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Benefits of Implementing Building Information Modeling (BIM) in Infrastructure Projects

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Abstract: The construction industry is changing constantly and becoming more complex. It requires new strategies for compliance with national and international scenarios. Developing each project is associated with many limitations, including time, cost, changes, wastes, and errors, which are often not avoidable. Due to numerous project stages and complexities in the construction industry, usually, different mistakes and duplications occur. Meanwhile, Building Information Modeling (BIM) has created one of the most important and essential changes in this industry and results in more in-depth cooperation among project stakeholders. BIM is one of the most recent innovations in the construction industry, which resolves the problems of projects faster. BIM can be applied by architects, engineers, contractors, project managers, etc. to achieve objectives such as reducing design errors, reducing time and cost, improving design and construction integration, and increasing coordination and cooperation among different sections. Given the significance of project success in every country and several problems in each project, using BIM is an appropriate solution, which its proper implementation requires understanding its benefits that is the main aim of this study. This research identifies and classifies these benefits through the Systematic Literature Review (SLR) method, describing the significance of using BIM in infrastructure projects.

Keywords: Building Information Modeling (BIM), infrastructure projects, Systematic Literature Review (SLR)

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1. Introduction

The construction industry is one of the greatest industries all over the world. It contributes to both economic and social development at the national and international levels (Othman and Ahmed, 2011). Since scheduling, designing, construction, and maintenance of building projects are truly complex, they require some experts to enhance the project integration among different stages. The need for efficiency and profitability of employers, designers, and contractors has made this industry more complicated (Kymmell, 2007).

The construction industry, due to its inefficiency and lack of productivity, is faced with many criticisms all over the world. These problems are attributed to the nature of project delivery and its separate essence. Therefore, this industry needs a changing paradigm to increase productivity, infrastructures' value, quality, sustainability, and reducing lifecycle costs and time through effective cooperation and communication between different stakeholders. A number of these solutions are presented for improving and success of projects, including new contracting combinations, integrated project delivery, and technology innovations in the design and construction processes, such as 3-D coding and modeling (Hergunsel, 2011).

Building Information Modeling (BIM) is one of the most creative processes that help continuous improvement in the construction industry to achieve better cooperation between different sections and ensuring successful project delivery. BIM simulates construction activities in a virtual environment. Applying BIM, owners can achieve a detailed virtual model with the required information about the building. This model is used for supporting design, logistics, construction, and physical activities and understanding the structure of the building. In addition, this model can be used for facilities management and maintenance after completion (Lu et al., 2014).

With the growing complexities of buildings, understanding the details of construction is also difficult for designers. Here, coordination and communication between project stakeholders, particularly designers and contractors, are very useful for their familiarity with characteristics and modern methods of construction. Designers can improve project performance through exchange with construction staff during the design phase. Applying BIM, designers can identify construction restrictions from different aspects, through closer communication with construction and implementation staff. These relations result in the improvement of the performance of the project as a whole (Eadie et al., 2013). In this regard, identifying the benefits of BIM is necessary for those involved in the construction industry. In fact, BIM, through cooperation between systems, provides accessibility to information for project stakeholders at any time. Moreover, it leads to easier integration of design, constructability analysis, construction coordination, building performance analysis, and better facilities management. These benefits result in better coordination between project stakeholders, and consequently reduce changes and duplications. This study aims to have a closer look at the benefits of BIM application in construction infrastructure projects, using an in-depth literature review method introduced in the next section.

2. Literature Review

2.1. Definition

National Building Information Modelling Standard (NBIMS) defines BIM as (Bazjanac, 2008): "A digital presentation of physical features of facilities, such that a knowledge source is shared and is used as a reliable base for decision making during the project lifecycle. BIM is introduced as a digital representation shared based on standards for cooperation. This definition includes all sufficient information of a project during its lifecycle. It is not for a specific group of stakeholders and it is used as a basic definition to achieve objectives of this study. In addition, the impact of this view refers to BIM maturity level in a particular organization and its understanding.

McGraw-Hill (Construction 2012) in "The Business Value of BIM" defines BIM as the process of creating and using digital models for projects' design, construction, and operation. This report mainly states contractors' viewpoints in the BIM definition. (Wong et al., 2018) state that BIM is often considered as an instrument for visualization and coordination of construction and avoiding mistakes. According to the mentioned definitions and the significance of using BIM in projects, its concepts and principles are addressed accordingly.

2.2. BIM Concepts and Principles

Before the 1980s, architects were drawing the maps of building components symbolically and manually. Then, in the early 1980s, computer aid design, such as AutoCad, automated this process. Following that, object-oriented CAD was introduced in the early 1990s. Recently, BIM is a new method, which is used for complex construction project management by creating appropriate opportunities for architecture, engineering, and the construction industry (Pena, 2011).

BIM is an affiliated network of policies, processes, and technology, which develops a method for essential management of building design and project information in a digital form during the project lifecycle (Porwal and Hewage, 2013). BIM is one of the promising developments in the construction industry. It means project "simulation" and includes 3-D models of project components with the relationships and the required information in project planning, construction or operation and destruction (Azhar et al., 2008).

BIM tools are included increasingly in the processes of modelling and common design with creating benefits for the exploitation of the design process. Constructing a building or a group of buildings is a complex effort, which includes several activities. Given the size of the company, even completion of small projects is beyond the scope of the abilities of a single company. Larger projects potentially require more interaction between organizational customers, architects, engineers, economists, contractors, and partial contractors. This process can lead to the cooperation of design staff in estimations, in which knowledge of software and hardware engineers are different from each other, and project successful completion needs intense cooperation during design, construction, repair, and maintenance stages (Wang and Chong, 2015).

BIM model is a database, which includes the required information for managing different processes, such as logistics, building construction and operation, facilities, and civil jobs. In summary, this model describes, models, and maintains project design and lifecycle by digital instruments (Wong et al., 2010). The main objective of BIM is to enhance project performance and produce better outcomes through a single source of truth.

BIM is not just a software, but it is a method of receiving information about the construction project in the design and pre-construction phases. BIM is an instrument for using and sharing knowledge. BIM process is one of the newest construction concepts for information collection during the construction process, and includes (Shahhosseini et al., 2014):

3D: Three dimensions including length, width, and height parameters

4D: Three dimensions with the construction schedule

5D: Four dimensions with estimating construction's cost

6D: Five dimensions with the site, which requires the integration of geographical information system and BIM. With GIS integration, all of the cases available in the project site, present detailed information about the location.

7D: Facilities management in the project lifecycle

The use of BIM in construction infrastructure projects can help projects to achieve their goals. There are many benefits for using simulated models. Using these methods helps users to see all elements of the building. These models allow them to be visualized at any time and from any situation (Smith, 2014). The most important benefits of BIM include reducing time, reducing costs, reducing wastes, and employers' satisfaction, improving project performance, better project simulation and visualization, increasing communication and collaboration, identifying conflicts, and reducing duplications (Hamada et al., 2016).

On the other hand, according to McGraw Hill survey (Bryde et al., 2013), BIM's top benefits include better and easier coordination among all types of software and project's staff, productivity development, improvement of project quality control, and communication improvement. BIM users are like a wide range of triggers with obstacles on their path. Generally, BIM users need to create a balance between the benefits obtained from productivity improvement and coordination with challenges of BIM costs and training issues and problems.

