

Investigating the effects of building information modeling capabilities on knowledge management areas in the construction industry

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ABSTRACT

In order to manage a project seamlessly, there is a need to establish effective communication between different departments and identify the risks in the project, determine the affected or influencing stakeholders, provide timely resources and logistics, and manage the available resources to make a framework for project implementation. In order to successfully complete the project it is also necessary to focus on approved costs, project completion time and quality within the specified range. Project management is the coordination among different parts of the project to achieve the main goals of the project and the stakeholders' expectations. To achieve this, there are several standards and one of the most recognized standards is the Project Management Knowledge Facility (PMBOK), which has come with the assistance of Project Managers for professional, targeted and comprehensive management. PMBOK is not just a guideline and a methodology for project management. Building Information Modeling (BIM), a project management methodology has been adopted in recent years to design a project integrated as a 3-D information model, which adds all project information in the various phases of the project to a 3-D information model. The purpose of this research is to gather some data from experts using some questionnaires in the area of project management to build an information modeling. The study determines that each of the basic BIM capabilities had positive effects on different domains of PMBOK knowledge. Moreover, using SAW analysis, the study suggests that BIM had the greatest impact on project integration management, and finally, the BIM general process model is introduced to implement each of the areas of knowledge.

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1. Introduction

The increasing acceptance of Project Management as a career, expresses that using the proper knowledge, processes, abilities, tools, and techniques, can have a considerable impact on projects success, and reduce the problems (that may rise) in a project. PMBOK project management standard and its body/fields of knowledge are widely accepted by the public as a proper method; this standard is more of guide than a special methodology (Larson & Gray, 2015). That is to say project management standards only specify the required framework to achieve the project goals, but they do not show/lead the way to them; thus, we need tools and techniques that lead us to the desired goals in a project. The construction industry has been continuously criticized world-wide for its unwillingness to employ and implement new technologies, slow pace of increasing productivity, and also for its limitations and inability in project management (Alshawi & Ingirige, 2003). Old-fashioned contracts, inexact building

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plans, disintegrate among project team members throughout the project, long and flawed processes of construction projects design and execution, unnecessary time consuming repetition (reworking) of tasks resulting from engineers' analytic mistakes, unwillingness of the design team to implement changes, difficult and vague value engineering, cost estimations based on imprecise and outdated price lists, and the lack of a comprehensive and understandable image of the project for the employer, are just some of the problems that construction companies are involved with on a daily basis. A main reason for the emergence of such problems in construction projects, is the lack of functioning data collection systems customized to meet the needs of construction industry. The use of a system that in addition to data collection and classification can be easily employed by the main agents involved in the project may enhance communications, and thus make a considerable contribution to the project management (Autodesk, 2011). Studies show that Building Information Modeling (BIM) contains such capacities, and its widespread employment in construction industry across the country can eliminate many problems; and play a significant role in increasing productivity and project management in the industry (Broquetas, 2010). BIM takes place before the execution of a project, and at each stage the required information are added to it by various teams and individuals. Not only is this information used during the design and construction [stages]; but, they are also useable to the users after the project delivery and during the utilization phase. Formation of a useful data base, cooperation and harmony among various project agents involved in the making of the model, organization of all production plans, decrease in design/planning errors, diagnosis of mistakes in design/plan, possibility of adding cost and timing information to the model, and assisting in facility management during the utilization phase, are just some of the capacities of such models (Azhar, 2011). The differentiating aspect between BIM and other methods of designing and presenting construction projects lies in their framework; information is the solution this method (BIM) suggests, (in other words) adding various data to the building model (including the timing, equipment, material, cost, and etc. data). Such data can be analyzed, and made available to the people who benefit from them when required (Young, et al., 2009; Golabchi et al., 2013).

In this research, we first review the knowledge management areas of the project and how they relate to each other, and then building information modeling (BIM) and its capabilities throughout the life cycle of the project will be introduced. Continuing through questionnaires from project management and BIM experts, the impact of each BIM capabilities on knowledge areas will be discussed. Then, using SAW analysis, we examine and rank the impact of each project management knowledge domain on BIM capabilities, and ultimately, the BIM process model for implementing knowledge management areas will be presented, we determine that we can use building information modeling as a suitable methodology for implementation of knowledge management areas of projects in projects.

2. Theoretical Foundations and Review of Literature

2.1. Project Management Body of Knowledge and Their Correlation

The acceptance of project management as a career, shows that using knowledge, processes, skills, tools, and techniques, can play an important role projects success. The PMBOK guide, represents a wide variety of project management knowledge subsets, and is generally recognized as a suitable approach. The necessary knowledge for project management, and project execution processes have been respectively categorized in 10 management-subgroups and 5 process-subgroups. In the field of Project Management knowledge, understanding the factors influencing the project and their management, can integrate the project execution processes to achieve the desired goal/purpose (Larson & Gray, 2015). Table 1 provides the definitions of Project Management fields of knowledge through the perspective of PMBOK.

Table 1
Project Management knowledge

Project Management knowledge	
Project Management fields of knowledge	Description
Integrated Management	Processes and activities needed to identify, define, combine, unify and harmonize process and activities in different procedure-groups of Project Management (Larson & Gray, 2015).
Scope Management	The required process to ensure that the project contains all the required tasks to achieve success. Project Scope Management encompasses defining and controlling all the things that the project includes (or does not include) (Larson & Gray, 2015).
Time Management	The needed processes for on-time delivery of the project (Larson & Gray, 2015).
Costs Management	The processes of cost-estimation, budgeting, and cost management to keep the project within the confirmed budget (Larson & Gray, 2015).
Quality Management	The processes and activities of executive organizations, which determine the policies, goals, and responsibilities in order to meet the required promises (Larson & Gray, 2015).
Risk Management	The process of directing and planning risk management, involves identifying, analyzing, reaction planning, supervising, and controlling the project risks (Larson & Gray, 2015).
Resource Management	Project resource management encompasses stages such as identifying, achieving, and managing the necessary resources for the successful delivery of the project. This process ensures that sufficient resources are available to the project manager and the project team where and when resources are needed (Larson & Gray, 2015).
Procurement Management	The needed procedures for purchasing or attracting products, services, or achieving results, outside the project team (Larson & Gray, 2015).
Communication Management	The on time and appropriate process of collecting, distributing, saving, and retrieving project data (Larson & Gray, 2015; Wong & Fan, 2013).
Stakeholders Management	The needed processes to identify individuals, groups, and organizations influencing or influenced by the project in order to have an analysis of stakeholder and how they affect the project; so that an appropriate management strategy can be employed to attract their participation in project decisions and execution (Larson & Gray, 2015).

A project is considered successful when, it is completed within the determined time and budget, has a quality that fits the expected scope, and the employer is satisfied about the execution process. Thus, time management, cost management, quality management, and scope management can be considered as the primary knowledge of project management; and knowledge fields of resources, communications, risks, procurements, and stakeholders are secondary and contributing to the primary fields. Finally, all such knowledge need to be coordinate and integrated to guarantee project success. Project management standard and its fields of knowledge are rather used as a guide instead of being an independent methodology. In other words, this standard indicates the necessary frameworks to achieve success in a project, but does not lead to it. Therefore, one can employ different methodologies, tools, and techniques (such as Agile or Waterfall methodologies) to create a project management framework that leads to project goals (Larson & Gray, 2015). Likewise, the present study introduces BIM as a constructive tool for integrated project management and the influence of such management on project management fields of knowledge.

