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Analysis of the Influence of Building Information Modeling (BIM) on Construction Project Management Areas of Knowledge: a Hybrid FANP-FVIKOR Approach

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KEYWORDS

Building information modeling (BIM);
PMBOK areas of knowledge;
Triangular fuzzy number;
Analytic hierarchy process (ANP);
VIKOR.

ABSTRACT

In order to manage a project with integrity, a cohesive communication between its various sections is required. Basic tools, including analysis of risk and stockholders, provision of necessary resources on time and managing their availability, focusing on the approved budget, and satisfactory quality of projects, are required to successfully implement projects based on project management standards such as PMBOK. In recent years, Building Information Modeling (BIM) as a novel method has presented new aspects of engineering and architecture and has become a widely accepted platform for planning and executing construction projects. This paper as a wide field study attempts to analyze the impact of this modeling method on the success of construction project implementation in terms of various aspects of PMBOK. Moreover, it seeks to identify and recognize the most significant aspects of BIM application in project management and in terms of each area of knowledge proposed by PMBOK. A hybrid Fuzzy ANP-VIKOR is also designed due to its inherent excellence to take into account the multiplicity of criteria, the relations between criteria and the difficulty of measurement, huge number of qualitative criteria, and mental judgments. Based on the results, all of PMBOK aspects equally benefit from the BIM application. In addition, it is shown that 3D BIM capacities, including clash detection and plan correction, are superior to 6D BIM and 7D BIM capacities.

1. Introduction

The increasing acceptance of project management as a career implies that the application of proper knowledge, processes, abilities, tools, and techniques can have a considerable impact on projects success and, also, reduce problems that may arise in a project. The project management standard (PMBOK) and its body of knowledge are widely accepted by the public as a proper tool, and it is more of a guide than a special methodology [1]. Project

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management standards only specify the required framework to achieve project goals; however, they do not suggest a way for implementation; thus, some tools and techniques that lead us to the desired goals in a project are required. The construction industry has been continuously criticized worldwide for its unwillingness to employ and implement new technologies, its slow pace of increasing productivity, and also its disqualification in project management [2]. Flawed building plans, disintegration among project team members throughout the project, long and flawed processes of construction projects design and execution, unnecessary time consumption in reworking of tasks, unwillingness of the design team to implement changes, 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. The main reason for the emergence of such problems in construction projects is the lack of a functioning data collection system customized to meet the needs of the construction industry. Such a system besides data collection and classification can be easily employed by the main agents involved in the project, which at last enhance communications and, thus, make a considerable contribution to the project management [3]. Studies show that Building Information Modeling (BIM) contains such capacities, and its widespread employment in the construction industry across the country can eliminate many problems; in addition, it plays a significant role in increasing productivity in project management in the industry [4]. BIM takes place before the execution of a project; in each stage, the required information is added to it by various teams and individuals. This information is used during the design and construction [stages]; and is, also, useable to the users after the project delivery and during the utilization phase. The formation of a useful database, cooperation and harmony among various project agents involved in the making of the model, organization of all production plans, a 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 merely some of the many capacities of such models [5]. BIM and other methods of designing and presenting construction projects are compared. The distinctive aspect lies in their framework; information is the solution as suggested by the method (BIM), which can be summarized in the form of adding various data to the building model (including the timing, equipment, material, cost, etc.). Such data can be analyzed and be available to the people who benefit from them, when required [6].

This article first introduces the knowledge areas of project management proposed by PMBOK guideline and by taking into account the existing dependencies and relationship among them. Then, the philosophy of integrating BIM with its various dimensions and its main capabilities during the life cycle are discussed. Therefore, in the first step, the key capabilities of building information modeling during the life cycle of the project through a huge survey and interviews are identified. Then, in the second step, by the approach of FANP-FVIKOR, the key capabilities and features of BIM that contribute to the successful implementation of the construction projects are found. Finally, we will show that BIM philosophy is an appropriate tool for implementing knowledge management areas during the life cycle of the projects. Moreover, considering the existing challenges and costs associated with the implementation of building information modeling and its important capabilities, authors are led to believe that greater attention should be allocated to choosing the areas where BIM capabilities are more significant.

2. Theoretical Foundations and Review of Literature

In this section, first, the management of construction projects and related areas of knowledge are discussed. In the second part, the building information modeling is introduced. Finally, the articles related to the building information modeling and knowledge areas are investigated and addressed; then, the research gap in this area is expressed.

2-1. Construction project management

The U.S. Census Bureau News (2013) estimated back then that the construction industry would spend more than $874 billion in 2013.

These projects are in the range from small residential or retail projects to mega multifunction projects. Needless to say, with any scale of a construction project, there is a necessity for managing it. The management of construction projects requires knowledge of modern management as well as an understanding of all construction processes. Along with the change in technology, organizational arrangement or procedures and new features and methods [7]. Construction project management is a series of activities for determining how, when, and by whom the work needs to be performed. Similar to the Project Management Body of Knowledge (PMBOK) definitions, the construction project manager handles project management planning, cost management, time management, quality management, contract administration, safety management and risk management. The project manager is also in charge of all stakeholders on the project including the owner, designers, engineers, professional crew, and administrative staff. Generally, construction project management shares common and overall characteristics of general projects; therefore, the rules and methods required for general project management can be applied to this type of projects [8]. A project is considered successful when it is completed within the determined time and budget; it has a quality that fits the expected scope, and the employer is satisfied with the execution process. Thus, time management, cost management, quality management, and scope management can be considered as the primary knowledge of project management; knowledge fields of resources, communications, risks, procurements, and stakeholders are secondary and contribute to the primary fields. Finally, all such knowledge needs to be coordinated and integrated to guarantee project success. Figure 1 shows how such knowledge fields are correlated.

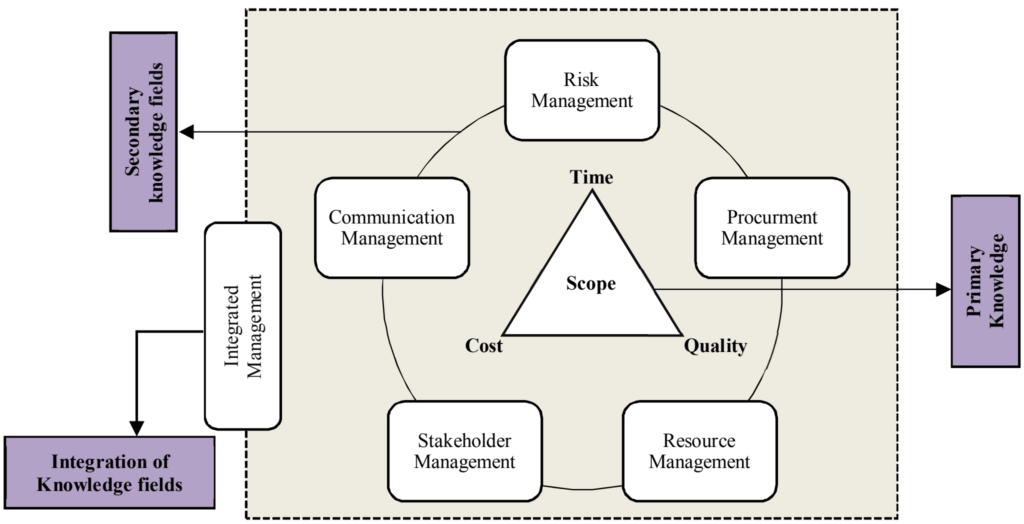

Fig. 1. Correlation of the Fields of Knowledge

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 recommends the necessary frameworks to ensure the success of a project. 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 [1]. Likewise, the present study introduces BIM as a constructive tool for integrated project management, and the influence of such management on project management body of knowledge of project management standard and its fields of knowledge are rather used as a guide rather than an independent methodology. In other words, this standard suggests necessary frameworks to achieve project success, yet does not necessarily 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 [1]. 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)

Although there was no such thing as "Building Information Modeling" back then, the history of what is presently called BIM dates back to 1970. It can be said that, in 1980, this method was known as “Building Production Modeling” in the United States of America and as “Product Information Modeling” (PIM) in Europe. In the 1990s, the two merged into one as Building Information Modeling (BIM) [9]. In the late 1990s, Joungsoo and Gibson presented the concept of BIM as Computer Integrated Construction (CIC). They defined CIC as “the integration of corporate strategy, management, computer systems, and information technology throughout the project’s entire life cycle and across different business functions” [10]. According to Eastman, BIM is the virtual presentation of building/construction process, aimed at easing data transmission within the framework of virtual data [11]. The BIM model is the result of a parametric, intelligent and object-based virtual presentation, and it encompasses a large amount of building information [12]. In other words, BIM is able to assemble all of the information needed during the project life cycle such as spatial relations, geographical position information, quantity and characteristic of building parts, cost estimation, list of materials, and the project timing. In the literature, BIM technology provides an opportunity to make an exact and virtual model for digital construction [14]. Based on the report by McGraw Hill Construction, Building Information Modeling is the process of making and utilizing virtual models for designing, construction, and implementation of projects [6]. BIM is digital, parametric, smart, and object-based and is full of data display; nevertheless, based on the users’ needs, any view can be extracted and analyzed from this model [15]. National BIM Standard recognizes BIM as the virtual presentation of the functional features and physical facilities of the project from A to Z [16]. By using BIM, the project information database for the participation of the stakeholders is manageable more easily during the construction life cycle [17].

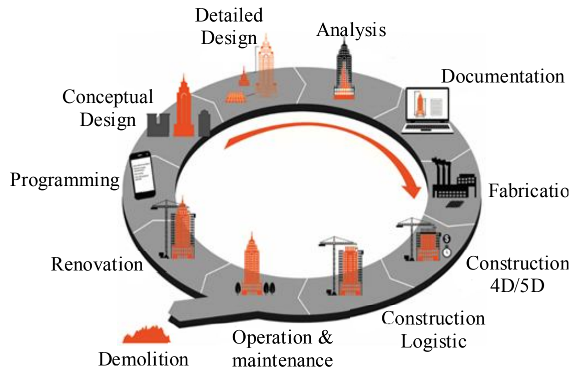

Fig. 2. Using of BIM during the project life-cycle

Building SMART is another term that defines Building Information Modeling as a digital model of the construct, in which all the project information is stored. A model can be 3D, 4D, or ND (including any kind of needed information during the project life-cycle). Purposes of BIM include the enhancement of the cooperation of stakeholders, reduction of the time for documentation, and production of the estimated results from the project” [18]. Figure 2 displays some of the uses of BIM during the project life-cycle from planning to demolition.