Generally, recent developments in BIM have published multi-dimensional usages of information in the construction industry, which create a value-added for the project. It seems that systematic classification and evaluation are among the benefits of using BIM and can show its implementation in this industry. In the next section, the research methodology adopted in this study is described.

3. Research Methodology

Generally, there are two types of reviews: systematic review and descriptive review. Each of these reviews has its own research questions and objectives, which should be stated clearly (Liberati and Taricco, 2010). The systematic review is basically used for responding to a research question based on the unbiased assessment of all the researches related to that question. Such reviews were introduced in the 1970s in social sciences, and then it was widely used in medical sciences and epidemiology. In fact, the main objective of the systematic review is weighting the existing texts for improving decisions (Strech and Sofaer, 2012). Generally, a systematic review is performed by using the following structure (Saffari et al., 2013):

- Finding all of the related researches
- Evaluating each study based on the defined criteria
- Incorporating findings in a non-biased manner
- Presenting a fair summary of findings that takes into account any defect, in order to show our awareness or knowledge about a specific subject.

Objectives of a systematic review can be different and include some issues, such as determining weaknesses and strengths of texts related to a question, summarizing large quantities of texts, resolving contradictions in texts and increasing generalizability of consequences of interventions (Lang and Secic, 2006). Many authors state almost the same stages for performing a systematic review, some of which may be integrated into others. Accordingly, we present a 7-step approach, which is used in systematic reviews. In order to conduct SLR in this study, 7 steps are presented as follows.

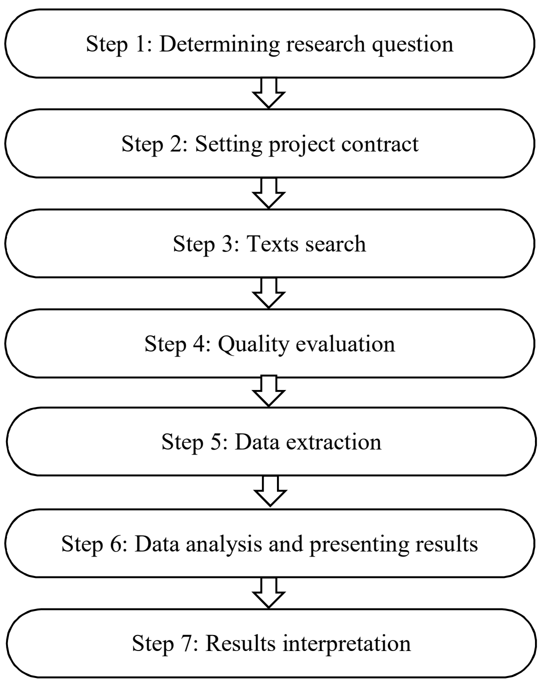

Fig.1. Steps for performing the SLR (Wright et al., 2007)

Many authors state almost similar stages for systematic review, some of which may be integrated in others. Accordingly, in this study, we have also used a seven-stage approach discussed in various sources (Glasziou et al., 2001, Wright et al., 2007, Henderson et al., 2010, Saffari et al., 2013, Lang and Secic, 2006) and frequently used in systematic reviews.

4. Data Analysis

According to the research subject, which is identifying the benefits of Building Information Modelling, in this section, the systematic review steps are implemented in order to realize the objective of this study. It is noteworthy that initially there were limitations on access to resources in this study, which we were able to overcome by limiting the use of additional databases.

Step 1: Determining research question

The first step in this process is defining the research question. Focusing on the research question is significant. If the question is very limited, it will result in identifying few studies and practically reduces the generalizability of findings to other populations. On the other hand, if a question is too broad, it may make functional conclusions difficult, even for a single population (Glasziou et al., 2001). Accordingly, the research question is defined as:

- What are the benefits of Building Information Modelling in projects? And how does it help improving project constructability?

Step 2: Setting project contract

The protocol of reviewing detailed planning is for directing SLR, and provides a method for selecting primary studies. This section introduces a protocol to direct studies utilized in this research, and includes the following stages (Henderson et al., 2010):

- Background

According to the research subject, which is identifying the benefits of BIM, in the previous section, we examined the definitions of BIM concepts and principles.

- Research question

The aim of conducting SLR is achieving the answer to the following question:

  - What are the benefits of Building Information Modelling in projects? And how does it help improving project constructability?

Research strategy and data sources

The aim of reviewing SLR is finding the most relevant answers to research questions by examining the literature review. In order to achieve this objective, we used the strategy presented in the following figure for conducting SLR.

Research results are greatly influenced by the database and keywords used in the study. The desired keywords are extracted from the research questions. In fact, research keywords are combinations of population and intervention. Regarding this question, we considered the following keywords.

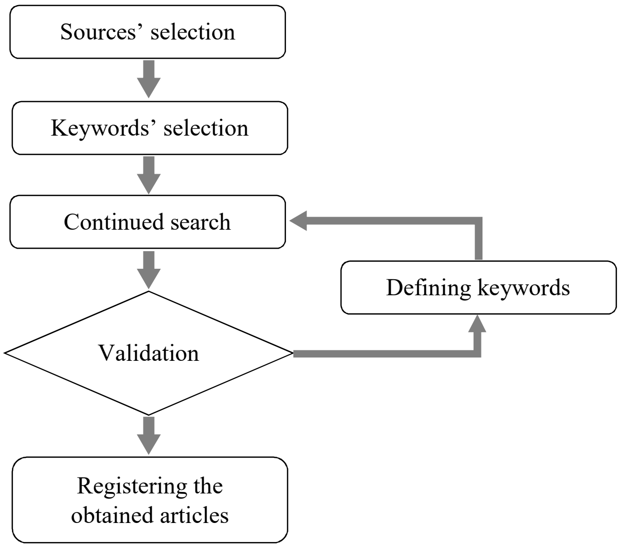

Fig. 2. Research Strategy

Research results are greatly influenced by the database and keywords used in the study. The desired keywords are extracted from the research questions. In fact, research keywords are combinations of population and intervention. Regarding this question, we considered the following keywords. These keywords are extracted from the research question in Step 1.

Table 1. Set BIM Keywords

Population	Intervention
"Building Information Modeling" OR "BIM"	"Benefits"

The following databases were used to obtain the desired articles.

- Google scholar (http://scholar.google.com)
- Science direct (http://www.sciencedirect.com)
- Springerlink (http://link.springer.com)
- ASCE (http://www.asce.org)
- Civilica (http://www.civilica.com)

Moreover, the search was conducted in the conferences of CIB databases with the desired keywords.

- www.cibworld.nl

In the next section, in order to determine the best articles, input and output criteria were defined. These criteria were applied based on the studies' title and abstract. Then, criteria were considered based on empirical issues, such as the article's language, author, population, research design, sampling method, date of release, etc.

Step 3: Texts search

The next step is searching the related studies in the available literature, which may answer the research question. Ensure that the text search is consistent with what is stated in the contract, and pay attention to input and output criteria for selecting articles (Wright et al., 2007). Input and output criteria considered for articles' selection, include the following items:

Input criteria:

- Primary studies related to the research question
- Article subject should be related to the research question.
- Articles should explain constructability.
- Full text of the article should be available.