2.2. Building Information Modeling (BIM)

During the early 1960s, the construction industry faced a gradual reduction in productivity of the human resources. Meanwhile, other industries were enjoying an enhanced productivity of the human resources (Rooke, et al., 2004). Island-like nature of the construction industry due to its approach to contracts, its use of 2D drawing methods (CAD Software), and the size and magnitude of the construction companies can be regarded as the main reasons for a low productivity indicator (Teicholz, 2004). Here, the inefficiency of 2D design methods in accomplishing an effective communication with the stakeholders can be pointed to as a significant factor. In a situation where each of the factors involved in the 2D plans corresponded to its related discipline, the plans that lacked the capacity to integrate and adapt to other plans, led to information conflicts and therefore a reduction in the workforce productivity (Teicholz, 2004). On the other hand, 2D designs lacked the capacity to integrate with and encompass the costs and planning information. Moreover, the downward flow of construction workforce payments had led to lack of pressure for an increase in worker's productivity. Thus, any attempts to come up with new methods was not economically justified (Teicholz, 2004). In 1997 a new revolution introduced a 3D design tool that used a shared data source. Such a shared data source made the changes in designs-at any point of the designs-possible and automatically applied the changes to other design documents. The database could also be shared between large numbers of users. Architecture, structure, and facility

models could be made as linked and merged together (Migilinskas, et al., 2013). According to Eastman et al. (2011), BIM is more than a software, it is a human activity that transforms design, construction, and construction management processes. General Services Administration (GSA) defines BIM as: “Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which, views appropriate to various users’ needs can be extracted and analyzed to generate feedback and improvement of the facility design” (Parvan, 2012). BIM has the capacity to bring together all the required information during the project lifecycle including, spatial relations, geographical position, quantity and specifications of building parts, cost estimation, list of materials, and the project schedule. The integrity of the information extracted from the design process, and its consequent coordination of information, make BIM stand out in comparison with the CAD-based design methods. In order to have a better understanding, CAD data can be compared to detached islands, while BIM data can be associated with connected and unified ones.

2.3. Various Aspects of Building Information Modeling

BIM is the digital evolution from the traditional 2D model to 3D and even to 4D (determining a time plan) and 5D (cost estimation) models; it uses a shared database throughout the construction life cycle. The characteristics of parametric modeling and the capacities of intersectional cooperation facilitate this evolution process. The aspects of BIM follow as such:

- ✓ **3D Model:** The mathematical presentation in any 3D level such as width, length, and height of an object. In other words, 3D BIM includes plan, spatial relations, geographical, and geometric information. For example, the width, length, and height of the building sections (Liu, 2010).
- ✓ **4D Model:** The addition of a fourth dimension—that is the time plan—to any 3D BIM model. The 4D establishes communication between 3D elements and the project delivery timeline, and thus provides the possibility of simulating the virtual process of project construction in a 4D environment to the users (Dang & Tarar, 2012).
- ✓ **5D Model:** The addition of a fifth dimension means to add the data of cost estimation to the 3D model. Any 5D model, for instance, connects the costs data to the list of amounts and materials (QTO)¹ derived from the 3D model, thus adding to the preciseness and trueness of the project cost estimation (Liu, 2010).

The items considered in this data model are:

- 1-The simultaneous estimation of costs based on the designed mental model, before the execution phase.
 - 2-The capacity to separate the costs of each section, and a more precise and complete estimation of the demanded items
 - 3-Value engineering based on the results
 - 4- Overcoming issues before they occur
 - 5-Estimation of the major costs
 - 6- Achieving a database for being used in similar cases
- ✓ **6D Model:** When the construction project is ready to be delivered, the 6D model is given to the owners for the purpose of managing the facilities. The model includes information such as the details and data of products, maintenance and utilization methods, photos, warranty data, communication links to online sources of production, contracts, construction information, etc. The model assists the managers of the building in its maintenance and utilization throughout the life time of the construct (Elbeltagi & Dawood, 2011).

¹ Quantity take-offs

- ✓ **7D Model:** The seventh dimension of BIM is related to maintenance and repair of the building facilities during the utilization time.

In Table 2, a set of BIM capabilities is expressed throughout the life cycle of the project.

Table 2
BIM Capacities and Functions

BIM Capacities and Functions		
1	Parametric members	Parametric data are the data that differentiate one part from other similar parts. For instance, although all of the walls are designed through a tool menu, they are also made of unique parameters, such as dimensions, materials, or a specific supplying company, which differentiate them from other walls. In addition, the intelligence of the parts in modeling is not limited to them, they are also assessable in relation to the rest of the parts (Eastman, et al., 2011).
2	3D Model, Increased Vision Precision, and Reduction of Claims	The complexity of work, length of the execution phase, and different interpretations of the project by the contract parties are the bed form which claims rise. Contract parties having access to a 3D model of the project before the execution, negates all the cases of various interpretations, work complexity, and extra time. That is to say, an appropriate project management reduces the rise of claims (Eastman, et al., 2011).
3	Integrated Change Management	The users can have access to any required 2D designs through BIM model (horizontal, vertical ...cuts). In case of changes to any of the parts, the change applies to any other dependent part(s) as a result of (the parts) being parametric (Winberg & Dahlqvist, 2010).
4	Fabrication	Because of the availability of all required constituent parts and sections, BIM, makes pre-construction (out of the construction site) possible (Winberg & Dahlqvist, 2010).
5	Documentation	At the end of the project, the project manager can present a comprehensive model of building information to the client. A model which includes information such as: links to approvals, maintenance and utilizing information, warranties, guarantees, security and safety information (such as lighting information and firefighting system, alarm, and smoke sensors); in addition the facilities management team, based on the information given to the client, can execute energy analysis and optimization systems during the facilities utilizing time period (Hergunsel, 2011).
6	Construction Process Simulation, and Saving Time during the Project Execution	A 4D model can be gained by integration of graphic images with the time dimension. In 3D modeling, a graphic model of 3 spatial dimensions is connected to the time dimension, so the order and sequences of different project steps are shown in real-time. 4D modeling tool enables the project planner to plan activities with respect to time and space dimensions. This makes, the coordination of execution methods with the [construction] site conditions, placement of crane tower, burrowing details, and such activities, possible. The studies show that 4D models indicate the design conflicts before the execution phase, and reduce the spatial-temporal conflicts and eliminate their ensuing rework (Eastman, et al., 2011).
7	5D Model, and Precise Quantity Surveying and Cost Estimation	A 5D model of building information requires integration of the 3D model with time and cost aspects of the project. This makes the anticipation and tracing of the project costs during any of the various phases possible (Dang & Tarar, 2012). In this system, the extraction of the work amounts and the required materials, also other dimension details, from the 3D model, are very easy (Hergunsel, 2011).
8	Equipment Management	The equipment management groups can utilize BIM for renovation, spatial planning, and building maintenance (Eastman, et al., 2011).
9	Facility Management	One of the most important functions of BIM in the management of the facilities is the collection and record of the needed data on the parts and equipment used in the building, to be referred to during the utilization period. The data regarding performance inspection, warranty period, equipment and materials features, etc. can play a problem-solving role in the maintenance process (Akula, 2013).
10	Sustainable Design and Construction	The smart data made through BIM, have the capacity to assess total building energy, simulate its (energy) performance, selecting the best approach/orientation to it, internal lighting analysis, and the presentation of such assessments (Krygiel & Nies, 2008).
11	Constructability	An established capacity of BIM is the coordination of the various groups of design (Architecture, construction, and facilities), and therefore maximal adaptation of design and construction processes. This has a meaningful effect on reducing the costs and time of the project.
12	Enhancing Safety	BIM is known as a tool for improving the safety and health of the workforce. BIM can be used for, training the workforce, safety-based design of the construction site, safety planning (analyzing workplace dangers,), identifying and analyzing the risk management factors, determining the excavation equipment scope of motion, determining the storage place of materials and pre-made parts, and determining the security and safety measures during the utilization and maintenance phases. Through making a shared 3D model of the buildings for the groups involved in design and construction, BIM reduces the risks during the construction (Khoshnava et al., 2010).
13	Conflict Detection	Since the virtual 3D model of the building is the source of all 2D and 3D plans, the design errors resulting from the 2D plans are eliminated. Conflicts and constructability problems are identified before happening in the site. Coordination between designers and contractors rises, and negligence is significantly reduced. This capacity accelerates the construction process, reduces costs, minimizes the probability of legal conflicts, and brings about an easier construction process for the project team (Eastman, et al., 2011).
14	Cooperation between the Project Team	The design and construction of a building are group and team activities. Naturally working with various models is more difficult and time-consuming, compared to working with an integrated 3D model. In such a 3D model, change control can be managed better, while cooperation through drawings is also possible. This reduces the design time and minimizes the mistakes and errors of the design process. It provides new insights regarding the design problems and also provides opportunities for the constant improvement of the design (Eastman, et al., 2011).
15	Improving Communication, and Reinforcing Cooperation and Coordination	By using BIM, anyone can see their task in relation to others. On a data exchange level, the building model, because of high readability, supports the automatic translation of BIM and accessibility of the design information for anyone-throughout the design and construction processes (Eastman, et al., 2011).
16	Quick Response to Changes in the Design	The changes in the proposed design can impact the construction model, and automatically apply the changes on the other objects. The updates are done automatically and are based on rational parametric laws. Moreover, the changes in design can be applied faster through BIM, that is because the corrections can be shared, analyzed, and applied without the time consuming paper-based processes (Eastman, et al., 2011).

