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BIM applications toward key performance indicators of construction projects in Iran

Mostafa Khanzadi[a], Moslem Sheikhkhoshkar[a] and Saeed Banihashemi[b]

[a]Department of Civil Engineering, Iran University of Science and Technology, Tehran, Iran; [b]Faculty of Built Environment & Design, University of Canberra, Canberra, Australia

ABSTRACT
Building Information Modeling (BIM) has recently emerged as a novel technology worldwide however literature review reveals a salient gap in the identification of BIM capabilities in Key Performance Indicators (KPI) of construction projects in Iran. Therefore, the aim of this research is to identify and prioritize the BIM applications toward KPIs in light of the construction stage of projects life cycle in Iran. To do this, a review of literature was performed on the KPIs and associated BIM contributions and the resultants were customized for Iranian context through a two-round Delphi study. An advanced Fuzzy-AHP approach was then applied in the prioritizations of KPIs and associated BIM capabilities via collecting data from construction practitioners. It was identified that quality improvement, sustainable construction and construction cost reduction are the top three KPIs that can be benefitted from BIM applications in the construction stage of building projects. It was also concluded that project coordination, clash detection, 4D and 5D BIM are the subsequent beneficial effects of BIM on the construction project KPIs in Iran. This study is a point of departure for BIM-based research and its managerial perspectives outlining an insight toward the application of BIM in the construction projects of Iran.

KEYWORD
BIM; Key performance indicators; fuzzy AHP; construction industry; Iran

Introduction

One of the major responsibilities of a project management team in construction industry is to finish the project within the budget, time and quality stipulated in the contract documents (Wang et al., 2004). As the time goes by, the construction process gets more complicated, hence controlling all aspects of a project requires a bird's eye view over its life cycle. Although the fundamental tenet in success of this end is having an efficient and organized system of management, monitoring, implementation, collection and dissemination of information from the project to the parties involved, dominance of the CAD have overshadowed this momentum (Banihashemi et al., 2011). Such shortcoming is particularly intensified in the developing countries such as Iran where low productivity, high-level of waste, recurrent cost overruns and chronic delays in completion of construction projects are still major issues (Ghoddousi et al., 2015). The common project management method applied in most construction firms today in Iran is document-based approach in which individuals are assigned to obtain data from different parties involved in the construction stage. As a consequence, wide range of construction data is typically collected in the field and in a fragmented nature without taking their holistic implications into account toward managing the construction process efficiently.

In the recent years, Building Information Modeling (BIM) has emerged as a comprehensive concept of process and tools which integrates all projects required data and information. BIM supports new information workflows and integrates them more closely with existing simulation and analysis tools used by consultants and contractors (Eastman et al., 2011). Since most processes in BIM are automated and the involvement of human resources is minimized, it is claimed that by using BIM, the efficiency of monitoring, controlling and managing in construction projects' life cycle is enhanced remarkably (Golparvar-Fard et al., 2015). But, in spite of the proven advantages of BIM employment in the construction projects and observed trend in its adoption worldwide, the rate of BIM implementation is far below the current potentials in Iran and in the construction stage, particularly (Hosseini et al., 2016a). The reason for this fact might lie in the silence of

CONTACT Moslem Sheikhkhoshkar msheikhkhoshkar@gmail.com

literature on the studies toward the investigation of BIM application in the construction stage of projects in Iran and its contribution to key indicators of managing these projects. There is a conspicuous lack of studies on the identification of BIM potential areas of utilization in the construction stage and the associations with the construction KPIs. Against this backdrop, an evaluation of decision criteria for construction aspects of BIM and their relative importance regarding the fundamental KPIs such as time, cost and quality can be a significant achievement for construction project practitioners and policy makers.

With this respect, the appropriate decision-making criteria grounded on BIM and KPIs should encapsulate a complex trade-off of different processes requiring all alternatives to be considered simultaneously. As a powerful approach in resolving multi-criteria decision-making problems, Analytic Hierarchy Process (AHP), introduced by Saaty (1988), has been used in diverse range of construction related researches such as risk assessment and identification (Aminbakhsh et al., 2013), sustainability assessment (Banihashemi et al., 2014) and KPIs (Ugwu and Haupt, 2007). However, incapability of AHP in minimizing the inherent subjectivity and uncertainty in correlating the judgment of an expert to a precise number necessitates its integration with more advanced methods. Thus, using fuzzy technique within the structure of AHP seems a promising approach to tackle with this challenge (Buckley, 1985).

A review of literature shows that no research hitherto studies the capabilities of BIM in the construction stage of buildings project life cycle in Iran and forges a link with construction KPIs through a robust and unified approach. Diverse capabilities of BIM in terms of enhancing performance and productivity have evidently been acknowledged in seminal studies in the construction field (Azhar, 2011; Sun et al., 2015). Accordingly, a growing interest towards BIM adoption and implementation has been observed throughout the construction industry globally. This includes a wide range of countries in the Middle East, which have attempted to promote BIM implementation on their construction projects (buildingSMART, 2011).

While anecdotal evidence attests to the fact that Iran is lagging in terms of adoption of BIM on construction projects, no research has been undertaken to provide a picture of the potential application of BIM use and practice in Iran. Existing studies from the Middle East e.g. (buildingSMART, 2011) have had a bias towards countries in the Persian Gulf and have not covered all the countries in the Middle East (i.e. Iran, Israel and Turkey). Other studies on BIM in developing countries have focused on countries other than Iran such as Malaysia, Sri Lanka (Rogers et al., 2015a, 2015b), and India (Kumar and Mukherjee, 2009). Factors determining the applications and practices associated with BIM are shaped by the industry context and have to be investigated within the natural context of a country or company (Aranda-Mena et al., 2009, Poirier et al., 2015). As such, findings of studies from other countries are not directly applicable to the Iranian context. Moreover, available published studies on BIM in Iran such as the paper by Kiani et al. (2015) merely focused on the application of BIM for scheduling projects, thus the broad status of BIM in Iran has remained unexplored. This research is to address these things. It is first intended to discover the construction KPIs in Iran's context. Then, the potential aspects of BIM application in the construction stage of building projects are identified in view of Iranian experts. Finally, the associations among the construction KPIs with BIM capability criteria and their relative importance are developed through Fuzzy-AHP approach.

Literature review

The recent trend towards economic growth in Iran has resulted in a demand for construction projects which in turn has flattered the attempts geared in good governance of these projects. Consequently, project managers in Iran are still lagging behind in embracing the concept of productivity and success in managing projects (Ghoddousi et al., 2015). In 2016, Iran has an estimated Gross Domestic Product (GDP) of 412.2 billion USD making it the second largest economy in the Middle East and North Africa (MENA) region, behind Saudi Arabia. Of this, the construction market in Iran comprised a huge 154 billion USD (Ghoddousi et al., 2015), and is expected to grow to 196 billion USD in 2020. The recent lifting of sanctions and consequent injection of foreign direct investment will serve to accelerate Iran's plans for infrastructure development. The size of the country's construction project is to be doubled, and many megaprojects for the development of dams, tunnels and industrial assets have been announced. In essence, construction projects managers in global and local context are expected to deliver projects within the managerial objectives however the low productivity and fragmentation rampant in the construction industry of Iran requires a serious paradigm shift in taking the construction KPIs into consideration in light of emerging methods and technologies.