Output criteria:

- Eliminating duplicate copies of studies
- Articles that do not explain the benefits of BIM.
- Articles that their language is not Persian or English.
- Published articles on the website of companies

The results of the literature reviews are presented in the following table. These results show the total number of found articles with utilized keywords. The number of searched articles by databases, such as science direct, google scholar, civilica, springer, and ASCE for the desired keywords were as the following. Then, articles with titles out of the scope of the review were removed, and 71 articles remained.

Table 2. BIM Initial Search Results

"BIM Benefits"	Search keywords	
71	Searched Articles	Google scholar
38	Selected Articles	
144	Searched Articles	Science Direct
6	Selected Articles	
112	Searched Articles	CIB
13	Selected Articles	
25	Searched Articles	Springer link
3	Selected Articles	
37	Searched Articles	ASCE
11	Selected Articles	
7	Searched Articles	Civilica
0	Selected Articles	

In the main search, there were a variety of different papers, including empirical academic papers, case studies, etc. At this stage, the search was conducted based on keywords and reviewing abstracts of papers. Finally, the author obtained 46 papers, as summarized in Table 3.

Table 3. Keywords and Reviewing Abstracts

"BIM Benefits"	Search Keyword
26	Google scholar
5	Science Direct
2	Springer link
5	CIB
7	ASCE
1	Civilica

Step 4: Quality evaluation

In order to evaluate the searched articles, a research contract was used. Finally, at different stages and by using the considered criteria and CASP checklist through scoring articles, their quality was evaluated. This job guarantees the quality of the findings. In the next section, codes are classified, which are stated in the step of presenting results.

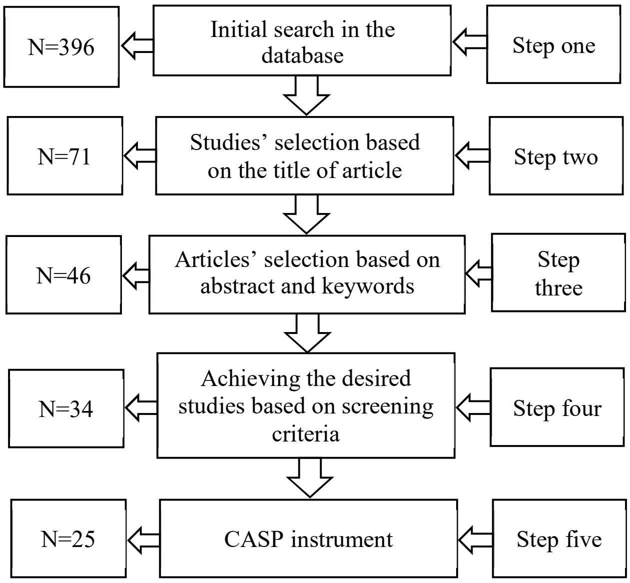

Fig. 3. Stages of selecting articles

The final stage passed through the CASP instrument filter (critical evaluation). In this instrument, a checklist composed of research objective indicators, research methodology, research design, sampling method, data collection, reflectivity, ethical considerations, the accuracy of analysis, clear presentation of findings, and research value was used. Through this instrument, each of the indicators received a score between 1-5, which indicates very good to very poor degrees, and the desired articles were classified. This rating by the researcher is valid. Accordingly, 9 articles were omitted due to gaining score less than the threshold limit, i.e. 20. As a result, among 34 articles, 25 ones were evaluated for more analysis and reaching the answer to the question. Finally, after careful examination, NVIVO QSR software was used for classifying the findings.

Step 5: Data extraction

The basis of extracting data can be responding to the following questions:

- Does the article address the benefits of BIM?
- Are the objectives of the article presented clearly?
- Does the article point to the answers to research questions?

Considering these criteria, data were extracted by the designed forms, and the entrance of duplicated articles was avoided. During primary and secondary analyses, by examining the title, abstract, and result and considered texts of the article, we studied the answers to research questions. Extracted data are presented in Appendix 1.

Step 6: Data analysis

At this stage, all of the extracted cases from articles by descriptive coding method, are categorized through pattern coding method. Each category is considered under a special group, which are presented in Appendix 2.

According to the results obtained at this stage, it can be said that the most benefits of using BIM with the highest repetition in the articles, are (Barlish and Sullivan 2012), (Eadie, Odeyinka et al. 2013), (Rokooei 2015), (Bryde, Broquetas et al. 2013), (Mohandes and Omrany 2013):

Reduced time and cost, reduced project changes and losses, increased integration and interaction between stakeholders, and reduced duplications.

It is worth noting that increased communication and collaboration among all project practitioners, simulating project environment and (Mohandes and Omrany 2013)risk reduction, improving knowledge management, finding conflicts and enhancing design quality, reducing losses and claims and increasing safety have also been emphasized in some articles.

It can be said that using all of these factors can help to improve projects' constructability. This is why focusing the investment of managers and employers on training the project team to use BIM before starting projects can help projects' improvement and success.

Step7: Results presentation and interpretation

By studying the selected articles, it was found that each article points to a number of benefits of BIM. Totally, by examining all benefits, the obtained results were categorized and the same items were considered as one. BIM has a high potential for responding to all problems at each stage of the project. By using BIM, effective factors can be minimized on timely completion and duplications, and prolongation of the project can be avoided. Moreover, using BIM is significant for companies to reduce delays.

Generally, using BIM in the building projects can reduce duplications, and increase employers' satisfaction. It results in project completion with determined budget, errors detection, improving communication between different sections, better understanding of project, and more accurate estimation of materials.

In fact, using BIM is considered as a competitive advantage for companies. BIM can be used at all stages of the project lifecycle, including design, construction, operation, and maintenance. In this section, considering the information obtained from different articles and identifying the benefits of BIM, these benefits can be categorized in four main groups: pre-construction, design, construction, and post-construction. Some of the benefits were at other stages of the project, due to interconnection of projects. Many benefits of using BIM, particularly at the design and construction stages of projects, indicate the significance of these stages and the role of BIM in project success and presenting solutions to solve the problems of these stages. The author found that these benefits at each stage of the project can have a significant role in improving project process and increasing its value. One of the important benefits is that it is a very reliable database of project information for data analysis, and consequently estimation of time, cost, the amount of materials, etc. Another significant benefit of it, is creating communication and coordination and integration in the entire project lifecycle and between different sections. Considering the conducted studies, this later benefit is one of the basic needs of project success, and finally results in improvement of project performance.

According to the stated materials, the following figure presents these benefits as a whole and is composed of four main stages.

