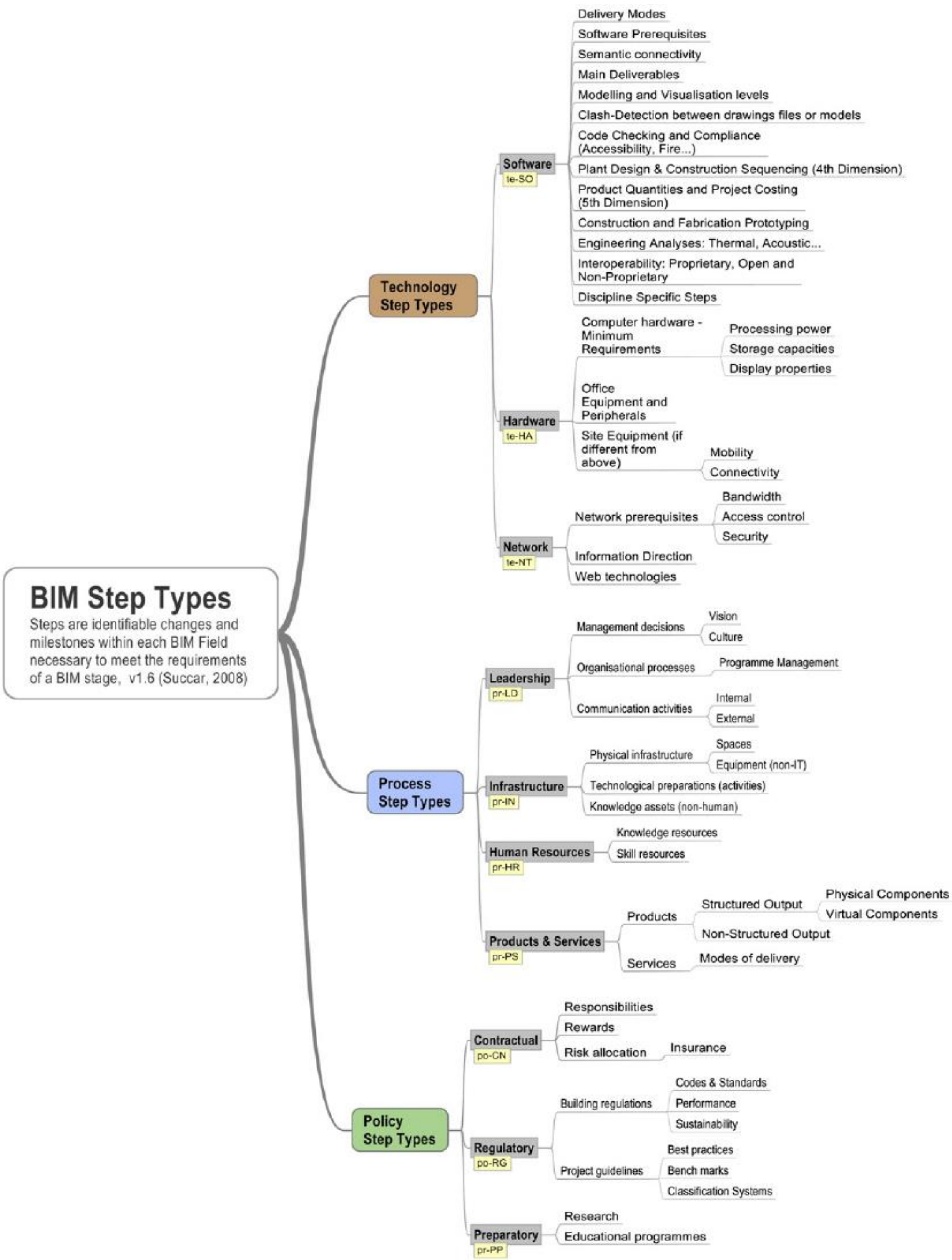


Figure 4-9: TTP fields included in BIM maturity steps. Source: (Succar, 2009)

The BIM steps matrix is used to help the AEC companies to measure BIM maturity level (Succar, 2009), where organizations can measure their BIM implementation efforts and development progress through this matrix. See Figure 4-10.

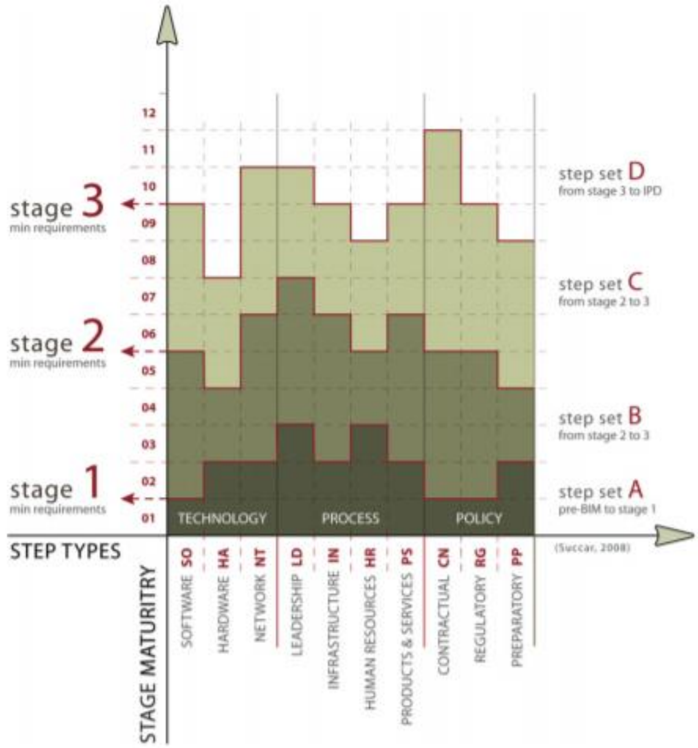


Figure 4-10: BIM maturity steps matrix. Source: (Succar, 2009)

The UK BIM maturity model (Figure 4-11) which was developed by the UK department of Business Innovations and Skills (BIS) is an example for a BIM implementation maturity level model where the model has defined the levels from 0 to 3 (Porwal & Hewage, 2013).

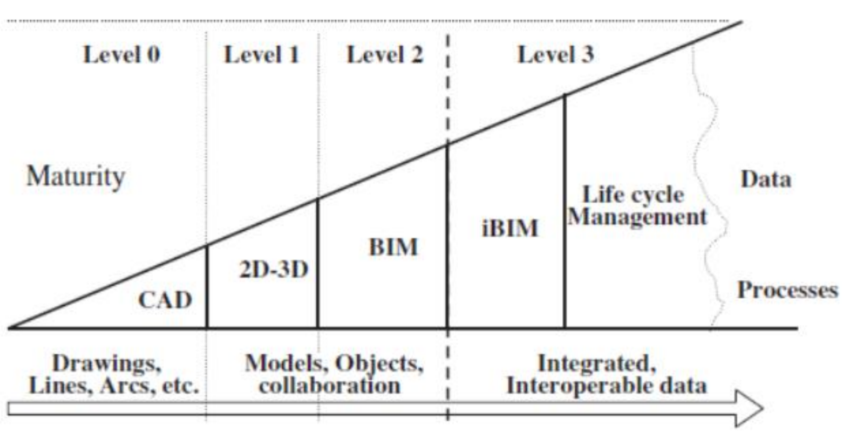


Figure 4-11: UK BIM maturity model developed by BIS. Source: (Porwal & Hewage, 2013)

Another example for the maturity level model is the Model Progression Specifications (MPS) for BIM (E202-2008), this model was developed by the American Institute of Architects (AIA) to address the adoption phases, milestones, and deliverables. Level of Details (LOD) was defined by MPS to describe the logical steps for the BIM model progress. The LOD is starting from LOD 100 to reach 500 (Table 4-3) as a beginning, and additional LODs can be added with the developing of the MPS after practicing (Porwal & Hewage, 2013).

Table 4-3: Model progression specifications (AIA). Source: (Porwal & Hewage, 2013)

LOD	100	200	300	400	500
Model concept	Conceptual	Approximate geometry	Precise geometry	fabrication	As-built
Design & coordination (function /form/behavior)	Non-geometric data or line work, areas, volumes, zones etc.	Generic elements shown in three dimensions • maximum size • purpose	Specific elements Confirmed 3D Object geometry • dimension • capacities •connections	Shop drawing/fabrication • purchase • manufacture • install • specified	As-built • actual

4.1.3 BIM guidance

In order to facilitate BIM implementation, the construction industry bodies (government, companies, and public authorities) need appropriate BIM guidelines to be mandated through contracts. The BIM guidance covers main topics like interoperability, collaboration modes, BIM Execution Plan (BEP), simulation & analysis, BIM manager role, schedule of payment, and operation & maintenance requirements (Sacks, Gurevich, & Shrestha, 2016). The BIM guidance topics are defined in the following Table 4-4.

(Sacks, Gurevich, & Shrestha, 2016) defined BIM guidance as “the national, organizational or project level documents that establish common ways of working and the contents of BIM exchanges that are appropriate within the relevant contexts and along project timelines.”

Table 4-4: BIM guidance topics. Source: adopted from (Sacks, Gurevich, & Shrestha, 2016)

Interoperability	Open data management, to stipulate how building data exchange

	between providers and in what formats for all building phases.
Role of BIM Manger	The responsibilities of every person involved in the project management. (Project model manager, project coordination manger, BIM facilitator).
Modes of collaboration	How project team collaborate. Such as defining the contract form to be used like (IPD).
(BIM proficiency)	The minimum skills and experience required regarding the project's design and construction team.
BIM functions through project phases	What are the project phases and deliverables in each phase.
Level Of Development / Level Of Details	Level of modeling requirements and definition, and level of maturity. Specifying the development of details required in the project.
Operation & maintenance requirements (COBie)	The required building information format for handover to be used in operation & maintenance.
BEP	BIM work plan, management plan, required data management, and specific plan for the BIM project's information flow (Asset Information Model (AIM))
Simulations	Building analysis and energy modeling tools if required in the project.
Schedule payments	Some document prepared by construction clients for early a percentage of the designers' fees earlier in the project because most of the project's fees stipulated due to the early developing of the project's details.

4.2 BIM adoption pillars and factors

(Hadzaman, Takim, & Nawawi, 2015), (Mohammad, Abdullah, Ismail, & Takim, 2018) have investigated many articles to recognize the main pillars and factors affect the BIM implementation roadmap for countries and organizations. (Mohammad, Abdullah, Ismail, & Takim, 2018) have classified the pillars into seven pillars each pillar has activities and factors according to its technical and functional requirements. The pillars activities and factors are illustrated in the following Table 4-5 as mentioned by (Mohammad, Abdullah, Ismail, & Takim, 2018).

Table 4-5: BIM adoption pillars and factors affecting BIM implementation roadmap. Source: (Mohammad, Abdullah, Ismail, & Takim, 2018)

Pillar	Activities	Factors
Standard and	BIM standard and common practices,	Process

Accreditation	guidelines, reference documents, accreditation for certification of BIM projects.	Policy Implementation plan
Collaboration and Incentives	Collaboration with other bodies and vendors, BIM funds and supports including cost software, hardware and training).	Infrastructure Compatibility Interoperability Vendor Complexity Equipment and Peripherals Organizational strategy Organizational vision Financial resources BIM risk External pressure External supports Subcontractor relationship
Education and Awareness	BIM conference, competition, promotion, award, training modules and syllabus.	Training Education
National BIM Library	BIM library standard, cloud computing, national BIM library	Data management
BIM Guidelines & Legal Issues	National BIM guide, legal issues	Security
Special Interest Group	BIM committee to share the information	Management
Research and Development	Research fund and sponsor	Relative advantage

4.3 BIM adoption in consultancy offices

BIM implementation requires gradually large changes in the organization business methods. As when the BIM maturity level increase in the organization, the demand for changing in the firm disciplines structure increase (Succar, Building information modelling framework: A research and delivery foundation for industry stakeholders, 2009).

4.3.1 Organizational adoption risks and challenges

Chapter 3 discussed the benefits of BIM to the construction industry that were numerous forming a great development in the construction practices and quality. However, the BIM implementation process needs a professional management to gain the benefits of adoption.

(Barakeh & Almarri, 2018) review many literature and have listed 30 risks that occur when adopting BIM in any organizations. The extracted risks mentioned in the following Table 4-6. Each risk is classified according to the TTP BIM activities fields depending on the risk type and its area of influence.