Table 1. Aspects of BIM application in the construction stage.

BIM Applications in Construction Stage	References
Safety	(Khoshnava et al., 2012, Zhang et al., 2013)
Prefabrication	(Winberg and Dahlqvist, 2010; Banihashemi, 2012)
Project Coordination	(Olofsson et al., 2007, Eastman et al., 2011)
Constructability	(Seo et al., 2012; Sulankivi et al., 2014)
Clash Detection	(Leite et al., 2011; Seo et al., 2012)
Project Supply Chain	(Aram et al., 2013; Irizarry et al., 2013)
Site Layout Planning	(Sulankivi et al., 2009; Kumar and Cheng, 2015)
Project Scheduling and Construction Sequencing	(Hallberg and Tarandi, 2011; Barlish and Sullivan, 2012)
Cost Estimation	(Shen and Issa, 2010; Lee et al., 2014)
Construction Monitoring	(Golparvar-Fard et al., 2015)
Integration of Subcontractor and Supplier Data	(Eastman et al., 2011; Ren et al., 2012)
Flexible Project Changes	(Shourangiz et al., 2011)
Project Logistic Optimization	(Said and El-Rayes, 2014)
Automatic Compliance Checking	(Eastman et al., 2009; Zhong et al., 2012)
Rework Reduction	(Issa and Suermann, 2009)

To address such a challenge, previous studies have outlined the principles of major indicators to be integrated into practices of construction project management. The literature shows that awareness of such indicators play more important role than social and cultural incentives in their integration with project management practices (Zhang et al., 2014). The seminal studies revealed that time, cost and quality constitute the mainstay of these construction KPIs (Chan and Chan, 2004). Recently, some other factors were also included such as safety (Chan et al., 2004) and sustainability (Lam et al., 2010). Furthermore, in a study focused on the identification of critical success factors for construction project practices in Iran, it was disclosed that encompassing these criteria within an integrated model could effectively shape the current course of construction industry into a more sustainable manner (Banihashemi et al., 2017a). As mentioned earlier, BIM, because of its superior capability in construction project process coordination and integration, can play a crucial role thanks to the construction KPIs. Therefore, in line with the objectives of this research, BIM applications with respect to the KPIs of construction projects were explored and identified through a comprehensive review of literature with a focus on the construction stage of building projects life cycle. This resulted in a list of 15 aspects which, for the sake of brevity, the findings of this review are summarised in Table 1.

BIM involves collating, applying and maintaining an integral digital representation of all building information for different phases of the project life cycle in the form of a data repository (Azhar, 2011; Volk et al., 2014). It provides a comprehensive concept as an umbrella for the processes and tools, which integrate all projects required data through containing information needed in particular phases of a building's life-cycle (scheduling, analysis, cost evaluation, etc.) (Eastman et al., 2011). Yet, BIM is much more than a data container for the building model; it is an object oriented building design and construction-specific model to assist the progress of the exchange and interoperability of data in the digital format (Babič et al., 2010). A major benefit of utilising BIM in the design and construction phase of a project is obviously coming through its ability to 'model' and test the constructability of the design within the model prior to setting foot on the project site (Taylor and Bernstein, 2009).

As a management paradigm, BIM can be implemented through chains of ICT (Information and Communication Technologies) including BIM authoring tools such as Revit, ArchiCad, Microstation and Navisworks (Banihashemi, 2012). Implementing BIM helps to avoid errors alongside improving the productivity, scheduling, safety, cost and quality of construction projects (Zuppa et al., 2009). BIM is a fast and effective process by which information pertaining to one project can be updated at any stage of project from any department or unit (e.g. engineering department) (Hosseini et al., 2016b). Accordingly, because of its efficiency in adopting and propagating changes in the model, editing objects and reloading updated links, the entire project model will be updated based on the changes on one aspect of the project (Shourangiz et al., 2011). It is asserted that BIM is capable of enhancing the performance within the industry along with overcoming the problems stemmed from the fragmented structure dominating the industry (Succar, 2009). Serving a catalyst of change for the construction industry, BIM encompasses a radical reorientation of 2D to 3D modelling and a recent shift to 4D (project scheduling integrated), 5D (project cost integrated) and 6D (facility management integrated), exploiting more intelligent data analysis techniques in order to achieve a superior performance in delivering an As-Built BIM (Oraee et al., 2017).

In developing countries, BIM has not become appreciated as a dynamic research area having few studies available (Aboushady and Elbarkouky, 2015; Rogers et al., 2015a; Hosseini et al., 2016a). The study by buildingSMART (2011) in a number of countries in the Middle East revealed that in spite of interest and optimism toward BIM, the construction industry is still in initial stages of its move towards harnessing the benefits of BIM. According to buildingSMART (2011) "overall the findings represent a market that is optimistic and aware, but inexperienced in BIM". In the same vein, BIM stands for the novelty within the Iranian construction industry, unlike various actions to promote BIM in Iran such as developing the guideline of BIM implementation. Therefore, the findings of review of literature reaffirm the discussions regarding the necessity of conducting an exploratory study on BIM in Iran as described next.

Research methodology

As discussed previously, the primary objective of this research is to identify BIM functional aspects with respect to the construction KPIs in the construction stage and reveal their corresponding weights and importance. To do so, a mixed methodology approach was adopted since it is regarded as one of the most practical methods for conducting research in the fields of management through combining qualitative and quantitative methods (Molina-Azorin, 2012). The procedural design of the *qual* → *QUAN* is comprised of conducting a preliminary qualitative-driven study to serve and enhance the findings of a subsequent quantitative approach (as the primary method), termed by Creswell et al. (2003) as 'sequential exploratory design'.

Qualitative stage (delphi)

This stage covered the customisation of the key criteria of construction project management and the preliminary list of BIM performance aspects in the construction stage, found from the literature, within the context of Iran. Construction KPIs are highly context-specific and have to be adapted in view of their corresponding context (Yalegama et al., 2016). Moreover, BIM technical benefits should be explored through the lenses of local and technological competencies. Hence, Delphi method was chosen for this purpose which is an organized procedure to reach a consensus agreement among an expert panel through running frequent discussions in the form of interview or questionnaire (Kennedy, 2004). Generally, the number of rounds varies between two and seven and the number of participants ranges from three to 15 people (Yeung et al., 2009). Running each round, the answers are analysed and based on the evaluations, the semi-structured interviews or questionaries are developed, adjusted and sent to the experts for the subsequent round. The iterative characteristic of this method provides the panel with the feedback and new information from different viewpoints. This opportunity allows them to reconsider their opinions responded in the previous round and revise based on the new comments (Mullen, 2003).

Quantitative stage (fuzzy-AHP)

This stage was to quantify the level of importance of construction KPIs and the BIM benefits in the construction stage of the building projects via Fuzzy-AHP method. It should be noted that in the Fuzzy-AHP integrated method based on Change's extent analysis and synthetic decision (Chang, 1992), the logic of integration follows AHP rules in the initial steps and when it runs up to the weighting step, the Fuzzy technique comes to the fore and is applied for calculations. Generally, this method is founded on the principles of statistical means of respondents' opinions, Saaty's normalization technique and triangular Fuzzy intervals. The most significant reason in using Fuzzy AHP lies in the lack of capability of conventional AHP in powerful handling of uncertainty when experts or policy makers are to select a number in the range of 1–9. To cope with this challenge, decision makers require more flexibility in the scales by using fuzzy membership functions and linguistic variables, e.g. very good or very poor, instead of applying deterministic values (Liyuan, 2010; Soroor et al., 2012; Lee, 2016). The description of the required steps taken for this method are as the below:

Step 1: constructing the problem in the form of a hierarchical model

In this step, the problem is broken down into smaller elements based on their attributes and development of a hierarchical model with various levels.