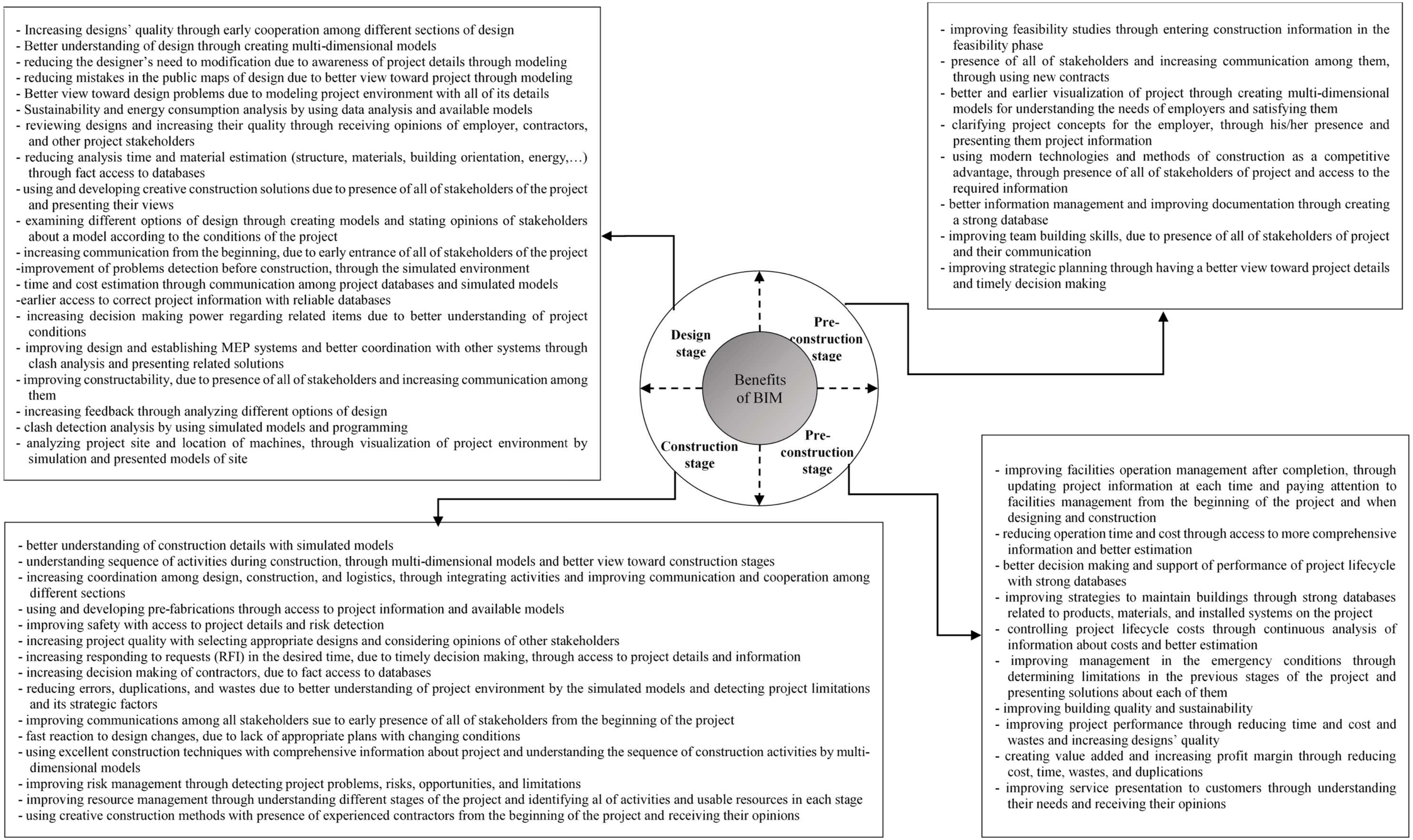

Fig. 4. The structure of BIM in projects

5. Discussion

According to the literature review, in order to maximize the benefits of BIM, it is important to use it at the beginning of the design phase. BIM can create a platform for communication between all practitioners and stakeholders of the project. That way, it can complete, extract, update, and/or edit information required to support all project processes (Newton and Chileshe 2012). The main difference of the BIM model and a 3D CAD model is storing the overall data of the manufacturing process with all of its components. This data includes items such as material specifications, price information, installation and assembly guide, product guarantee services, maintenance requirements, etc. BIM is able to store any information about the project, if it is connected to a database. Therefore, information integration, coordination enhancement, reduction of errors and improvement of constructability are the results of using BIM as a common source of information between the design and implementation teams (Zekavat et al., 2013).

One of the most important uses of BIM is for designers and contractors to exchange design decisions with team members and the employer. A 3D BIM model, in addition to showing the complete project virtually, has the ability to exchange information about systems, materials, and products used to build it (Young et al., 2009).

On the other hand, BIM can simulate different design and construction options, as well as analysis of different options by the project team. Another important benefit of it, is allowing the contractor team to analyze and review several implementation methods before starting the operation. This capability will cause finding conflicts among different project sectors and possible problems and identifying risks. After identifying executive problems, the contractor will discuss the issue with the designer to make the necessary reforms (Sanguinetti et al., 2012).

Using modern construction methods can create a platform for communication between the employer, the consultant, and the contractor. Information and its exchange and organization, play a significant role in the projects' success. This issue matters when it is considered that reducing time and cost is a major challenge in project management (Shoubi et al., 2015). Therefore, it is necessary to use modern tools and methods of Information and Communication Technology (ICT).

It can be concluded that BIM is not a building model, but a construction model. In fact, BIM makes a significant contribution to constructability by modeling construction processes. It is also important that all BIM benefits are interrelated and each one affects others directly or indirectly.

According to what was discussed, it is quite evident that using BIM requires understanding this concept by the project stakeholders, in order to provide the necessary investment for training human resources, and ultimately, proper implementation of BIM in the project. In addition, applying BIM from the beginning of the project will have a direct impact on improving the project implementation.

6. Conclusion

This study identifies BIM benefits to improve the effective performance of projects. According to the conducted studies through SLR, BIM benefits were classified into four groups: pre-construction, design, construction, and post-construction stages. Employers can use BIM processes easily. In each phase, temporal processes and step by step instructions are explained based on key activities and questions of employers to meet their needs to ensure the completion of activities and processes according to their resources. The presence of employers, contractors, and consultants is a key factor for integrating project necessary information to improve the performance of the project. BIM is a relatively new process and still requires more knowledge, understanding its principles and concepts, and mastering its implementation. Managers 'and employers' commitment to use new methods and non-resistance to change is critical to the improvement and success of projects. Spending money initially will result in all costs being reimbursed at the end of the project, which in turn encourages employers to use BIM in projects.

BIM creates more responsibility against problems for sustainable and continuous improvement, increasing quality and productivity, and reducing costs. In addition, it prevents the occurrence of problems, and assigns responsibilities to groups to resolve problems and helps continuous improvement of the process. In order to improve quality and increasing efficiency, and consequently continuous reduction of costs, it improves the wastes system.

Beyond these short-term effects on productivity and quality, BIM is able to change the process of the project.

BIM presents a method in the construction industry, which emphasizes on the integration of different stakeholders of the project. This coordination and integration is a potential factor for improving the productivity of the project. On the other hand, through coordination and communication, it increases the designs' quality, which is one of the most significant issues in reducing duplications and errors.

According to what is identified through SLR and as discussed in the article, it is observed that using BIM in projects, due to its various benefits, will improve projects' constructability. It is important that managers pay attention to this issue, in order to use their investment for training their project team to help project improvement and success.

Generally, using BIM at the design and construction stages results in achieving construction objectives, including time, cost, and quality. Thus, using BIM, due to its various benefits, is suggested for all activists in the construction arena to improve project results.