Fig. 1 illustrates the capabilities of building information modeling throughout the project cycle.

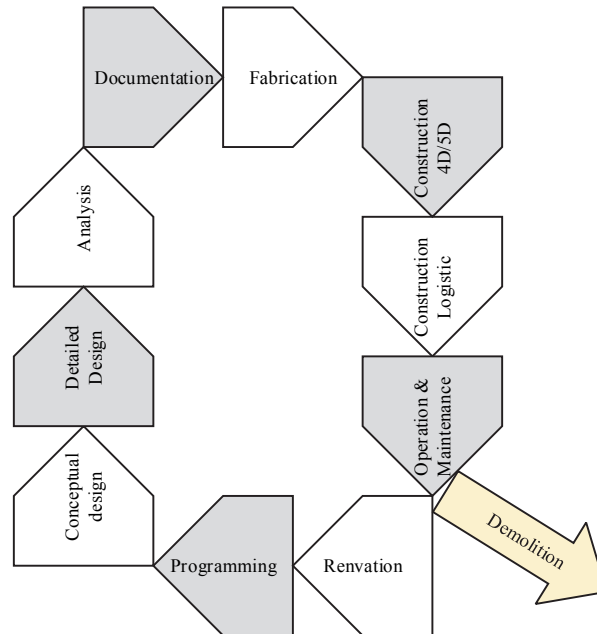


Fig. 1. BIM Capacities and Functions

2.4. A Review of the Previous Studies [conducted] on PMBOK & BIM Fields

Bryde et al. (2013) discuss the benefits resulting from using BIM in projects. The paper analyzes the degree to which BIM is used in construction projects. The data of 35 construction projects which employed BIM are examined and reviewed in this paper. According to the reports of these projects using BIM results in benefits such as, saving time, reducing costs, and controlling through the project life-cycle. Azhar (2011) examined the benefits, risks, and challenges of BIM. The paper talks about the benefits, the probable risks, and the future challenges of the construction Industry. Initially the BIM concept is introduced with its benefits and applications (computer programs) in the construction industry. Then, based on three recent polls, the role of BIM in the construction industry and universities is discussed. Afterwards the case study of Hilton Aquarium in Atlanta is exemplified in quantities, demonstrating reductions in costs and time by making a Building Information Modeling. The information is related to 10 construction projects for the purpose of determining savings and investment returns in BIM. Finally, the risks and future challenges of BIM for the construction industry are examined. Fazli et al. (2014) assessed the effectiveness of BIM in project management. For a long time, the construction industry in Iran has been criticized for its lack of efficiency; it has been claimed that 80 percent of the data in the process of construction is similar for all of the projects; therefore, there are vast opportunities for improvement, and the presence of a project management is essential for the successful delivery of construction projects. The purpose of examining them (the construction projects in Iran) is, analyzing the ways how BIM can be used as an efficient tool by project managers to simulate the project situation in order to avoid reworking and waste of time and money. The conclusion was that, generally, project managers have little awareness of BIM, resulting in problems in understanding their plans. The study demonstrated that BIM can contribute to successful management of the projects. Compared to the traditional projects, BIM is presented as a more reliable basis for decision making. In his 2015 paper, some researchers, analyzed the challenges, consequences, and requirements of BIM in project management. The goal of the study was to demonstrate the relation between BIM and the role of project managers in construction projects; the study emphasizes the significance of having the adequate BIM knowledge and experience for the project management in order to achieve success. The paper also focuses on the necessity of, project managers having BIM knowledge and enrichment of

their experience. Bodaghee and Mahaamy (2014) focus on utilizing BIM in project management fields of knowledge, in a 2017 paper. The paper evaluates the advantages of using BIM, and its role in project management fields of knowledge (based on PMBOK standard). Moreover, it mentions the advantages of using BIM for project managers. Jupp (2017), focuses on environmental planning and management in 4D Building Information Modeling. His paper discusses the way for environmental planning and management by using the 4D potentials. The 4D modeling technologies and analysis besides structured work cycle, are presented as a basis for shaping an efficient environmental management and planning framework. The study introduces five technical prerequisites for an environment friendly construction planning. The five prerequisites are: planning and simulation, modeling environmental equipment, construction site modeling, modeling and envisioning the environmental significance, and the ability to comply with regulations. The paper also identifies the prerequisites for developing cooperation and supervision of environmental management systems before selecting the direction, for the further studies.

Murguia et al. (2017), while analyzing process combination framework for planning stage of residential buildings; debate that during the design process, BIM contributes to the enhancement of communication and vision, and also that it opens ways for continuation of improvement. The goal of the study is coordinating BIM, PMBOK (including communications and management of stakeholders), and LPDS, also development of a process combination framework for enhancing vision and communication during the design stage. In addition, the study is applied on case study of designing a residential building in Lima (Murguia et al., 2017). According to past studies, research on the impacts of BIM capabilities on each of the areas of knowledge management in a project has not been conducted. Therefore, in this research, we try to determine the effect of each BIM capabilities on each of the Knowledge areas of project management and examine the impact of each of the project management knowledge areas on BIM capabilities through SAW analysis and rank the knowledge management areas of the project in terms of impact, and in Finally, we present the BIM process model can have great impact alongside with the project knowledge areas of management on implementations of the project.