Table 4-6: BIM risks classification. Source: (Barakeh & Almarri, 2018) (modified)

Risk	Type
Unawareness of standards for BIM implementation	Policy
Unawareness of the contractual implications of BIM implementation	Process
Need for various new software licenses with different languages	Technology
Long project lifetimes cannot keep up with rapid BIM technological change	Technology
Discrepancy in legal BIM frameworks between different countries	Policy
Lack of distribution of operational/developmental costs of BIM between industry stakeholders	Process
Fear of low success/high failure due to team's lack of experience in BIM	Policy
Interoperability between BIM programs and loss of valuable data	Technology
Uncertain ownership of BIM model	Process
The significance of the training and recruiting costs in the BIM process	Technology
Lack of collaboration of stakeholders	Process
Absence of higher management support and an organizational culture that supports BIM implementation	Policy
Resistance to change at cultural and operational levels and difficulty of adapting to a new system	Policy
Lack of contractual agreements and legal instruments for BIM	Process

High overall initial investment costs in BIM	Policy
The organization as a whole lacks experience in dealing with the BIM system	Policy
BIM's collaborative approach increases risk sharing between stakeholders and reduces definition of clear liabilities	Process
Time spent to learn using BIM	process
Lack of client demand in certain industries	Policy
Unawareness about BIM and its major enhancements to the project delivery process	Policy
The fragmented nature of the construction industry (lack of high-level collaboration, integration of database and commitment to incorporate BIM)	Policy
Lack of electronic BIM standards for coding objects and methods of measurement	Policy
BIM's collaborative approach makes project participants assume accurate input from others	Process
BIM's added dimensions (cost and scheduling) creates difficulty in unifying the software and analysis platforms between stakeholders	Process
The need for sophisticated equipment and programming services requires radical changes in the organization's working system	Technology
BIM specialist usually require higher salaries than traditional CAD designers	Process
Gap in staff skills in cost estimating and 4D modelling which both have great value to project and organization	Process
Difficulty of BIM adoption in small firms due to investment cost	Policy
Reluctance of team members to share information and communicate effectively	Process
The use of different BIM models between engineers lacks integration and reduces modelling efficiency	Policy

(Barakeh & Almarri, 2018) then suggest a four-level strategy to mitigate the risks according to the: (strategic/Market – contractual/Stakeholders – organization – project team).

- **Strategic/Market**: Governments and public authorities are the first and main pushing driver towards BIM adoption. Governments act on pushing the construction sector to implement BIM by mandating it in the construction industry strategy through its public authorities. In addition, governments should support the privet sector in enhancing the quality of the implementation process where the efficiency of the implementation in the organizations deliverables are working as a pulling force towards BIM adoption.

- **Contractual/Stakeholders**: BIM contracts define the legal issues for a framework that can enhance BIM model collaboration, better client participation, increase the project team capability for BIM implementation, and fulfill the government standard. Contracts also solve the problem of the BIM model ownership between the stakeholders.
- **Organization**: should upgrade their managerial structure to incorporate the new job positions for the BIM process. In addition, design firms need to develop the skills of their experts and staff, adopt motivation strategies and training to fasten the implementation process and reduce the staff resistance to change. Moreover, organizations need to develop a lifecycle cost analysis for the projects to encourage their clients to ask for using BIM in their projects and focus on the selection of the BIM team members especially for the managerial positions.
- **Project team**: supporting open communication and knowledge between the project team reduces the risks of losing data and minimize the costs and time of recruiting and training. The project manager should control the input of each team member in the central model to avoid liability issues and set the number of coordination meetings needed between departments to ensure the integration between the building systems in the model.

4.3.2 Implementation drivers and management practices among organizations

The four-level strategy is used in solving the risks of implementing BIM in an organization. As stated before, for a successful implementation many researchers argued that the change in the organization structure is necessary for gaining the benefits of the BIM implementation (Lindblad & Vass, 2015). Moreover, BIM adoption is linked to the consistent support from the top management of the design firms (Lines & Vardireddy, 2015). In this context, (Olatunji, 2011) stated that the major required changes for the shifting to BIM process are (developing workable architecture facilitate and efficient information repository interoperation between disciplines, launch new values, behavior, and attitudes for sharing information, establishing a database that can support integration between networks, protect model ownership, and adopting a flexible project delivery system that can support integration like the IPDs systems). (Olatunji, 2011) illustrates the implementation change agents and drivers as shown in Figure 4-12, the proper management of these agents and drivers should lead a smooth and efficient transition from the traditional system to the BIM system.

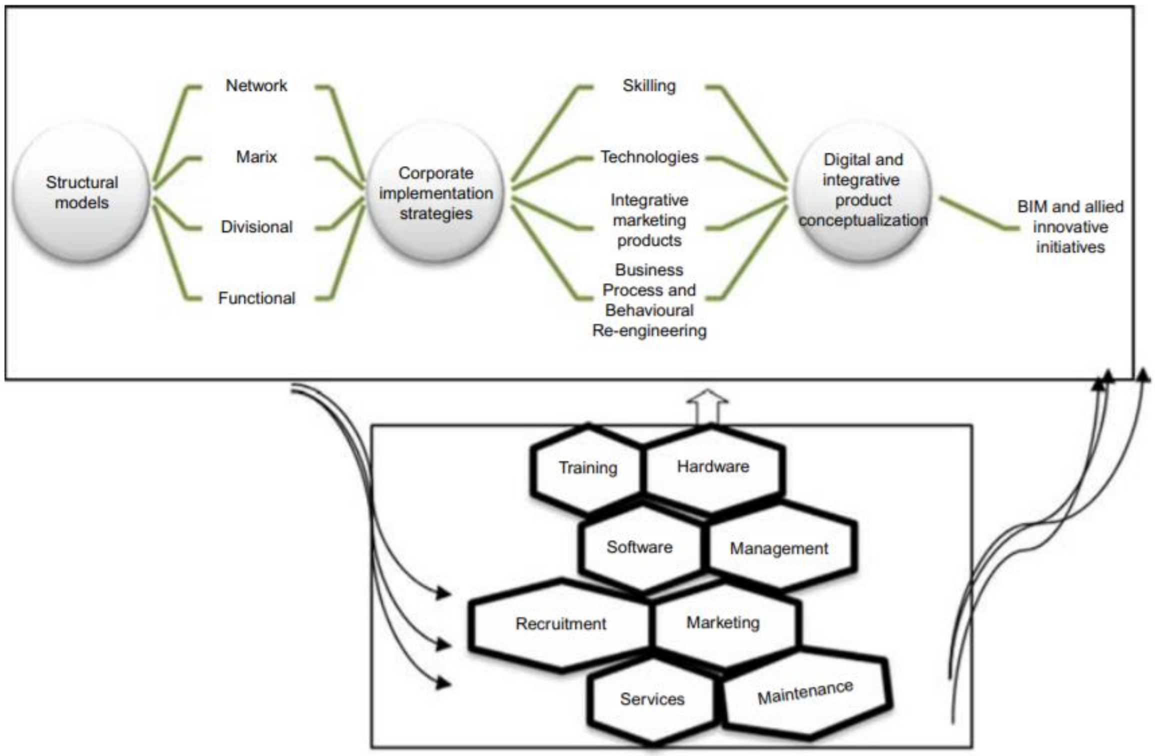


Figure 4-12: Change agents and drivers of BIM implementation at corporate level. Sourse: (Olatunji, 2011)

(Lines & Vardireddy, 2015) mentioned the change management practices for BIM implementation in the following Table 4-7. The researchers have recognized these practices from testing organizational change initiatives across a broad number of organizations all over the world. The study found:

1- The changes in the management practices are consistent across industries.
2- Employees' passion for the change is the core of any shifting plan.
3- Successful adoption needs an effective change management strategy, where industry professionals are learning from practicing and can take actions to improve the change management practices when needed.

Table 4-7: Recommended change management actions for organizational BIM adoption. Sourse: (Lines & Vardireddy, 2015)

Change management practices	Recommended actions for change practitioners
Change agent effectiveness	Identify change agents who are influenced by the change from senior executives. Designate time & resources for change agent job responsibilities (i.e., not overburdening for the change). Ensure change agents are active, visible, and available to help employees throughout the change.
Communicated benefits	Answer the question, "What's in it for me?" for all stakeholders within the company. Create urgency by illustrating the disadvantages of the status quo. Celebrate intermediate wins with employees to showcase relatable results.
Measured benchmarks	Clearly identify (and track) the quantifiable performance outputs expected. Define any new abilities, capabilities, processes, and functions that the company will acquire. Ensure accuracy of the performance data and use the data to enforce positive accountability.
Realistic timescale	Develop an implementation plan that accounts for all major change-related transition activities. Avoid the temptation to push aggressively for a quick fix; rather, maintain focus on long-term adoption. Set leadership expectations for patience and forgiveness of minor setbacks, which will encourage the change.
Senior leadership commitment	Provide visible demonstrations of commitment for the duration of the change. Be sure to walk the talk wherever possible by participating in the company's new practices.

	Illustrate that the change is not a fad by showing that leaders are focused on long-term adoption.
Training resources	Provide up-front training and guides to minimize uncertainty before initiating change processes. Establish avenues to encourage employee questions. Provide on-the-job training for each employee's job function.

4.3.3 Drivers

(Azmi, Chai , & Chin, 2018) organized the drivers from (Olatunji, 2011) in three BIM components drivers (Culture Case, Technology case, and Business case) which are organized among stakeholders.

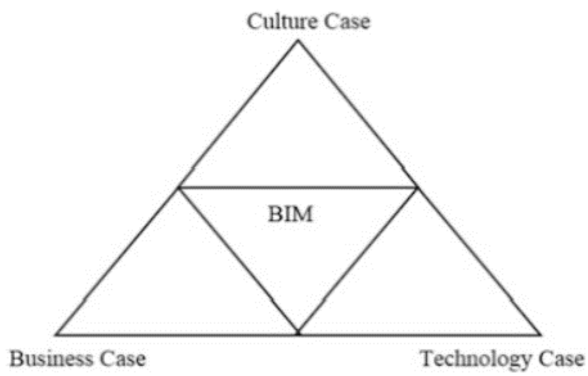


Figure 4-13:BIM Drivers. Source: (Azmi, Chai , & Chin, 2018)

- **Culture case:** human cultural factors like personal initiative, mutual respect, trust, and comfort with work progress, productivity, and work behavior, the effect of technology on design, legacy, and owner suspend auto-ship impact the effort of BIM adoption. For instance, a strong team that can communicate and collaborates with each other is highly needed in the BIM environment. In addition, the project team should be trained on the management integrity to support the organizational work environment.
- **Technology case:** the project team management abilities to integrate software is highly required in the BIM process, as the quality of the hardware and software is not enough for producing a successful BIM model. Furthermore, the proper use of the technology will facilitate the collaboration and communication between the project teams. Moreover,

the software can be used in developing one data management practices to suit both the project's and employees' requirements.

- **Business case:** Return On Investment (ROI) topics related to the model ownership, insurance, and standard procedure in firms "in the long run" are the issues concerned by the organization stakeholders, as the BIM software tannings and the software and hardware cost are the major challenges in the implementation process. Stakeholders should believe in the value gained from BIM in order to invest in implementing it.

4.4 Global adoption

BIM adoption in the construction industry has started from the mid- 2000s to overcome the fragmentation of the construction industry and seeking to increase the efficiency of the industry through applying ICT innovation in it (Mehran, 2016). BIM implemented for the first time in 2006 by the United State Army Corps of Engineers (USACE). Then in 2007, the United States General Services Administration (GSA) decided to implement BIM to improve the construction projects' design quality and deliverables (Cheng & Lu, 2015). In the UK, the Royal Institute of British Architects (RIBA) set a work plan in 2013 that aims to address the fragmentation and coordination issues in the UK construction industry and find a proper solution for eliminating these problems. Later on, the UK government has set a plan to mandate the use of 3D BIM in all the country governmental construction projects by 2016 (Mehran, 2016). Recently in 2016, the National BIM Specification (NBS) reported that BIM usage in the UK increased from 13% in 2011 to reach 54% in 2016 (McAuley, Hore, & West, 2017). Sequentially, governments across the globe increasingly started to adopt BIM as they have recognized the benefits that can be gained from the transition towards BIM in the construction industry (McAuley, Hore, & West, 2017). The European Commission understands the ability of BIM on strengthening its energy and environmental transition policy. Accordingly, the commission established the EUBIM task group that represents the public sector organizations and ministries of the construction industry from 21 European (EU) countries in July 2017. The aim of the group is to strengthen the public sector BIM implementation capabilities by supporting the central governments' departments in applying BIM in their projects. The EUBIM handbook mentions that the group aims to enable a new construction sector era by adopting BIM in the construction industry and claims that by the spreading the BIM digital practices in the construction projects, the EU can save about €130 billion from the construction industry expenses (EUBIM, 2017). (McAuley, Hore, & West, 2017) reported that BIM contractors all over the world had adopted BIM in 30% of their projects. The overall global BIM adoption map is available at the end of the chapter, Figure 4-20.

