Organization, Technology and Management in Construction 2023; 15: 136–156

Research Paper

Open Access

Sajjad Ali Mahmood Alkaabi*, Ahmed Mohammed Raoof Mahjoob

Using the ordinal priority approach for selecting the contractor in construction projects

DOI 10.2478/otmcj-2023-0010
Received: November 12, 2022; Accepted: June 4, 2023

Abstract: Effective decision-making process is the basis for successfully solving any engineering problem. Many decisions taken in the construction projects differ in their nature due to the complex nature of the construction projects. One of the most crucial decisions that might result in numerous issues over the course of a construction project is the selection of the contractor. This study aims to use the ordinal priority approach (OPA) for the contractor selection process in the construction industry. The proposed model involves two computer programs; the first of these will be used to evaluate the decision-makers/experts in the construction projects, while the second will be used to formulate the OPA mathematical model. The experts' interview was used to identify the criteria of evaluation process of the decision-makers/experts, while Delphi survey with principal component analysis (PCA) was conducted to identify the required selection criteria of the construction projects contractors. The results illustrate that there are 20 criteria for selecting the construction contractor, and 7 criteria for evaluating the decision-makers/experts in the construction projects. Finally, the proposed model has been applied in a real construction project, and showed good results.

Keywords: contractor selection, decision-making, Delphi survey, experts' evaluation, multi-criteria, ordinal priority approach

1 Introduction

A project owner makes a variety of decisions that have substantial effects in the construction project. Among the most important decisions made by the owner is the selection of the contractor for implementing the construction project, in a way that would meet the client's expectations the closest (Plebankiewicz 2014). Contractor selection is one of the main decisions required on the part of the owner of a construction project (Cheng and Li 2004). Choosing the right contractor increases the chances of reaching the goals of the project, including, first of all, preserving the cost, time and quality as planned (Plebankiewicz 2014). Since the bid price is unquestionably a key factor in choosing a contractor, Brauers et al. (2008) claim that the majority of building contracts are awarded to the lowest bidders. The selection of a contractor is an important issue in the construction field that determines the success or failure of a project, and it is usually influenced by the quality of the contractor. The methods used in selection of contractors were examined, and the results found that some of the procedures are biased and non-exhaustive, and that there are few possibilities to assess a contractor's abilities while meeting time, price, quality and security requirements (Fong and Choi 2000). So, the model for selecting contractors must be able to meet the owner's expectations as part of the hiring procedure for construction firms (Zagorskas and Turskis 2006).

Multi-criteria decision-making (MCDM) approaches were used to establish a trade-off between criteria enabling an assessment of what the best decision would be (Jahan and Edwards 2013; Cheng and Li 2004). There are many causes that lead to uncertainty in MCDM processes, and some of these uncertainties are related to human error; data collection instrument and methodology; the collected data; data analysis tool and methodology; and the interpretation of results (Javed et al. 2020). Ataei et al. (2020) have stated that many issues exist in some MCDMs, and that these could result in inaccuracies in the process of decision-making and, as a result, a loss of confidence in the decision-making outcomes. The present study will propose a model for enhancing the decision-making process in construction projects by using a modern method of MCDM called

***Corresponding author: Sajjad Ali Mahmood Alkaabi,** Department of Research and development, Building directorate, Ministry of Housing, Construction, and Public Works, Baghdad, Iraq,
E-mail: s.mahmood1901p@coeng.uobaghdad.edu.iq
Ahmed Mohammed Raoof Mahjoob, Department of Civil Engineering, University of Baghdad, Baghdad, Iraq

ordinal priority approach (OPA) to overcome the problems characterising the traditional MCDM methods. Figure 1 describes the common problems that are associated with the traditional MCDM methods. Also, this study will conduct an experts' interview to identify the key criteria and sub-criteria for evaluating the decision-makers/experts in a construction project. Additionally, for the identification of the selection criteria applicable to the construction project contractor, the same procedure that was presented in the study of Alkaabi and Mahjoob (2022, 2023), which used the Delphi survey with principal component analysis (PCA), will also be used in the proposed model. Finally, the proposed model will be applied in a real construction project for verification and to extract conclusions.