3. Presentation of the proposed process model for implementation of BIM in order to influence on knowledge areas owing to the fact that it has great frame work for project management as a standard

A standard for each aspect of the project, such as range, time, cost, and quality (as the main objectives), to the management of resources, logistics, risk, communications and stakeholders (as knowledge of achieving these goals), has certain purposes and ultimately integrates them seamlessly; however, achieving these goals and processes in the form of project management (not at the management level, but at the level of engineering and implementation) requires a tool that is in line with the goals And the foregoing frameworks can make planning and processes in different areas of knowledge; we need to use tool and methodology in order to make optimal use of resources, to better manage risks, to establish relationships in a secure way between stakeholders, and to control project procurements; as a result, eventually to have a project with predetermined quality in the related scope. To find this tool and methodology we look at building information modeling, a concept that is rapidly expanding and is being implemented in advanced countries as a requirement. The BIM has proven that the more time spent on designing and constructing the model and attaching information to the information model, the more value it adds to the project and its stakeholders, and with a great deal of potential in the various phases of the project that it presents. It improves almost all aspects of the project. That is why its use has become so popular all over the world, and in some countries the BIM multi-dimensional model is a requisition for obtaining construction permission. In the following research, we try to identify the effects of BIM capabilities on the PMBOK knowledge areas and, by interviewing experts and questionnaires, we have will discuss the opinion of the experts on these two domains in relation to their mutual effects on each other. First, we introduce the various BIM capabilities described in the previous section, and select some of them that are most important for the majority of experts, and then examine their

impact in each of the PMBOK knowledge domains. In the following, according to the collected opinions, we tried to summarize the sets of experts' views in Table 3. Then, through the questionnaires, the effectiveness of each of the areas of project management knowledge on the capabilities BIM will be measured, and we obtain and rank them through SAW analysis. Finally, in Figure 3, we introduce a proposed model for implementing BIM to influence the knowledge areas of project management.

Table 3

The effect of the capabilities of BIM on project management fields of knowledge

Row	capabilities of building's information modeling	Project management fields of knowledge	
		Integration management	Scope management
1	Creating a 3D model of project and modifying the model, plans and schedules automatically in case of changes in project design and execution (Parametric capability of the 3D model)	<ul style="list-style-type: none"> • Integrated recording of project information on a 3D information model • Making integrated changes in 3D information model automatically; drawing (cut, view), total costs of the project, the amount of materials and time in case of any changes in design • Warnings from the system in case of any mistake in design and conflict between various disciplines (architecture, facilities, power, mechanics) on 3D information model 	<ul style="list-style-type: none"> • Visual display of design, 3D model and clarifying the scope of the project to the stakeholders since the information model is highly detailed • Modifying the scope of the product automatically in case of any changes in design or using the parametric capability
2	High accuracy in estimation of costs and project required tools and value engineering, all in a short period of time (Accurate quantity surveying and estimating)	<ul style="list-style-type: none"> • Integrated recording of materials information on a 3D information model and determining the accurate amount of materials since the information model is highly detailed and automatic modification of materials in case of any changes in design • Integrated recording of the total costs of materials on a 3D information model and determining the accurate costs of materials since the information model is highly detailed and automatic modification of the project costs in case of any changes in design 	<ul style="list-style-type: none"> • A completely specified scope – accurate estimation of materials and their costs • Automatic update of costs and amount of materials in case of any changes in design and scope of the project • The capability of value engineering of various design alternatives in any phase of design based on different scopes
3	Resolving the errors and conflicts in various disciplines design before construction phase and so avoiding reworks and waste of time and costs (Clash detection)	<ul style="list-style-type: none"> • Detecting conflicts, errors and contrasts between various disciplines (architecture, facilities, power, mechanics) due to the integrated design of the information model and resolving these conflicts before project construction phase 	<ul style="list-style-type: none"> • Reducing reworks and their effects (costs, time, quality and etc.) by presenting a completely specified and explicit scope with no conflict, error and contrast before construction phase
4	Creating a comprehensive and common online data base for the stakeholders in order to have an easy access to the information and Decrease commute documents, engineering documents and drawing (Archiving)	<ul style="list-style-type: none"> • Integrated attachment of the information of the project (guaranties, warranties, catalogs, costs of materials, the quantity and type of materials, graduates, etc.) from the planning phase to the operation phase • having the 3D information model in a cloud environment and online using of the information of the project by the key stakeholders on a 3D information model and using this information in future projects 	<ul style="list-style-type: none"> • High details and Integrated design – accurate and explicit scope • A correct perception and an appropriate vision of project through an accurate and explicit scope; so every stakeholder's duty in execution of the project will be more precise and the stakeholders will be providing with the information of different phases of the project
5	Development of collaboration and optimal design of the project using all key stakeholders in the process of design and using their opinions before the execution phase (Integrated design and development of collaboration)	<ul style="list-style-type: none"> • using different opinions and viewpoint of all key stakeholders (client, contractor, designer and beneficiary) in the process of design and planning of the project since the information model is 3D and due to their appropriate view on project • attaching project information by every stakeholder in a cloud environment on a 3D information model and reducing the information traffic and reworks by stakeholders and increasing the collaboration between them • exchanging opinions between various professional teams involved in the project in an integrated cloud environment 	<ul style="list-style-type: none"> • reducing the probability of changing the scope and its effect on project lifecycle due to the collaboration of all key stakeholders in the process of design and applying their opinions in 3D information model and finally determining an explicit and confirmed scope
6	Accurate analyzing of light and energy and stable design in order to reducing the use of energy (Sustainable design)	<ul style="list-style-type: none"> • Integrated modification of the 3D information model based on the integrated analysis of light, energy, brightness, energy of the wind and the effects of the stable designing on costs and time of the project 	<ul style="list-style-type: none"> • changing scope in consideration of energy, light and providing a stable and optimal project scope regarding energy

Row	capabilities of building's information modeling	Project management fields of knowledge	
		Integration management	Scope management
7	Presenting a full package of both project and model information such as construction and utilizing all this information in order to make the operation management simple and smart (Operation\maintenance and repair management)	<ul style="list-style-type: none"> Effective maintenance and repair planning due to the integration of the 3D information model and its details and accurate information on the model Reducing difficulties of the phase of operation due to the integrated design and increasing the collaboration between colleagues and using the views of beneficiary on model 3D design 	<ul style="list-style-type: none"> Creating a 3D information model such as construction and an explicit and accurate scope corresponding to the finished project and recording all the required information in order to use in the operation phase (guarantees, seller's information, costs, catalogs and etc.)
8	Accurate estimate of required activities for project and facilitate the work breakdown structure in 3D form and the process of project construction (Simulating the construction process)	<ul style="list-style-type: none"> A better view on construction method by simulating the construction process and a better perception of the work breakdown structure by Navisworks software due to the integrated design of the information model and its details and the capability of detecting conflicts Automatic update of the schedule in case of any changes in the design 	<ul style="list-style-type: none"> A completely specified and explicit scope since the 3D information model is highly detailed and does not change over the time – accurate estimation of project completion time and a better perception of work breakdown structure and facility in required workloads
9	Increase in fabricating and expanding industrialization on complicated designs (fabricating capability)	<ul style="list-style-type: none"> Increase in accuracy of prefabricating since the 3D information model is highly detailed by any discipline and applying these decisions on the model and observing the changes in costs and time and other part of the project all in an integrated way 	<ul style="list-style-type: none"> Assisting in prefabricating since the 3D information model is highly detailed and an explicit and specified scope
10	Creating a 3D model of project and modifying the model, plans and schedules automatically in case of changes in project design and execution (Parametric capability of the 3D model)	<ul style="list-style-type: none"> Having updated as-built maps in every stage of the project due to the parametric capability of the project and reducing the time required in order to prepare as-built maps An appropriate and perfect view on project scope by key stakeholders and decrease in changes and claims during the project execution and their following effects on time 	<ul style="list-style-type: none"> An appropriate and perfect view on project by every stakeholder involved in the project before the construction phase and reducing reworks caused by inappropriate view and claims that may be followed and their costs and effects
11	High accuracy in estimation of costs and project required tools and value engineering, all in a short period of time (Accurate quantity surveying and estimating)	<ul style="list-style-type: none"> The ability of value engineering of different alternatives in every stage of design and reducing the time of the value engineering process Reducing the time required by inaccurate traditional quantity surveying and estimating through automatic software computation More precise time scheduling of project necessary activities by accurate quantity surveying and estimating and therefore computation of required workloads for project execution 	<ul style="list-style-type: none"> Accurate quantity surveying and estimating and computing costs of the project execution since the 3D information model is highly detailed Computing quantities and costs caused by them and its automatic modification in case of any changes in design
12	Resolving the errors and conflicts in various disciplines design before construction phase and so avoiding reworks and waste of time and costs (Clash detection)	<ul style="list-style-type: none"> Resolving conflicts, contrasts and errors in the design within the shortest period of time and reducing the documents traffic between stakeholders Reducing reworks caused by conflicts between various disciplines and so their effects on time 	<ul style="list-style-type: none"> Reducing the costs caused by reworks through detecting conflicts and errors in design and contrasts between various disciplines before the construction phase
13	Creating a comprehensive and common online data base for the stakeholders in order to have an easy access to the information and Decrease commute documents, engineering documents and drawing (Archiving)	<ul style="list-style-type: none"> Having an online information base used by every stakeholder based on their authority level in each stage Reducing the time wasted on documents traffic in the traditional form and recording information in a single 3D model 	<ul style="list-style-type: none"> Utilizing financial information of project and the lessons learned in order to manage the costs of future projects due to the great potency of documentation of 3D information model
14	Development of collaboration and optimal design of the project using all key stakeholders in the process of design and using their opinions before the execution phase (Integrated design and development of collaboration)	<ul style="list-style-type: none"> The ability of team working in an integrated virtual environment (cloud) so there would be no need for their presence in a specific site Reducing team physical sessions in a specific site 	<ul style="list-style-type: none"> Reducing the effects of reworks on costs due to the participation of all key stakeholders in design of the project and decreasing the claims that follow before the construction stage