2-3. A review of the previous studies on PMBOK & BIM fields

There are some discussions on the benefits that result from using BIM in the projects. The paper analyzes the degree to which BIM is used in construction projects. The data of 35 construction projects that employed BIM are examined and reviewed in this paper. According to the reports of these projects, benefits such as saving time, reducing costs, and controlling through the project life-cycle are identified [19]. In 2014, Agers and others examined the benefits, risks, and challenges of BIM. They explained the benefits, probable risks, and 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 surveys, the role of BIM in the construction industry and universities is discussed. Afterward, the case study of Hilton Aquarium in Atlanta is exemplified, demonstrating reductions in costs and time by using Building Information Modeling. Finally, the risks and future challenges of BIM for the construction industry are examined [20]. In 2014, Fazli and others 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 are similar for all of the projects; therefore, there are many opportunities for improvement, and the presence of project management is essential for the successful delivery of construction projects. The purpose of examining them (the construction projects in Iran) is to analyze the ways that 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. It was concluded that, generally, project managers had almost no awareness of BIM, resulting in difficulty understanding their plans. The study demonstrated that BIM could contribute to the successful management of the projects. Compared to the traditional projects, BIM was presented as a more reliable basis for decision-making [21]. Jupp focused on environmental planning and management in 4D Building Information Modeling, considering the way that 4D potentials are used for environmental planning and management by using. The 4D modeling technologies and analysis besides a structured work cycle were presented as the basis for shaping an efficient environmental management and planning framework. The study introduces five technical prerequisites for environmentally friendly construction planning. The five prerequisites include planning and simulation, modeling environmental equipment, construction site modeling, modeling and envisioning the environmental significance, and the ability to comply with regulations. This study also identifies the prerequisites for developing cooperation and supervision of environmental management systems before selecting the direction for the further studies [22]. Having analyzed the process combination framework for the planning stage of residential buildings, Murguia and others claimed that BIM contributed to the enhancement of communication and vision during the design process. In addition, this can pave the way for the continuation of improvement. The goal of this study is to coordinate BIM, PMBOK (including communications and management of stakeholders), and LPDS and to develop a process combination framework for enhancing vision and communication during the design stage. In addition, the study is applied to the case study of designing a residential building in Lima [23].

Based on the construction of an urban project, Lou, Xu, Wang analyzed the construction characteristics and construction quality control difficulties of the project. Then, by integrating BIM technology with AR technology in the concrete application of the construction stage, the project construction quality is enhanced using prior-control, process-control, and post-control [24]. By utilizing the BIM model and BIM5D software in the construction schedule management, ahead of schedule can be aware of the next-step schedule of the required resource requirements, equipment demand, and capital requirements. Moreover, in the actual construction process, timely monitoring of the completion progress of the percentage of the plan, the use of the amount of aggregated funds, etc. can form a set of complete construction schedule management modes that are used to observe the construction quality and safety issues, record defects on the spot, and integrate data with the associated model [25]. Xu analyzed the current situation of the development of the construction industry and, also, investigated the application of BIM and the modeling flow of BIM 5D. Moreover, he focused on the issue of the integrated application of BIM5D in the construction stage by taking the central grand project as the carrier, including the visualization of the end, the paper review and collision detection, 5D construction simulation, etc. and, then, measured their effect on the application of BIM [26]. Sigalov, König focused on the estimation of the similarity in construction schedules using feature-based methods and similarity measure definitions. Another emphasis is given to the preparation of schedules for the recognition of process patterns, including decomposition of schedules into smaller parts, referred to as sub schedules, and normalization of features. The core of this concept is demonstrated by two different case studies [27]. Murguia et al. developed a process-integration framework to improve visualization and communication in the design phase, considering BIM, Project Management Book of Knowledge areas, and the learning loops of the Lean Project Delivery System (LPDS). A residential building in Lima has been considered a case study here. Direct observation during the design phase helps one understand the process alignment [23]. Considering the previous studies, we find that the previous researches have not focused on the influence of BIM on the project management body of knowledge. Further, more importantly, the significance of the aforementioned capacities with regard to the project management body of knowledge has not been considered, too. Therefore, this study aims to, first, identify the primary capacities of BIM and, then, prioritize them with FANP-FVIKOR decision-making hybrid approach (while considering the fields of project management). Specifying these capacities needs greater attention to the successful execution and delivery of a commercial center construction.

3. Methodology

he executive steps for writing this article are shown in Figure 3.

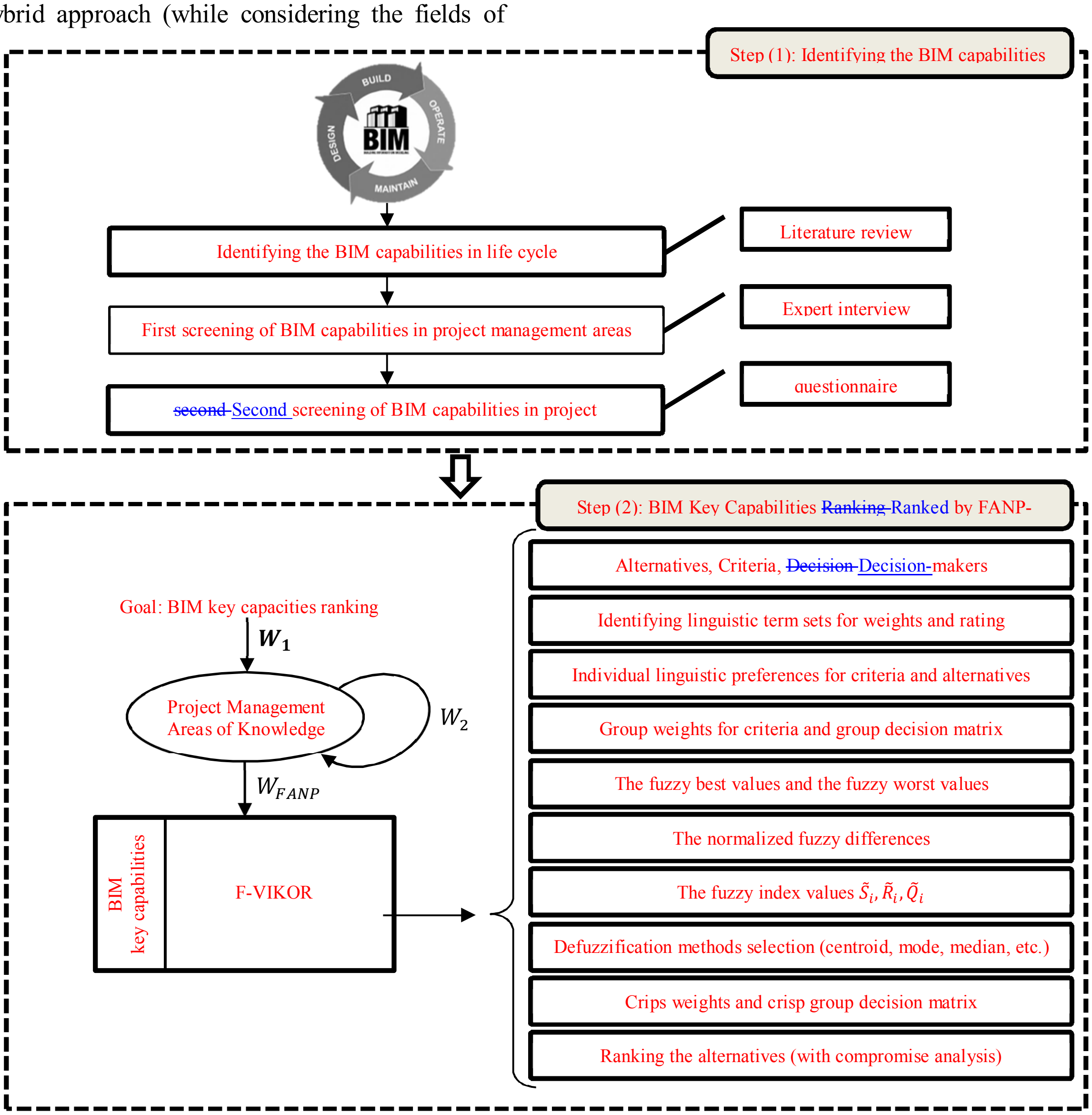

Fig. 3. Proposed methodology of this field study

3-1. Step (1): BIM key capacities Identification

3-1-1. Parametric design and the ability to cooperate in BIM

Building Information Modeling is a digital presentation of the physical features of a building. This methodology is the shared base of knowledge that encompasses the information on a building, providing a basis for decision-making throughout the project life cycle. The primary principle of BIM is the cooperation of the involved agents in various stages of the project [28]. Such a cooperation is achieved by working on the shared model, on which the data-bank of the building is also based. All of the modeling software products also benefit from the idea of parametric design in building information modeling. According to this construction idea, instead of using planning and designing tools (such as lines and dots), buildings are designed by building objects that have static or dynamic parameters. Parametric data are those that differentiate a certain member (object) from other similar members [13]. The design and construction of a building is a team activity. To achieve this, there is a need for invention of a 'shared language' between the different sections of a project. Such a shared language is the standard model through which various construction groups can easily cooperate and exchange information. One of the most significant standards is IFC (for planning, designing, construction, and management of a building). The IFC standard has been designed and developed by the Building Smart institute; nowadays, it is used in many of related software tools and, to some extent, has contributed to the formation of the shared language among various tools. However, this language is still incomplete and has yet a long way to go to become a complete language that can communicate generated concepts and information in software to another [9].

3-1-2. Various dimensional of building information modeling

BIM is the digital evolutionary form of the traditional 2D model to 3D, 4D (determination of 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 evolutionary process. The aspects of BIM follow the order below:

3D Model: The mathematical presentation at any 3D level such as width, length, and height of an object. In other words, 3D BIM includes plan, spatial relations, and geographical and geometric information. For example, the width, length, and height of the building sections should be considered [15].

4D Model: The addition of a fourth dimension, that is, the time plan-to any 3D BIM model. The 4D establishes a communication line 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 [29].