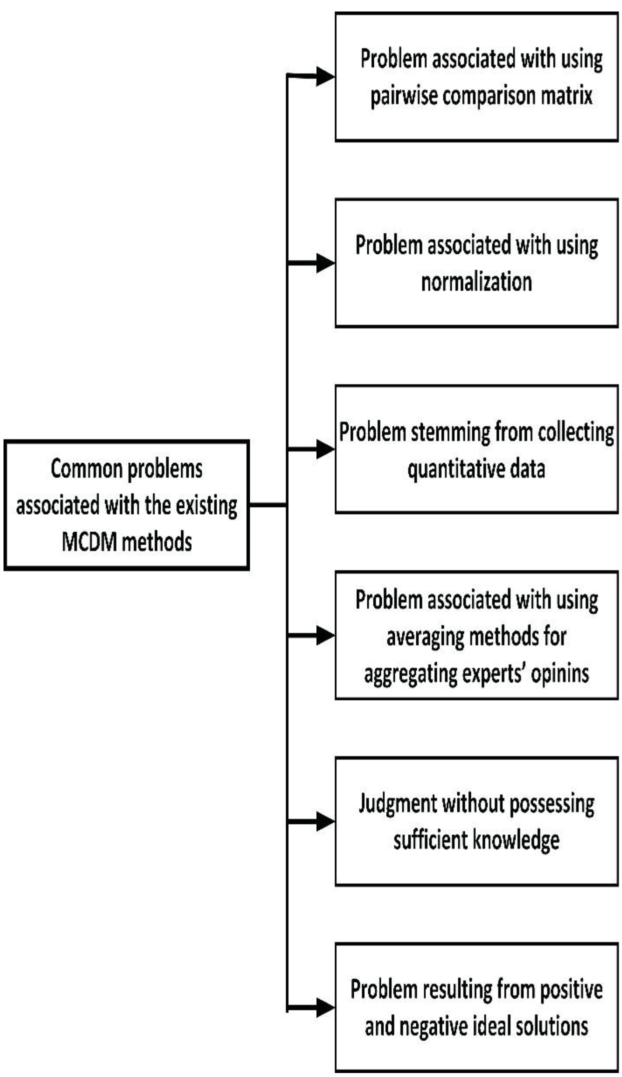

Fig. 1: Common problems associated with some of the MCDM methods. (Mahmoudi et al. 2020). MCDM, multi-criteria decision-making.

2 Literature review

2.1 Contractor selection

The contractor can be defined as a person or firm who handles the construction project, and ensures the execution of tasks planned for implementation at the construction site by directly communicating with other staff in the site, and involving them in the needed day-to-day activities whose performance is needed for the project's ultimate fulfilment. The conventional roles of a contractor are known – such as responsibility for preparing and handling the subcontractor's work with other personnel in a construction project (CITB 2015). Before a construction project commences, the contractor and the client are bounded through contracts that have been signed by both parties; and thus, to fulfil the client's requirements, the contractor needs to use his experience and knowledge pertaining to construction activity and organise all the necessary resources (Yongtao 2008). There are many crucial factors that must be considered during the contractor's evaluation and selection process, and these exercise a significant influence on project implementation. Fong and Choi (2000) identified eight 'uncorrelated' criteria for contractor selection, namely the following: tender price; financial capability; past performance; past experience; resources; current workload; past relationship; and safety performance. These are intended for application in contractor selection. According to numerous studies comprised in the literature (Cheng and Li 2004; Lam et al. 2005; Elazouni 2006; Brauers et al. 2008; Mitkus and Trinkūnienė 2008; El-Sayeg 2009; Mohamed and Majeed 2016), there are several criteria commonly used for contractor evaluation in the construction industry, namely the following: financial standing, technical ability, management capability, health and safety, and reputation.