Row	capabilities of building's information modeling	Project management fields of knowledge	
		Integration management	Scope management
15	Accurate analyzing of light and energy and stable design in order to reducing the use of energy (Sustainable design)		<ul style="list-style-type: none"> increasing costs due to the analysis of energy and light in the design stage but a total decrease in costs concerned with energy consumption in project lifecycle and operation stage, considering the fact that the effects of reducing costs in operation stage cannot be compared to the costs of analysis
16	Presenting a full package of both project and model information such as construction and utilizing all this information in order to make the operation management simple and smart (Operation\maintenance and repair management)	<ul style="list-style-type: none"> Speeding up project operation and reducing difficulties and reworks followed by project closure and operation due to the project integrated design by every stakeholder involved 	<ul style="list-style-type: none"> Reducing costs of maintenance and repair due to the full information recording of the project (guarantees, warranties, seller's information, catalogs, equipment instructions and etc.) and presenting a precise time schedule for maintenance and repair on the 3D model
17	Accurate estimate of required activities for project and facilitate the work breakdown structure in 3D form and the process of project construction (Simulating the construction process)	<ul style="list-style-type: none"> The ability of simulating the construction process and detecting possible problems or opportunities of improving the time schedule 	<ul style="list-style-type: none"> Reducing the costs caused by selecting inappropriate construction method through the construction process and the project logistics
18	Increase in fabricating and expanding industrialization on complicated designs (Fabricating capability)	<ul style="list-style-type: none"> Reducing the project cycle time by prefabricating and outsourcing since the 3D information model is highly detailed 	<ul style="list-style-type: none"> Reducing the costs through prefabricating considering the difficulties of working in site in some specific projects
19	Creating a 3D model of project and modifying the model, plans and schedules automatically in case of changes in project design and execution (Parametric capability of the 3D model)	<ul style="list-style-type: none"> Improving project quality through appropriate and perfect views of key stakeholders and applying their opinions in 3D information model before the construction stage and reducing reworks and their following impacts on project quality Presenting precise workshop drawing with high quality 	<ul style="list-style-type: none"> Reducing risks caused by reworks and claims through appropriate and perfect views of key stakeholders and representing a 3D information model
20	High accuracy in estimation of costs and project required tools and value engineering, all in a short period of time (Accurate quantity surveying and estimating)		<ul style="list-style-type: none"> Reducing risks caused by uncertainty in cost and quantity of materials required by project through accurate and automatic quantity surveying and estimating Reducing risks caused by claims between contractor and employer over project costs
21	Resolving the errors and conflicts in various disciplines design before construction phase and so avoiding reworks and waste of time and costs (Clash detection)	<ul style="list-style-type: none"> Improving project quality by Conflict detection, resolving errors and contrasts of the design before the project execution phase and reducing reworks and their following impacts on quality 	<ul style="list-style-type: none"> Reducing risks caused by reworks and their effects including: increase of time, increase of cost, decrease of quality and etc. through conflict detection, detecting errors in design and contrasts between various disciplines before the execution phase
22	Creating a comprehensive and common online data base for the stakeholders in order to have an easy access to the information and Decrease commute documents, engineering documents and drawing (Archiving)		<ul style="list-style-type: none"> Reducing risks caused by documents and plans getting lost through documentation on a 3D information model instead of using thousands of paper sheets
23	Development of collaboration and optimal design of the project using all key stakeholders in the process of design and using their opinions before the execution phase (Integrated design and development of collaboration)	<ul style="list-style-type: none"> Improving project quality by reducing claims and the following reworks due to the integrated design by key stakeholders and cooperation between them from primary stages on a 3D information model 	<ul style="list-style-type: none"> Reducing risks (related to cost, time and reworks) caused by inappropriate view and perception of stakeholders and their claims by using their opinion in 3D information model and reaching an agreement before the construction phase Reducing risks caused by lack of constructability before the construction phase by using contractor and project executive manager's point of views in design
24	Accurate analyzing of light and energy and stable design in order to reducing the use of energy (Sustainable design)		<ul style="list-style-type: none"> Reducing cost-related risks, increase in energy prices during the project operation time by accurate design and analysis of energy and light in the design phase