5D Model: A fifth dimension is the addition of the cost estimation data to the 3D model. Any 5D model, for instance, connects the costs data to the list of amounts and materials (QTO) derived from the 3D model [15].

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. Achievement of a database for use 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 lifetime of the construct [30].

7D Model: The seventh dimension of BIM involves maintenance and repair of the building facilities during the utilization time.

3-1-3. The capacities of building information modeling during the project life-cycle

BIM has some specific features that can effectively be used in project management. These features, which are increasingly developed, can be summarized as follows [31]:

Clash Detection: One of the common problems of different disciplines' plans for a construction project is the geometrical design inconsistency. This issue occurs when there is an overlap between the plans of different disciplines. By using BIM, it is possible to bring the plans together and detect the clashes. Modifying the aesthetic problems is another possibility of this visual checking.

Constructability: By using BIM, it is possible for teammates in a project to review and handle constructability issues and (if needed) promote issues into RFIs. In addition, visual information can be provided from a vantage point to show the problems. This visual information accompanying markup allows further investigation for finding solutions, thus mitigating the risks.

Analysis: Helping the project managers, designers, and engineers in doing more analyses and enabling better decision-making is another aspect of BIM. By linking the building information models to appropriate tools, it is possible to analyze the energy consumption of a construction project and, then, find better solutions such as changing materials and orientation, mass and space, etc. Moreover, light, mechanical, and acoustic analyses are also available to be performed by BIM.

Time & Cost Estimation (4D & 5D): Time and cost estimation are other features of BIM that enable project managers to visualize the construction project at any point in time and have a clear understanding of project phases. Time and cost estimation, which are generally called 4D and 5D, can be properly utilized in the first stages of a project and facilitate the decision-making process with minimum cost and required time. Furthermore, BIM has the capability to simulate various alternatives for a construction project and, hence, help project managers and executives to reliably predict the consequences of their decisions.

Integration: The project team can deal and interact with a unified model when a composite model is built from an amalgam of various disciplines' models. By considering this capability and through different phases of the construction project, BIM can coordinate the design, analysis, and construction activities on a project and, therefore, produce the integrity of projects.

Quantity Take-off: Quantity takeoffs in a BIM model can be very helpful for the project teams and managers to analyze their decision and have a clear and reliable insight into various alternatives in the design phase or even throughout the project lifecycle. Since there is a possibility of integration between the BIM model and a database containing cost estimation, an accurate estimation can be obtained faster. Moreover, these takeoff items can be used easily in the procurement procedure.

Element Based Models: Since the BIM models are generally composed of objects (not geometries such as line, surface, etc.), the whole model can be divided into a specific number of smaller objects. This breakdown makes it possible to have a defined and clear scope of projects. The distinction between the elements will result in a better management design, estimation, and construction.

Collaboration and Team Building: Collaboration and team building is another key factor in BIM success regarding construction projects. All efforts made by various specialties on a project are unified and applied to one model. This results in direct correspondence and team building. All disciplines have to work on a unified model as a team and have an effective collaboration during a project using the BIM concept.

Communication: The nature of a unified model to input, modify, and analyze the data in BIM models will improve communication and collaboration between all parties involved on the construction project including project managers, architects, engineers, and contractors. These unique building models facilitate communication throughout the project and lessen the disputes between different parties.

The application of BIM adds many capacities to the various sections of the design, engineering, and management of the building; however, new challenges may emerge by using any new methods. Regardless of its challenges that have been a subject of study for the researches since the appearance of BIM, BIM's various advantages and uses have led to facilitating the operation process in the construction industry. The mentioned applications appear in various phases from the early studies and concept design to the phases of design and execution and, lastly, utilization and demolition phases. In many cases, the advantages of BIM cannot be assigned to a certain stage; thus, we believe that BIM advantages can have synchronic uses in various phases. The following items form a list of advantages and uses of BIM extracted from papers, interviews, and comments of experts. (Table 1)

Tab. 1. List of capacities and uses of BIM throughout the project life-cycle

Row	*Usage Description*
1	Automatic correction of plans and programs in case of changes in design
2	High precision in the estimation of time and costs and controlling the project
3	3D design and providing a better understanding of the ensuing building
4	Contribution to tenders resulting from a more precise estimation
5	Resolving the existing errors and conflicts in plans before the construction phase, thus preventing rework and waste of time and money

6	Increasing safety during construction through precise determination of stages
7	Formation of an extensive and shared data bank among stakeholders in line with thhhe facilitation of access and a better understanding of project goals by them
8	Optimal design of building through the participation of all stakeholders in the design process and integrated design
9	Precise analysis of energy and stability in line with stable design
10	Efficient analysis of[construction] site and building interactions through BIM & GIS
11	Contribution to the employer's decision-making during the project feasibility stage
12	Contribution to organized demolition of the building at the end of its lifetime
13	Reducing legal disputes in construction as a result of the high level of interaction with stakeholders and clarity and documentation of the project processes
14	Providing a comprehensive model and information of the building in order to facilitate smart management of facilities
15	Exact estimation of the work amount in a short period of time by means of virtual simulation of the building model
16	Increasing precision in pre-construction and development of industrialization in complex projects
17	Knowledge management through automatic data recording on the model
18	Facilitation of construction management and stable management of changes in the plans and clarity in the procedures of different work groups

In this stage, after making the above list of BIM capacities and capabilities, by using statistical decision-making, we will try to select primary capacities. Through a poll, experts are asked to assign a score ranging from 1 (least significance) to 10 (most significance) to BIM capacities and capabilities regarding the Commercial Center project. Then, the average of scores assigned by the experts for each item is calculated, and the capacities and capabilities that have an average score above 5 will be selected as primary. Table 2 is the result of this process and is extracted from the above list.

Tab. 2. List of selection capacities and uses of BIM throughout the project life-cycle

Row	*Code*	*Usage Description*
1	B1	Automatic correction of plans and programs in case of changes in design (Parametric capability of the 3D model)
2	B2	High precision in the estimation of time and costs and controlling the project (Accurate quantity surveying and estimating)
3	B3	Resolving the existing errors and conflicts in plans before the construction phase, thus preventing rework and waste of time and money (Clash detection)
4	B4	Formation of an extensive and shared data bank among stakeholders in line with facilitation of access and a better understanding of project goals by them (Archiving)
5	B5	Optimal design of building through the participation of all stakeholders in the design process and integrated design (Integrated design and development of collaboration)
6	B6	Precise analysis of energy and stability in line with stable design (Sustainable design)
7	B7	Providing a comprehensive model and information of the building in order to facilitate smart management of facilities (Operation\maintenance and repair management)
8	B8	Exact estimation of the work amount in a short period of time by means of virtual simulation of the building model (Simulating the construction process)
9	B9	Increasing precision in pre-construction and development of industrialization in complex projects (fabricating capability)

3-2. Step (2): BIM key capacities ranking by using by FANP-FVIKOR approach

In this stage, considering that each of the areas of knowledge is affecting each other and that we are involved in the preparation of questionnaires with uncertainty, then, first, with the FANP approach, the importance of each one is determined. In this part, knowledge areas are at focus; then, the FVIKOR approach to ranking each of the BIM capabilities is used.

3-2-1. Using the FANP approach to obtaining importance of knowledge areas

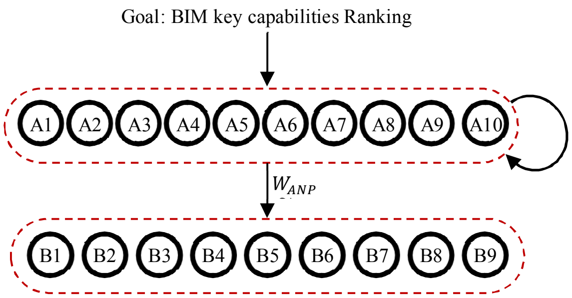

Fig. 4. Network Research Chart

The network diagram of the present research is shown in Figure 4 that aims to gain the weight of the criteria (the weight of the project management knowledge). As a next step input, the options (BIM capabilities) are classified through the fuzzy VIKOR approach

In order to achieve the research goal, paired comparison questionnaires were designed and distributed among the experts. According to the fuzzy approach in this research, the verbal expressions and fuzzy numbers contained in Table 3 were used.

Tab. 3. Fuzzy spectrum and corresponding verbal phrase

Fuzzy number	verbal expressions	Code
(1.1.1)	equal preference	1
(1.3.5)	low preference	2
(3.5.7)	High preference	3
(5,7,9)	Pretty much	4
(7,9,9)	Pretty much	5

In this section, according to Fig. 1, paired comparison tables are performed and, according to the modified method of Toomi et al. (2009), the weight of the components is obtained and prioritized. In this study, for the purpose of calculating the compatibility, the Googoos and Boucher method has been used. The description is presented below.