Many researches (e.g. Zavadskas and Kaklauskas 1996; Ginevičius and Vaitkūnaitė 2006; Zavadskas and Vilutiene 2006) have pointed out that in construction it is essential to be able to consider the impacts of cultural, social, moral, legislative, demographic, economic, environmental, governmental and technological change, as well as impacts of changes in the business world on international, national, regional and local real estate markets, when selecting a contractor. The evaluation of contractors based on multi-attributes is becoming more popular and is, in essence, largely dependent on the uncertainty inherent in the nature of construction projects and subjective judgement of decision-makers. As we have identified through our literature review, there are many methods and techniques that have been used in contractor selection processes, as illustrated and summarised in Table 1; some of these methods are based on a pairwise comparison, decision matrix, averaging and normalisation procedures, and ideal solutions.

2.2 OPA method

The OPA is a new method of objective decision-making that can be used to handle situations involving numerous attributes. It is a cutting-edge method for solving MCDM issues using a linear mathematical model. OPA uses an easy method to determine the weights of alternatives, experts and attributes all at once. Ataei et al. (2020) suggested OPA as a solution for the tackling of MCDM issues that may be constructed using ordinal relationships while also addressing the shortcomings of some MCDM approaches. Ataei et al. (2020) demonstrated the effectiveness of OPA over similar decision-making approaches by using various arguments, as presented below:

Tab. 1: Some of the contractor selection methods from the literature review.

No.	Contractor selection methods	Authors
1.	MOORA method	Brauers et al. (2008)
2.	A fuzzy neural network approach	Lam et al. (2010)
3.	The ANP	Cheng and Li (2004)
4.	The AHP	Razi et al. (2019)
5.	AHP and TOPSIS model	Othoman et al. (2013)
6.	The PCA method	Lam et al. (2005)
7.	BWM and Fuzzy-VIKOR techniques	Naghizadeh Vardin et al. (2021)
8.	An evidential reasoning approach	Sönmez et al. (2001)
9.	SAW-G and TOPSIS GREY techniques	Zavadskas et al. (2010)
10.	The PIPS	Kashiwagi and Byfield (2002)
11.	COPRAS-G	Zavadskas et al. (2009)
12.	The Fuzzy Sets theory	Plebankiewicz (2014)

AHP, analytical hierarchy process; ANP, analytic network process; BWM, Best-Worst Method; COPRAS-G, complex proportional assessment of alternatives with grey relations; MOORA, Multi-objective optimization based on ratio analysis; PCA, principal component analysis; PIPS, performance information procurement system; SAW-G, Simple Additive Weighting with grey relations; TOPSIS, Technique for Order of Preference by Similarity to Ideal Solution; VIKOR, Vise Kriterijumska Optimizacija I Kompromisno Resenje.

(a) Instead of a pairwise comparison or a decision matrix, the OPA method requires the order of attributes and alternatives.
(b) The OPA method uses a mathematical model to solve MCDM problems.
(c) The weights of experts, attributes and alternatives are all outputs of the OPA method at the same time.
(d) Since the OPA technique simply employs the order as input data, it does not require normalisation.
(e) The OPA technique does not require any averaging and instead uses a mathematical model to aggregate expert opinions.
(f) In the OPA technique, experts can choose not to comment on specific attribute alternatives.
(g) Normalisation procedures, as well as negative and positive ideal solutions, are not required for OPA. Furthermore, OPA can deal with decision-making issues using partial data. Experts are allowed to dismiss part of the alternatives relating to a specific attribute when lacking the necessary expertise or relevant experience in the judgement process. This feature improves the precision of the final results as well as decision-making efficiency.

OPA was used to resolve project selection issues in the context of project management with huge and partial data sets (Mahmoudi et al. 2020). Additionally, to address the uncertainty in practical situations, OPA was expanded in fuzzy and grey settings (Mahmoudi et al. 2021a, 2021b). There are several studies (e.g. Mahmoudi and Javed 2021; Quartey-Papafio et al. 2021; Sadeghi et al. 2021; Shajedul 2021) offering a confirmation of the soundness of OPA for solving MCDM problems objectively, flexibly and effectively, as well as in the absence of there needing to be concerns with regard to pairwise comparisons and normalisation and completeness of data.