Row	capabilities of building's information modeling	Project management fields of knowledge	
		Integration management	Scope management
25	Presenting a full package of both project and model information such as construction and utilizing all this information in order to make the operation management simple and smart (Operation\maintenance and repair management)		<ul style="list-style-type: none"> Reducing risks followed by problems and difficulties during the operation time, or late project operation through applying operator's point of view from the primary stages to the closure stage
26	Accurate estimate of required activities for project and facilitate the work breakdown structure in 3D form and the process of project construction (Simulating the construction process)	<ul style="list-style-type: none"> Improving execution quality by simulating the construction process and selecting an appropriate method for execution 	<ul style="list-style-type: none"> Reducing risks caused by incorrect and inaccurate planning (such as costs related to maintenance and repair of materials, project logistics plan) by simulating the construction process
27	Increase in fabricating and expanding industrialization on complicated designs (fabricating capability)	<ul style="list-style-type: none"> Increase in the quality of building components through more focused prefabricating by manufacturers and decrease in risks and difficulties related to fabricating these components in the site of the project 	<ul style="list-style-type: none"> Reducing risks caused by inadaptability of project components in the site of project through accurate and high quality prefabricating of components in factories
28	Creating a 3D model of project and modifying the model, plans and schedules automatically in case of changes in project design and execution (Parametric capability of the 3D model)	<ul style="list-style-type: none"> A lot of human resources are used in order to modify plans which BIM aims to avoid 	<ul style="list-style-type: none"> 3D displays of the project logistics (exact time of materials arrival to the site, and equipment and labors' working schedule) and an appropriate view on execution and project logistics before the execution phase Visual display of design and making sure that every stakeholder understands the design and the existing situation Automatic update of the quantity of materials in case of any changes in design
29	High accuracy in estimation of costs and project required tools and value engineering, all in a short period of time (Accurate quantity surveying and estimating)	<ul style="list-style-type: none"> Determining the precise quantity of required materials, along with the following costs automatically Saving resources and their related costs automatically through value engineering 	<ul style="list-style-type: none"> Accurate and automatic quantity surveying and estimating before the construction phase and facilitating the process of bidding Reducing claims between contractor and employer in the execution phase due to the costs, for accurate estimating of cost and materials before the execution phase
30	Resolving the errors and conflicts in various disciplines design before construction phase and so avoiding reworks and waste of time and costs (Clash detection)	<ul style="list-style-type: none"> Decrease in wasting of resources due to the reworks caused by conflicts between various disciplines during execution by detecting conflicts, errors and contrasts in design before the construction phase 	<ul style="list-style-type: none"> Reducing problems and claims between contractor and plan consultant in the execution phase through detecting conflicts, errors and contrasts in the design before the execution of project
31	Creating a comprehensive and common online data base for the stakeholders in order to have an easy access to the information and Decrease commute documents, engineering documents and drawing (Archiving)	<ul style="list-style-type: none"> Accurate and comprehensive documentation of utilized resources and their following costs along with a full package of information (including: seller's information, cost, guarantees, catalogs etc.) and applying this information in future projects 	<ul style="list-style-type: none"> Recording all of the information related to contract, guarantees, warranties, catalogs and invoice on a 3D information model and reducing the possible claims between project factors
32	Development of collaboration and optimal design of the project using all key stakeholders in the process of design and using their opinions before the execution phase (Integrated design and development of collaboration)	<ul style="list-style-type: none"> Reducing reworks and their effects on resources (resources which are lost due to the reworks, human resources in order to do the tasks over again) by applying stakeholders' point of views in design before the execution phase Team members collaboration in a virtual integrated environment (cloud) so that there would be no need to their physical presence in one specific site 	<ul style="list-style-type: none"> Reducing claims between project factors and the following effects (such as: increase in cost of the project, increase in time, lost benefit) through their integrated collaboration in the early stages of the project on a 3D information model and reaching an agreement before the execution phase
33	Accurate analyzing of light and energy and stable design in order to reducing the use of energy (Sustainable design)		
34	Presenting a full package of both project and model information such as construction and utilizing all this information in order to make the operation management simple and smart (Operation\maintenance and repair management)	<ul style="list-style-type: none"> Increasing the lifetime of the resources utilized in project through accurate maintenance and repair planning 	<ul style="list-style-type: none"> Recording every information related to the project (including: guarantees, warranties, guidelines for maintenance and repair of the components, safety tips such as fire containment) on the 3D information model and utilizing this information in the project operation phase

Row	capabilities of building's information modeling	Project management fields of knowledge	
		Integration management	Scope management
35	Accurate estimate of required activities for project and facilitate the work breakdown structure in 3D form and the process of project construction (Simulating the construction process)	<ul style="list-style-type: none"> Accurate estimating of the required work resources through simulating the construction process and project logistics 	<ul style="list-style-type: none"> Synchronization between ordering materials, fabrication of components and delivery schedule for every component based on simulating the construction process and project logistics Improvement in managing suppliers through simulating the project logistics (such as: order time, order size, duration of retaining materials, paid expenses etc.)
36	Increase in fabricating and expanding industrialization on complicated designs (fabricating capability)	<ul style="list-style-type: none"> Optimal balance by cost of components prefabricating in factories comparing to the work resources required in order to fabricate project elements in site of the project and its following costs 	<ul style="list-style-type: none"> Increase in precision, quality and speed of fabricating project required elements through prefabricating by suppliers (who no longer considered suppliers but as subcontractors) since the 3D model is highly detailed
37	Creating a 3D model of project and modifying the model, plans and schedules automatically in case of changes in project design and execution (Parametric capability of the 3D model)	<ul style="list-style-type: none"> Visual, detailed display of design and making sure that every stakeholder understands the design and the existing situation 	<ul style="list-style-type: none"> Explicit and appropriate views of the key stakeholders on project and reaching an agreement before the execution phase
38	High accuracy in estimation of costs and project required tools and value engineering, all in a short period of time (Accurate quantity surveying and estimating)	<ul style="list-style-type: none"> Creating clear connections and displaying accurate information of required resources and their costs 	<ul style="list-style-type: none"> Reaching of an agreement based on project required materials and their following costs Presenting various alternatives based on value engineering so it is possible for the stakeholders to decide based on project cost and material
39	Resolving the errors and conflicts in various disciplines design before construction phase and so avoiding reworks and waste of time and costs (Clash detection)		<ul style="list-style-type: none"> Avoiding hostile relationships and quarrels between stakeholders due to the opposite interests by conflict detection, clarifying, detecting errors and problems before the execution stage
40	Creating a comprehensive and common online data base for the stakeholders in order to have an easy access to the information and Decrease commute documents, engineering documents and drawing (Archiving)	<ul style="list-style-type: none"> Having an up-to-date and precise information base of project information (including updated and accurate drawing, time schedule, quantities, cost and quantity schedules) 	<ul style="list-style-type: none"> Monitoring every activities done for all key stakeholders in a cloud environment and inform them of work progress and using their point of views in every moment and recording this information in a 3D information model
41	Development of collaboration and optimal design of the project using all key stakeholders in the process of design and using their opinions before the execution phase (Integrated design and development of collaboration)	<ul style="list-style-type: none"> Increasing coordination and effective relationships considering every member's authority level on a 3D information model The ability of exchanging and adapting models of other professional groups involved in the project (structure model, facility model and architecture model) in an integrated environment and improving relationships between different professional groups 	<ul style="list-style-type: none"> Considering stakeholders' requirements and their agreements on a 3D model before the execution phase through their collaboration during special sessions and receiving their point of views and applying them on the information model Receiving stakeholders' point of views in every moment of the project lifecycle in a cloud environment so that there would be no need to their physical presence
42	Accurate analyzing of light and energy and stable design in order to reducing the use of energy (Sustainable design)		
43	Presenting a full package of both project and model information such as construction and utilizing all this information in order to make the operation management simple and smart (Operation\maintenance and repair management)		<ul style="list-style-type: none"> Facilitating maintenance and repair and operation management by stakeholders due to the integrated design and applying operator's point of views from the beginning of the project and specially in the design phase Increasing the lifetime of the components applied in the project and therefore satisfy stakeholders due to the decrease in costs
44	Accurate estimate of required activities for project and facilitate the work breakdown structure in 3D form and the process of project construction (Simulating the construction process)	<ul style="list-style-type: none"> Developing effective relationships between project team members by simulating the construction process and project logistics before the construction phase 	<ul style="list-style-type: none"> Apprehensible display of construction stage and project logistics for stakeholders in order to satisfy them for executing the project
45	Increase in fabricating and expanding industrialization on complicated designs (fabricating capability)	<ul style="list-style-type: none"> Improving effective relationships with suppliers like business partners and using their point of views during the project construction lifecycle and prefabricating of components and developing long term relationships and cooperation with suppliers 	<ul style="list-style-type: none"> Improving cooperation and effective relationships with suppliers such as key stakeholders and business partners through prefabricating and applying suppliers' point of views in design since the 3D information model is highly detailed

3.1. The extent of the impact of knowledge management areas on project knowledge from each of the BIM capabilities through SAW analysis

The SAW technique is one of the most used MADM techniques. It is simple and serves the basis of most MADM techniques such as AHP and PROMETHEE which benefits from additive property to calculate final scores of alternatives. In SAW technique, final score of each alternative is calculated as follows

$$P_i = \sum_{j=1}^K W_j \times r_{ij}$$

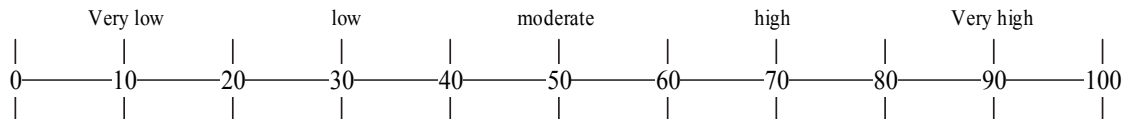
The steps taken to calculate the extent of the impact of knowledge management areas of the project on building information modeling capabilities:

1) First, through questionnaires of experts, the effectiveness of each of the project management knowledge areas (options) from the BIM capabilities (indicators) using the 3-parameter beta distribution and Likert scale (Effective) has been demonstrated.