Step 2: making pair-wise comparisons

Pairwise comparisons of the elements in each specific level are made in accordance with a particular element in the immediate upper level. For n criteria, $(n^2-n)/2$ comparisons have to be made.

Step 3: fuzzy-based pairwise comparison matrix creation

The pairwise comparisons are performed by using linguistic terms and according to the triangular fuzzy numbers of $\tau_{ij} = (a_{ij}, b_{ij}, c_{ij})$.

$$\widetilde{A} = \begin{bmatrix} (1,1,1) & \begin{Bmatrix} \widetilde{a}_{121} \\ \widetilde{a}_{122} \\ \vdots \\ \widetilde{a}_{12P_{12}} \end{Bmatrix} & \cdots & \cdots & \begin{Bmatrix} \widetilde{a}_{1n1} \\ \widetilde{a}_{1n2} \\ \vdots \\ \widetilde{a}_{1nP_{1n}} \end{Bmatrix} \\ \begin{Bmatrix} \widetilde{a}_{211} \\ \widetilde{a}_{212} \\ \vdots \\ \widetilde{a}_{21P_{21}} \end{Bmatrix} & (1,1,1) & \cdots & \cdots & \begin{Bmatrix} \widetilde{a}_{2n1} \\ \widetilde{a}_{2n2} \\ \vdots \\ \widetilde{a}_{2nP_{2n}} \end{Bmatrix} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \begin{Bmatrix} \widetilde{a}_{n11} \\ \widetilde{a}_{n12} \\ \vdots \\ \widetilde{a}_{n1P_{n1}} \end{Bmatrix} & \begin{Bmatrix} \widetilde{a}_{n21} \\ \widetilde{a}_{n22} \\ \vdots \\ \widetilde{a}_{n2P_{n2}} \end{Bmatrix} & \cdots & \cdots & (1,1,1) \end{bmatrix}$$

where P_{ij} is the number of people who give the prioritization to the vector of i with respect to j.

Step 4: statistical mean of the judgments

The statistical mean of the judgments received from the respondents are computed through the below matrix and the Eq. (1):

$$\widetilde{A} = \begin{bmatrix} (1,1,1) & \widetilde{a}_{12} & \widetilde{a}_{1n} \\ \widetilde{a}_{21} & (1,1,1) & \widetilde{a}_{2n} \\ \vdots & \vdots & \vdots \\ \widetilde{a}_{n1} & \widetilde{a}_{n2} & (1,1,1) \end{bmatrix}$$

$$\widetilde{a}_{ij} = \frac{\sum_{k=1}^{P_{ij}} a_{ijk}}{p_{ij}} \quad i,j = 1,2,\ldots,n \tag{1}$$

where $\tilde{a}_{ij}$ is the statistical mean of the vectors of *i, j, k* is a coefficient ranging from 1 to *i, j*.

Step 5: summing up the statistical means of each row

Where the statistical means of each fuzzy element are aggregated and summed up.

$$\widetilde{s}_i = \sum_{j=1}^{n} \widetilde{a}_{ij} \quad i = 1,2,\ldots,n \tag{2}$$

Step 6: normalizing the summations

In which the summated values are normalised based on the applied normalisation method by Montgomery and Runger (2010).

$$\widetilde{M}_i = \widetilde{s}_i \otimes \left[\sum_{i=1}^{n} \widetilde{s}_i\right]^{-1} \quad i = 1,2,\ldots, n \tag{3}$$

Step 7: determining the degree of importance of each row

In this step, the degree of importance of each $i\mu$ to the other $i\mu$ should be calculated *(d'(Ai))*. The degree of importance of a triangular fuzzy element of $\mu_2=(l_2, m_2, u_2)$ to $\mu_1=(l_1, m_1, u_1)$ is determined as the following:

$$V(M_2 > M_1) = Sub_{y \geq x}\left[\min\left(\mu_{M_1}(x), \ \mu_{M_2}(y)\right)\right] \tag{4}$$

Where V is the relative triangular importance of M_2 to M_1 and x and y forms the grounded fuzzy functions. This equation can be depicted as the Figure 1:

In the Figure 1, *l, m* and *u* stand for the lower, medium and upper bounds of a triangular element and *d* is the dimension of the highest point of collision between two membership functions of M_1 and M_2.

Step 8: normalizing

Normalizing each weight vector leads to the corresponded normalized weight.

$$W = \left[\frac{d'(A_1)}{\sum_{i=1}^{n} d'(A_i)}, \frac{d'(A_2)}{\sum_{i=1}^{n} d'(A_i)}, \ldots, \frac{d'(A_n)}{\sum_{i=1}^{n} d'(A_n)}\right]^T \tag{5}$$

Repeating this procedure results in the calculation of defuzzified weights (w) of all matrices.

Step 9: finalizing

$$\widetilde{U}_i = \sum_{j=1}^{n} \widetilde{w}_i \widetilde{r}_{ij} \tag{6}$$

Summation of the weights of all matrices (W_i) multiplied by the AHP criterion is resulted in the final weighting of AHP criteria.

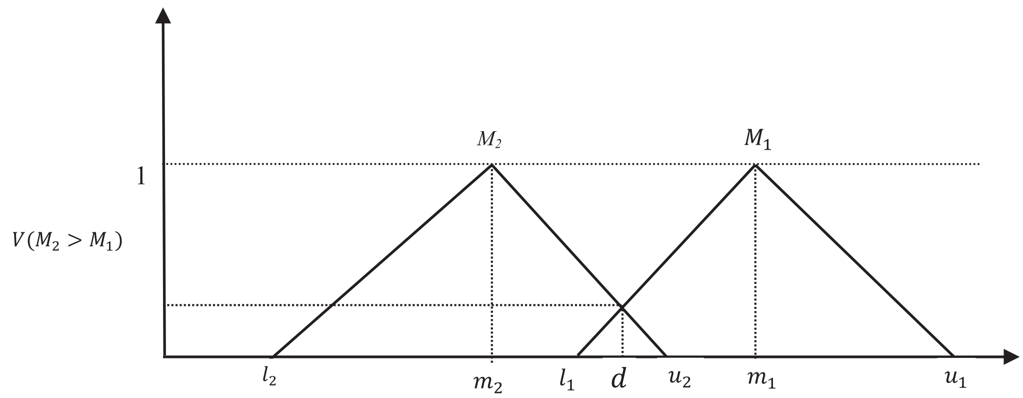

Figure 1. Determination of degree of importance for the fuzzy membership functions.

Table 2. Delphi respondents profile.