4.4.1 Macro diffusion dynamic model

(Succar & Kassem, 2015) developed the macro diffusion model to evaluate and compare the directional pressures and mechanisms that describe how the transmission to BIM takes place. The model includes three dynamic diffusions: Top-Down, Middle-Out, and Bottom-down. See Figure 4-14

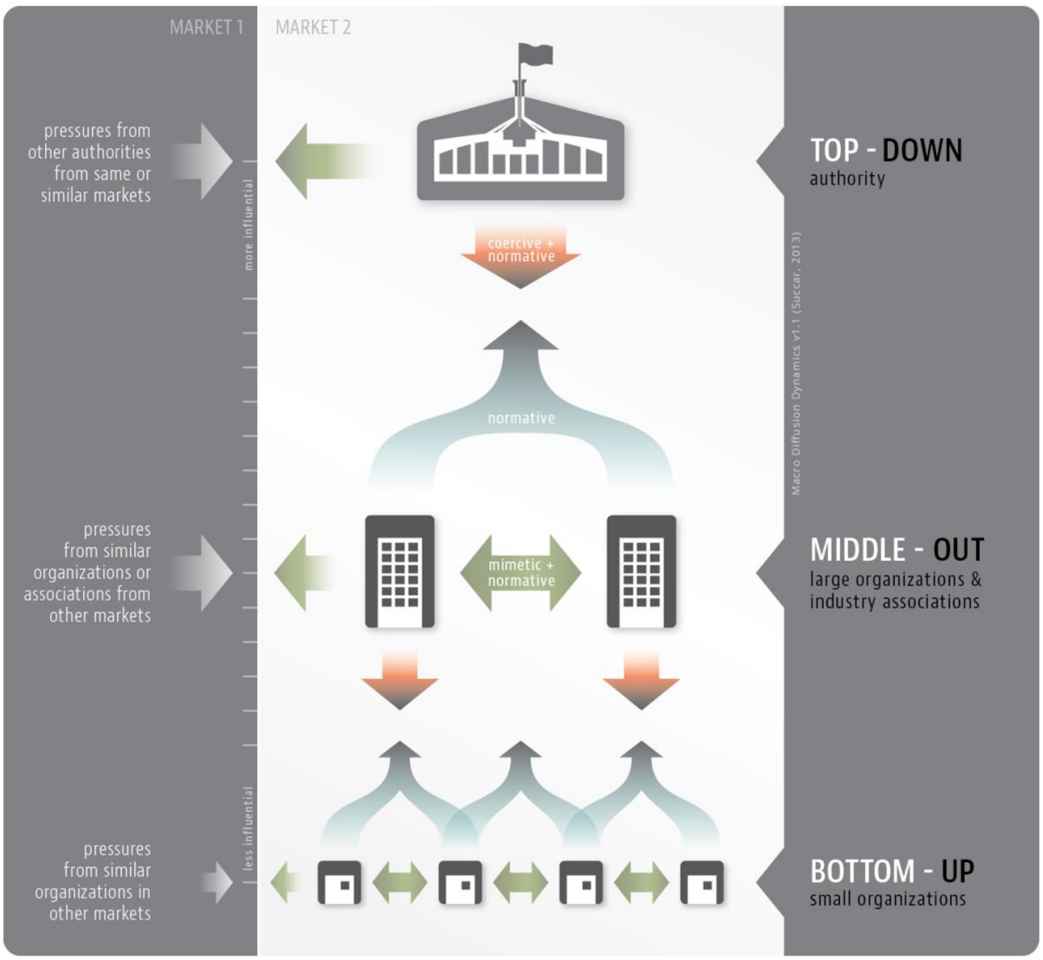


Figure 4-14: . Macro Diffusion Dynamics model. Source: (Succar & Kassem, 2015)

4.4.2 Role of governments and public sector

In order to recognize the role of the governments and public sectors in the BIM adoption methods, the following Table 4-8 shows the BIM adoption situation in six countries that have the best practices (USA, UK, Singapore, Hong Kong, Qatar, and United Arab Emirates (UAE)). Each country BIM adoption experience will be discussed to figure the BIM implementation approaches in each of the six countries and identify the best approach required for BIM adoption on the governmental level.

Table 4-8: Role of governments and public sectors in BIM adoption "six countries". Sourse: (Hore, McAuley, West, Kassem, & Kuang, 2017)

Country	Government	Public sector
USA	Multiple Mandates through different states	GSA USACE National Institute of Building Science buildingSMART USA
UK	Mandated since 2016	UK BIM Alliance Construction Industry Council UK BIM Task Group buildingSMART UKI
Singapore	Mandated in place since 2015	Building and Construction Authority buildingSMART Singapore
Hong Kong	Mandated since 2014	The Hong Kong Institute of BIM (HKIBIM) Hong Kong Housing Authority (HKHA) Real Estate Developer Association buildingSMART (Hong Kong)
AUE	Mandated since 2013	Dubai Municipality Emirates BIM Group
Qatar	No regulations to date	Q BIM Future BIM Implementation Qatar 2017

4.4.2.1 The USA BIM adoption experience

As stated before, the USA was the pioneer of the BIM implementation globally. The BIM usage by professionals was increased from 28% in 2007 to 71% in 2012 which is the highest growth in BIM implementation all over the world (Hore, McAuley, West, Kassem, & Kuang, 2017).

USACE was the first to implement BIM after then the GSA leads the BIM implementation in the USA. In 2013, GSA established the 3D and 4D BIM in order to increase the work efficiency and design quality to meet the highest construction project requirements quality. Consequently, the GSA from 2003 to 2007 constructed 35 pilot projects with BIM successfully and BIM becomes an obligation on all the projects submitted to the Public Service Commission (Tekin & Atabay, 2018). In addition, the GSA required a model-based design with BIM and all the deliverables should be submitted in the IFC format for all the projects. The GSA required BIM submission as mandatory for all the public projects since 2008 (Silva, Salvado, Couto, & Azevedo, 2016). Despite the national government BIM standards, the BIM implementation in USA has many standards and guidance according to the state or public bodies' requirements. For instance, the three states of Ohio, Wisconsin, and Tennessee have developed BIM standards by their city government bodies. Wisconsin state; for example, issued guidance that required using BIM for all projects with over than $ 5 million and $ 2.5 million for the new construction projects. Many other standards and guidance was developed by public bodies and universities in different states (Cheng & Lu, 2015). For example, Indiana University required BIM for all projects with funding over than $ 5 million. Figure 4-15 shows the BIM standards and guidance developed by states governments and universities.

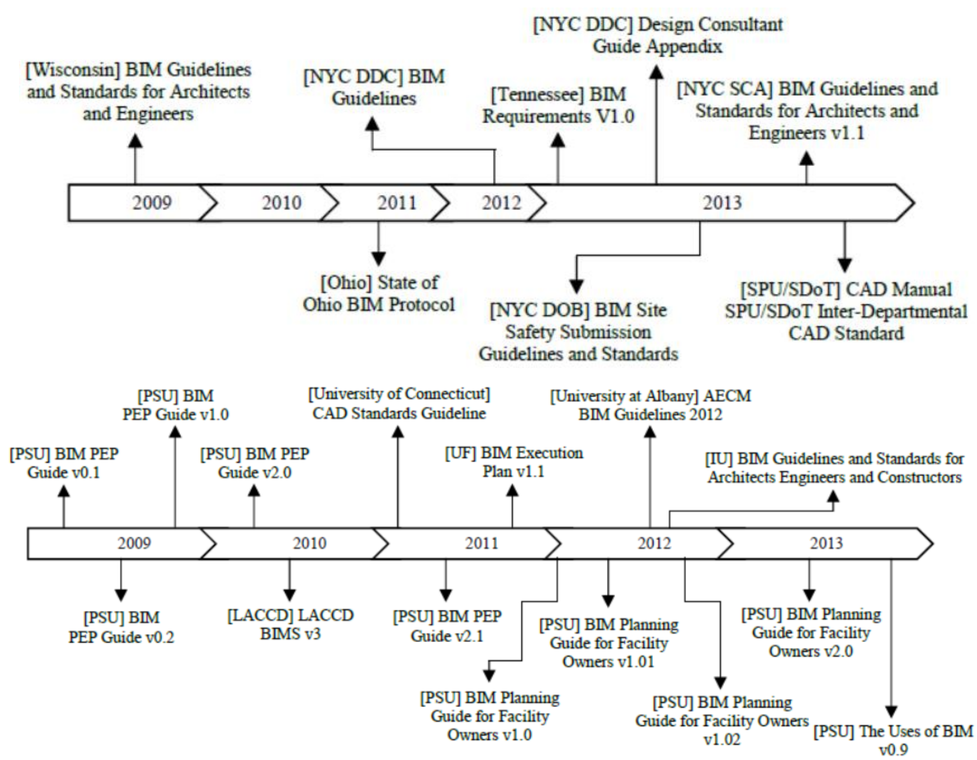


Figure 4-15: USA BIM standards & guidance. (Cheng & Lu, 2015)

In 2013, the AIA (an example for the public sector initiative in BIM implantation in the USA) established the contract documents G202-2013 to coordinate with the E203-2013 (BIM and Digital Data Protocol Exhibit). The purpose of the document is to write the agreement protocols and procedures for governing the development transmission, use, and exchange of the BIM models on the project (G202-2013 Project BIM Protocol, 2013). (Harley & Gambill, 2014) reviewed the AIA 2017 contracts documents updates and stated, “The new 2017 documents now require that the parties agree on protocols governing the use of, reliance on, and transmission of digital data. The General Conditions further require the use of E203 (Building Information Modeling and Digital Data Exhibit), G201 (Project Digital Data Protocol), and G202 (Project BIM Protocol) to establish those protocols. In fact, the AIA owner-contractor agreements expressly incorporate by reference the E203 BIM and Digital Data Exhibit. If the parties reach an agreement as in the transmission of digital data, or if the parties do not negotiate or agree upon this item, then the AIA standard protocols govern”. Other BIM standards developed by public sector are mentioned in Figure 4-16.

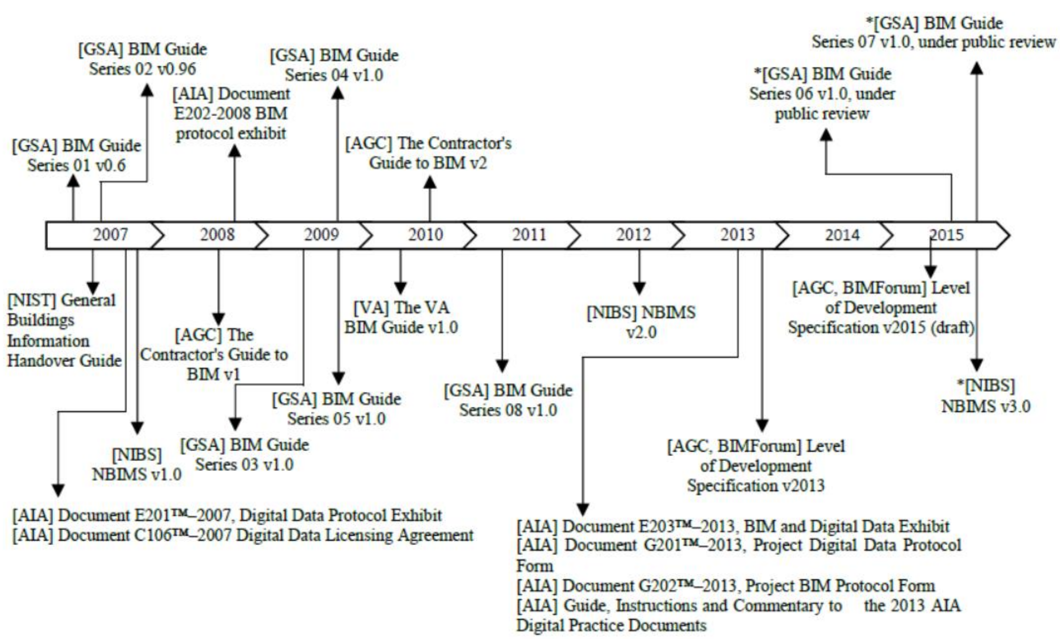


Figure 4-16: Pubic sector BIM standards and guidance. Source: (Cheng & Lu, 2015)