It is hoped that by increasing BIM usage, coordination and communication are also increased, and separation in the construction industry is decreased, and in this way, project costs are reduced and its performance is improved.

For academic and applied innovation, according to the objectives of this study, it can be effective and useful at both academic and applied levels of projects. Contributions of the study to academic sciences are summarized below:

- Familiarity with the benefits of BIM and the possibility of further studies about the benefits of BIM at the operation and maintenance stages.
- Using the constructive communication model and BIM to reduce losses, delays, and duplications.

This study could be applied and executive sciences from the following perspectives:

- Using BIM benefits according to the objectives of the project for making them constructible and consequently reducing delays, duplications, time, and cost.
- Increasing integration and communication through creating an appropriate context using BIM
- Increasing employers' knowledge of new technologies in order to satisfy them and reduce changes of the project.

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Appendix 1: **Evaluation by Casp**

achieved score	The value of research	Provide clear findings	Analysis accuracy	Ethical considerations	Reflectivity	Collecting data	Sampling	Research project	Research Methodology	research goal	number of pages	Year of publication	Article name	Row
45	5	5	5	4	4	5	4	5	5	5	11	2012	How to measure the benefits of BIM — A case study approach	1
42	4	5	4	4	4	5	3	4	4	5	9	2013	From justification to evaluation: Building information modeling for asset owners	2
36	4	4	3	4	4	3	3	4	3	4	7	2013	BIM implementation throughout the UK construction project lifecycle: An analysis	3
47	5	5	5	4	4	5	4	5	5	5	10	2013	The project benefits of Building Information Modelling (BIM)	4
35	3	4	4	3	3	4	3	4	3	4	6	2013	Building Information Modeling (BIM) Application in Malaysian Construction Industry	5
33	3	4	3	3	3	4	3	3	4	3	9	2013	Benefits and Barriers of BIM Adoption in the Iraqi Construction Firms	6
27	3	3	2	3	3	3	2	3	2	3	7	2007	BIM Implementation—A Bibliographic Study of the Benefits and Costs Involved	7
32	3	4	3	4	3	3	2	3	3	4	13	2014	The Benefits of, and Barriers to, Implementation of 5D BIM for Quantity Surveying in New Zealand	8
19	1	2	2	3	3	2	2	1	2	1	22		Building information modelling (BIM) for sustainable building design	9
21	2	4	3	1	1	2	1	2	2	3	9	2015	Building Information Modeling in Project Management: Necessities, Challenges and Outcomes	10
18	1	2	1	2	2	1	2	2	2	3	5		An Examination of the Potential of Building Information Modelling to Increase the Efficiency of Irish Contractors on Design and Build Projects	11
19	1	2	2	2	2	1	2	2	2	3	20		Building Information Modelling (BIM) for facilities Management (fM): the Mediacity case study Approach	12

37	3	4	3	4	4	3	4	3	4	5	15	2016	BIM Benefits-maturity relationship awareness among UK construction clients	13
17	1	2	2	1	1	2	1	2	2	3	5		BIM Perspectives on Construction Waste Reduction	14
16	1	2	2	1	1	2	2	2	2	1	10		BIM Platform with Coworking Design Process Benefits	15
16	1	2	1	2	2	1	2	1	2	2	16		Building Information Modelling (BIM), Utilised During the Design and Construction Phase of a Project Has the Potential to Create a Valuable Asset in Its Own Right ('BIMASSET') At Handover That in Turn Enhances the Value of the Development	16
38	4	4	4	3	3	5	3	4	3	5	14	2015	A Study on Risks and Benefits of Building Information Modeling (BIM) in a Construction Organization	17
31	3	4	3	3	3	4	3	2	3	3	8	2011	Building Information Modelling (BIM) Framework for Practical Implementation	18
37	4	4	3	4	4	4	4	3	4	3	15	2013	An Analysis of The Drivers for Adopting Building Information Modelling	19
39	4	5	4	3	3	4	3	4	4	5	10	2014	A Benefits Realization Management Building Information Modeling Framework For Asset Owners	20
30	3	4	4	2	2	4	1	4	2	4	10	2016	Building Information Modelling (BIM) in Facilities Management: Opportunities to be considered by Facility Managers	21
36	4	4	4	3	3	4	3	3	4	4	17	2010	The Perceived Value of Building Information Modeling in The U.S. Building Industry	22
14	1	2	1	1	1	1	1	2	1	3	8		Project Management Innovation Based on Building Information Modeling	23
44	4	5	5	4	4	5	4	5	4	4	11	2010	Analysis of Benefits, Advantages and Challenges of Building Information Modelling in Construction Industry	24
42	4	5	5	4	4	4	3	4	4	5	18	2012	Building Information Modeling in Construction Industry: Review Paper	25
43	4	5	5	4	4	4	4	5	4	4	18	2012	Building Information Modelling (BIM) Implementation and Remote Construction Projects: Issues, Challenges, and Critiques	26
19	1	3	2	2	3	2	1	2	1	2	12		Enabling Building Information Modeling (BIM) Practices in the Canadian Construction Industry: A Case for an Academic Program	27

47	5	5	5	4	4	5	4	5	5	5	12	2011	Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry	28
20	2	2	1	2	2	1	2	2	3	3	8	2013	The Benefits, Obstacles and Problems of Practical BIM Implementation	29
18	1	2	1	2	2	1	2	2	2	3	11		Current Status of BIM Benefits, Challenges, and the Future Potential for the Structural Discipline	30
43	5	5	4	4	4	3	4	5	4	5	9	2015	The Benefits of BIM Integration with Facilities Management: A Preliminary Case Study	31
40	5	4	5	4	3	4	4	4	3	4	14	2017	Parallel impact of IPD and BIM approaches on facilitating constructability implementation.	32
31	4	3	4	4	2	3	1	4	3	3	13	2018	Building information modeling (BIM) systems and their applications in Turkey	33
42	5	5	4	5	3	4	2	5	4	5	58	2019	Building information modelling for off-site construction: Review and future directions	34