The core idea of the OPA technique is to build a comprehensive model that accounts for all aspects of decision-making challenges, including experts, criteria and alternatives. The experts offer an unbiased opinion based on the importance of the criteria and alternatives. As a result, (I * j) rankings are produced for each of the (k) current choices. The sets, parameters and variables employed in the OPA method's mathematical model are listed in Table 2.

where *k* alternatives will be based on the stages below:
(a) Experts rank the attributes.
(b) The ranking carried out by the experts would be based on experience, educational level, background, organisational chart and other factors.

Tab. 2: Sets, indices and variables for the OPA method (Ataei et al. 2020).

Sets	
I	Set of experts $\forall i \in I$
J	Set of attributes $\forall j \in J$
K	Set of alternatives $\forall k \in K$
Indices	
I	Index of the experts (1,..., *p*)
J	Index of preference of the attributes (1,..., *n*)
K	Index of the alternatives (1,..., *m*)
Variables	
Z	Objective function
w_{ijk}^{r}	Weight (importance) of *k*th alternative based on *j*th attribute by *i*th expert at *r*th rank
A_{ijk}^{r}	The *k*th alternative based on attribute *j* by expert *i* at rank *r*

OPA, ordinal priority approach.

(c) Each expert ranks the alternatives based on each criterion.

As a result, the following are the main steps of the OPA method (Ataei et al. 2020):
1. Specification of the criteria
2. Identifying and ranking experts
3. Ranking of the criteria, carried out by each expert
4. Specifying the priorities of alternatives in each criterion
5. Using the OPA model to determine experts, criteria and the alternative's weights

Ataei et al. (2020) stated that the linear model (Eq. [1]) should be created based on the data acquired in the previous steps.

$$\text{Objective function} = \text{Max } Z \tag{1}$$

S.t.,

$$z \le i\left(j\left(r\left(w_{ijk}^{\ \ r} - w_{ijk}^{\ \ r+1}\right)\right)\right) \quad \forall i, j, k \, and \, r$$

$$z \le ijmw_{ijk}^{\ \ m} \quad \forall i, j \, and \, k$$

$$\sum_{i=1}^{p} \sum_{j=1}^{n} \sum_{k=1}^{m} w_{ijk} = 1$$

$$w_{ijk} \ge 0 \quad \forall i, j \, and \, k$$

where Z is unrestricted in sign.

Eqs, (2)–(4) can be used to solve the model and determine the expert(s), criterion and alternative weights. Eq. (2) will be applied to obtain the weights of the alternatives.

$$W_K = \sum_{i=1}^{p} \sum_{j=1}^{n} W_{ijk} \quad \forall k \tag{2}$$

In order to determine the weights of criteria, Eq. (3) will be employed.

$$W_j = \sum_{i=1}^{P} \sum_{k=1}^{m} W_{ijk} \quad \forall j \tag{3}$$

In order to calculate the weights of experts, Eq. (4) will be utilised.

$$W_i = \sum_{j=1}^{n} \sum_{k=1}^{m} W_{ijk} \quad \forall i \tag{4}$$

2.3 Delphi survey

As a research method, the Delphi survey tries to generate a 'consensus opinion of a panel of specialists through a recurrent exercise in which participants have the option to adjust their opinions without being forced through the appropriate management of controlled feedback from the coordinator' (Hasson and Keeney 2011). Even when the participants know each other, without fear of collusion or coercion, the Delphi method is an excellent research instrument for tackling difficult problems in the engineering sector (Ogbeifun et al. 2016). Practically, the Delphi approach is the only study method that allows participants to react with one other's viewpoints without being forced to do so, alter their positions as needed and maintain anonymity. Three or four rounds are commonly involved in a Delphi study (Welding 2013). The approach has various advantages, including the following (Ralitsa et al. 2005):

(a) It offers the ability to carry out research in a geographically distant setting without physically bringing the participants together.
(b) Time and cost-effectiveness are both important considerations.
(c) Issues of a broad and complicated nature are discussed.
(d) Participants will have enough time to synthesise their thoughts.
(e) Participants can answer whenever they choose.
(f) There is a record of the group's activities that may be seen in further detail.
(g) The anonymity of the participants allows them to openly share their thoughts and positions.
(h) The method has been demonstrated to work in a variety of fields.