***Method of studying the compatibility of Googoos and Boucher*:**

Guogos and Boucher (1998) [32] suggested that, for the compatibility check, two matrices (mid-number and fuzzy numbers) of each fuzzy matrix need to be derived; then, the compatibility of each matrix is calculated based on the Saati method. The steps in calculating the compatibility rate for the fuzzy matrixes of the pairwise comparisons are presented as follows:

Step 1: First, divide the fuzzy triangle matrix into two matrices. The first matrix of middle numbers consists of triangular judgments, and the second matrix contains the geometric mean of the upper and lower bounds of triangular numbers.

$$A^g = \sqrt{a_{iju}.a_{iju}}$$

Step 2: Calculate the weight vector of each matrix using the Saati method below (Eq. (1) & Eq. (2))

$$w_i^m = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ijm}}{\sum_{i=1}^{n}a_{ijm}} \quad Where \quad w^m = [w_i^m] \tag{1}$$

$$w_i^g = \frac{1}{n}\sum_{j=1}^{n}\frac{\sqrt{a_{iju}.a_{iju}}}{\sum_{i=1}^{n}\sqrt{a_{iju}.a_{iju}}} \quad Where \quad w^g = [w_i^g] \tag{2}$$

Step 3: Calculate the largest special value for each matrix using the following relationships: (Eq (3) & Eq (4))

$$\lambda_{max}^m = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n}a_{ijm}\left(\frac{w_j^m}{w_i^m}\right) \tag{3}$$

$$\lambda_{max}^g = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n}\sqrt{a_{iju}.a_{iju}}\left(\frac{w_j^g}{w_i^g}\right) \tag{4}$$

Step 4: Calculate the compatibility index using the following: (Eq. (5) & Eq. (6))

$$CI^m = \frac{(\lambda_{max}^m - n)}{(n-1)} \tag{5}$$

$$CI^g = \frac{(\lambda_{max}^g - n)}{(n-1)} \tag{6}$$

Step 5: To calculate the consistency rate (CR), divide the CI by the random variable (RI). If the resulting value is less than 0.1, then the matrix is compatible and usable. Saaty [33] made 100 matrices with random numbers to obtain the values of random indices (RI) and calculated the incompatibility values and their mean values. However, since the numerical values of fuzzy comparisons are not always integer, even in this case, the geometric average converts them into non-integer numbers; even if the (9.1) scale is used, the RI table cannot be used. Consequently, Gogus and Boucher produced a randomized index table (RI) with 400 randomly generated matrices for fuzzy pairwise matrices. (Table 4)

Tab. 4. Random Indicators (RI)

RI^g	RI^m	Matrix Size
0	0	1
0	0	2
0.1796	0.4890	3
0.2627	0.7937	4
0.3597	1.0720	5
0.3818	1.1996	6
0.4090	1.2874	7
0.4164	1.3410	8
0.4348	1.3793	9
0.4455	1.4095	10
0.4536	1.4181	11
0.4776	1.4462	12
0.4691	1.4555	13
0.4804	1.4913	14
0.4880	1.49861	15

To generate random matrices, first, the middle value of a fuzzy triangular number was generated randomly in the interval form. Then, the lower limit of each triangular number at the interval [the average produced amount, $\frac{1}{9}$] and its upper limit at the interval [$\frac{1}{9}$, the average produced amount] generated randomly and, finally, by dividing the randomized matrix into two matrices of the midpoint and geometric mean, the random index is obtained. It is noteworthy that the amount of incompatibility in RI^m column is more than that in RI^g. This difference is due to the fact that the range of random $[\frac{1}{9}, 9]$ numbers generated is for the midpoint. However, the range of upper and lower bounds based on the average number produced is more limited. Therefore, there is less probability for inconsistency in them. By the calculation of the inconsistency rate for two matrices, they are compared with the threshold of 0.1: (Eq. (7) & Eq. (8))

$$CR^g = \frac{CI^g}{RI^g} \tag{7}$$

$$CR^m = \frac{CI^m}{RI^m} \tag{8}$$

If both of these indices are less than 0.1, then the fuzzy matrix is consistent. If both were more than 0.1, the decision-maker would be forced to reconsider the priorities. If one of them was only more than 0.1, the decision-maker should reconsider the middle value of fuzzy judgment.

Steps to gain the weight of the components by analyzing the fuzzy network:

Based on super matrices, the stages of computing the weight of the components are as follows:

Stage One: To summarize expert opinions, geometric meanings are taken from paired comparisons.

Stage two: special vector calculation: To calculate the special vector of each of the paired comparison tables, the logarithmic least squares method is used according to Equation (9):

$$w_k^s = \frac{(\prod_{j=1}^{n} a_{kj}^s)^{1/n}}{\sum_{i=1}^{n}(\prod_{j=1}^{n} a_{ij}^m)^{1/n}}, \quad s\epsilon\{l, m, u\} \tag{9}$$

While:

$\widetilde{w}_k = (w_k^l, w_k^m, w_k^u) \quad k = 1, 2, \ldots, n$

The following tables show the geometric meanings of expert opinions. In the final column of these tables, a special vector is shown. (Tables 5 & 6)

Tab. 5. The average pair comparison compared to the key capabilities of BIM influencing the implementation of knowledge management areas of the project

goal	Integration	Scope	Time	Cost	Quality	Resource	Communication	Risk	Procurement	Stakeholder	Eigenvector
Integration	(1,1,1)	(1.442,1.71,1.913)	(1,2.08,2.924)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1.442,2.466,3.271)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(0.117,0.159,0.186)

Risk	Communication	Resource	Quality	Cost	Time	Scope
(0.306,0.405,0.693)	(0.523,0.585,0.693)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.342,0.481,1)	(0.523,0.585,0.693)
(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1,1)
(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)	(0.585,0.693,1)
(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)	(0.585,0.693,1)
(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)	(0.585,0.693,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)	(0.585,0.693,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1,1)
(0.585,0.693,1)	(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)
(0.07,0.08,0.099)	(0.078,0.083,0.094)	(0.074,0.081,0.097)	(0.087,0.109,0.127)	(0.092,0.113,0.127)	(0.083,0.105,0.127)	(0.07,0.077,0.094)

Stakeholder	Procurement
(0.523,0.585,0.693)	(0.523,0.585,0.693)
(1,1.442,1.71)	(1,1,1)
(1,1.442,1.71)	(0.585,0.693,1)
(1,1,1)	(0.585,0.693,1)
(1,1.442,1.71)	(0.585,0.693,1)
(1,1.442,1.71)	(1,1,1)
(1,1,1)	(1,1,1)
(1,1.442,1.71)	(1,1,1)
(1,1.442,1.71)	(1,1,1)
(1,1,1)	(0.585,0.693,1)
(0.091,0.115,0.13)	(0.074,0.08,0.094)

$CR^m = 0.007$ $CR^g = 0.012$

Compatible

Tab. 6. Average comparison with respect to Integration

Integration	Scope	Time	Cost	Quality
Scope	(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)
Time	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(0.585,0.693,1)
Cost	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)
Quality	(1,1.442,1.71)	(1,1.442,1.71)	(1,1,1)	(1,1,1)
Resource	(0.585,1,1.71)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)
Communication	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.523,0.585,0.693)
Risk	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)
Procurement	(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)
Stakeholder	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.585,0.693,1)
Eigenvector	(0.083,0.104,0.126)	(0.074,0.085,0.106)	(0.074,0.082,0.1)	(0.07,0.08,0.104)

	Stakeholder	Procurement	Risk	Communication	Resource
	(1.442,1.71,1.913)	(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)	(0.585,1,1.71)
	(1.442,1.71,1.913)	(1,1.442,1.71)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1.442,1.71)
	(1.442,1.71,1.913)	(1,1.442,1.71)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1.442,1.71)
	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1.442,1.71)
	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)
	(1,1.442,1.71)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)	(0.585,0.693,1)
	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)
	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)
	(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)
	(0.122,0.158,0.181)	(0.096,0.113,0.129)	(0.096,0.117,0.137)	(0.12,0.149,0.172)	(0.09,0.113,0.137)

$CR^m = 0.006$ $CR^g = 0.01$

Compatible

The rest of the questionnaires are in the Appendix (questionnaire related to the ANP network)

Third Stage: Generation of special vector matrices (w_{ij}): These matrices include special vectors that are derived from the second-order pairwise comparisons.

In general, these matrices can be divided into two categories:

1. Matrices that contain special vectors that represent inter-surface relationships (vertical). If there is no inter-surface relationship between the two components, then the value in the matrix is (0,0,0) at the intersection of the two components.
2. Matrices that contain special vectors that represent horizontal relations (in-surface). These matrices are square and the main diameter is (1,1,1). If there is no inter-surface relationship between the two components, then, at the intersection of the two components, the matrix has a value (0,0,0).

Note that if one or more trays in the original diameter won't become (1.1.1) in the special vector matrix, this is because of the column normalization. In normalization, all the fuzzy numbers of that column are divided by the sum of the mean values of the fuzzy numbers of that column. Tables 7 & 8 show the special vector matrices.

Tab. 7. Special vector level 2 matrix versus level 1

Integration	(0.117,0.159,0.186)
Scope	(0.07,0.077,0.094)
Time	(0.083,0.105,0.127)
Cost	(0.092,0.113,0.127)
Quality	(0.087,0.109,0.127)
Resource	(0.074,0.081,0.097)
Communication	(0.078,0.083,0.094)
Risk	(0.07,0.08,0.099)
Procurement	(0.074,0.08,0.094)
Stakeholder	(0.091,0.115,0.13)

Tab. 8. Special vector level 2 matrix versus level 2

	Integration	Scope	Time	Cost	Quality	Resource
Integration	(0.5,0.5,0.5)	(0.042,0.052,0.063)	(0.037,0.042,0.053)	(0.037,0.041,0.05)	(0.035,0.04,0.052)	(0.045,0.056,0.069)
Scope	(0.038,0.041,0.047)	(0.5,0.5,0.5)	(0.06,0.071,0.081)	(0.064,0.081,0.092)	(0.057,0.07,0.08)	(0.045,0.058,0.072)
Time	(0.032,0.036,0.045)	(0.043,0.048,0.058)	(0.5,0.5,0.5)	(0.06,0.079,0.091)	(0.045,0.049,0.055)	(0.053,0.065,0.074)
Cost	(0.038,0.043,0.048)	(0.066,0.079,0.087)	(0.05,0.059,0.07)	(0.5,0.5,0.5)	(0.066,0.079,0.087)	(0.051,0.06,0.069)
Quality	(0.039,0.042,0.05)	(0.042,0.044,0.05)	(0.047,0.052,0.056)	(0.066,0.079,0.087)	(0.5,0.5,0.5)	(0.066,0.079,0.087)
Resource	(0.039,0.044,0.053)	(0.048,0.051,0.055)	(0.044,0.048,0.053)	(0.063,0.073,0.083)	(0.044,0.046,0.05)	(0.5,0.5,0.5)
Communicati	(0.047,0.048,0.05)	(0.044,0.048,0.053)	(0.047,0.048,0.05)	(0.045,0.047,0.052)	(0.05,0.051,0.052)	(0.066,0.076,0.082)
Risk	(0.049,0.067,0.083)	(0.049,0.051,0.055)	(0.049,0.055,0.062)	(0.046,0.051,0.058)	(0.046,0.049,0.055)	(0.049,0.051,0.055)
Procurement	(0.056,0.056,0.056)	(0.052,0.053,0.056)	(0.056,0.058,0.059)	(0.052,0.053,0.056)	(0.056,0.056,0.056)	(0.056,0.056,0.056)
Stakeholder	(0.035,0.039,0.05)	(0.048,0.056,0.065)	(0.059,0.075,0.084)	(0.045,0.054,0.065)	(0.048,0.059,0.069)	(0.045,0.054,0.065)