4.4.2.2 The UK BIM adoption experience

UK BIM implementation strategy is the most ambitious and advanced central driven strategy in the world. One of its objectives is to make the UK construction industry a global BIM leader. The government has mandated BIM for all public projects start from £5 million since 2016 (Silva, Salvado, Couto, & Azevedo, 2016). In addition, the central government is targeting 20% saving in procurement costs through BIM implementation (Smith P. , 2014). The government established the BIM task group to assist the public sector clients and the private sector supply chain in restructuring their work practices to facilitate the BIM implementation process. The UK AEC consultancy firms were affected dramatically by this shift. For example, some firms are facing a problem with the technological requirements capabilities that are needed to adopt BIM, as BIM needs advanced hardware and software infrastructure (Cheng & Lu, 2015). For fulfilling the ambitious governmental strategy, the Construction Industry Council (CIC) worked with the British Standards Institute (BSI) and the UK-AEC committee to develop BIM standard for the digital data exchange. The BSI developed two standards: PAS 1192-2: 2013, which is specified in the information management process to support BIM level two requirements – PAS 1192-3: 2014 to assist in the operation phase (Tekin & Atabay, 2018). In addition, to strengthen the BIM deliverables efficiency and the use of the BIM model in building systems analysis and simulation, the National BIM Standard (NBS) developed the online BIM library, which includes the construction products with all its required data (manufacture, cost, specifications, etc.…) to be imported in the model during design. By using the data offered on the product manufacturer model, more accurate analysis of the building systems is acquired (NBS, n.d.). The UK construction industry strategy for 2025 means to reduce the initial cost of construction and the whole buildings lifecycle by 33%, fasten the construction deliverables for new buildings and refurbished ones by 50%. The strategy also plans to reduce greenhouse gases emission in the built environment 50% and improve construction product exporting by 50% to reduce the trade Gap between importing and exporting (GOV.UK, 2013). For this ambitious strategy, the government decided to invest in people and technology to reach these aims and established the 2050 group to develop the core set of skills and training requirements for technical experts and young users to expert the BIM technology (Tekin & Atabay, 2018).

4.4.2.3 The Singapore BIM adoption experience

The Singapore construction industry starts to transform to BIM since 2003, the purpose of the transformation was to establish the fastest building permission and increase the construction sector productivity (Tekin & Atabay, 2018). The Singapore Building and Construction Authority (SCA) has mandated BIM since 2015. The government established a Construction Productivity and Capability Fund (CPCF) to support BIM adoption by S$250 million (Cheng & Lu, 2015). Earlier in the 2000s, the Construction Real State Network (CORENET) program was developed by the Building construction Authority (BCA) as the first world e-submission platform for the construction projects. The CORENET includes infrastructure for information exchange between project participants; in addition to a center for building codes, regulations, and circulars published by various building and construction regulatory agencies. The CORENET e-Plan assists architects and engineers in checking the BIM designed building for regulations through the online gateway (Edirisinghe & London, 2015). In 2010 and 2011 the BIM model e-submission was accepted by the building authority (Tekin & Atabay, 2018), and the Singaporean building authority accepted the IFC standard for the BIM documents submittals (Cheng & Lu, 2015). In 2012, the SCA mandated BIM for the public sector building projects. In 2013, architectural BIM model e-submission was mandated for all new building projects greater than 20,000 m2. In 2014, engineering BIM model e-submission was mandated for all new building projects greater than 20,000 m2. In 2015, architectural and engineering BIM model e-submission was mandated for all new building projects greater than 5,000 m2. The Singaporean BIM Guide was first launched in 2012 consists of BIM modeling and collaboration procedures and BIM specifications (Edirisinghe & London, 2015). Universities and polytechnics contribute to the BIM transaction by offering BIM training courses, seminars, and workshops regularly. In addition, the National University of Singapore (NUS) published its first BIM version NUS BIM to be merged with the SG BIM guide in 2015 (Mustaffa , Salleh , & Ariffin, 2017).

4.4.2.4 The Hong Kong BIM adoption experience

The HKHA was the first to adopt BIM in Hong Kong since 2006 and aimed to fully adopt BIM in all of its projects by 2014. Since 2006, the HKHA adopted BIM in over 19 pilot public housing projects and prepared in-house BIM standards, guide, and library component design guide (Edirisinghe & London, 2015). In 2013, the CIC established the BIM workgroup to develop a BIM roadmap to mandate the BIM implementation in the county's construction industry. The CIC organized seminars and promotion activates to promote the roadmap that was developed in the same year. "BIM Year 2014" launched the BIM excellence awards for the best BIM practices and contribution among the local parties and the complete version of CIC BIM standard was released by the HKIBIM for public review. HKIBIM developed the BIM standards and with the cooperation with buildingSMART Hong Kong, they organized seminars to educate the local construction industry on the BIM benefits and requirements (Cheng & Lu, 2015).

4.4.2.5 The Qatar BIM adoption experience

Although there are no governmental BIM standards, guidance, or mandate plan, the BIM presence in Qatar increases gradually. (Hore, McAuley, West, Kassem, & Kuang, 2017) returned this presence to the Qatar national vision 2030 to develop megaprojects where the nature and size of projects influence Qatar to use BIM to facilitate the ambitious building time schedule. For example, the Doha's Metro station and the great number of stadiums are to be built and operated for the FIFA world cup 2022 that makes BIM the best choice for efficient time and quantities management and building quality requirements. These projects follow the protocols (AIA or PAS 1192-2 standards) for the BIM model management according to the firm strategy or the client's requirements. In addition, many conferences conducted to show BIM cases in Qatar like the BIM user day 5 in 2015 at Qatar University and the Future BIM Implementation conference in 2017 to show the BIM implementation capabilities in improving the management of complex construction and infrastructure projects in Qatar. Qatar BIM Guidance Group was established and forms several meetings with the Qatar University BIM Group (Q-BIM) a group of researchers who are supported by the Qatar Foundation. The Q-BIM interests in supporting and growing BIM standards through mentoring, networking, strategic alliances, and recognizing excellence in BIM adoption (Hore, McAuley, West, Kassem, & Kuang, 2017).

4.4.2.6 The UAE BIM adoption experience

In 2013, Dubai Municipality mandated BIM for architecture and MEP on buildings over 40 stories or more than 27,871m2, and government projects including schools, universities, and hospitals. In 2015, the Municipality expanded the users of BIM to include projects owners, consulting firms, contractors, and governmental departments. The update also includes the BIM uses by architecture and MEP on buildings to be over 20 stories and required structural models for buildings over 40 stories. In 2016, the municipality called the local construction firms to support and provide data for the national bank for research and development in order to form a best practice references and develop BIM standards for the UAE (Hore, McAuley, West, Kassem, & Kuang, 2017). (Mehran, 2016) outlined that there is a higher demand for BIM projects from the industry clients as they are understanding the benefits of BIM projects (Mehran) also mentioned that the Emirates BIM Group have been assisting in introducing BIM software for new users.

4.4.3 Best practices and approaches to BIM adoption

Governments and public authorities are playing the key role in BIM adoption. As discussed, the BIM adoption leading countries (USA, UK, and Singapore) have an active governmental and public sector efforts in implementing and improving the BIM practices. The main driver for these countries is the ambitious construction strategies plans to improve the efficiency, productivity, and sustainability of the construction industry. Unlike the other countries, the UK government was the first to mandate BIM in the country through its public projects (Up-Down diffusion). Other countries like USA, Singapore, Hong Kong, and UAE, the BIM was first mandated by the public authorities and then adopted within the governmental strategies (Middle-Out diffusion). Other drivers like the complexity of the construction projects and catching the new trends in the construction industry technologies are influencing countries like Qatar through the AEC firms (Bottom-UP diffusion). The successful BIM implementation requirements are recognized in the following:

- The collaboration between the government, industry leaders, and public authorities.
- Proper implementation scheduling.
- Pilot projects (business case) to measure the success.
- Education and training.
- Increasing of the level of maturity gradually.
- National standards, guides, and protocols.
- Project delivery system like (IPD).
- National and international object library.
- Change in the construction business environment.

(bimSCORE, 2013) organized the approach to BIM adoption in countries from minimal existence to fully adopted BIM, Figure 4-17. This work was developed to The Asia-Pacific Economic Cooperation (APEC) on the support of green building industry.

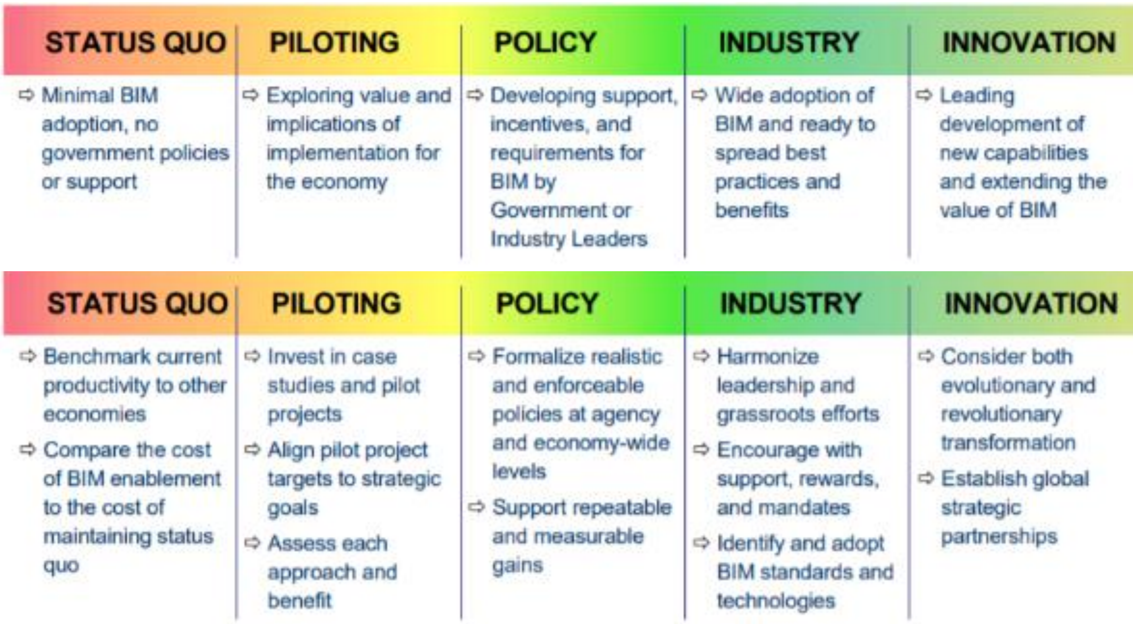


Figure 4-17: BIM adoption stages and actions. Source: (bimSCORE, 2013)

4.5 BIM adoption role in sustainable construction

Resulting from reviewing the countries BIM implementation approaches, the sustainability of the construction industry needs a country vision that is supported by policies and action plans for education, resources conservation, sustainable building guides, and innovative inputs. For example, the UK government has a clear vision for sustainable construction by 2025 (GOV.UK, 2013). The strategy is to reduce energy and water consumption, increase the use of renewable energy, reduce CO2 emissions, increase the use of recycled building materials and sustainable materials, and reduce construction waste generation. In addition, the vision aims to sustain the leadership of the UK construction industry worldwide and develop the industry technicians' skills and qualifications. Accordingly, the smart construction and digital design were one of the priorities in the UK action plan towards sustainable construction. The UK is investing in training people and improving technologies to assist in achieving the planned goals. BIM adoption plan is the technological pillar that was chosen by the UK government to form a transition digital revolution on the construction market. As adopting BIM with the green building policies and regulation and the construction product improvement is part of the UK construction industry vision 2025 (GOV.UK, 2013).

The "pyramid of coordinated actions" was developed by (bimSCORE, 2015) to illustrate the required actions towards sustainable construction. First, the government vision is at the top of the pyramid to develop policies and regulations. Then the industry professionals and academic institutes are establishing supportive standards to support the national vision. Finally, a broad base of projects, teams, professionals, and enterprises needed to evaluate, track, and maintain the plans are at the base of the pyramid, see Figure 4-18. This holistic approach should enhance the construction sector sustainability.