There is no consensus on panel size for Delphi investigations, nor is there a clear definition of 'small' or 'big' samples. There could be as few as 3 people on a Delphi panel or as many as 80. It is rare to find a Delphi research with less than 10 participants (Malone et al. 2005). It is important to select people who are knowledgeable in the field of study and are willing to commit themselves to multiple rounds of questions or interactions on the same topic (Grisham 2009). Wainwright et al. (2010) and Crane et al. (2017) stated that in Delphi exercises, a minimum of 12 respondents is generally considered to be sufficient to enable consensus to be achieved; larger sample sizes can provide diminishing returns regarding the validity of the findings.

2.4 PCA

PCA is the most widely used multivariate analysis technique, with applications in practically every scientific field. One of the main uses of PCA, which has been widely used by academics in a range of domains, is dimensionality reduction (Preetha and Vinila 2020). As its name implies, instead of studying every aspect of a problem, the PCA can help with some of the most crucial aspects and identify key components. In fact, the PCA extracts the attributes with a factor pattern coefficient greater than 0.3 that are the most valuable (Ringnér 2008; Lever et al. 2017).

3 Research method

The goals of the present study are:
1. To propose a suitable evaluation system for experts/decision-makers in construction projects, in order to ensure the selection of suitable experts and their ranking in the decision-making process;
2. To identify the key selection criteria needing to be used for selection of the contractor in construction projects by using the same approach that was adopted by Alkaabi and Mahjoob (2022, 2023) (the Delphi technique with PCA);
3. To enhance the decision-making process for contractor selection by using the OPA method.

The literature review, Delphi survey, PCA and experts' interviews were used to collect the required data. XLSTAT software: https://www.xlstat.com/en/ was used in the statistical analysis process to which the collected data were subject; and Visual Basic software, MATLAB software and LINGO software: https://www.lindo.com/ were used for the building and solving of the OPA mathematical model. A proposed model for enhancing the decision-making process in construction projects was created in the present study and applied in one Iraqi construction project to select the best bidder/contractor for implementing the project.

4 Results and discussions

4.1 Identification of the main criteria/attributes for selecting the contractor in the construction project

A review of the literature and field visits to the related government directorates in Iraq (e.g. The Housing Directorate, Buildings Directorate, National Center for Engineering Consultancy and Al-Mansour General Engineering Company) were conducted to collect the related data about the criteria that will be used in the decision-making process for selecting the contractor of the construction project. The Delphi survey with 12 experts was performed to identify the selection criteria/attributes. All the selected experts are working in the planning and management of construction projects and possess an experience of more than 15 years; additionally, they also have a willingness to participate in this process. Figures 2–4 show the working sector, the academic degrees and the specialisation for the

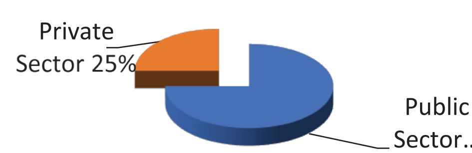

Fig. 2: Experts' work sector.

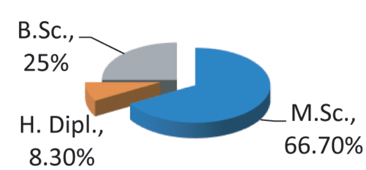

Fig. 3: Experts' academics degree.

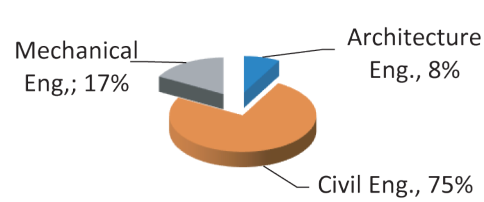

Fig. 4: Field of specialisation for experts.

Tab. 3: The occupational information pertaining to experts' sample in the Delphi survey.