Qualification	Educational Areas	Executive Responsibility	Years of Work Experience
BSc	Civil Engineering	Site Manager	16
BSc	Civil Engineering	Technical Manager of a Construction Contractor Company	18
MSc	Civil Engineering	General Director of a Housing Organization	15
MSc	Civil Engineering	R&D Manager of a Construction Company	5
MSc	Civil Engineering	Project Planning and Control Manager	5
MSc	Architectural Engineering	Urban Planning Manager	5
PhD	Civil Engineering	Research Fellowship	3
PhD	Civil Engineering	Research Fellowship	3

Findings of Delphi

The problem targeted to this Delphi was to synthesize the construction KPIs and the relevant BIM functionalities for the construction stage of building project life cycle in the context of Iran. The knowledge areas required for this Delphi inquiry involve with architecture, civil engineering and construction project management. To single out potential interviewees, the 'purposive sampling' strategy was used for controlling the variation level among interviewees (Bazeley, 2013). For this reason, it was intended to establish a survey sample covering these expertise fields considering below recruitment criteria:

- Academic qualification of at least a bachelor degree in architecture and civil engineering and 15 years of work experience in running construction projects.
- Academic qualification of at least a master degree in architecture and civil engineering and 5 years of work experience in construction project management.
- PhD degree and conducting high profile research and development in the aforementioned areas.

That is why, for reaching the most consolidated results, only academics and/or professionals qualified with at least one of the recruitment criteria were invited to the study. Total number of invited respondents was around 15 people in which 8 people accepted the invitation. This sample size could be regarded sufficient as participants for a typical Delphi study generally range from 3 to 15 (Zahoor et al., 2017). Fortunately, the invited participants possessed a good variety of academic qualifications including civil engineering and architecture and different professional areas. This diversity of participation was not arbitrary and it was chosen on purpose in order to reflect a wide range of perspectives on inquires. The profile of the respondents can be seen in Table 2.

Handing over the background information of the problem to the respondents is a normal procedure during any Delphi study. Likewise, the study synopsis along with the main findings of the literature review were sent on-line to the participants to brief them with the aim and objectives of the study, the literature and the scope of this research. This study comprised of two-round inquiries along with a third round on confirmation that was administered through the face to face semi-structured interviews with the participants. The logic of doing 3 rounds of this Delphi is that the first round was to discuss the construction project performance indicators, the second round was to analyse BIM applications in the construction stage with respect to the acquired KPIs and the third round was to confirm the outcomes via the Kendall's coefficient of concordance W.

In the round one, the respondents were provided with the five key criteria of project performances of *time, cost, quality, safety* and *environmental sustainability*, derived from the literature. Three levels of modifications classified into agree, disagree and detailed modification advice including; add, delete or combine factors, were conducted based on the experts' advice. According to the comments, time, cost and quality were maintained as the key indicators however, two experts advised on the combination of two indicators of safety and environmental sustainability into one category of sustainable construction. Furthermore, one respondent also recommended on the inclusion of the constructability as a unique indicator of a successful project in the construction stage. Following with a constructive discussion among the experts, they reached a consensus agreement and five indicators of *time efficient construction delivery, construction cost reduction, quality improvement, constructability improvement* and *sustainable construction* were fixed for the next round.

In the round two, 15 aspects of BIM functionality for the construction stage, explored from the literature (Table 1), were presented to the panel and they were tasked with check-marking this list in light of the results derived from the previous round and the technological potentials of Iran. First, as the factor of *construability* was already included in the tier one KPI list as the *constructability improvement*, it was removed from the tier two list in light of its significance as the project performance indicator. Then, through a normative assessment method; the comparison of each element within its peers, only factors ticked by 50% of experts or above were chosen to be analysed (Chan et al., 2001). Ultimately, it was revealed that five variables did not meet the 50% cut-off criterion and were not chosen for further study due to the reasons such as immature state of BIM technology in Iran, mentioned by the panel.

In the round three, for the sake of providing a measure of consistency, a statistical analysis was performed to compute the Kendall's Coefficient of Concordance (W) (Kendall and Smith 1939), for the responses provided by the 8 experts. Kendall's W is a nonparametric test, running for the normalisation of Friedman statistic test, that can be used for assessing an agreement among participants. If the Kendall concordance coefficient equals to 1, all the survey scorers have been unanimous and they rate the variables identical. On the contrary, if the test results in 0, it means that there is no overall trend of unanimity among the assessors and they rank completely different (Corder and Foreman, 2009). In this case, it was identified that there is no change in the ranking of BIM applications and the consistency of the experts' ratings was improved from 0.121 in Round 2 to 0.217 in Round 3 and it was statistically significant at 1% significance level. More precisely, this coefficient of concordance has been consolidated by 79.3% improvement between Rounds 2 and 3 performance index.

Findings of fuzzy-AHP

Respondent profile

The companies that are highly experienced in delivering and handling construction projects and those companies which are to some extent experienced in BIM applications in Iran were identified through the list of databanks, word of mouth and in-person observations. Eventually, 90 invitations to participate in the research study were sent in-person or by email to the members of these companies attached with an invitation letter and the research brief. Follow up calls were conducted which resulted in receiving 60 duly completed questionnaires. As illustrated in Figure 1, the proportions of the respondents in terms of years of experience were: 5–10 years (51.6%); 10–15 years (19.4%) and more than 15 years (29%). Hence, around half of the respondents had more than 10 years of experience in delivering construction projects.

The proportions of the respondents in terms of role of their company in the construction industry were: 40% in contractor companies while 38% and 22% were working in consulting and developer companies. Besides, 52% had master degrees whereas 41% were qualified with bachelor and 7% had got PhD degree. The profile of the respondents was regarded as an evidence of the breadth of knowledge regarding the strategic and operational levels in the Iranian construction industry (in view of the years of experience, variety of roles and academic qualifications in the sample). Thus, respondents were deemed adequately knowledgeable on the topic of the inquiry.

Fuzzy-AHP stage wise development

For this study, a three level AHP model was developed in which, the highest level was the focus of the problem; the intermediary levels represented the defined categories of construction KPIs and the lowest level included the criteria of BIM applicability in the construction stage with respect to the upper level (Figure 2).

To evaluate the weights of five KPIs, ten pair-wise comparisons and to find the weights of the BIM