Appendix 2: Extract data from BIM articles

Row	References	Benefits of Building Information Modeling
1	(Eadie et al., 2013)	1. Improvement of scheduling, 2. Increasing coordination and cooperation, 3. Reducing duplications, 4. Better project visualization, 5. Improvement of productivity, 6. Reducing costs, 7. Increasing relations, 8. Reducing conflicts, 9. Increasing safety, 10. Reducing changes, 11. Quality improvement, 12. Reducing change requests, 13. Reducing contractors' costs, 14. Increasing productivity, 15. Analysis of energy consumption, 16. Improvement of risk management
2	(Hamada et al., 2016)	1. Minimizing project costs, 2. Increasing employer satisfaction, 3. Reducing safety risks, 4. Estimation of project time, 5. Improvement of project visualization, 6. Enhancing cooperation, 7. Improvement of communication, 8. Clash detection, 9. Reducing duplications, 10. Increasing productivity, 11. Better information management, 12. Increasing integration
3	(Bryde et al., 2013)	1. Organizing schedules and costs, considering the design team, 2. Controlling change and information demand through employing contractors, 3. Employer satisfaction, 4. Increasing profit margin, 5. Faster data analysis in project lifecycle, 6. Eliminating wastes, 7. Increasing feedback, 8. Better decision making, 9. Reducing delays, 10. On time delivery, 11. Integration of design and construction, 12. Survey all members, 13. Better management and reengineering processes, 14. Better access to project information, 15. Reducing time and cost, 16. Simulation of project environment, 17. Increasing coordination and cooperation, 18. Improvement of documents' quality, 19. Development of sustainable design, 20. Reducing operation and maintenance costs, 21. Improvement of project risk management and reducing risks by better decision making, 22. Increasing safety, 23. Better understanding of project conditions, 24. Improvement of documentation
4	(Barlish and Sullivan, 2012)	1. Better organization and flexibility, 2. Improvement of information technology infrastructures, 3. Integration of assets, 4. As a competitive advantage, 5. Establishing relations and external coherence, 6. Employer satisfaction, 7. Support of organizational changes, 8. Performance integration, 9. Helping to improve decision making, 10. Enhancing resource management, 11. Performance improvement, 12. Reducing time and cost, 13. Quality improvement, 14. Reducing changes, 15. Increasing safety, 16. Better information management
5	(Love et al., 2013)	1. Increasing coordination and cooperation, 2. Wastes reduction, 3. Project visualization, 4. Reducing costs, 5. Increasing communication among stakeholders, 6. Reducing changes, 7. Increasing integration, 8. Better process management
6	(Latiffi et al., 2013)	1. Increasing the accuracy of project information, 2. Improvement of schedules and sequence of activities, 3. Better communication and improvement of decision making, 4. Analysis of clash detection, 5. Increasing design quality, 6. Cooperation of different working groups, 7. Time and cost estimation, 8. Cost reduction, 9. Better resource management, 10. Effective management of facilities, 11. Maintenance review, 12. Document management
7	(Pimentel, 2016)	1. Early detection of conflicts, 2. Avoiding duplications, 3. Better project visualization and more appropriate design, 4. Better communication and cooperation, 5. Time and cost reduction, 6. Improvement of schedules, 7. Better facilities management, 8. Better decision making about productivity, 9. Performance improvement
8	(Stanley and Thurnell, 2014)	1. Better understating of project, 2. Improvement of communication and cooperation, 3. Improvement of project quality, 4. Designs' analyzability, 5. Cost estimation, 6. Increasing accountability to RFI in real time, 7. Risks' detection
9	(Rokooei, 2015)	1. Clash detection, 2. Constructability improvement, 3. The possibility of various analyses, 4. Time and cost estimation, 5. Increasing integration, 6. Estimating the amount of materials, 7. Component-based modeling, 8. Improvement of team building and communication, 9. Increasing cooperation, 10. Increasing coordination among stakeholders, 11. Improvement of productivity through reducing duplications, conflicts, and changes, 12. Improvement of project quality, 13. Faster delivery, 14. Reducing wastes, 15. Reducing costs
10	(Dakhil et al., 2016)	1. Improvement of information control, 2. Improvement of project schedule 3. Increasing cooperation and communication, 4. Increasing process integration, 5. Improvement of project quality, 6. Improvement of decision making process, 7. Improvement of time and cost control, 8. Reducing the number of RFI in the construction stage, 9. Reducing changes, 10. Reducing material costs, 11. Reducing duplications, 12. Improvement of relations among stakeholders, 13. Improvement of access to information, 14. Increasing information accuracy, 15. Reducing services

11	(Sai Evuri and Amiri-Arshad, 2015)	1. Better information exchange among stakeholders, 2. Increasing cooperation, 3. Project visualization before construction, 4. Reducing conflicts, 5. Reducing duplications, 6. Proper management of changes, 7. Improvement of project quality, 8. Sustainable development of design and construction, 9. Time and cost reduction, 10. RFI reduction, 11. Improvement of energy consumption, 12. Fast and correct response to changes, 13. Cost estimation, 14. Problems detection before construction, 15. Improvement of facilities management, 16. Reducing wastes
12	(Jung and Joo, 2011)	1. Better use of three-dimensional models for entering the desired information, 2. Project visualization, 3. Integration, 4. Better data analysis, 5. Coordination and cooperation, 6. Focus on project
13	(Eadie et al., 2013)	1. Improvement of time, cost, and energy consumption analysis, 2. Better cooperation of stakeholder, 3. Improvement of facilities management, 4. The possibility of creative design, 5. Better decision making and reducing changes, 6. Reducing duplications, 7. Increasing employer satisfaction, 8. Better visualization of construction sequence, 9. Increasing safety, 10. Simulation of project environment and risk reduction, 11. Increasing relations among all of the stakeholders of project, 12. Increasing constructability, 13. Cost reduction, 14. Time reduction, 15. Clash detection analysis, 16. Improvement of establishing MEP systems, 17. Improvement of facilities management, 18. Improvement of design quality
14	(Love et al., 2014)	1. Better resource management, 2. Cost reduction, 3. Saving materials and reducing wastes, 4. Better management and productivity improvement, 5. Correct information, 6. Meeting the requirements (safety control such as environmental protection, energy resources management), 7. Space optimization, 8. Improvement of product management, 9. Better conflict management, 10. Risk reduction, 11. As a competitive advantage, 12. Increasing coordination and cooperation and communication, 13. Increasing information exchange
15	(Aziz et al., 2016)	1. Reducing operation costs, 2. Better decision making in a shorter time, 3. Access to the required resources and information for decision making, 4. Better system for document maintenance, 5. Increasing cooperation and flexibility, 6. Updating information, 7. Clash detection, 8. Creating a strong database, 9. The ability to analysis the entire system, 10. Better facilities management
16	(Becerik-Gerber and Rice, 2010)	1. Increasing project profitability, 2. Improvement of design, 3. Documentation of the construction documents, 4. Presenting a multi-dimensional model, 5. Cost and time reduction, 6. Increasing documents' accuracy, 7. Creating value added in projects, 8. Increasing cooperation and coordination, 9. Reducing conflicts, 10. Reducing mistakes, 11. Better changes management
17	(Diaz, 2016)	1. Increasing constructability, 2. Better decision making, 3. Energy consumption analysis, 4. MEP analysis, 5. Estimating the amount of materials, 6. Increasing cooperation and coordination, 7. Cost estimation, 8. Early detection of mistakes, 9. The analysis of construction scheduling, 10. Productivity improvement, 11. Improvement of customer services, 12. Time and cost reduction, 13. Increasing quality
18	(Mohandes and Omrany, 2013)	1. Mistakes reduction, 2. Reducing clashes, 3. Increasing integration, 4. Time and cost reduction, 5. Improvement of integration of the design and construction phases, 6. Increasing cooperation among different sections of a project, 7. Better project visualization, 8. Easier estimation of the required materials, 9. Increasing analyzability of complex details, 10. Using 4D and 5D models to estimate time and cost, 11. Reviewing and analyzing project site, 12. Analyzing the location of machines and equipment, 13. Improvement of project schedule, 14. Evaluating items related to safety, 15. Evaluating different options in real models, 16. Constructability analysis, 17. Better project team management, 18. Operation control
19	(Arayici et al., 2012)	1. Increasing presence of stakeholders in the project, 2. Increasing creativity and teamwork, 3. Increasing communication and coordination, 4. Improvement of logistics management, 5. Creating a correct schedule, 6. Estimating the amount of materials, 7. Exchanging project information among all of the stakeholders, 8. Increasing productivity and performance, 9. Increasing quality and reducing time and cost, 10. Reducing duplications, 11. Increasing safety, 12. Reuse of databases, 13. Using previous projects' experiences and lessons learned, 14. Information exchange among stakeholders for better communication and cooperation, 15. Comparability, 16. Detection of errors and barriers, and increasing employer satisfaction, 17. Reviewing plans and modifying them, 18. Improvement of design and technical review of projects to identify potential problems, 19. Better access to information for project team
20	(Azhar, 2011)	1. Correct geometric representation of different sections of building in the form of an integrated environment, 2. Increasing speed and effectiveness of processes due to high exchange of appropriate information, 3. Creating value added in the project, 4. Better design, analyzing the objectives of construction and using innovative responses, 5. Better understanding of costs of project lifecycle, 6. Better and higher quality, 7. Presenting better services to customers, 8. Appropriate access to all of information of project lifecycle, 9.