Experts' names	Institution name	Work sector	Current position
(1) A. J.	Buildings Directorate	Public sector	Planning Engineer
(2) S. J.	Al-Mansour General Engineering Company	Public sector	Division Manager
(3) H. M. J.	Al-Arabia Company for Engineering Technologies and Contracting	Private sector	Project Manager
(4) A. M. J.	The General Company for Iraqi Railways	Public sector	Project Manager
(5) A. A. A.	National Center for Engineering Consultancy	Public sector	Depart. Manager
(6) M. W.	Buildings Directorate	Public sector	Planning Engineer
(7) K. W.	Debajeh Engineering Consulting Office	Private sector	Project Manager
(8) H. S.	Buildings Directorate	Public sector	Division Manager
(9) A. M.	Al-Khwarizmi Engineering Consulting Office	Private sector	Project Manager
(10) H. H.	X-Line Engineering Office	Private sector	Project Manager
(11) A. S.	Office Of Externally Funded Projects	Public sector	Division Manager
(12) S. Y.	Buildings Directorate	Public sector	Division Manager

selected sample; and Table 3 lists occupational information pertaining to the experts' sample in the Delphi survey.

The form's questions of the first round of the Delphi were formulated. Similar to the approach adopted in the studies of Al-Agele and Al-Kaabi (2016) and Mohammed and Jasim (2018), and as indicated in Table 4, the Likert 5-scale with weighted value (WV) was utilised.

Tab. 4: WV of descriptive frequencies (Jeleva et al. 2017; Mohammed and Jasim 2018).

Descriptive frequency	CI	WV
Very low	1 ≤ CI ≤ 1.8	1
Low	1.8 < CI ≤ 2.6	2
Medium	2.6 < CI ≤ 3.4	3
High	3.4 < CI ≤ 4.2	4
Very high	4.2 < CI ≤ 5	5

CI, class interval; WV, weighted value.

The 12 experts were asked to rank the importance of the 40 selection criteria included in the questionnaire form; the participants had the option to add more criteria if they felt the need to do so. Face-to-face interviews were conducted with each participant in the first round to ensure that the format of the round's questions was clear. After Delphi's first round, the responses and recommendations of the selected experts were thoroughly examined and statistically analysed using XLSTAT software, using which were computed the mean (M), the standard deviation (SD) and the Cronbach's alpha (α). The mathematical formula for determining the Cronbach's alpha (α) is shown in Eq. (5) (Al-farra 2009):

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum si^2}{st^2}\right) \tag{5}$$

where K represents the number of elements in the group, si the element variance and st the variance of the total score of the elements.

The results of the analyses showed that the mean of Cronbach's alpha (α) for all questions was more than (0.7). In the second round of the Delphi survey, the criterion with an average value less than (3.4) will be excluded. In addition, a number of criteria were incorporated or cancelled based on the opinions of the participants. Therefore, the list of criteria/attributes used in the decision to select the best bidder or contractor in the implementation of a construction project include 23 criteria at the end of the first round. These selection criteria/attributes that resulted from the first round will be used in the second round of the Delphi survey. In the second Delphi round, experts were asked to rank a list of 23 selection criteria that resulted from the first round of Delphi. Statistical analysis of expert responses in the second Delphi round showed an average Cronbach's alpha (α) value equal to (0.97), and there were 20 criteria having an average value above (3.4); accordingly, only three criteria will be excluded.

In the third round of the Delphi procedure, the selection criteria from the second round will be applied. The same appointed experts were asked to re-evaluate the relative weight of the selection criteria that had passed from the second Delphi round. The results of the statistical analysis of the third round showed that all criteria/attributes of the selection process for the best bidder/contractor for the implementation of the construction project obtained an average value of more than (3.4) (high–very high, an important degree in the decision-making process), with a Cronbach's alpha (α) of (0.959), as illustrated in Figure 5. Therefore, the results of the third round, as presented in Table 5, demonstrate lack of need for a fourth round, because the responses of the experts were consistent.