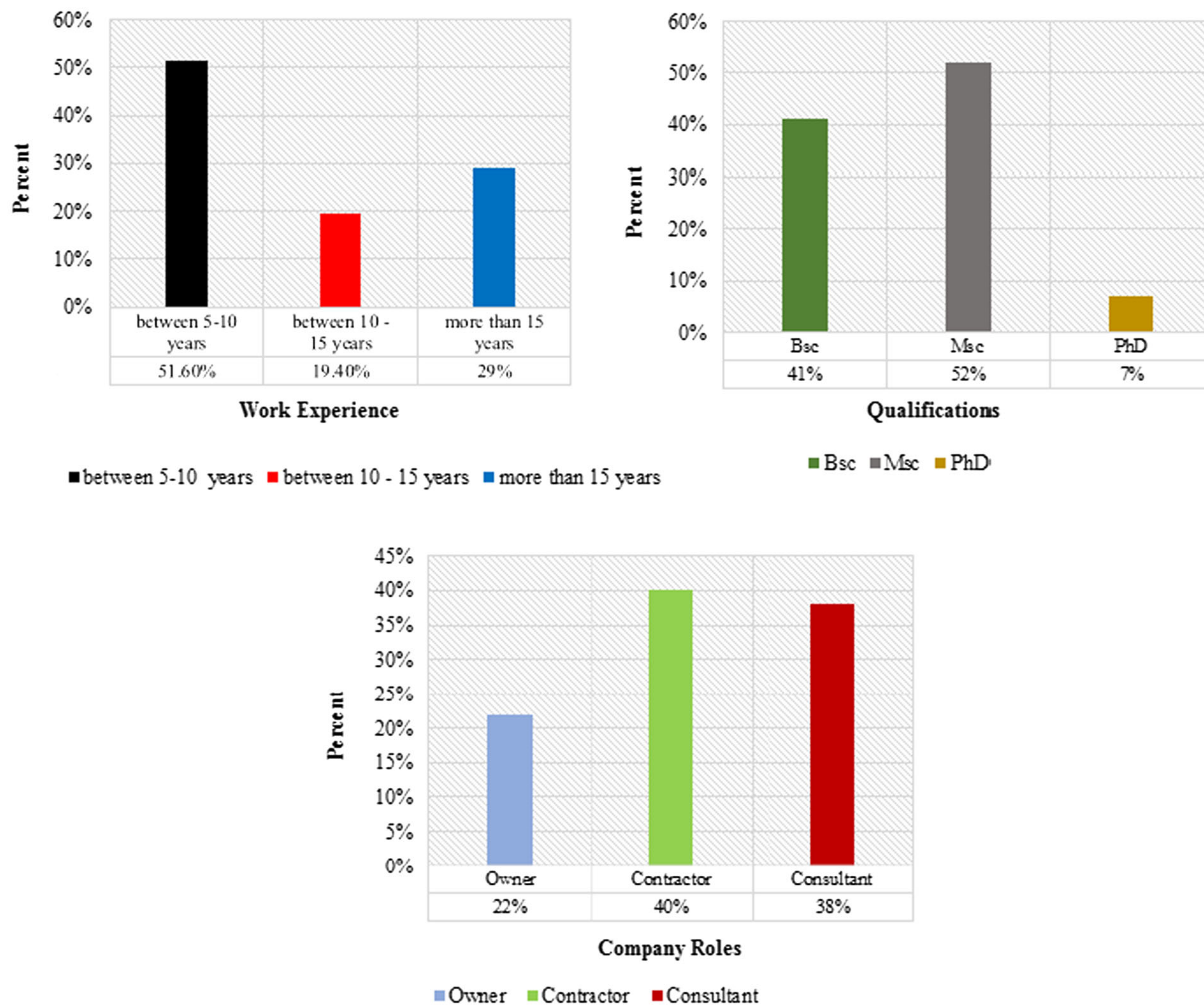

Figure 2. Fuzzy-AHP respondent profile.

Table 3. Triangular fuzzy number and importance scale.

TFN	Linguistic Scale of Importance	Triangular Fuzzy Scale	Bottom Level	Medium Level	Top Level
$\tilde{1}$	Equally Preferred	(1,1,1)	1	1	1
$\tilde{2}$	Equally to Moderately Preferred	(1,3/2,3/2)	1	1.5	1.5
$\tilde{3}$	Moderately Preferred	(1,2,2)	1	2	2
$\tilde{4}$	Moderately to Strongly Preferred	(3,7/2,4)	3	3.5	4
$\tilde{5}$	Strongly Preferred	(3,4,9/2)	3	4	4.5
$\tilde{6}$	Strongly to Very Strongly Preferred	(3,9/2,5)	3	4.5	5
$\tilde{7}$	Very Strongly Preferred	(5,11/2,6)	5	5.5	6
$\tilde{8}$	Very Strongly to Extremely Preferred	(5,6,7)	5	6	7
$\tilde{9}$	Extremely Preferred	(5,7,9)	5	7	9

applications within each KPI, 36 pair-wise comparisons were made respectively. Nine linguistic terms including; Equally Preferred (EP), Equally to Moderately Preferred (EMP), Moderately Preferred (MP), Moderately to Strongly Preferred (MSP), Strongly Preferred (SP), Strongly to Very Strongly Preferred (SVSP), Very Strongly Preferred (VSP), Very Strongly to Extremely Preferred (VSEP) and Extremely Preferred (EP), Triangular Fuzzy Numbers (TFN) ranging 1–9 were used to develop fuzzy comparison matrices. These nine linguistic variables are described by fuzzy numbers as denoted in Table 3 or by membership functions as illustrated in Figure 3.

Once the pairwise comparison matrices were conducted, the associated statistical means were computed for the KPIs and for the nine BIM applications as the sub-criteria of each KPI. The statistical means were summed up and the normalization step was then run. Table 4 exemplifies this procedure performed for the five main KPIs. In the next step, the degree of importance for each matrix was computed and its representative Cartesian dimension in order to