		Change reduction, 10. Cost estimation, 11. Time and cost reduction, 12. Increasing cooperation and coordination, 13. Increasing integration in the project, 14. Pre-fabrication, 15. Improvement of construction sequence (requesting materials,…), 16. Clash detection, 17. Barriers analysis, 18. Improvement of facilities management, 19. Increasing information accuracy
21	(Migilinskas et al., 2013)	1. Delays reduction, 2. Time reduction, 3. Early detection of project problems, 4. Increasing quality and productivity, 5. Increasing cooperation and coordination, 6. Reduction of duplications, 7. Cost reduction, 8. Simulation with project details, 9. High information exchange among project team, 10. Errors reduction, 11. Improvement of the design process, 12. Better resources management
22	(Terreno et al., 2015)	1. More cooperation among project team members and the ability to respond to problems, 2. Improvement of labor productivity, 3. Increased efficiency, 4. Strategic planning with more details, 5. Clarification of design and construction requests, 6. Reducing reaction time to problems, 7. Increasing integration in the entire project lifecycle, 8. Reducing the need to reentrance of information, 9. The possibility to review design, 10. Asset increase, 11. Easier access to information, 12. Maintenance improvement, 13. Increasing readiness in critical conditions, 14. Better planning considering more cooperation among sections, 15. Access to more correct information, 16. Updating model automatically, 17. Improvement of facilities management
23	(Jadidoleslami and Saghatforoush, 2017)	1. Reducing the probability of error, 2. Reducing mistakes, 3. Earning the most profit and reducing costs, 4. Realistic simulation of project information, 5. Facilitating the constructability implementation, 6. Reducing duplications, 7. Preventing conflicts, 8. Improving the quality of production, 9. Creating a clear view of the project to improve decisions, 10. Understandable proposal for the employer
24	(Kalfa, 2018)	1. Accurate visualization and simulation of the project, 2. Increased coordination and cooperation, 3. Conflict detection and risk reduction, 4. Faster planning without losing cost and quality, 5. Increased flexibility, 6. Easy maintenance of the building lifecycle, 7. Optimizing the plan and costs, 8. Poor implementation of construction, 9. Reducing mistakes, 10. Reduced total project duration, 11. Careful monitoring of construction
25	(Yin et al., 2019)	1. Increased productivity through interoperability, 2. Facilitating decision making about various aspects of construction, 3. Managing building defects, 4. Improving the coordination of building parties, 5. Reducing the environmental impacts of the construction process, 6. Reducing duplications, 7. Facilitating data processing, 8. Improved efficiency and design quality, 9. Sharing information among stakeholders (designer, manufacturer, contractor, etc.), 10. Improving the construction process, 11. Improving the supply chain performance in terms of cost, planning, quality, and environmental sustainability, 12. Improving facilities management, 13. Improving facility management and safety analysis

Appendix 3: Extract BIM Benefit Codes

Stage	Considered codes for benefits	References
Design	Enhancing designs' quality and sustainable development of design	(Bryde et al., 2013), (Hamada et al. 2016), (Eadie et al., 2013), (Yin et al., 2019), (Becerik-Gerber and Rice 2010), (Eadie, Odeyinka et al. 2013), (Sai Evuri and Amiri-Arshad 2015)
	Better plan visualization	(Eadie et al., 2013), (Hamada et al., 2016), (Bryde et al., 2013), (Barlish and Sullivan, 2012), (Pimentel, 2016), (Stanley and Thurnell, 2014), (Rokooei, 2015), (Sai Evuri and Amiri-Arshad, 2015), (Jung and Joo, 2011), (Eadie et al., 2013), (Mohandes and Omrany, 2013), (Azhar, 2011), (Jadidoleslami and Saghatforoush, 2017), (Kalfa, 2018)
	Reducing the need of designer to modification	(Eadie et al., 2013), (Bryde et al., 2013), (Barlish and Sullivan 2012), (Dakhil et al., 2016), (Jung and Joo 2011), (Eadie et al., 2013), (Becerik-Gerber and Rice, 2010)
	Reducing errors in public maps of design	(Latiffi et al., 2013)
	Better view of design mistakes and barriers	(Latiffi et al., 2013), (Eadie et al., 2013), (Arayici et al., 2012)
	Energy consumption and sustainability analysis	(Barlish and Sullivan, 2012), (Sai Evuri and Amiri-Arshad, 2015)
	Reviewing plans and improving their quality	(Eadie et al., 2013), (Arayici et al., 2012), (Terreno et al., 2015)
	Reducing analysis time and estimating the related items (structure, materials, building orientation, energy, …)	(Rokooei, 2015), (Eadie et al., 2013), (Love et al., 2014), (Diaz, 2016), (Mohandes and Omrany, 2013), (Arayici et al., 2012)
	Evaluating different options of design	(Latiffi et al., 2013), (Stanley and Thurnell, 2014), (Rokooei, 2015), (Mohandes and Omrany, 2013)
	Increasing communication and coordination and integration	(Hamada et al., 2016), (Bryde et al., 2013), (Barlish and Sullivan, 2012), (Love et al., 2013), (Latiffi et al., 2013), (Pimentel, 2016), (Stanley and Thurnell, 2014), (Rokooei, 2015), (Dakhil et al., 2016), (Love et al., 2014), (Becerik-Gerber and Rice, 2010), (Diaz, 2016), (Mohandes and Omrany, 2013), (Arayici et al., 2012), (Azhar, 2011), (Migilinskas et al., 2013), (Terreno et al., 2015), (Kalfa, 2018), (Yin et al., 2019)
	Improving problem detection before construction	(Pimentel, 2016), (Sai Evuri and Amiri-Arshad, 2015), (Diaz, 2016), (Migilinskas et al., 2013)
	Better estimation of time and cost	(Hamada et al., 2016), (Latiffi et al., 2013), (Stanley and Thurnell, 2014), (Rokooei, 2015), (Dakhil et al., 2016), (Sai Evuri and Amiri-Arshad, 2015), (Diaz, 2016), (Mohandes and Omrany, 2013)
	Earlier access to the correct information of project	(Bryde et al., 2013), (Love et al., 2013), (Dakhil et al., 2016), (Aziz et al., 2016)
	Improving decision-making power	(Bryde et al., 2013), (Love et al., 2013), (Latiffi et al., 2013), (Pimentel, 2016), (Dakhil et al., 2016)، (Eadie et al., 2013), (Aziz et al., 2016), (Diaz, 2016)
	Improving design and establishing MEP systems and better coordination with other systems	(Eadie et al., 2013)
	Constructability improvement	(Rokooei, 2015), (Eadie et al., 2013), (Diaz, 2016), (Mohandes and Omrany 2013), (Arayicigbu et al., 2012), (Jadidoleslami and Saghatforoush, 2017)
	Improving feedback	(Bryde et al., 2013)
	analysis clash detection	(Hamada et al., 2016), (Latiffi et al., 2013), (Rokooei, 2015), (Eadie et al., 2013), (Azizi et al., 2016), (Mohandes and Omrany 2013), (Arayici et al., 2012)
	Project site and machines' location analysis	(Mohandes and Omrany, 2013)
Pre-construction	Presence of all stakeholders and increasing relations among them	(Eadie et al., 2013), (Barlish and Sullivan, 2012), (Love et al., 2013), (Rokooei, 2015), (Dakhil et al., 2016), (Sai