$\frac{a+4b+c}{6}$ = average Weighted impact rate		
The Lowest Effect = a	The Most Effective Level = b	Maximum Effect = c

2) From the questionnaires prepared by different experts, we make an average of the arithmetic to determine the decision-making matrix of the impact level of knowledge management areas of the project.

- Given that the type of all indicators (BIM capabilities) is the same and of a type of positive effect, so there is no need to be quantified and the weight of each of the indicators is calculated by adding The influence of each indicator into the elements of the decision making matrices.



- The weight gain of indicators is determined by the multiplication of indicators weights in to the degree of impressibility of every one the project management knowledge areas.

In Table 4, the decision matrix resulting from the average of the arithmetic of the various questionnaires and the desirability (effectiveness) of each of the areas is shown.

Table 4
Matrix of decision making and calculation of the saw method

	Decision making Average										Uj
integrated	74.3	76.2	76.5	77.3	71.8	30.1	64.6	78.5	66.7	71.5	Uj
scope	73.3	68.8	62.5	55.8	36.5	20.8	38.8	51.1	61.4	55.2	
time	69.2	63.3	68.5	61.8	67.7	23.0	32.7	62.5	41.5	58.0	
cost	39.5	63.9	65.4	55.1	36.4	37.8	29.9	38.4	52.3	48.2	
quality	56.0	11.5	74.0	8.5	37.0	53.3	47.5	29.5	64.6	42.4	
risk	52.3	59.3	60.0	46.4	52.1	11.3	35.3	35.7	47.6	47.8	
resource	46.2	63.9	65.4	31.2	58.1	21.0	41.0	40.9	34.4	47.4	
procurement	49.1	61.9	68.6	57.5	61.2	6.3	39.1	53.0	63.3	55.2	
communication	35.3	39.9	50.0	51.2	70.2	3.8	20.5	39.8	32.9	41.7	
stakeholder	54.4	38.5	42.3	49.8	58.1	5.0	19.7	39.4	29.4	40.7	
4317.75	549	547	633	494	549	212	369	468	494	sum	4317.75
total sum	13%	13%	15%	11%	13%	5%	9%	11%	11%	Wj	total sum

In Fig. 2, the impact diagrams of each of the project management knowledge areas are illustrated by the BIM capabilities using questionnaires.

As outlined in the diagram, BIM capabilities are influential in all areas of knowledge and have the greatest impact on integration management, which can also be expected according to the type of building information modeling system, as BIM seeks to Integrate all project information into a 3-D information model and can be used as a suitable methodology along with different standards. Now, in Fig. 3 and Fig. 4, the BIM proposed process model for implementing knowledge management areas of the project is shown.