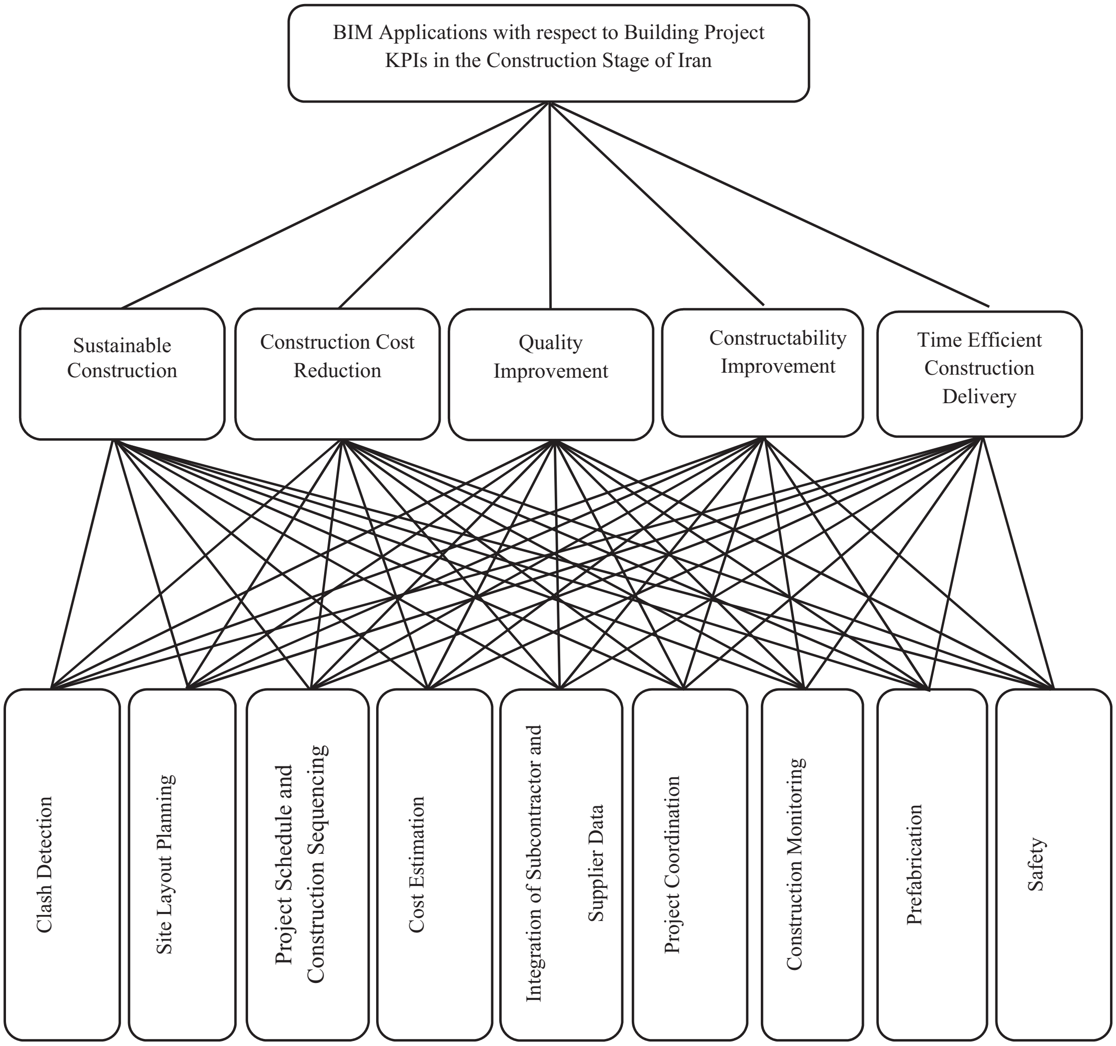

Figure 3. The hierarchy structure of BIM applications and the associated KPIs.

Table 4. Pairwise comparison matrix for the main KPIs.

Criteria	Sustainable Construction	Construction Cost Reduction	Quality Improvement	Constructability Improvement	Time Efficient Construction Delivery	Normalized
Sustainable Construction	(1,1,1)	(1,1.3,1.5)	(0.8,0.9,1.1)	(0.9,1.2,1.4)	(0.9,0.2,1.4)	(0.14,0.19,0.28)
Construction Cost Reduction	(1,1.3,1.5)	(1,1,1)	(0.8,0.9,1.2)	(0.9,1.1,1.3)	(0.8,1.2,1.3)	(0.17,0.19,0.27)
Quality Improvement	(1.1,1.5,1.6)	(1.1,1.6,1.7)	(1,1,1)	(1.3,1.7,1.9)	(1.05,1.5,1.6)	(0.17,0.25,0.33)
Constructability Improvement	(1.07,1.3,1.5)	(0.8,1.2,1.3)	(0.6,0.8,1)	(1,1,1)	(0.9,1.2,1.4)	(0.13,0.19,0.26)
Time Efficient Construction Delivery	(1.1,1.4,1.6)	(0.7,1.03,1.2)	(0.8,1,1.3)	(0.7,1.02,1.2)	(1,1,1)	(0.13,0.18,0.27)

find the highest point of collision between their upper and lower bounds. Each weight factor was normalized again and accordingly, defuzzified weights for all matrices were resulted. Ultimately, the relative weights of the KPIs and the relative weights of BIM functionality aspects within each KPI were obtained. Table 5 indicates the procedures undergone for reaching the final weights of KPIs and Table 6 presents the final relative weights of BIM applications regarding each KPI. Finally, the absolute weights and ranking of BIM applications are illustrated in Table 7. In the end of this section, Figure 4 illustrates and synthesizes the ultimate flow of this research from its first to the final stage.

Results and discussion

The overall Fuzzy-AHP findings, in terms of the relative importance of each KPI compared to the others,

Table 5. The degree of possibility and final weights of main KPIs.

Criteria	Sustainable Construction	Construction Cost Reduction	Quality Improvement	Constructability Improvement	Time Efficient Construction Delivery	Final Degree of Possibility	Normalized Weights
Sustainable Construction	–	1	0.668	1	1	0.668	0.188
Construction Cost Reduction	0.97	–	0.641	0.987	1	0.641	0.18
Quality Improvement	1	1	–	1	1	1	0.281
Constructability Improvement	0.982	1	0.633	–	1	0.633	0.178
Time Efficient Construction Delivery	0.933	0.962	0.612	0.951	–	0.612	0.172

Table 6. Final weights of sub-criteria regarding the main criteria.

Criteria / Sub-criteria	Sustainable Construction	Construction Cost Reduction	Quality Improvement	Constructability Improvement	Time Efficient Construction Delivery
Clash Detection	0.142	0.128	0.152	0.152	0.124
Site Layout Planning	0.081	0.123	0.06	0.094	0.099
Project Schedule and Construction Sequencing	0.133	0.115	0.124	0.122	0.18
Cost Estimation	0.073	0.168	0.092	0.085	0.07
Integration of Subcontractor and Supplier Data	0.113	0.122	0.145	0.139	0.129
Project Coordination	0.149	0.123	0.165	0.099	0.17
Construction Monitoring	0.064	0.047	0.08	0.069	0.04
Prefabrication	0.096	0.06	0.088	0.168	0.091
Safety	0.15	0.115	0.092	0.128	0.097

Table 7. Final weight matrix of sub-criteria; BIM applications.

Sub-criteria	Final Absolute Weight	Ranked
Project Coordination	0.156	**1**
Project Schedule and Construction Sequencing	0.133	**2**
Clash Detection	0.132	**3**
Integration of Subcontractor and Supplier Data	0.131	**4**
Safety	0.114	**5**
Cost Estimation	0.097	**6**
Site Layout Planning	0.088	**7**
Prefabrication	0.087	**8**
Construction Monitoring	0.062	**9**

show that quality improvement has received the highest level of attention amongst all. The descending order of other categories in terms of the level of importance is as follows; sustainable construction, construction cost reduction, constructability improvement and time efficient construction delivery. Such a result is corroborated with the weight of 0.281 for the quality improvement category which far outweighs the rest of the indicators when they are assessed with respect to the BIM technology and the construction stage of project life cycle (see Table 5). It has been confirmed that BIM has the huge potential to improve the construction quality management process by changing the way project participants interact with each other and maintaining the information in a seamless database (Chen and Luo, 2014).

In the second layer of this Fuzzy-AHP study, for the quality improvement category as the first priority of KPIs, it was elucidated that project coordination with the relative importance of 0.165 is the most important factor and clash detection and integration of subcontractor and supplier data are the second and third items, respectively (Table 6). This finding also supports the result of a recent research on the BIM adoption status in Iran (Hosseini et al., 2016a) where 59% of respondents affirmed the positive collaborating and coordinating effects of BIM on the construction industry. Project coordination is one of the most significant drivers for applying BIM during the design development and construction phases through enabling the project stakeholders to envisage and understand evolving designs and collaboration processes