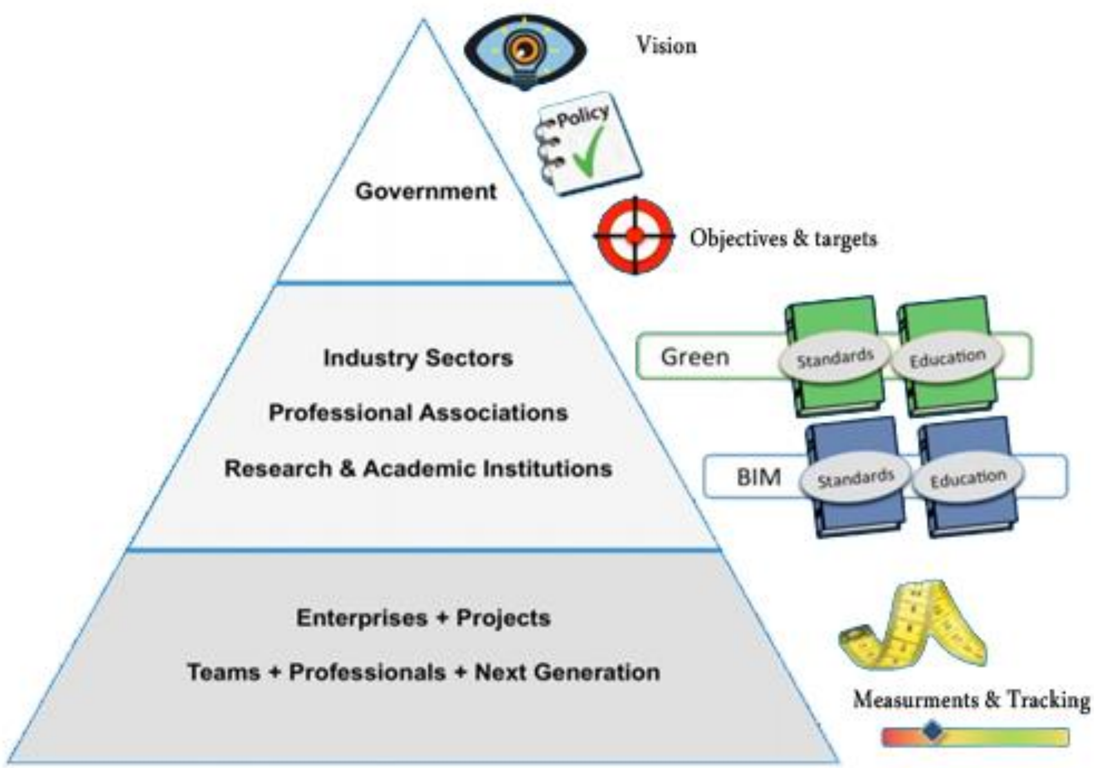


Figure 4-18: Coordinated action pyramids. Source: (bimSCORE, 2015)

4.6 BIM adoption in Egypt

The literatures that are discussing the BIM implementation practices in Egypt are limited. However, three researches are found in the topic or near to it. First, (Elyamany, 2016) discussed the current BIM practices within the Egyptian construction industry. Second, (Khodeir & Nessim, 2017) discusses BIM and energy modeling in the Egyptian architectural firms, and finally, (Gerges, et al., 2017) investigated the BIM implementation in the Middle East and Egypt was mentioned in the study. A quantitative approach was used in the three studies, as questionnaires were developed and spread to a large number of participants to collect data. The gap in the three studies was that there was no face-to-face interview conducted with the interviewees in order to get a closer view on the BIM implementation in the Egyptian design firms.

(Gerges, et al., 2017) sent online questionnaires to 297 participants all over the Middle East countries 200 of them are valid with 67.34% response rate. 19% of the respondents who are using BIM in their companies are from Egypt. The study claimed that Egypt comes after the UAE in using BIM in the infrastructure projects. However, 37% of the Egyptian respondents stated that this is due to the international projects they are working in through their companies Figure 4-19.

(Elyamany, 2016) has conducted an online survey and sent it to120 contracting companies and 10 consultancy firms, the rate of respond was 17.2% and the author explained that the low response rate may be related to the lack of the BIM understanding in the Egyptian firms. As a result of the survey, the participants think that BIM is a helping tool towards sustainable buildings and it is expanding in the construction firms.

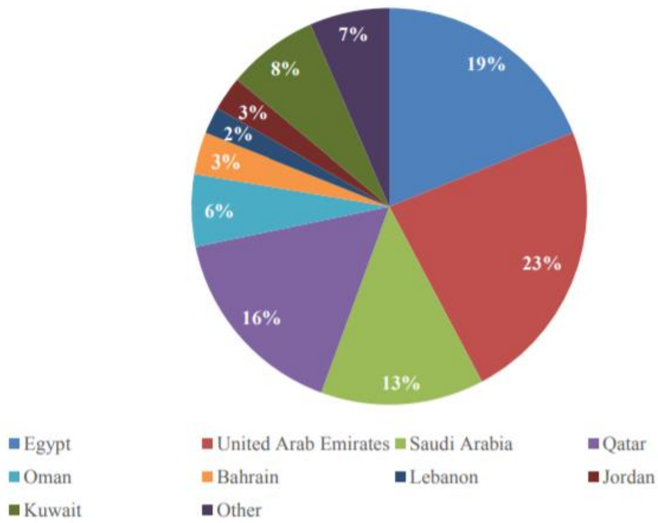


Figure 4-19: Countries' respondents who are involved in construction projects using BIM. Source (Gerges, et al., 2017)

In addition, the research pointed to the absence of any governmental actions in the BIM implementation where 79% of the respondents believe that the government is not on the right track towards BIM adoption and the involvement of the government will push the BIM adoption process. The study also highlighted many important issues related to the BIM adoption in the Egyptian firms; for example, the survey found that the main concept of applying BIM in the construction industry is still not clear for most of the participants. However, they know the benefits of BIM adoption in the construction industry and believe that the BIM technology is vital for the design of sustainable building. In addition, 84% of the respondents thought that manufacturers should provide BIM objects in order to use accurate data in the model design. Moreover, 70 % of the participants thought that the construction players need to gain more knowledge about BIM (Elyamany, 2016).

(Khodeir & Nessim, 2017), this study spread its questionnaire among architecture firms working with green buildings the survey was sent to 98 architecture organizations, 22 "house of experience" and 76 Multi-disciplinary. The research found that BIM is still in its early stage in Egypt. The study also claimed that firms use BIM because they know its potential in coordination, clash detection, and saving time and resources, which is opposite to the two up mentioned studies which return the BIM adoption among the Egyptian firms to the increasing demand for using BIM in international projects. Moreover, the study claimed that 62% of the respondents use energy modeling software in the design phase, which is not a norm in Egyptian firms and may be related to the survey sampling. In addition, the study stated that the barriers of BIM adoption in Egypt returns to the lack of client demand, training, and studies concerning the BIM implementation return of investment for companies. The study also mentioned that architecture firms are playing a leading role in adopting BIM in Egypt.

4.7 Chapter summary

This chapter discusses the BIM adoption activities, maturity levels, and guidance. In addition, the chapter investigates the BIM implementation through consultancy firms' pillars and factors, risks and challenges, and the implementation drivers and management practices. Furthermore, the chapter shows the BIM adoption strategies in different counties, the best adoption practices, and the BIM role in the countries sustainable construction strategies. Finally, the chapter discussed the BIM adoption in Egypt situation through literature.

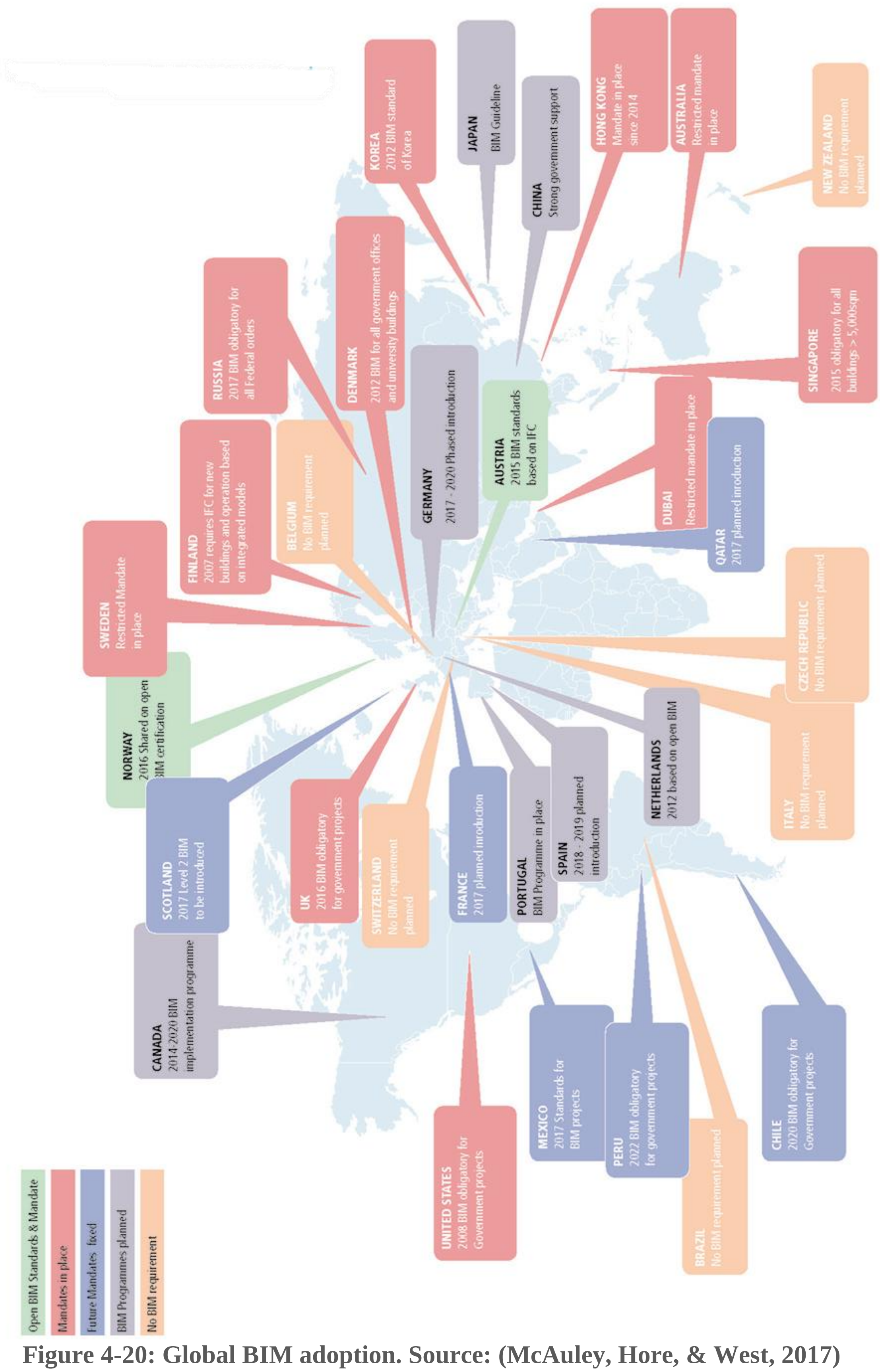


Figure 4-20: Global BIM adoption. Source: (McAuley, Hore, & West, 2017)

CHAPTER 5 : METHODOLOGY

Research methodology is "the principles and procedures for logical thought processes" (Fellows & Liu, 2015). As the research is exploratory in nature, the social science research technique was chosen as a research methodology. For the exploratory study, literature review and interviews were found to be the most appropriate approach for the research nature.

After reviewing numerous literature regarding the aspects of BIM benefits for the construction industry and its role in the sustainable construction industry in addition to the BIM implementation approaches for organizations and countries, the methods by which this research proceeded is to be discussed in this chapter.

Research approach, research method adopted, data sampling method, interview questions design, and the process forms the foundation for the subsequent chapter of analysis and discussion. Research ethics, limitation, and challenges also represented in this chapter.

5.1 Research approach

The inductive "down-up" approach is adopted for this research, as the kind of the research is the learning process type that encourages the progress of the research from specific to general (Deduction & Induction, n.d.), See Figure 5-1. This research aims to explore the Benefits of BIM for construction industry and the implementation approach for sustainable construction industry in Egypt.