		Evuri and Amiri-Arshad, 2015), (Jung and Joo, 2011), (Arayici et al., 2012)
	Earlier and better project visualization	(Eadie et al., 2013), (Barlish and Sullivan, 2012)
	Clarification of project concepts for the employer and improving his/her satisfaction	(Bryde et al., 2013), (Love et al., 2013), (Latiffi et al., 2013), (Eadie et al., 2013), (Arayici et al., 2012), (Jadidoleslami and Saghatforoush, 2017)
	Using modern construction technologies and methods as a competitive advantage	(Love et al., 2014)
	Better information management and documentation improvement	(Hamada et al., 2016), (Bryde et al., 2013), (Love et al., 2013), (Latiffi et al., 2013), (Dakhil et al., 2016), (Love et al., 2014), (Aziz et al., 2016), (Becerik-Gerber and Rice, 2010), (Arayici et al., 2012), (Azhar, 2011)
	Improving team building skills	(Rokooei, 2015), (Mohandes and Omrany, 2013)
	Better understanding of construction components	(Barlish and Sullivan 2012), (Eadie et al., 2013)
	Understanding sequence of activities during construction	(Eadie et al., 2013), (Azhar, 2011)
	Increasing coordination and integration among design, construction, and logistics	(Bryde et al., 2013), (Mohandes and Omrany, 2013)
	Using and developing pre-fabrications	(Azhar, 2011)
	Improving safety with access to project details and risk detection	(Hamada et al., 2016), (Bryde et al., 2013), (Barlish and Sullivan, 2012), (Love et al., 2013), (Eadie et al., 2013), (Love et al., 2014), (Mohandes and Omrany, 2013), (Arayici et al., 2012), (Yin et al., 2019)
	Improving project quality	(Barlish and Sullivan 2012), (Love et al., 2013), (Stanley and Thurnell, 2014), (Rokooei, 2015), (Dakhil et al., 2016), (Sai Evuri and Amiri-Arshad, 2015), (Diaz, 2016), (Mohandes and Omrany 2013), (Azhar 2011), (Migilinskas et al., 2013), (Jadidoleslami and Saghatforoush, 2017), (Yin et al., 2019)
	Improving responsiveness to requests (RFI) on time	(Bryde et al., 2013), (Barlish and Sullivan, 2012), (Love et al., 2013), (Pimentel, 2016), (Rokooei, 2015), (Sai Evuri and Amiri-Arshad, 2015), (Terreno et al., 2015)
Construction	Increasing decision making power of contractors	(Eadie et al., 2013), (Love et al., 2013), (Eadie et al., 2013)
	Reducing project construction time and cost	(Eadie et al., 2013), (Hamada et al., 2016), (Bryde et al., 2013), (Barlish and Sullivan, 2012), (Love et al., 2013), (Latiffi et al., 2013), (Pimentel, 2016), (Rokooei, 2015), (Dakhil et al., 2016), (Sai Evuri and Amiri-Arshad, 2015), (Jung and Joo, 2011), (Eadie et al., 2013)، (Becerik-Gerber and Rice, 2010), (Diaz, 2016), (Mohandes and Omrany, 2013)، (Arayici et al., 2012), (Azhar, 2011), (Migilinskas et al., 2013), (Terreno et al., 2015), (Jadidoleslami and Saghatforoush, 2017), (Kalfa, 2018)
	Productivity improvement	(Hamada et al., 2016), (Barlish and Sullivan, 2012), (Love et al., 2013), (Rokooei, 2015), (Love et al., 2014), (Diaz, 2016), (Arayici et al., 2012), (Migilinskas et al., 2013), (Yin et al., 2019)
	Reducing mistakes, duplications, wastes, and delays	(Eadie et al., 2013), (Hamada et al., 2016), (Barlish and Sullivan, 2012), (Pimentel, 2016), (Rokooei, 2015), (Dakhil et al., 2016), (Sai Evuri and Amiri-Arshad, 2015), (Eadie et al., 2013), (Love et al., 2014), (Becerik-Gerber and Rice, 2010), (Mohandes and Omrany, 2013), (Arayici et al., 2012), (Terreno et al., 2015), (Jadidoleslami and Saghatforoush, 2017), (Kalfa, 2018), (Yin et al., 2019)
	Improving communication among all stakeholders	(Eadie et al., 2013), (Barlish and Sullivan, 2012), (Yin et al., 2019)
	Fast reaction to design changes	(Barlish and Sullivan, 2012)

	Reducing conflicts	(Barlish and Sullivan, 2012) ,(Pimentel, 2016), (Sai Evuri and Amiri-Arshad, 2015), (Love et al., 2014), (Becerik-Gerber and Rice, 2010), (Jadidoleslami and Saghatforoush, 2017), (Kalfa, 2018)
	Risk management improvement	(Bryde et al., 2013), (Barlish and Sullivan, 2012), (Stanley and Thurnell, 2014), (Eadie, Odeyinka et al. 2013), (Love et al., 2014)
	Resources management improvement	(Barlish and Sullivan, 2012), (Latiffi et al., 2013), (Love et al., 2014), (Migilinskas et al., 2013)
	Timely delivery	(Bryde et al., 2013), (Rokooei, 2015)
Post-construction	Facilities management improvement	(Pimentel, 2016), (Sai Evuri and Amiri-Arshad, 2015), (Eadie et al., 2013), (Aziz et al., 2016), (Azhar, 2011), (Terreno et al., 2015), (Yin et al., 2019)
	Reducing maintenance cost	(Bryde et al., 2013), (Aziz et al., 2016)
	Better decision making and support of performance of project lifecycle	(Love et al., 2013)
	Improving strategies of building maintenance	(Latiffi et al., 2013), (Kalfa, 2018)
	Project performance improvement	(Love et al., 2013), (Pimentel, 2016), (Terreno et al., 2015), (Yin et al., 2019)
	Creating value added and increasing profit margin	(Bryde et al., 2013), (Becerik-Gerber and Rice, 2010), (Azhar, 2011), (Jadidoleslami and Saghatforoush, 2017)