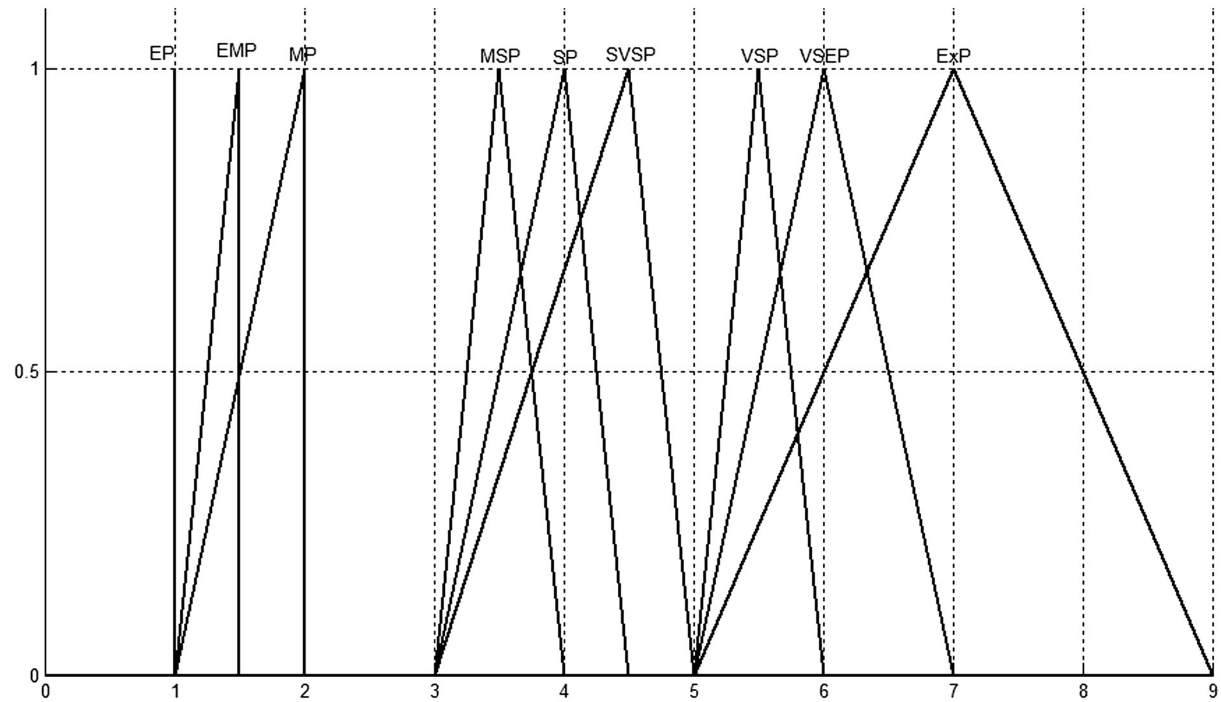

Figure 4. Membership functions for the applied linguistic values.

(Oraee et al., 2017). It leverages the overall quality of a project if can be combined with clash detection and other BIM capabilities to minimise the errors and omissions, enhances efficiency and precision and upgrades design evaluation and communication (Chen and Luo, 2014).

The contribution of BIM toward the project safety has been identified as the first sub-criterion among the sustainable construction KPI. This factor is closely followed by project coordination and clash detection in the subsequent orders (Table 6). BIM promotes the sustainable construction KPI in the design stage especially where advanced techniques such as energy efficient design could be provided and integrated (Banihashemi et al., 2015). However, in the construction stage, the facts such as occurring 46% of the total job accidents in the construction industry in Iran (Jahangiri et al., 2013) puts highlight on the safety factor for the sustainable construction. In the same vein, BIM is utilised in enhancing the safety of construction execution via digital representation of vulnerable areas and hazard simulation analysis (Zhang et al., 2013). Particularly, BIM facilitates the rule-based checking construction process, the detections of spatial conflict or congestion of construction operations and simulate hazard risks on site.

Construction cost reduction is mostly recognised as a key asset in the construction industry turnover and it seems more imperative for Iran's context since the Iranian construction industry has poor profitability and high company failure rates due to irregularity of payments by clients (Ghoddousi and Hosseini, 2012). This is further exacerbated by the recent nationally economic downturn due to the widespread recession stemming from international sanctions (BMI Research, 2017). Evidently, the first rank BIM-associated application for this indicator is the cost estimation which can be implemented by the powerful impetus of 5D BIM; automated quantity take-off. 5D BIM develops precise bill of quantity exporting the required quantities, using a specialised measurement tool and solid solutions to keep the homogeneity of cost data (Plebankiewicz et al., 2015). More cost efficiency can be materialized when clash detection, site layout planning and project coordination are brought to light (Table 6).

The next KPI, constructability is defined as "the design efforts that can be used in the construction phase, and let contractors implement activities easily and smoothly" (Sulankivi et al., 2014). Based on this definition, the designer must have the understanding of construction but due to the lack of sufficient communication and coordination in the local context, the designer common lacks this notation (Ghoddousi et al., 2011). The respondents have attributed prefabrication (industrialised building system) and clash detection to the first and second priority of BIM contribution for constructability KPI (Table 6). Parametric proficiency inherited in BIM allows for modular coordination and standardisation of

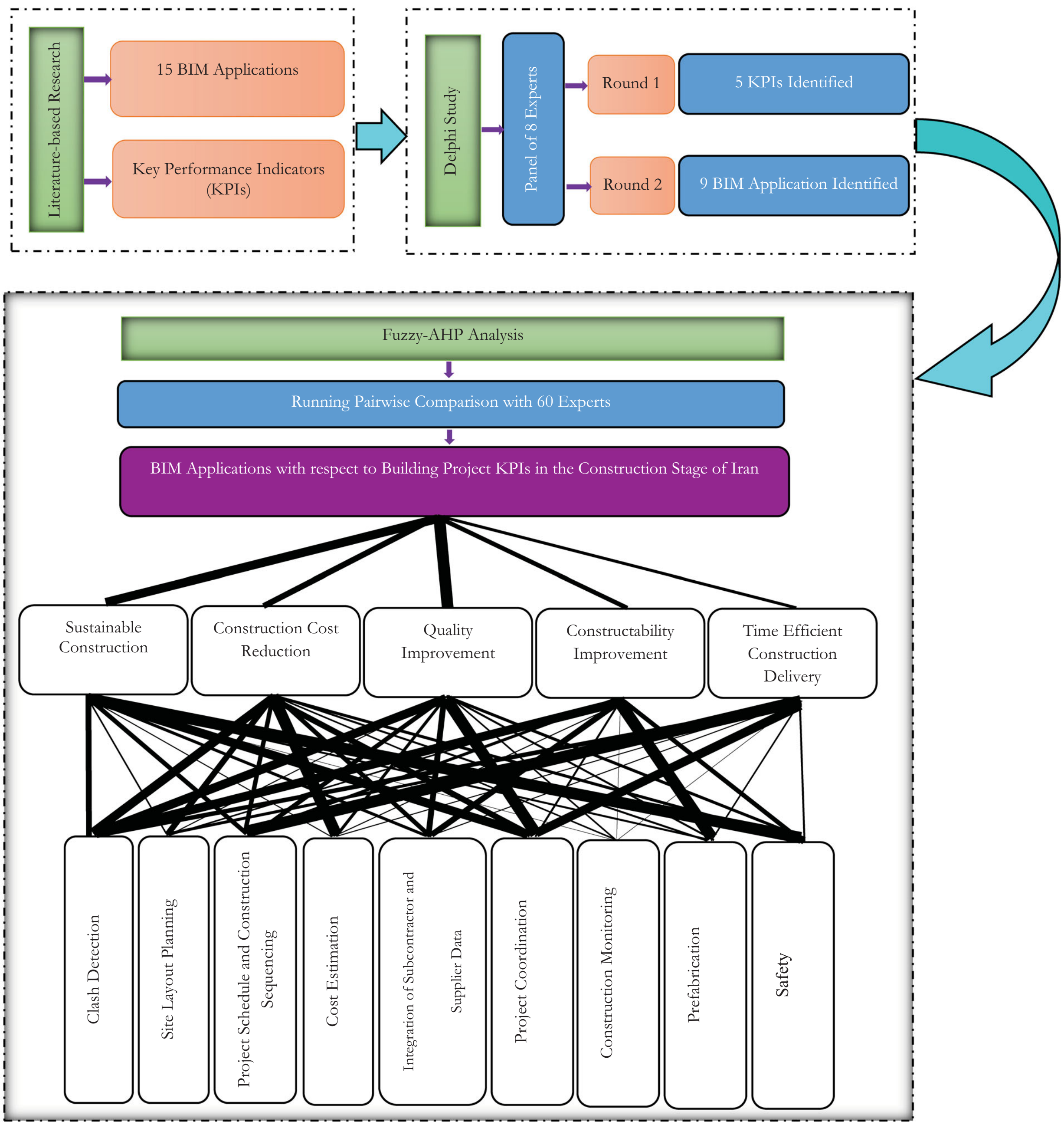

Figure 5. The overall pattern of this research.