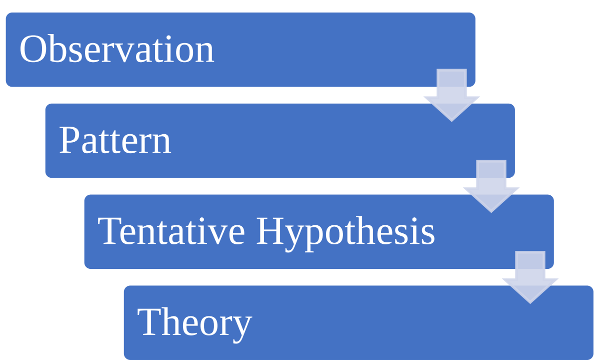


Figure 5-1: Inductive "Down-Up approach. Source: (Deduction & Induction, n.d.)

5.2 Qualitative research

As BIM usage in Egypt is a newly evolved concept in most of the construction consultancy firms, solely interview with BIM experts is chosen to let them talk freely and share their experience. In addition, the interview should give a clear in-depth image about the BIM situation inside the consultancy organization.

5.3 Data sampling & ethics

In order to ensure the reliability and validity of the research, respondents were selected to represent different consultancy firms and disciplines. All of the participants are to be BIM experts with a high level of professional experience (BIM managers) who are participating in the BIM implementation process within their organizations. The snowball technique, where the interviewee nominated other proposed interviewee to participate in the research was chosen because of the difficulty of finding the samples. Furthermore, the sample was selected after reviewing its LinkedIn profile and make sure that it is following the selection criteria. An interview request was sent to 30 proposed interviewees where 12 of them accepted to participate in the study, in addition to two invalid samples because they are not meeting the selection criteria.

Participant’s permission for audio recording was requested from the participant before starting the interview and the participant was informed about the research objectives briefly. Also, the confidentiality of the collected data was cleared to the participant before starting the interview. The Institutional Review Board (IRB) approval and interview request forms are attached in the appendix (1, 2). The research questions can be viewed in appendix 3.

5.4 Data collection

(Fellows & Liu, 2015) stated that interview survey is an effective method to get unbiased information from the participants. Accordingly, the qualitative semi-structured interview has been chosen where the framework of themes is involved in the questions and used to analyze the collected data from the interviewees. The same sets of questions were asked of the interviewees in order to collect reliable comparative data for the study. The participants were free to talk, but the discussion was guided in order to analyze, summarize, and report the collected data. The interview was 30 minutes over phone interview to give the interviewee the flexibility in selecting the interview time. The data collection reached the saturation point after the seventh interview where there is no more new data occur from the interviewing more percipients. However, the data collection process stops after the 12 interviewees as the nominated names began to repeat and the author become confident that the required data saturated.

5.5 Interview questions design

Semi-structured and informal interview to gain a better understanding of the BIM implementation techniques and uses in the pre-construction phase within the design consultancy firms in Egypt.

The questions were divided into 6 sections to insure the research reliability and allow a holistic image about the BIM implementation situation in the organizations (strength and weaknesses), implementation drivers, and the expected role of the government from the participant perspective, kind of projects, and BIM role in the sustainable building from the respondent experience. The questions were to answer the gap that was still existed after literature review in order to meet the research objectives.

5.6 Data analysis method

The inductive coding style "grounded analysis" method for the qualitative approach was selected to meet the themes generated from the questions. The grounded analysis was described as a qualitative procedure to identify concept or idea for a process, action, or interaction about a substantive topic (Fellows & Liu, 2015). Consequently, the data analysis codes and themes were generated from the interview questions.

5.7 SWOT analysis

The SWOT analysis technique was used to understand the strengths and weaknesses of the BIM implementation situation in Egypt within the pre- construction phase through the consultancy firms, in addition to the opportunities and threats for the Egyptian construction industry.

5.8 Limitations

The sharing of documented data about case studies were not available because either it is not allowed by the consultancy firm or the project's owner what makes analyzing data about the projects mentioned by the interviewee not applicable. Accordingly, limited data projects' experiences were addressed. Although three of the participant have a LEED AP certificate, and 2 are experts in the sustainable building design practices, none of them has experienced using BIM for sustainable design, except for one participant uses it for free license projects without targeting any certificates. Moreover, the limited data about the construction sector behavior and development in Egypt show unclear, unpublished or no vision for managing the fragmentation in the construction industry in Egypt

CHAPTER 6 : BIM SITUATION IN EGYPT: ANALYSIS AND DICUSSION

In addition to the literature review regarding the BIM adoption situation in Egypt in chapter four, investigating the current efforts in the Egyptian construction industry to adopt BIM is important. Finally, the data analysis form the experts' interviews gives strength to the research outcome and help the author in developing the SWOT analysis in order to give recommendations.

6.1.1 BIM adoption efforts in Egypt

6.1.1.1 BIM Egypt day (BIM Egypt Day, 2018)

The first Egypt BIM day took place in January 2018. Speakers; who are BIM experts from different AEC firms shared their personal experiences with implementing BIM and the benefits they gained in increasing the quality and reducing cost and time. Autodesk as one of the technology providers showed its marketing strategies and different sale plans to help medium and small firms to purchase the licensed software. The conference to be held annually to show the progress and discuss the BIM adoption situation in the Egyptian market.

6.1.1.2 TEMPUS project (Erasmus, 2018)

TEMPUS IV "Building Information Modeling: Integrated Design Environment for Engineering Education", with participation of 4 European (Northumbria University, Leeds Metropolitan University, University of Twente and Chalmers tekniska högskola AB) and 6 Egyptian Universities (Cairo University, Mansoura University, El Shrouk Academy, The German University in Cairo, Beni Suef University, Sohag University), 2 industry partners (Kemet Corporation, Orascom Construction Industries) and the Egyptian Ministry of Housing. The project was a fund from the European Commission that started in 2013 and ended in 2017.

(Erasmus, 2018), "The project aims at promoting Digital Engineering for Construction (DE4C) and the related BIM concept of Integrated Project Delivery (IPD) to professionals from different disciplines within the Built Environment in Egypt in order to develop skills and create better value through smarter and more sustainable processes." Although the project's results did not published yet on the website, one of its objectives was to establish MSc degree in (DE4C) technologies and IPD, this master's degree have started at Cairo University from 2015 with fund from the TEMPUS. The fund was stopped by 2017 by the end of the project period and still available at the University till know (Lab, n.d.). In addition, the program aimed to establish training centers in each of the six joined Egyptian Universities and that is the case know the six Universities.

6.1.1.3 BIM in Universities

(Admed, 2016) investigated BIM education in some of the Egyptian universities both governmental and privet universities. (Admed, 2016) stated that 60% of architecture students in Cairo University, and from 60 to 70% of Ain Shams University use BIM in their projects and it is a part of their curriculums. In Al Azhar University, 35% of the students are using BIM in their projects although it is not a part of their study in the university. Private universities like the American University in Cairo (AUC), British University in Egypt (BUE), and the Canadian University in Cairo (CIC) are teaching BIM in their curriculums and it is planned to develop their curriculums to involve BIM in all the study years. Also, the German University in Cairo (GUC) is teaching BIM in the engineering curriculums and has a BIM unit that has conducted BIM forum in 2017. The forum was a cooperation between the GUC and NourthUmbria University & BIM Academy and discussed the latest development of the BIM practices in the built environment (Unit, 2017).

6.2 Interviews data analysis and discussion

The interview questions objectives were to complete the gap with the previous studies concerning the BIM implementation in Egypt by using the themes generated from the interview questions as following:

1- Factors that influence consultancy firms to implement BIM (drivers)

2- Barriers to BIM implementation in the Egyptian companies

3- Success factors of the implementation

4- BIM maturity level within the companies

5- The protocols or BIM guidance used in the projects

6- Impacts of BIM adoption in the company

7- The need for a government involvement for the BIM adoption process in Egypt

8- BIM implementation can assist in providing a sustainable construction industry in Egypt, participants' opinions.

75% of the interviewees are architects and 25% are mechanical engineers who are responsible for MEP management and coordination within their companies. All of the participants have experience in BIM implementation with their current companies in addition to previous experience with other firms. Four of the participants companies' scope is BIM implementation and they are managing BIM implementation in different Egyptian consultancy and construction firms. Two of the participants are carrying the "Certificate in Building Information Modelling (BIM): Project Management" from the Royal Institution of Chartered Surveyors (RICS). Three of the participant their main study is interest in BIM and its application in sustainable building in Egypt whether in their master's degree, teaching experience, or work experience.

The background about respondents that define (who was interviewed, their level of education, status in their organizations, how long they are working with BIM and their current firm experience with BIM implementation) was summarized in Table 6-1.

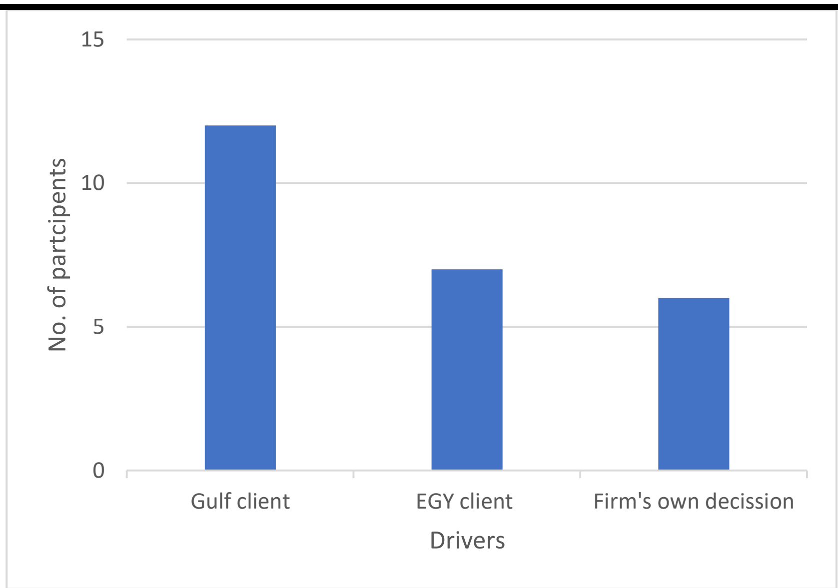
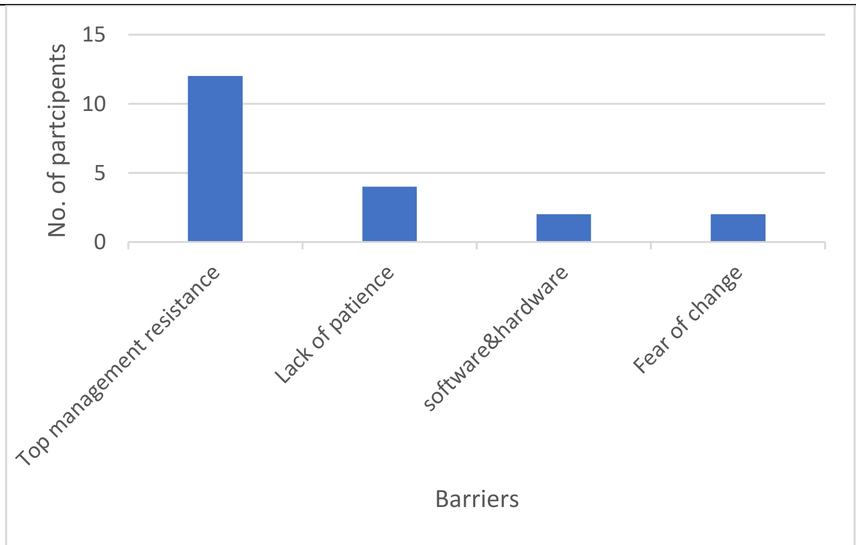
The interviews results are shown in the following Table 6-2, the above objectives numbering used as a code for the objectives in the table.