Procurement	Risk	Communication
(0.048,0.056,0.065)	(0.048,0.059,0.069)	(0.06,0.074,0.086)
(0.039,0.042,0.05)	(0.038,0.041,0.048)	(0.041,0.043,0.048)
(0.053,0.06,0.066)	(0.05,0.055,0.062)	(0.048,0.054,0.061)
(0.033,0.038,0.047)	(0.039,0.047,0.056)	(0.03,0.033,0.039)
(0.048,0.059,0.069)	(0.042,0.044,0.05)	(0.042,0.046,0.053)
(0.069,0.081,0.089)	(0.044,0.046,0.05)	(0.044,0.046,0.05)
(0.047,0.05,0.053)	(0.044,0.046,0.05)	(0.5,0.5,0.5)
(0.049,0.051,0.055)	(0.5,0.5,0.5)	(0.055,0.076,0.088)
(0.5,0.5,0.5)	(0.056,0.056,0.056)	(0.056,0.058,0.059)
(0.04,0.045,0.055)	(0.037,0.041,0.05)	(0.061,0.076,0.085)

Fourth Step: Calculate the final level of weights. To calculate the final weight of the components of each level, we must multiply the product of the special vector matrix of the internal relations in the special vector of the same level in the final weight of the higher level. (Eq 10)

$$w_i^* = w_{ii} \times w_{i(i-1)} \times w_{i-1}^* \qquad (10)$$

If there was no matrix in a level, then a matrix should be replaced. In other words, you should use the following formula:

$$w_i^* = I \times w_{i(i-1)} \times w_{i-1}^* \qquad (11)$$

Table 9 represents the final weights.

Tab. 9. The final weights matrix of criteria relative to the ranking of key BIM capabilities with an impact on the implementation of the project knowledge management

Defuzzify Weight	*Final Fuzzy weight*	*Criteria*
0.117	(0.088,0.118,0.145)	Integration
0.09	(0.072,0.088,0.113)	Scope
0.103	(0.078,0.102,0.13)	Time
0.11	(0.085,0.11,0.137)	Cost
0.104	(0.081,0.103,0.128)	Quality
0.098	(0.077,0.097,0.124)	Resource
0.095	(0.076,0.094,0.117)	Communication
0.086	(0.069,0.085,0.109)	Risk
0.09	(0.073,0.089,0.113)	Procurement
0.113	(0.086,0.113,0.139)	Stakeholder

3-2-2. The FVIKOR approach to ranking key BIM capabilities

The fuzzy VIKOR suggested by Opricovic [23] is explained here. As briefly mentioned already, it focuses on ranking alternatives and determines compromise solutions for a problem with conflicting criteria. While the fuzzy VIKOR is introduced here only, the VIKOR is the same with the fuzzy VIKOR except for using the crispy numbers instead of Triangular Fuzzy Numbers (TFNs).

Verbal expressions have been used to evaluate the options in this research. The verbal expressions and corresponding fuzzy numbers are shown in Table 10.

Tab. 10. Fuzzy numbers and verbal expressions

Fuzzy numbers	verbal expressions
(1,1,3)	very weak
(1,3,5)	weak
(3,5,7)	moderate
(5,7,9)	okay
(7,9,11)	Very good

The evaluation of options based on the criteria according to the fuzzy numbers and the phrases in the table above is shown in Table (2). The numbers in Table 11 are the average fuzzy opinions of the experts.

Tab. 11. Fuzzy numbers and verbal expressions

	B1	B2	B3	B4	B5	B6	B7	B8	B9	*Criterion Weight*
A1	(6.5,8.5,10.5)	(5.5,7.5,9.5)	(6,8,10)	(7,9,11)	(5.5,7.5,9.5)	(1.5,2,4)	(5,7,9)	(5.5,7.5,9.5)	(5,7,9)	(0.088,0.118,0.145)
A2	(6,8,10)	(6,8,10)	(5,7,9)	(4,6,8)	(1.5,2.5,4.5)	(1,1.5,3.5)	(2,3,5)	(4,6,8)	(4.5,6.5,8.5)	(0.072,0.088,0.113)
A3	(5,7,9)	(5,7,9)	(5.5,7.5,9.5)	(3.5,5.5,7.5)	(5,7,9)	(1.5,2,4)	(1.5,2,4)	(4,6,8)	(2.5,4.5,6.5)	(0.078,0.102,0.13)
A4	(2,3,5)	(4,6,8)	(3.5,5.5,7.5)	(4,5.5,7.5)	(2,2.5,4.5)	(1.5,2,4)	(1,1.5,3.5)	(1,3,5)	(4,5.5,7.5)	(0.085,0.11,0.137)
A5	(4,6,8)	(1,1,3)	(6.5,8.5,10.5)	(1,1,3)	(2,2.5,4.5)	(5.5,7,9)	(4,5.5,7.5)	(1.5,2,4)	(5,7,9)	(0.081,0.103,0.128)
A6	(3,5,7)	(4,6,8)	(3.5,5.5,7.5)	(2.5,3.5,5.5)	(3,5,7)	(1,1,3)	(2,3.5,5.5)	(1,3,5)	(3.5,5.5,7.5)	(0.077,0.097,0.124)
A7	(3.5,5.5,7.5)	(3.5,5.5,7.5)	(4.5,6.5,8.5)	(2,3.5,5.5)	(4,6,8)	(1.5,2,4)	(2.5,4,6)	(2,4,6)	(2,3,5)	(0.076,0.094,0.117)
A8	(4,5.5,7.5)	(4,6,8)	(5,7,9)	(4,6,8)	(4,6,8)	(1,1,3)	(1.5,3,5)	(2.5,4.5,6.5)	(4.5,6.5,8.5)	(0.069,0.085,0.109)
A9	(2,2.5,4.5)	(2.5,4,6)	(4.5,6,8)	(3.5,5.5,7.5)	(5,7,9)	(1,1,3)	(1.5,2,4)	(2.5,4.5,6.5)	(3,4.5,6.5)	(0.073,0.089,0.113)
A10	(3.5,5.5,7.5)	(2,3,5)	(2.5,3.5,5.5)	(3,5,7)	(3.5,5.5,7.5)	(1,1,3)	(1,1.5,3.5)	(1.5,3.5,5.5)	(1.5,2.5,4.5)	(0.086,0.113,0.139)

Step 1. Construct the fuzzy performance matrix and weight vector:

$$\widetilde{D} = \begin{bmatrix} \tilde{f}_{11} & \cdots & \tilde{f}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{f}_{m1} & \cdots & \tilde{f}_{mn} \end{bmatrix}$$

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n] \quad \& \quad \sum_{j=1}^{n} w_j = 1$$

where A_i denotes the alternative $i, i = 1, \dots, m$; C_j represents the criterion (or attribute) $j, j = 1, \dots, n$; $\tilde{f}_{ij}$ indicates the fuzzy performance rating of alternative A_i (district in this study) with respect to criterion C_j (indicator in this study); $\widetilde{w}_j$

indicates the fuzzy weight for each criterion. Here, $\tilde{f}_{ij} = (l_{ij}, m_{ij}, r_{ij})$ is defined as a TFN.

Step 2. Determine the ideal $f_i^+ = (l_i^+, m_i^+, r_i^+)$ and the nadir $f_i^- = (l_i^-, m_i^-, r_i^-)$ values of all criteria function according to the benefit or cost functions. The set of criteria representing benefits (good effects) is denoted by I^b, and a set I^c represents costs. (Eq. (12) & Eq. (13))

$$\tilde{f}_i^+ = \max \tilde{f}_{ij}, \qquad \tilde{f}_i^- = \max \tilde{f}_{ij} \qquad for\ i \in I^b \tag{12}$$

$$\tilde{f}_i^+ = \max \tilde{f}_{ij}, \qquad \tilde{f}_i^- = \max \tilde{f}_{ij} \qquad for\ i \in I^c \tag{13}$$

Step 3. Compute the normalized fuzzy difference $\tilde{d}_{ij}$: (Eq. (14) & Eq. (15))

$$\tilde{d}_{ij} = \frac{\tilde{f}_i^+ \ominus \tilde{f}_{ij}}{r_i^+ - l_i^-} \qquad for\ \ i \in I^b \tag{14}$$

$$\tilde{d}_{ij} = \frac{\tilde{f}_{ij} \ominus \tilde{f}_i^+}{r_i^- - l_i^+} \qquad for\ \ i \in I^b \tag{15}$$

Table 12 shows the normalized values of the evaluation matrix.

Tab. 12. Normalized Decision Table

	B1	B2	B3	B4	B5
A1	(-0.368,0.053,0.474)	(-0.263,0.158,0.579)	(-0.316,0.105,0.526)	(-0.421,0,0.421)	(-0.263,0.158,0.579)
A2	(-0.444,0,0.444)	(-0.444,0,0.444)	(-0.333,0.111,0.556)	(-0.222,0.222,0.667)	(0.167,0.611,0.944)
A3	(-0.438,0.063,0.563)	(-0.438,0.063,0.563)	(-0.5,0,0.5)	(-0.25,0.25,0.75)	(-0.438,0.063,0.563)
A4	(-0.214,0.214,0.571)	(0.071,0.643,1)	(0,0.571,0.929)	(0.071,0.571,0.929)	(-0.214,0.143,0.5)
A5	(-0.158,0.263,0.684)	(0.368,0.789,1)	(-0.421,0,0.421)	(0.368,0.789,1)	(0.211,0.632,0.895)
A6	(-0.429,0.143,0.714)	(-0.571,0,0.571)	(-0.5,0.071,0.643)	(-0.214,0.357,0.786)	(-0.429,0.143,0.714)
A7	(-0.429,0.143,0.714)	(-0.429,0.143,0.714)	(-0.571,0,0.571)	(-0.143,0.429,0.929)	(-0.5,0.071,0.643)
A8	(0.125,0.563,0.813)	(0.125,0.625,0.875)	(0.25,0.75,1)	(0.125,0.625,0.875)	(0.125,0.625,0.875)
A9	(0.063,0.563,0.875)	(-0.125,0.375,0.813)	(-0.375,0.125,0.563)	(-0.313,0.188,0.688)	(-0.5,0,0.5)
A10	(-0.615,0,0.615)	(-0.231,0.385,0.846)	(-0.308,0.308,0.769)	(-0.538,0.077,0.692)	(-0.615,0,0.615)