prefabrication components which in turn, leads to the effective space and measurement reviews of constructability (Banihashemi et al., 2017b). Additionally, integration of architectural, structural and MEP (mechanical, electrical, plumbing) models in a 3D environment facilitates the identification of any constructability clashes before their occurrence.

Last but not least, project schedule and construction sequencing, project coordination and integration of subcontractor and supplier data constitute the first, second and third ranks of the factors for time efficient construction delivery KPI, respectively. It is obvious that 4D BIM simulation technique; the integration of project scheduling and planning with 3D model, reduces the construction project delivery time by virtue of automatic delay identification and collaborative atmosphere among the contractor and sub-contractors (Oraee et al., 2017). It visualises the work breakdown structure of construction process over the planning and scheduling of all components of 3D model and streamlines superior decision makings on the proper sequence and time management of building projects (Zhang and Hu, 2011). Then, proper coordination and timely delivery of construction components via the

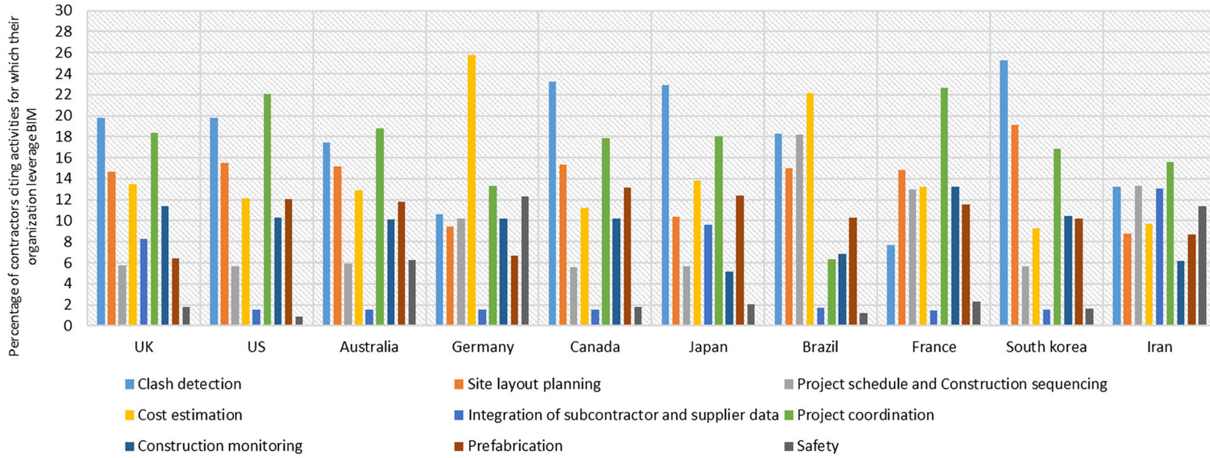

Figure 6. BIM applications priority in comparison between Iran and global context.

integration of subcontractor and supplier data contribute more to the time efficient construction delivery.

To indicate the status of Iranian BIM scenario *vis-à-vis* BIM priority in the global context, the identified nine applications of BIM, with respect to the discussed KPIs, were depicted together with the outcomes of McGrawHill smart market report on the business values of BIM for construction projects (McGrawHill, 2014), in Figure 5. As it can be seen, for each application, the survey responses from contractor of nine exemplified countries have been compared with Iran's data, resulting from this research. For clash detection, the experts from South Korea rated this capability with 25% of application in their projects and Iran, Germany and France are the last three countries of clash detection application.

Germany and Brazil are the first countries to prioritise cost estimation while Iran stands in the middle range for this virtue. As depicted, for the categories such as site layout planning, project schedule and construction sequencing, construction monitoring and prefabrication, there are not that variations and the trends are generally similar. Iran has given the first rank to the integration of contractor and sub-contractor data among these nine countries. This fact shows the significance of this want for Iranian contractors and it may be in view of the lack of any integrated database of construction companies in Iran. Another significant observation is in the light of safety application via BIM. For this category, Germany, Iran and Australia are the first, second and third rank of recommending BIM for safety in construction. As mentioned earlier, construction industry in Iran has big share of work-related accidents. Therefore, Iranian contractors put more highlight on this approach as they see BIM as a new technological opportunity which may alleviate this problem.

Conclusion

This research provides a basis to fill a gap in the body of knowledge namely lack of studies on the BIM based applications toward driving the KPIs in the construction stage of project life cycle in Iran. As the first study in its kind, it was grounded on the literature of significant KPIs and BIM aspects in the construction industry, conducted through an initial Delphi study to align those arenas with the conditions of Iran and followed by the advanced method of Fuzzy-AHP in associating, prioritising and weighting them.

The findings of the study showed interesting results that reflect the perception of building design and construction practitioners in Iran with regard to the BIM benefits for the indicators of construction project performances. That is, they attributed the main roles to the quality improvement and sustainable construction indicators and assigned relatively lower roles to the construction cost reduction and time efficient construction delivery. This is in contradiction with the general notion of project-based industries (e.g. construction) in Iran that is; due to the low profitability and high firm failure rates, construction companies adopt new methods and change their traditional approaches such as CAD as long as they benefit from money-back and proven return of investment leading to a default preference on the monetary values rather than quality and sustainability principles.

Screening the final weights of the sub-criteria multiplied by their respected criteria's weights, it was also deduced that project coordination and clash detection are the main determinants of BIM application toward enhancing the quality and 4D BIM (project schedule and construction sequencing) and 5D BIM (construction cost estimation) are the subsequent beneficial effects on the construction project KPIs in Iran. In essence, the trigger of change and implementation occurs within the Iranian construction industry as a precursor for employment of these variables.

However, the findings should be considered with caution due to a number of limitations in conducting the present study. That is, the results may not be directly applicable to the other phases of project life cycle as the scope was solely focused on the construction stage. Moreover, the sample selected was relatively small and thus might not reflect the perception of the large community of Iran's construction industry. This calls for further investigation by validating the model and using larger samples covering different sizes and various types of companies.

This is a point of departure for BIM-based research and its managerial perspectives that outline an insight toward the application of BIM in the construction projects of Iran. Although some applications of BIM might seem idealistic for the current conditions of this country, it is holistically important from a practical and analytical standpoint, because the proposed Fuzzy-AHP model can enhance the experts' ability in identifying the most influential aspects of BIM in the construction KPIs.

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