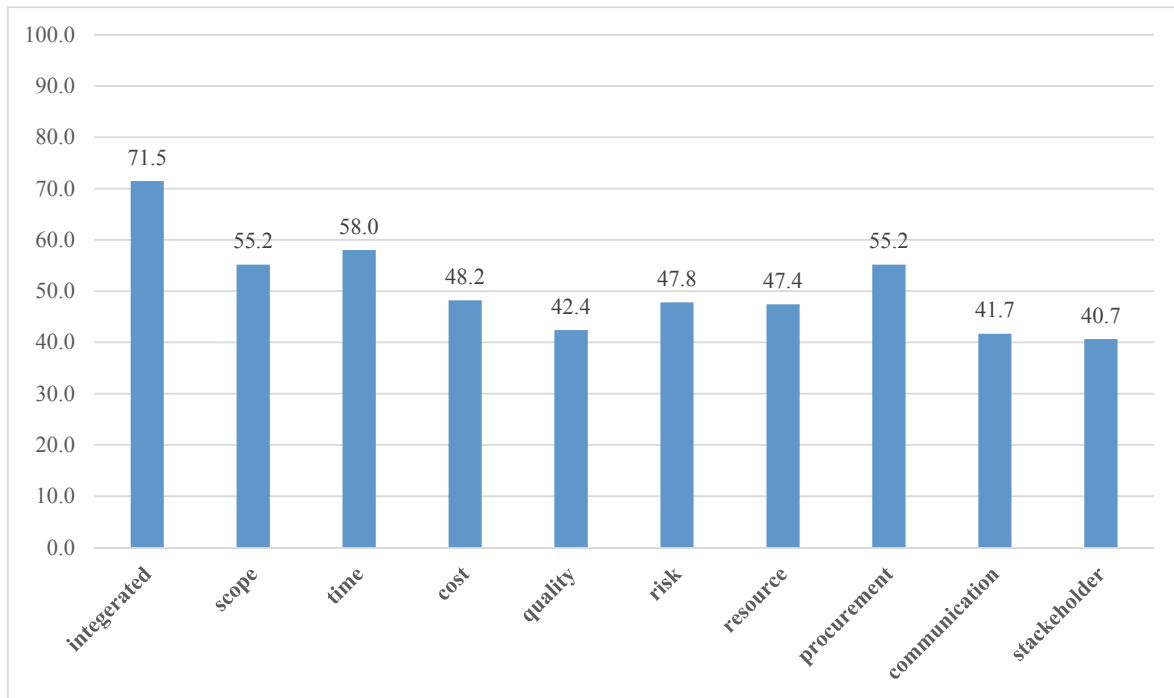


Fig. 2. Graph of the extent of the impact of knowledge areas on BIM capabilities

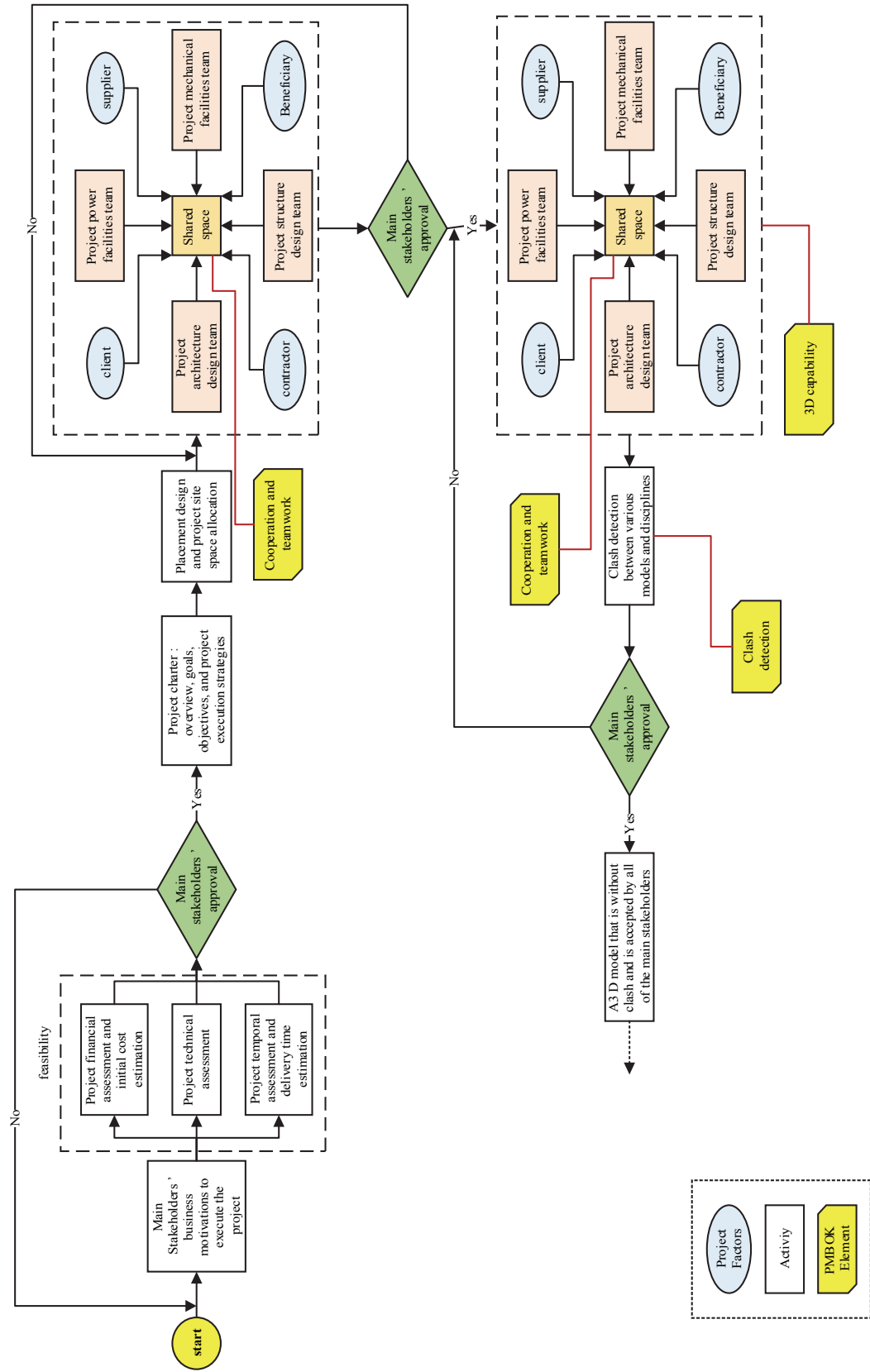


Fig. 3. BIM proposed process model for implementing knowledge management areas

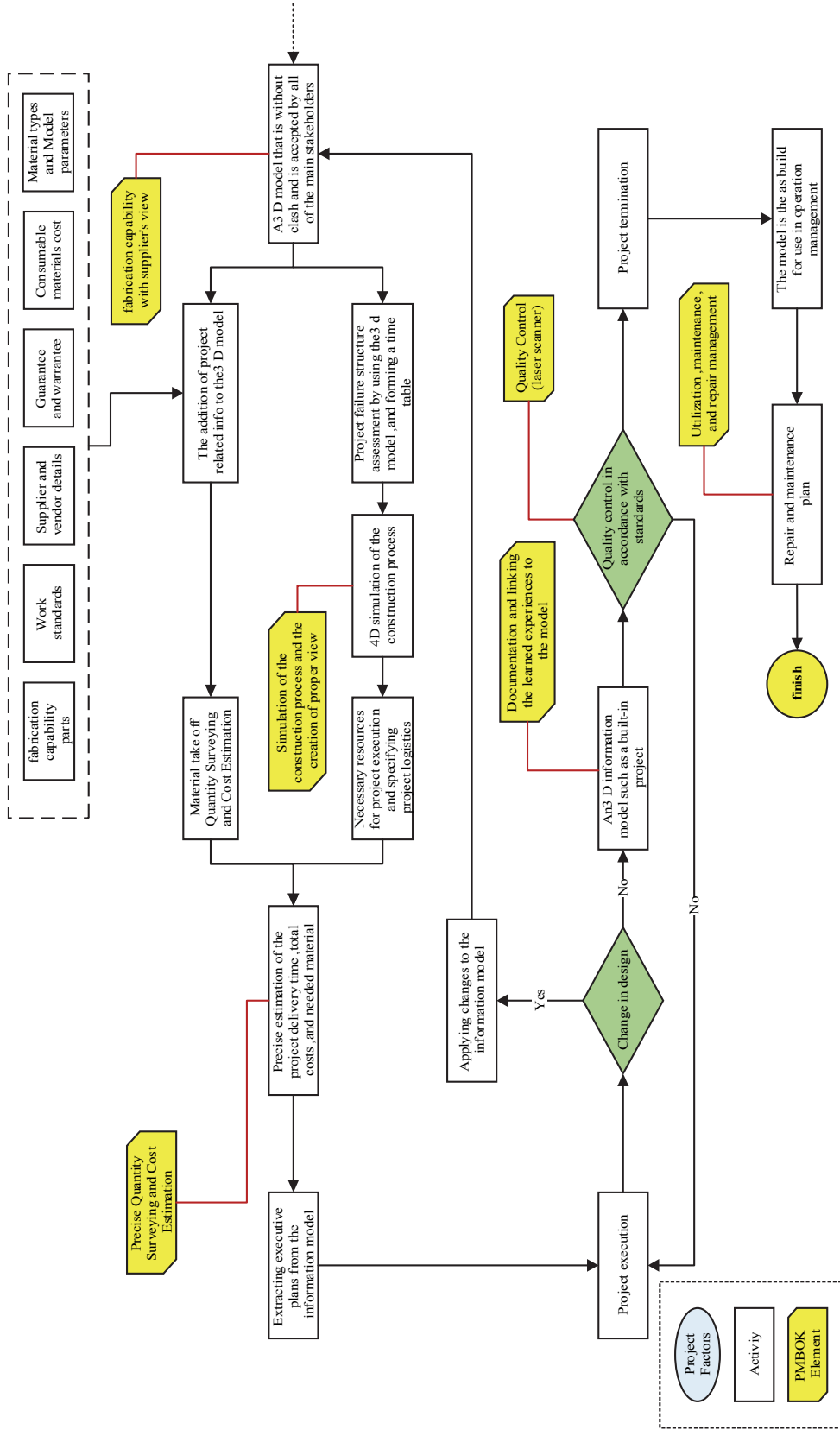


Fig. 4. BIM proposed process model for implementing knowledge management areas (continue)

4. Conclusion

According to the collected questionnaires, we can summarize the impact of building information modeling capabilities in Table 5.

Table 5

Summary of the Effects of Building Information Modeling Capabilities on Project Management Knowledge Areas

Knowledge areas of project management	Influence of Building Information Modeling
Integration management	Integrated 3-D information model and its parametric functionality
Limited management	Determine the precise scope of the project through the 3-D information model
Time Management	Reduce project execution time by reducing duplication
cost management	Reduce costs through metering and accurate estimation and reduction of recycling
Quality management	Improve the quality of the project by providing detailed project details and interoperability
risk management	Reducing negative risks through a proper vision of the project
resource management	Identify the logistics of the project and the resources required through simulation
supply Management	Determine the exact materials and machinery needed for the project
Communication management	Increasing communication and teamwork based on IPD contracts
Stakeholder management	Enhance collaboration among key stakeholders and manage them better

So, we see that the application of the concept of BIM in all areas of PMBOK can be very effective. In fact, in addition to a few cases, most of the major BIM applications identified have affected all areas of project management knowledge. Therefore, BIM application directly facilitates project management, and many construction management problems. BIM application and can be used as a methodology for PMBOK standard project management.

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