B9	B8	B7	B6
(-0.211,0.211,0.632)	(-0.263,0.158,0.579)	(-0.211,0.211,0.632)	(0.316,0.737,1)
(-0.278,0.167,0.611)	(-0.222,0.222,0.667)	(0.111,0.556,0.889)	(0.278,0.722,1)
(-0.125,0.375,0.875)	(-0.313,0.188,0.688)	(0.188,0.688,1)	(0.188,0.688,1)
(0.071,0.571,0.929)	(-0.357,0.214,0.571)	(-0.357,0,0.357)	(-0.286,0.071,0.429)
(-0.263,0.158,0.579)	(0.263,0.684,0.947)	(-0.105,0.316,0.684)	(-0.263,0.158,0.526)
(-0.5,0.071,0.643)	(-0.143,0.429,1)	(-0.214,0.357,0.857)	(0.143,0.714,1)
(-0.071,0.5,0.929)	(-0.214,0.357,0.929)	(-0.214,0.357,0.857)	(0.071,0.643,1)
(0.188,0.688,0.938)	(-0.063,0.438,0.688)	(-0.188,0.25,0.5)	(-0.25,0,0.25)
(-0.188,0.313,0.75)	(-0.188,0.313,0.813)	(0.125,0.625,0.938)	(0.25,0.75,1)
(-0.154,0.462,0.923)	(-0.308,0.308,0.923)	(0,0.615,1)	(0.077,0.692,1)

Step 4. Compute the values $\tilde{S}_j = (S_j^l, S_j^m, S_j^r)$ and $\tilde{R}_j = (R_j^l, R_j^m, R_j^r)$ by the relations: (Eq. (16) & Eq. (17))

$$\tilde{S}_j = \sum_{i=1}^{n} \tilde{w}_j \otimes \tilde{d}_{ij} \quad (17)$$

$$\tilde{R}_j = \max \tilde{w}_j \otimes \tilde{d}_{ij} \quad (18)$$

Step 5. Compute the values $\tilde{Q}_j = (Q_j^l, Q_j^m, Q_j^r)$ by the relation: (Eq. (19))

$$\tilde{Q}_j = \vartheta \frac{\tilde{S}_j \ominus \tilde{S}^+}{S^{-r} - S^{+l}} \oplus (1-\vartheta) \frac{\tilde{R}_j \ominus \tilde{R}^+}{R^{-r} - R^{+l}} \quad (19)$$

where $\tilde{S}^+ = \min \tilde{S}_j$, $S^{-r} = \max S_j^r$, $\tilde{R}^+ = \min \tilde{R}_j$ and $R^{-r} = max\, R_j^r$. Additionally, ϑ is introduced as a weight for the strategy of "the majority of criteria" $\tilde{S}_j$, whereas $1-\vartheta$ is the weight of the individual regret $\tilde{R}_j$.

The weighting parameter, ϑ, is the maximum utility of a group whose value can be between 0 and 1, which is considered in this research as 0.5.

Step 6. Defuzzify $\tilde{S}_j$, $\tilde{R}_j$, and $\tilde{Q}_j$ using Eq.

Table 13 shows the fuzzy and Defuzzify values of S, R, and Q.

Tab. 13. Fuzzy and Defuzzified values of S, R, and Q

	S	S_g	R	R_g	Q	Q_g
B1	(-0.235,0.188,0.803)	0.236	(0.009,0.05,0.099)	0.052	(-0.737,0,0.74)	0.001
B2	(-0.15,0.32,0.932)	0.356	(0.03,0.081,0.137)	0.082	(-0.626,0.166,0.93)	0.159
B3	(-0.243,0.202,0.811)	0.243	(0.017,0.064,0.127)	0.068	(-0.709,0.055,0.847)	0.062
B4	(-0.124,0.343,0.964)	0.381	(0.03,0.081,0.128)	0.08	(-0.616,0.175,0.91)	0.161

B5	(-0.198,0.233,0.848)	0.279	(0.017,0.065,0.115)	0.065	(-0.692,0.072,0.815)	0.067
B6	(0.041,0.519,1.034)	0.529	(0.028,0.087,0.145)	0.087	(-0.559,0.265,1)	0.243
B7	(-0.071,0.391,0.965)	0.419	(0.015,0.07,0.139)	0.073	(-0.651,0.153,0.951)	0.151
B8	(-0.144,0.326,0.976)	0.371	(0.021,0.07,0.128)	0.073	(-0.655,0.129,0.916)	0.13
B9	(-0.121,0.349,0.979)	0.389	(0.013,0.063,0.128)	0.067	(-0.677,0.11,0.917)	0.115

Step 7. Rank the alternatives and sort the crisp values in decreasing order. The results are three ranking lists $\{A\}_S$, $\{A\}_R$, and $\{A\}_Q$ according to crisp(S), crisp(R), and crisp(Q), respectively.

Step 8. Propose a compromise solution, alternative $A^{(1)}$, which is the best-ranked solution by measure Q if the following two conditions are satisfied: (Table 14)

Tab. 14. Rating options based on R, S, and Q

	R	S	Q
B1	1	1	1
B2	8	4	7
B3	4	2	2
B4	7	6	8
B5	2	3	3
B6	9	9	9
B7	6	8	6
B8	5	5	5
B9	3	7	4

In this step, decision is made according to R, S, and Q values of the options that are sorted in descending order (Table 14). In order to make a decision, the following two conditions are considered:

C1. "Acceptable advantage": $Ad\vartheta \geq DQ$

where $Ad\vartheta = \frac{[Q(A^{(2)})-Q(A^{(1)})]}{[Q(A^{(m)})-Q(A^{(1)})]}$ is the advantage rate of alternative $A^{(1)}$ ranked first compared with the alternative with the second position $A^{(2)}$ in $\{A\}_Q$ and the threshold $DQ = \frac{1}{(m-1)}$

C2. "Acceptable stability in decision-making": Alternative $A^{(1)}$ must also be the best ranked by S or R.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed that consists of the following:

CS1. Alternatives $A^{(1)}$ and $A^{(1)}$ if only condition $C2$ is not satisfied, or

CS2. Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if condition $C1$ is not satisfied; $A^{(M)}$ is determined by the relation $\frac{[Q(A^{(M)})-Q(A^{(1)})]}{[Q(A^{(m)})-Q(A^{(1)})]} < DQ$ for maximum M. The positions of these alternatives are in proximity.

According to the above, the final options are determined according to the third mode:

Tab. 15. Final ranking of options

Ranking	Alternative
1	B1: (Parametric capability of the 3D model)
2	B3: (Clash detection)
3	B5: (Integrated design and development of collaboration)
4	B9: (fabricating capability)
5	B8: (Simulating the construction process)
6	B7: (Operation\maintenance and repair management)
7	B2: (Accurate quantity surveying and estimating)
8	B4: (Archiving)
9	B6: (Sustainable design)

Therefore, Options 1, 3, and 5 are among the best BIM capabilities that can cover most of the knowledge management areas of the project. Option 1 means 3D design and parametric design that makes it a great prospect of the project, which needs to be built, and the results of the changes made in the project can be seen so fast that help us with making quick decisions. Option 3 means eliminating the errors and interactions in the maps before the phase of construction and avoiding duplication and cost and time wasting, meaning that it should focus more on the planning phase. To avoid problems in the construction phase, which is exactly the same as the BIM philosophy. Option 5, due to increased collaboration and teamwork, is an important factor in the success of the project that affects almost all areas of knowledge. With regard to the BIM philosophy that all project components work on a 3D model, they can easily express their ideas in a coherent phase before they enter the construction phase to prevent replenishment. We see that the last option is Option 6 for sustainable design and optimal energy consumption. It is obvious that less attention and less investment is paid to this issue in developed and in developing countries. Given the importance of energy and sustainability in daily life, this ability can be further addressed in the future.

4. Conclusion

Considering the findings, two good conclusions can be drawn. Regarding the influences, uses, and advantages of BIM on the project management body of knowledge PMBOK, it can be observed that the influence is all inclusive and almost equal for all of the fields of knowledge. BIM can contribute to the integrity of the project as well as its time and cost management. It also influences the fields of stakeholders and communications. It directly affects the project goals (Time-Cost-Quality) and some of the project management fields such as resources and risks. Therefore, the application of BIM and the existence of platform for working with this concept can contribute to the project management in various directions/aspects and help achieve the goals. From the second point of view, we have the ranking and scoring based on the influence on project management. Here, the differences are clear and meaningful, and it can be said that based on the characteristics of Iranian construction community, B3 and B1 benefits (related to resolving conflicts and plan error and automatic correction in drawing plans form the point of view of the Iranian engineering and construction community) have the highest effect on construction project management. Moreover, stable designing, optimization of energy consumption, smart-making of the buildings are the least honored uses of BIM from the view of these experts. Of note, these results were obtained from the current traditional systems of construction in Iran. Issues related to plans, constant changes, and numerous corrections guide projects in fulfilling the primary goals; thus, the BIM experts see it as a solution to these problems, which is exactly what has been observed in the projects that have moved in the direction of using BIM. To put it differently, since BIM is new and young in Iran, its use in the present situation is 3D BIM at the functional and expected level, which houses the best advantages of BIM in management of construction projects. 6D and 7D BIMs related to the stability, energy, and facilities of the buildings are insignificantly regarded. Because of time and cost aspects, 4D and 5D BIMs are also included in this obscurity. Clearly, with the passage of time and widespread employment of BIM in construction projects and the resolving of the issues that are very bold at this time, the aspects that are less regarded will be met more warmly. In the future, the weight of BIM advantages will move contrary to the presented results and towards more balance. Several extensions may be directed in this field of interest. The qualitative analysis and problem structuring of the paper could be developed by considering cognitive mapping approaches. To extend the applicability of the proposed model, combining the structuring with DEMATEL can be another worthwhile direction for researchers to estimate the severity of the impact and effectiveness of each criterion. Moreover, the existing dependency among BIM capabilities can be also left for future research in the developed methodology.

Reference

[1] Larson, E.W. and C.F. Gray. *A Guide to the Project Management Body of Knowledge: PMBOK (®) Guide*. Project Management Institute, (2015).