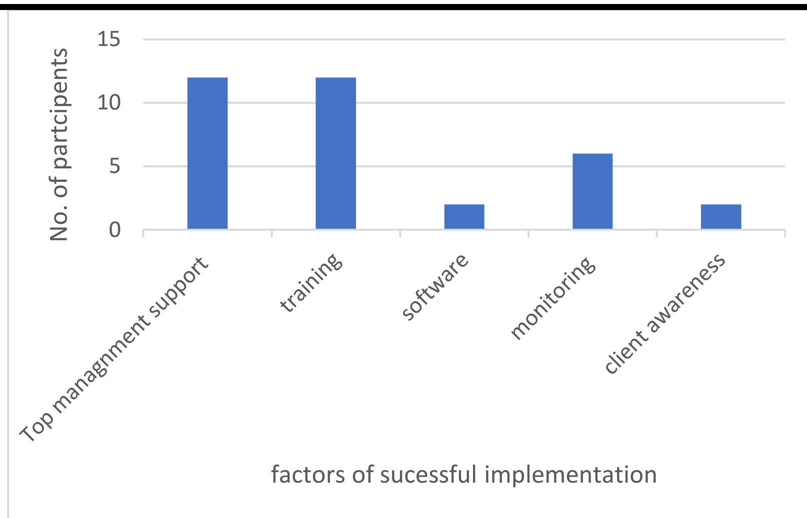
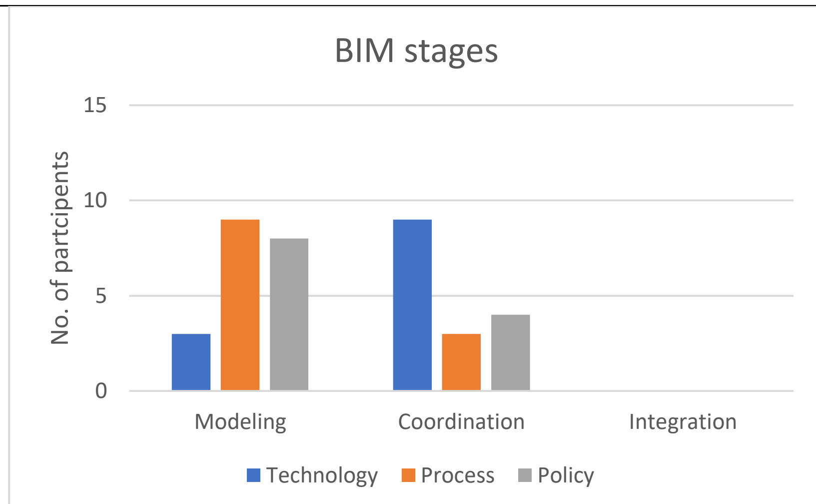
Table 6-1: Interviewees' profiles summary. By the author

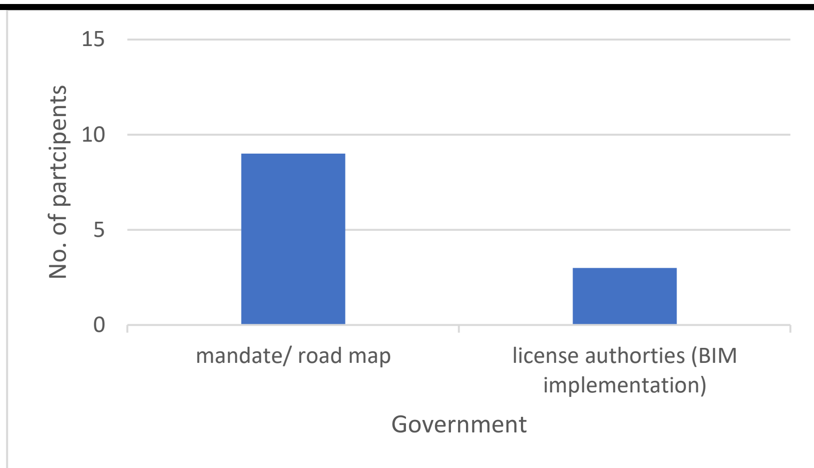
	Participant information	BIM for..Y (participant)	BIM for..Y / Company scale (current company)
P1	Head of BIM unit department, MSc. In BIM, RICS certified, PHD candidate in BIM. (architect)	7	-/ Large (engineering consultation) / International firm
P2	Owner, BIM implementation consultant and training (mechanical)	10	4/ small (BIM consultation and training) Egyptian firm
P3	Owner, BIM implementation consultant, engineering consultant,	12	12/ small (engineering consultation, BIM

	training (architect)		consultation, training) Egyptian firm
P4	(implementation), RICS certified, teacher assistant (architect)	10	1/ medium (engineering consultation) Egyptian firm
P5	BIM implementation & consultation (mechanical) BIM instructor	8	10/ medium (BIM consultation and management) International firm
P6	BIM/ sustainability consultant, LEED AP (architect)	9	4/ large/ engineering consultation international
P7	MSc. Sustainable technologies, PHD candidate , BIM manager, teacher assistant (architect), LEED AP	4	4 / medium / engineering consultation
P8	BIM consultant, MSc in BIM (mechanical)	7	7/ BIM consultation & management / Egyptian firm
P9	BIM manager, MSc holder, LEED AP	6	8 / large/ Engineering consultation & construction/ Egyptian firm (public sector)
P10	BIM implementation (architect)	7	2 / medium/ architecture services/ Egyptian firm
P11	BIM manager (architect)	7	2/ medium/ engineering consultation/ Egyptian firm
P12	BIM unit head (architect)	6	Over 10 y/ large/ engineering consultation/ international firm

Table 6-2: Interview results. By the author

Objective	Result
1	
2	

3	
4	
5 Used protocols	Mixed between [(PAS1192-2/3), NBS standard USA, AIA standards]
6 BIM Benefits	- Accurate and high quality deliverables - Organized models - Facilitate the coordination process - Disciplines communicate and understand each other - Early clash detection - Quick response for client changes

7		
8 BIM for sustainable building in Egypt	- Facilitate proposals analysis and decision-making process - All data and information needed for environmental analysis are included in the model elements. - BIM process is the same as the LEED process in project management - Accurate data and information save cost, time, and materials - Remove the headache of tracking changes and focus on design an engineering	

6.2.1 Drivers

The Gulf market; especially in the UAE and Qatar are the main drivers for the Egyptian companies in BIM implementation. Although BIM Implementation is an adding cost for the companies due to the need for training, hardware and software upgrading, and the recruitment of skilled staff, companies invest in adopting BIM to keep their market share in the gulf area market that is acting as a pushing force towards BIM adoption. P12 said, “UAE construction market is our company’s main market, so in order to sustain our existence in a like competitive market we have to implement BIM.”

Egyptian clients have discovered the benefits of BIM adoption from the GCC experience. The factors that are influencing the Egyptian market to adopt BIM is the accuracy of the deliverables, cost reduction, and the early clashes detection before the construction phase. In addition, BIM is assisting in a better decision -making during the design stage. P2 claimed, “the client’s demand for BIM projects in the Egyptian market is a healthy indicator, as it is showing the increasing awareness of BIM benefits and forming a force over the consultancy and construction firms to implement BIM in Egyptian project."

The consultancy firms have two choices, whether totally convert to BIM or keep both the BIM and CAD units. After the BIM experience, some companies totally convert to BIM because of the quality of the BIM outputs. According to P3, "we are totally shifted to BIM since 2015, it more productive than CAD as BIM is saving time and cost." Other firms are moving gradually towards only using BIM, as they are still building their BIM system and still have projects required with CAD system in progress. In this context P7 said, "We are moving from CAD to BIM, but it will take a time to build our capacity and infrastructure, we started by adding extra time to the project's time plan and it was interesting when we deliver the project even before the actual time." On the other hand, there are companies that choose to keep the both delivering systems, as the construction environment is not ready yet to the complete transform from CAD to BIM and the clients still requiring the CAD system deliverables in the Egyptian construction market. P12 said, "We still need the CAD unit as long as there is a demand on it. Our clients are from different Middle East countries and BIM is not the norm yet in most of them."

6.2.2 Barriers

Top managers are the common barrier towards successful implementation as they are resisting the change. Their resistance to change returns to their fear of losing control on the project's deliverables time schedule or the final product quality. In addition to the fast track project approach in the Egyptian market recently, which makes BIM implementation a risky decision if the client does not require it. P7 said, "There is a great pressure over the top management to meet the project's delivery time, what do not make them ready to waste any time in trying new technologies."

BIM adoption needs patience, as it is a long-term process. Most of the companies that decided to adopt BIM and return back was because they were not patient enough to gain the benefits, four of the participants agreed with that were they have experienced this situation with many of the companies that they were implementing the m BIM system for them. Staff training, recruitment of skilled team, and the development of the company infrastructure needs investments in cost and time as the production and the quality rates are decreased at the beginning of the adoption. Hardware and licensed software are critical issues in the BIM implementation process, as they need a lot of investment. P1and P7 said that using a less qualified hardware or unlicensed software cause damages in the project's files and losing data, what makes them keep saving a lot of the project's file versions in case the latest one damaged. P1, "The hardware in our firm need to be upgraded, we are working at a large scale projects and we lose time in saving the project and in some cases we lost data." P4 said, "licensed software is impotent for the quality of the project's file, especially if we are going to export the file from file extension to another. Autodesk is offering flexible sale plans that may help in using licensed software. It is good as almost Autodesk is the BIM software market leader in the Egyptian market.

Although some companies know the benefits of BIM, they are afraid of change because of the high required initial cost needed for the transition to BIM process and the lack of client's demand.

6.2.3 Success factors

Moving the barriers towards BIM implementation is the biggest success factor. Thus, the top management support instead of resistance leads to a successful implementation. P6, "it is totally different when you are working with a manger who is understanding the BIM process and needs than working with other who lacked the BIM basic knowledge. The educated BIM manger gives you confident and accepts mistakes at the initial stage of implementation as he understands the process." Some of the interviewees mentioned that in most of the cases, the top management began to be supportive when they discover the BIM benefits by themselves, and that is usually happens after the first project delivered by BIM. Developing the hardware and software also considered as a major factor for successful implementation, as the more developed technology infrastructure, the smoother and faster production process. In addition, training the company current staff and hiring skilled ones is a success factor.

The most important factors that the participants who are working in BIM implementation for many companies mentioned are monitoring and evaluation. Some firms adopt BIM but they do not follow up the quality, solving the released up problems, or work on developing the transformation process. Continuous monitoring and evaluation is extremely important for a successful and smooth movement to BIM. P8 said, "Some companies asked us to train their staff and implement the BIM system for the company without doing any monitoring the process gradually which is important for improving the implementation process and move for more advanced steps with it. In sometimes the lack of monitoring and evaluating where we were and where we need to go, spoil the BIM transition process and can stop it.”

6.2.4 BIM maturity in companies

According to (Succar, 2009) BIM maturity levels, the TTP activities fields is measured in the BIM maturity matrix to measure the BIM maturity level in companies. From the interviewees' responses, the maturity level of the Egyptian consultancy firms is the “Modeling stage” level. As for the technology aspect, the need for licensed software and upgrading for the hardware are one of the most common barriers towards using BIM. For the process field, the client requirements to have high-quality construction documents while the model is not required for the construction process show the lack of awareness regarding the BIM levels and LODs. In addition, one of the problems that were highlighted by P4 and P12 is that firms are using BIM as a drafting tool to produce free error drawings and they are not using BIM for coordination between disciplines and clashes detection, for example. For the policy field, in most of the firm's departments are working on separate models without coordination and there is still a gap in the collaboration and communication between the project’s team. As P11 said, “We have just replaced CAD by BIM. We are using the traditional delivering system but with BIM. We are still receiving clashes and change requests from the site and the disciplines drawings coordination is done manually.” Accordingly, BIM is in its early stages and people are using it mainly in 3D visualization, error-free drawings, clash detection, quantity survey, and decision making but with the traditional management method.

6.2.5 Guidance

PAS 1192-2/3, AIA, and NBS are the main BIM protocols used by the Egyptian firms where each consultancy firm adopts what suits its contractual and policy issues and the Egyptian construction regulations and building codes form the three protocols. However, P2 claimed that some companies are not using guidance or protocols. They are just using the BIM templates to manage the design process and they do not need to use protocols as they are in the early level of maturity and by increasing the awareness and educating the managerial team, companies can implement the holistic BIM approach and use guidance. P11 said, “Each company is adopting what suits its rules and contractual issues. It will be great if we are all working according to the same protocols to avoid conflicts.”

6.2.6 Impact on company

At the beginning of the BIM implementation, the low productivity rate is expected but after practicing in many projects, the productivity rate increases. The improving productivity and quality influence companies to a complete switch to BIM. However, this long period may take from 6 months to one year as P7 claimed. Therefore, the choosing the first project and the passionate team are very important for getting benefits during this important period, P8 claimed. The disciplines communication and understanding are one of the gains of using BIM, as regular coordination meetings and model visualization make it easier for the project's team and client for taking faster decision and communication. However, according to P4 and P12 the communication process is still in its early stage and the organization layout needs to be developed to encourage communication and collaboration between the project's team

6.2.7 Government expected role

"BIM is no more the future; it becomes the current construction industry management and production approach" P3 claimed. Thus, the market is moving towards BIM adopting even if the government is not involved, P1, P2, P3, and P7 said. However, all the participants agreed that a roadmap for BIM adoption is important to fasten the adoption process and organize the construction industry transformation. In addition, the government should implement BIM in its license authorities, as it takes a long time to convert the project's files from BIM to CAD system that is used by the licensing authorities. According to P5, "I am not optimistic that the government will have a role in mandating BIM, but at least it has to implement BIM in the building licensed authorities to facilitate the license process for us."