[2] Alshawi, M. and B.J.A.i.c. Ingirige, *Web-enabled project management: an emerging paradigm in construction.* Vol. 12, No. 4, (2003), pp. 349-364.

[3] Rezahoseini, A., et al., *Investigating the effects of building information modeling capabilities on knowledge management areas in the construction industry.*Vol. 4, No. 1, (2019), pp. 1-18.

[4] Broquetas, M.J.M.d.d., University of Applied Sciences, Stuttgart, *Using BIM as a project management tool: how can BIM improve the delivery of complex construction projects?* (2010).

[5] Herr, C.M., T.J.J.o.C.D. Fischer, and Engineering, *BIM Adoption Across the Chinese AEC Industries: An Extended BIM Adoption Model.* (2018).

[6] Young, N.W., et al., *The business value of BIM-getting building information modeling to the bottom line.* Vol. 51, (2009).

[7] Hendrickson, C., T.J.E. Au, Architects, and P.H. Builders, Pitsburgh, *Project Management for Construction: Fundamental Concepts for Owners.* (2000).

[8] Rokooei, S.J.P.-S. and B. Sciences, *Building information modeling in project management: necessities, challenges and outcomes.* Vol. 210, (2015), pp. 87-95.

[9] Eastman, C., et al., *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors.* (2011), John Wiley & Sons.

[10] Jung, Y. and G.E.J.J.o.c.i.c.e. Gibson, *Planning for computer integrated construction.* Vol. 13, No. 4, (1999). pp. 217-225.

[11] Eastman, C.M., *Building product models: computer environments, supporting design and construction.* (2018), CRC press.

[12] Kymmell, W., *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations (McGraw-Hill Construction Series): Planning and Managing Construction Projects with 4D CAD and Simulations.* (2007), McGraw Hill Professional.

[13] Azhar, S., et al. *Building Information Modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects.* in *Proc., First International Conference on Construction in Developing Countries.* (2008).

[14] Kerzner, H. and H.R. Kerzner, *Project management: a systems approach to planning, scheduling, and controlling.* (2017), John Wiley & Sons.

[15] Liu, Z., *Feasibility Analysis of BIM Based Information System for Facility Management at WPI.* (2010), Worcester Polytechnic Institute.

[16] Kassem, M., B. Succar, and N. Dawood, *A proposed approach to comparing the BIM maturity of countries.* (2013).

[17] Altaf, M.S., *Integrating occupational indoor air quality with building information modeling (BIM).* (2011).

[18] Succar, B.J.A.i.c., *Building information modelling framework: A research and delivery foundation for industry stakeholders.* Vol. 18, No. 3, (2009), pp. 357-375.

[19] Bryde, D., M. Broquetas, and J.M.J.I.j.o.p.m. Volm, *The project benefits of building information modelling (BIM).* Vol. 31, No. 7, (2013), pp. 971-980.

[20] Azhar, S.J.L. and m.i. engineering, *Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry.* Vol. 11, No. 3, (2011), pp. 241-252.

[21] Fazli, A., et al., *Appraising effectiveness of Building Information Management (BIM) in project management.* Vol. 16, (2014), pp. 1116-1125.

[22] Jupp, J.J.P.e., *4D BIM for environmental planning and management.* Vol. 180, (2017), pp. 190-201.

[23] Murguia, D., et al., *Process Integration Framework for the Design Phase of a Residential Building.* Vol. 196, (2017), pp. 462-469.

[24] Lou, J., J. Xu, and K.J.P.e. Wang, *Study on construction quality control of urban complex project based on BIM.* Vol. 174, (2017), pp. 668-676.

[25] Li, X., J. Xu, and Q.J.P.e. Zhang, *Research on construction schedule*

management based on BIM technology. Vol. 174, (2017), pp. 657-667.

[26] Xu, J.J.P.e., *Research on application of BIM 5D technology in central grand project.* Vol. 174, (2017), pp. 600-610.

[27] Sigalov, K. and M.J.A.E.I. König, *Recognition of process patterns for BIM-based construction schedules.* Vol. 33, (2017), pp. 456-472.

[28] Ashcraft, H.W.J.C.L., *Building information modeling: A framework for collaboration.* Vol. 28, (2008), p. 5.

[29] Dang, D.T.P. and M.J.C.U.O.T.G. Tarar, Sweden, *Impact of 4D modeling on construction planning process.* (2012).

[30] Elbeltagi, E. and M.J.A.i.C. Dawood, *Integrated visualized time control system for repetitive construction projects.* Vol. 20, Vol. 7, (2011), pp. 940-953.

[31] Lahdou, R. and D. Zetterman, *BIM for Project Managers How project managers can utilize BIM in construction projects.* (2011).

[32] Gogus, O., T.O.J.F.S. Boucher, and Systems, *Strong transitivity, rationality and weak monotonicity in fuzzy pairwise comparisons.* Vol. 94, No. 1, (1998), pp. 133-144.

[33] Saaty, T.L. and L.G.J.O.R. Vargas, *Diagnosis with dependent symptoms: Bayes theorem and the analytic hierarchy process.* Vol. 46, No. 4, (1998), pp. 491-502.

APPENDIX

questionnaire related to the ANP network (Continuation)

Tab. X1. Average comparison with respect to Scope

Scope	Integration	Time	Cost	Quality	Resource	Communication	Risk	Procurement	Stakeholder	Eigenvector
Integration	(1,1,1)	(0.523,0.585,0.693)	(0.481,0.523,0.585)	(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)	(0.585,0.693,1)	(0.076,0.082,0.093)
Time	(1.442,1.71,1.913)	(1,1,1)	(0.585,0.693,1)	(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(1,1.442,1.71)	(0.119,0.142,0.162)
Cost	(1.71,1.913,2.08)	(1,1.442,1.71)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(1,1.442,1.71)	(0.129,0.163,0.184)

Stakeholder	Procurement	Risk	Communication	Resource	Quality
(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)
(0.585,0.693,1)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1,1)
(0.585,0.693,1)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.585,0.693,1)	(0.585,0.693,1)
(0.585,0.693,1)	(0.585,0.693,1)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1,1)
(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)	(1,1.442,1.71)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)
(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)
(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)
(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)
(0.085,0.103,0.129)	(0.078,0.085,0.099)	(0.077,0.083,0.095)	(0.082,0.086,0.095)	(0.09,0.117,0.145)	(0.114,0.14,0.16)

Compatible $CR^m = 0.004$ $CR^g = 0.007$

Tab. X2. Average comparison with respect to Time

Time	Integration	Scope	Cost	Quality	Resource	Communication
Integration	(1,1,1)	(1,1.442,1.71)	(1.71,1.913,2.08)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1.442,1.71)
Scope	(0.585,0.693,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(1,1.442,1.71)	(1,1,1)
Cost	(0.481,0.523,0.585)	(0.585,0.693,1)	(1,1,1)	(0.523,0.585,0.693)	(0.585,0.693,1)	(0.585,0.693,1)
Quality	(0.585,0.693,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)	(1,1.442,1.71)	(1,1,1)
Resource	(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1.442,1.71)	(0.585,0.693,1)	(1,1,1)	(0.585,0.693,1)
Communication	(0.585,0.693,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(1,1.442,1.71)	(1,1,1)
Risk	(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1.442,1.71)
Stakeholder	(0.585,0.693,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(1,1.442,1.71)	(1,1,1)
Procurement	(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1.442,1.71)	(0.585,0.693,1)	(1,1,1)	(1,1,1)
Eigenvector	(0.064,0.072,0.091)	(0.086,0.096,0.115)	(0.12,0.158,0.181)	(0.09,0.098,0.111)	(0.107,0.13,0.148)	(0.097,0.109,0.123)

Procurement	Stakeholder	Risk
(1.442,1.71,1.913)	(1,1.442,1.71)	(1.442,1.71,1.913)
(1,1.442,1.71)	(1,1,1)	(1,1.442,1.71)
(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)
(1,1.442,1.71)	(1,1,1)	(1,1,1)
(1,1,1)	(0.585,0.693,1)	(1,1,1)
(1,1,1)	(1,1,1)	(0.585,0.693,1)
(1,1,1)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)	(1,1,1)
(0.107,0.12,0.132)	(0.097,0.104,0.115)	(0.101,0.111,0.124)

Compatible $CR^m = 0.006$ $CR^g = 0.01$

Tab. X3. Average comparison with respect to Cost

Cost	Integration	Scope	Time
Integration	(1,1,1)	(1.71,1.913,2.08)	(1.442,1.71,1.913)
Scope	(0.481,0.523,0.585)	(1,1,1)	(0.585,0.693,1)
Time	(0.523,0.585,0.693)	(1,1.442,1.71)	(1,1,1)
Quality	(0.481,0.523,0.585)	(1,1,1)	(0.585,0.693,1)
Resource	(0.523,0.585,0.693)	(1,1.442,1.71)	(1,1,1)
Communication	(1.442,1.71,1.913)	(1.913,2.08,2.08)	(1.442,1.71,1.913)
Risk	(1,1,1)	(1.442,1.71,1.913)	(0.585,1,1.71)
Procurement	(1,1.442,1.71)	(1.442,1.71,1.913)	(1.442,1.71,1.913)
Stakeholder	(0.523,0.585,0.693)	(1,1.442,1.71)	(1,1,1)
Eigenvector	(0.076,0.085,0.095)	(0.132,0.158,0.173)	(0.101,0.117,0.14)

Stakeholder	Procurement	Risk	Communication	Resource	Quality
(1.442,1.71,1.913)	(0.585,0.693,1)	(1,1,1)	(0.523,0.585,0.693)	(1.442,1.71,1.913)	(1.71,1.913,2.08)
(0.585,0.693,1)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.481,0.481,0.523)	(0.585,0.693,1)	(1,1,1)
(1,1,1)	(0.523,0.585,0.693)	(0.585,1,1.71)	(0.523,0.585,0.693)	(1,1,1)	(1,1.442,1.71)
(0.585,0.693,1)	(0.481,0.523,0.585)	(0.481,0.523,0.585)	(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1,1)
(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.523,0.585,0.693)	(1,1,1)	(1,1.442,1.71)
(1.442,1.71,1.913)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1,1)	(1.442,1.71,1.913)	(1.442,1.71,1.913)
(1.442,1.71,1.913)	(0.585,0.693,1)	(1,1,1)	(0.523,0.585,0.693)	(1,1.442,1.71)	(1.71,1.913,2.08)
(1.442,1.71,1.913)	(1,1,1)	(1,1.442,1.71)	(0.585,0.693,1)	(1,1.442,1.71)	(1.71,1.913,2.08)
(1,1,1)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(1,1,1)	(1,1.442,1.71)
(0.111,0.125,0.142)	(0.066,0.076,0.094)	(0.079,0.093,0.112)	(0.06,0.066,0.078)	(0.103,0.12,0.139)	(0.133,0.159,0.175)
Compatible	$CR^m = 0.008$	$CR^g = 0.019$			

Tab. X4. Average comparison with respect to Quality

Quality	Integration	Scope	Cost	Resource	Communication	Risk	Procurement
Integration	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)	(1,1.442,1.71)
Scope	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)	(1,1.442,1.71)
Cost	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(1,1,1)	(1,1,1)	(0.523,0.585,0.693	(0.523,0.585,0.693)	(0.585,0.693,1)
Resource	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(1,1,1)	(1,1,1)	(0.523,0.585,0.693	(0.523,0.585,0.693)	(0.585,0.693,1)
Communication	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)	(1,1.442,1.71)
Risk	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)	(1,1.442,1.71)
Procurement	(0.585,0.693,1)	(0.585,0.693,1)	(1,1.442,1.71)	(1,1.442,1.71)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)
Stakeholder	(0.585,0.693,1)	(0.585,0.693,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)	(0.585,0.693,1)	(1,1,1)
Time	(0.585,0.693,1)	(1,1,1)	(1.442,1.71,1.913)	(1.442,1.71,1.913)	(0.585,0.693,1)	(1,1,1)	(1,1,1)
Eigenvector	(0.078,0.085,0.1)	(0.083,0.089,0.1)	(0.133,0.158,0.175)	(0.133,0.158,0.175)	(0.083,0.092,0.106)	(0.083,0.089,0.1)	(0.096,0.117,0.137)

Time	Stakeholder
(1,1.442,1.71)	(1,1.442,1.71)
(1,1,1)	(1,1.442,1.71)
(0.523,0.585,0.693)	(0.585,0.693,1)
(0.523,0.585,0.693)	(0.585,0.693,1)
(1,1.442,1.71)	(0.585,0.693,1)
(1,1,1)	(1,1.442,1.71)
(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)
(0.094,0.104,0.112)	(0.09,0.108,0.129)

Compatible $CR^m = 0.006$ $CR^g = 0.011$

Tab. X5. Average comparison with respect to Resource

Resource	Integration	Scope	Cost	Quality
Integration	(1,1,1)	(1,1.442,1.71)	(0.843,1.186,1.913)	(1,1,1)
Scope	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)
Cost	(0.523,0.843,1.186)	(1,1,1)	(1,1,1)	(0.523,0.585,0.693)
Quality	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)
Communication	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)
Risk	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)
Procurement	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(1,1,1)	(0.523,0.585,0.693)
Stakeholder	(0.585,0.693,1)	(0.585,0.693,1)	(1,1.442,1.71)	(0.585,0.693,1)
Time	(0.585,0.693,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)
Eigenvector	(0.079,0.089,0.106)	(0.095,0.102,0.111)	(0.125,0.146,0.165)	(0.088,0.092,0.1)

Time	Stakeholder	Procurement	Risk	Communication
(1,1.442,1.71)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1,1)	(0.523,0.585,0.693)	(0.523,0.585,0.693)
(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(0.523,0.585,0.693)	(0.585,0.693,1)	(1,1,1)	(0.523,0.585,0.693)	(0.523,0.585,0.693)
(0.585,0.693,1)	(1,1,1)	(1,1.442,1.71)	(0.585,0.693,1)	(0.585,0.693,1)
(1,1,1)	(1,1.442,1.71)	(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(0.088,0.096,0.106)	(0.096,0.128,0.155)	(0.138,0.162,0.177)	(0.088,0.092,0.1)	(0.088,0.092,0.1)

$CR^m = 0.006$ $CR^g = 0.011$

Compatible

Tab. X6. Average comparison with respect to Communication

Communication	Integration	Scope	Cost	Quality	Resource	Time
Integration	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)
Scope	(1,1,1)	(1,1,1)	(0.585,0.693,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)
Cost	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Quality	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Resource	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(1,1,1)	(1,1,1)	(1,1,1)	(0.523,0.585,0.693)
Time	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)
Risk	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.442,2.466,3.271)	(1,1,1)
Procurement	(1,1,1)	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(1,1,1)
Stakeholder	(0.523,0.585,0.693)	(0.523,0.585,0.693)	(0.306,0.405,0.693)	(0.523,0.585,0.693)	(1,1,1)	(0.523,0.585,0.693)
Eigenvector	(0.094,0.096,0.1)	(0.088,0.096,0.106)	(0.089,0.094,0.104)	(0.101,0.102,0.104)	(0.133,0.152,0.165)	(0.094,0.096,0.1)

Stakeholder	Procurement	Risk
(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(1.442,1.71,1.913)	(1,1.442,1.71)	(1,1,1)
(1.442,2.466,3.271)	(1,1,1)	(1,1,1)
(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(1,1,1)	(0.523,0.585,0.693)	(0.306,0.405,0.693)
(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(1.442,1.71,1.913)	(1,1,1)	(1,1,1)
(1,1,1)	(0.523,0.585,0.693)	(0.523,0.585,0.693)
(0.144,0.171,0.19)	(0.094,0.1,0.106)	(0.088,0.092,0.1)

$CR^m = 0.01$ $CR^g = 0.022$

Compatible

Tab. X7. Average comparison with respect to Risk

Risk	Integration	Scope
Integration	(1,1,1)	(0.585,0.693,1)
Scope	(1,1.442,1.71)	(1,1,1)
Cost	(0.585,1,1.71)	(1,1,1)
Quality	(1,1.442,1.71)	(1,1,1)
Resource	(1,1.442,1.71)	(1,1,1)
Communication	(0.585,0.693,1)	(0.585,0.693,1)
Time	(1,1.442,1.71)	(1,1,1)
Procurement	(1,1.442,1.71)	(1,1,1)
Stakeholder	(1,1.442,1.71)	(1,1,1)
Eigenvector	(0.097,0.135,0.167)	(0.097,0.101,0.11)

Stakeholder	Procurement	Time	Communication	Resource	Quality	Cost
(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1.442,1.71)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,1,1.71)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)
(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)	(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(0.585,0.693,1)	(0.585,0.693,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)	(1,1,1)	(1,1,1)
(0.097,0.101,0.11)	(0.097,0.101,0.11)	(0.097,0.11,0.124)	(0.11,0.152,0.177)	(0.097,0.101,0.11)	(0.092,0.097,0.11)	(0.092,0.101,0.117)

Compatible $CR^m = 0.004$ $CR^g = 0.007$

Tab. X8. Average comparison with respect to Procurement

Procurement	Integration	Scope	Cost	Quality	Resource	Communication	Risk
Integration	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Scope	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1.442,1.71)	(1,1,1)
Cost	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Quality	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Resource	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Communication	(1,1,1)	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Risk	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Stakeholder	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Time	(1,1,1)	(1,1,1)	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
Eigenvector	(0.111,0.111,0.111)	(0.105,0.107,0.111)	(0.105,0.107,0.111)	(0.111,0.111,0.111)	(0.111,0.111,0.111)	(0.111,0.116,0.118)	(0.111,0.111,0.111)

Time	Stakeholder
(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)
(1,1.442,1.71)	(1,1,1)
(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)
(1,1,1)	(1,1,1)
(0.111,0.116,0.118)	(0.111,0.111,0.111)

Compatible $CR^m = 0.002$ $CR^g = 0.004$

Tab. X9. Average comparison with respect to Stakeholder

Stakeholder	Integration	Scope	Cost	Quality
Integration	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,2.08,2.924)
Scope	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)
Cost	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)
Quality	(0.342,0.481,1)	(1,1,1)	(1,1,1)	(1,1,1)
Resource	(0.585,0.693,1)	(1,1,1)	(1,1,1)	(1,1,1)
Communication	(0.523,0.585,0.693)	(0.585,0.693,1)	(0.585,0.693,1)	(0.585,0.693,1)
Risk	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)
Time	(0.523,0.585,0.693)	(0.585,0.693,1)	(0.342,0.481,1)	(0.585,0.693,1)
Procurement	(1,1,1)	(1,1.442,1.71)	(1,1.442,1.71)	(1,1.442,1.71)
Eigenvector	(0.07,0.078,0.1)	(0.096,0.113,0.13)	(0.091,0.108,0.13)	(0.096,0.118,0.138)

Procurement	Time	Risk	Communication	Resource
(1,1,1)	(1.442,1.71,1.913)	(1,1,1)	(1.442,1.71,1.913)	(1,1.442,1.71)
(0.585,0.693,1)	(1,1.442,1.71)	(0.585,0.693,1)	(1,1.442,1.71)	(1,1,1)
(0.585,0.693,1)	(1,2.08,2.924)	(0.585,0.693,1)	(1,1.442,1.71)	(1,1,1)
(0.585,0.693,1)	(1,1.442,1.71)	(0.585,0.693,1)	(1,1.442,1.71)	(1,1,1)
(0.585,1,1.71)	(1,1.442,1.71)	(0.585,0.693,1)	(1,1.442,1.71)	(1,1,1)
(0.523,0.585,0.693)	(1,1,1)	(0.523,0.585,0.693)	(1,1,1)	(0.585,0.693,1)
(1,1,1)	(1.442,1.71,1.913)	(1,1,1)	(1.442,1.71,1.913)	(1,1.442,1.71)
(1,1,1)	(1,1,1)	(0.523,0.585,0.693)	(1,1,1)	(0.585,0.693,1)
(1,1,1)	(1,1,1)	(1,1,1)	(1.442,1.71,1.913)	(0.585,1,1.71)
(0.079,0.09,0.11)	(0.118,0.15,0.169)	(0.074,0.082,0.1)	(0.122,0.153,0.171)	(0.091,0.108,0.13)

$CR^m = 0.008$ $CR^g = 0.013$

Compatible

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