6.2.8 Sustaining the construction environment:

Building simulations are all about the availability of information on the model elements and its surrounding which is applicable with BIM modeling. The gbXML exchange interface helps in transferring data from the BIM model to the simulation programs. The problem is that sustainable buildings are not required from the Egyptian's clients. P6 said that he influenced his clients by producing high-performance building without mentioning sustainable or green building! and BIM is assisting him in decisions like the materials selection, building orientation, and sun shading tools selection. P6 also stated, "BIM as a technology facilitates the analysis and simulation needed for producing sustainable building; however, governmental support towards sustainable building practices is needed."

6.2.9 Case studies

As mentioned in chapter five sharing data about case studies was not available as the interviewees was not have the permission for sharing the data. However, they all agreed that the Egyptian client usually require BIM for projects with complex structure or tough topography, as applying BIM for like projects provides accurate construction documents and materials quantity take-off that allowed them to control the project budget and time. For example, a mega project in Giza with very complex structure, 70% of the drawings produced utilizing BIM were approved from revision A While 60% of drawings produced utilizing CAD were approved from revision D, according to P3 experience. Another example, 400 bed hospital in the New Cairo, 5th district, the owner is a foreign organization. P9, claimed that the project's documents were not be delivered, nether in the time or quality it delivered with, if they used the CAD system instead of the BIM system, as the hospital design was a complex design. P2 also mentioned a project a housing compound with rigid topography where they were designing and modifying the building types at the same time the construction process was started at the site. Using BIM assists the project team in controlling the rapid changes requested by the client quickly and efficiently.

6.3 SWOT analysis

Combining the data received from the literature review, the interviews, and current BIM implementation and awareness efforts in Egypt, a SWOT analysis for the situation of BIM implementation in Egypt is developed in Table 6-3.

Table 6-3: SWOT analysis. By the author

Strengths	• International project's experience • Young trained employers • Increasing implementation rate • Increasing client's demand • BIM education increases in universities
Weaknesses	• Absence of governmental support or

	implementation • Education do not support integration between disciplines • Expensive technological infrastructure • Change resistance from top management • Lack of BIM experts
Opportunities	• Some Egyptian companies have international experience • Increasing awareness in BIM benefits • Egyptian companies to lead the construction market practices in middle east • Technology providers design new sales strategies to support medium and small companies.
Threats	• Competition from the surrounding markets • High initial implementation cost • Lack of sharing best practices • Un professional implementation process

CHAPTER 7 : CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The objective of this study was to investigate the BIM adoption benefits towards providing sustainable construction in Egypt. In this context, the study discussed the sub objectives:

1- BIM sustainable practices in the pre-construction phase through the consultancy firms.
2- BIM adoption in different countries.
3- BIM implementation situation in Egypt.
4- Recommendation for actions needed towards successful BIM adoption in Egypt.

Throughout the research literature, the research covered its objectives and the recommendation are presented in this chapter. The following are the key conclusion of the research:

- The study shows that BIM implementation has many benefits for the construction practices that positively influence the sustainability of the industry. As BIM adoption improves the management of the construction project information, enhances the quality of deliverables, offers better collaboration between the project team, facilitates and improves environmental building analysis, and contributes to materials waste reduction.
- Barriers towards a successful BIM implementation are many for companies and countries. Barriers like top management resistance to change, technology cost, insufficient implementation, and lack of training and experts, are the main obstacles in the adoption process.
- Implementing BIM is not the goal by itself; the technology is a part of a main goal towards improving the construction industry practices and sustainability of the sector to achieve the sustainable development strategies.
- The main driver that influences BIM implementation in the Egyptian consultancy firms is mandating BIM in some of the GULF countries, as the Gulf Cooperation Council (GCC) countries area construction market is a vital market for Egyptian firms.
- The Egyptian client requires BIM for developing their project's construction documents, especially in the large and complex projects. Their main goals are to reduce construction conflicts and disputes, getting accurate materials take-offs, and time schedules.
- Experts believe that BIM has the ability to facilitate and support sustainable building in Egypt; however, the problem is the lack of demand on sustainable buildings and it is not supported by the country.

- Regardless the slow implementation rate, the research revealed that there are some promising initiatives from the universities and the private sector towards improving the BIM practices in Egypt.
- Experts also stressed on the role of the government in expanding the use of BIM to achieve sustainability in the construction industry and the design of sustainable buildings. In addition, the literature also supported this vision, as the governments and public authorities' role in BIM adoption is vital, as they can form a pressure towards implementing BIM throughout countries.

7.2 Recommendations

Building on the literature review and the interviews the study recommended some actions that should be taken by the Egyptian government, construction industry stakeholders for adopting BIM towards sustainable construction industry.

7.2.1 Government and public authorities

- Adopt BIM in the 2030 sustainable development strategy in the area of sustaining the built environment towards improving the construction industry practices.
- Set broad goals for the BIM adoption with the cooperation with the industry stockholders and set a time frame for reaching these goals.
- Release a roadmap for mandating BIM in the construction industry.
- Provide professional BIM education.
- Implement BIM in the building license authorities.
- Increase the awareness among the AEC stakeholders for the importance of BIM adoption.
- Collaborate with the private sector to develop BIM standards and guidance based on their experience.
- Form a benchmark and best practices platform in order to help more firms in the implementation process.
- Make a partnership with the international organizations that support BIM adoption through countries like the BIM task group or buildingSMART organizations.
- Encourage the AEC firms to implement BIM and sustainable buildings by providing training, reducing taxes, and provide loans to update the companies' technological infrastructure.

7.2.2 Universities and educational centers

- The rapid development in the construction technologies and practices towards more sustainable practices need adaptive curriculum that can follow and update the students' knowledge and skills.
- Use BIM applications in the environmental courses to train the students on using simulation to measure the building performance.
- Encourage the collaboration and communication between the engineering departments through shared projects.

7.2.3 AEC companies and manufactures

- Set goals, form a BIM implementation plan, and inform the company's staff with the plan to support the implementation process.
- Monitor the plan gradually and update it when needed.
- Measure the implementation maturity level and evaluate the performance of the implementation process.
- Celebrate each goal achievement and support the staff by giving rewards and accepting errors at the beginning.
- Inform the top management with the BIM benefits through providing training in the BIM management tools and its ability to enhance the quality and improve the productivity on the long run, in addition to showing them successful implementation and projects cases.
- Invest in the staff training and upgrading the firm's technological infrastructure.
- Make any required change in the company's business or disciplines structure to support collaboration and communication between the project team.
- Manufacturers and suppliers should provide the design team with BIM objects for their products to be used in the building analysis and simulation.

7.3 Recommendation for further researches

- **A Roadmap towards BIM mandate in the Egyptian construction industry**: the next step needed after this study is suggesting a road map for the BIM adoption in Egypt. This step needs communication with governmental bodies and public authorities in order to form a complete perspective on the construction industry practices and visions, in addition to communication with the private sector to evaluate the current BIM practices and implementation process to assist in forming the road map.

- **BIM best practices platform:** as mentioned in the thesis, publishing case studies was not applicable. There is a need for evaluating case studies to measure the effect of using BIM in the Egyptian market and the quality of the outcomes.
- **BIM implementation process practices:** work directly with number of firms to investigate the implementation process different practices and the challenges they are facing.

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Appendix 1

CASE #2017-2018-086

THE AMERICAN UNIVERSITY IN CAIRO
INSTITUTIONAL REVIEW BOARD

To: Amira Mohamed

Cc: Muhammad Khaled

From: Atta Gebril, Chair of the IRB

Date: Jan 21, 2018

Re: Approval of study

This is to inform you that I reviewed your revised research proposal entitled "**BIM implementation for sustaining the construction industry in Egypt**" and determined that it required consultation with the IRB under the "expedited" category. As you are aware, the members of the IRB suggested certain revisions to the original proposal, but your new version addresses these concerns successfully. The revised proposal used appropriate procedures to minimize risks to human subjects and that adequate provision was made for confidentiality and data anonymity of participants in any published record. I believe you will also make adequate provision for obtaining informed consent of the participants.

This approval letter was issued under the assumption that you have not started data collection for your research project. Any data collected before receiving this letter could not be used since this is a violation of the IRB policy.

Please note that IRB approval does not automatically ensure approval by CAPMAS, an Egyptian government agency responsible for approving some types of off-campus research. CAPMAS issues are handled at AUC by the office of the University Counsellor, Dr. Ashraf Hatem. The IRB is not in a position to offer any opinion on CAPMAS issues, and takes no responsibility for obtaining CAPMAS approval.

This approval is valid for only one year. In case you have not finished data collection within a year, you need to apply for an extension.

Thank you and good luck.

Atta Gebril

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Appendix 2

THE AMERICAN UNIVERSITY IN CAIRO
INSTITUTIONAL REVIEW BOARD

Documentation of Informed Consent for Participation in Research Study

Project Title: BIM implementation for sustaining the construction industry in Egypt

Principal Investigator: [*insert name and contact information*]

*You are being asked to participate in a research study. The purpose of the research is *to investigate the benefits, barriers, and the main factors influencing the adoption of Building Information Modeling (BIM) in Egypt for the early stage of building design and how it could support sustainable buildings in Egypt*, and the findings may be *published and presented in scientific research only*. The expected duration of your participation is *30 minutes over phone*.

The procedures of the research will be as follows *literature review, followed by interviews and case studies then analysis and discussion*.

*There *will not be* certain risks or discomforts associated with this research.

*There *will not be* benefits to you from this research.

*The information you provide for purposes of this research *is confidential*.

Questions about the research, my rights, or research-related issues should be directed to (Amira Elshazly Mohamed) at (01003383054)."

*Participation in this study is voluntary. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or the loss of benefits to which you are otherwise entitled.

Signature ________________________________

Printed Name ________________________________

Date ________________________________

Appendix 3

Interview Questions

1. **Background Information**
   - State your name and the name of the company.
     - What is your title/position and what are your responsibilities in the company?
     - What is your company yearly revenue? How many employees do you have?
   - Have you already implemented BIM? Y/N
     - How many years of experience do you (personally) have with BIM?
     - How many years of experience does your company have with BIM?
2. **Organizational experience**
     - What are the factors that influence BIM implementation?
     - Did the organization switches to BIM totally or partially?
     - What is the impact of BIM on design/engineering (cost, time, overall project delivery time, quality)?
   - Has the composition of the design staff changed? Y/N
     - What are new roles that arose with this technology?
   - How the work flow affected? Is there is integration between the design team (Architecture / structure/ MEP)?
   - What are critical factors in successful implementation of BIM?
   - What issues and concerns are you encountering on projects that incorporate BIM in design?
   - What do you think are the risks emerging with BIM implementation?
3. **BIM uses and level of development**
   - BIM uses in the design phase (conceptual design/ design/ construction drawings and coordination)?
   - After obtaining a list of uses and their description, then investigate the following for different uses:
     - How do you decide what to include in the model and at what level of detail for achieving the objective (Contents; Level of Detail)?

    - How do you create the model? What process, applications and data exchange/file formats (Modeling Process; Applications; Data Exchange/File Formats)?
    - What team competencies are needed (Team Competencies)?

4. As there is no BIM protocol in Egypt

  - Which is the BIM protocol your company is following?
  - Do you think that we in Egypt need to have our own protocol and implantation road map?
  - What are the market forces that drive the Egyptian construction market towards BIM adoption?
  - What are the barriers and challenges for BIM implementation in Egypt?
  - Do you think BIM can support or enhance sustainable building movement in Egypt?

5. Project: Case Study

- Do you have particular projects that you can identify that have gained significant value through the use of BIM? Y/N (prefer Green Building if any)
    - If so, what tasks were performed in BIM?
    - Why do you feel there was significant value gained?
    - Would you be willing to share additional information with us regarding the case study, or is the case study documented so that we can review additional details?

6. Conclusion

- What is the current trend within your company toward performing more projects with BIM?
- What do you feel are the high value future industry trends in BIM?
- Do you have any additional comments or items that you feel are important to consider?
- Can you refer us to other BIM experts or companies we can interview?

Thank you for your time!