4.2 Applying the PCA

It is necessary to complete the Kaiser–Meyer–Olkin (KMO) test before performing the PCA. KMO is capable of determining whether the data are appropriate for performing the PCA. It is not acceptable to conduct the PCA if the KMO is smaller than (0.5) (Mahmoudi et al. 2020). Kaiser (1974) developed the equation of the KMO calculation, as shown in Eq. (6):

$$KMO = \frac{\sum_i \sum_{j \neq i} r_{ij}^2}{\sum_i \sum_{j \neq i} r_{ij}^2 + \sum_i \sum_{j \neq i} u_{ij}^2} \quad (6) \text{ (Kaiser 1974)}$$

where R = $r$ij is the correlation matrix and U = [$u$ij] is the partial covariance matrix.

The KMO value was calculated using XLSTAT software. The results showed that the specific criteria/attributes that were used to select the best bidder/contractor for the implementation of the construction project had a KMO value of (0.672). Also, the PCA value showed that 20 criteria/attributes are the most valuable, and there is no way to reduce them because they all have factor pattern parameter values of more than (0.3). Table 5 shows the final results of the selection criteria/attributes of the best provider/contractor for the implementation of the construction project.

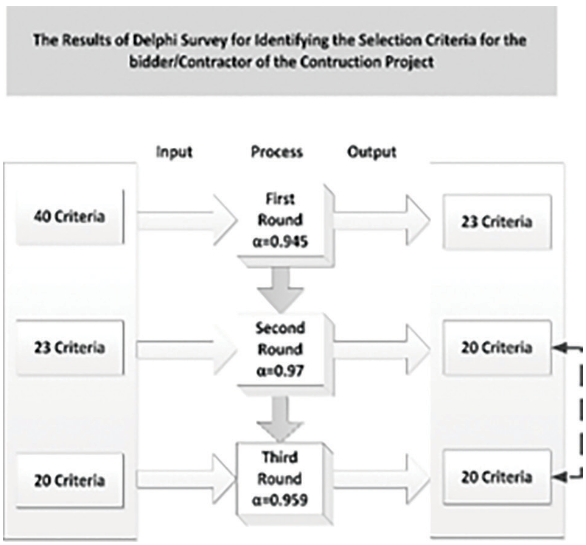

Fig. 5: A summary of the Delphi survey for identifying the selection criteria.

Tab. 5: The final main criteria/attributes of selection of the best bidder/contractor for the implementation of the construction project that resulted from the Delphi survey and PCA third round.

		Third round analysis results		PCA results	
No.	**Criteria**	**Mean**	**SD**	**KMO**	**Factor pattern coefficient**
1.	The technical expertise of the contractor's current team	4.5833	0.66856	0.759	0.810
2.	Previous experience in the project field (similar projects)	4.5000	0.90453	0.725	0.776
3.	Contractor bid price	4.5000	0.67420	0.775	0.727
4.	Collaboration with other designers and contractors	4.4167	0.51493	0.661	0.815
5.	Contractor's cash flow	4.4167	0.90034	0.585	0.691
6.	General experience of the contractor	4.3333	0.65134	0.792	0.774
7.	History of legal disputes	4.3333	0.77850	0.675	0.856
8.	Technical bid quality and organising	4.3333	0.88763	0.598	0.526
9.	Number of failed projects in the contractor's record	4.2500	0.86603	0.579	0.679
10.	Technical approach and work progress program	4.2500	0.96531	0.771	0.847
11.	Number and status of the contractor's current projects (under construction)	4.1667	0.38925	0.661	0.757
12.	Financial stability of the contractor	4.1667	0.71774	0.674	0.770
13.	Complete projects within the specified time	4.0833	0.79296	0.672	0.784
14.	Financial obligations and debts	4.0833	0.90034	0.729	0.867
15.	Willingness to offer advice and suggest construction methods	4.0000	0.60302	0.546	0.322
16.	Quality systems and cost control	4.0000	0.73855	0.695	0.803
17.	Availability of construction equipment and tools	3.9167	0.51493	0.708	0.560
18.	The occupational safety program	3.9167	0.79296	0.668	0.765
19.	Relationship with the employer or his representative	3.7500	0.62158	0.548	0.455
20.	Record of accidents during previous years	3.7500	0.62158	0.607	0.371
Total				0.672	

KMO, Kaiser–Meyer–Olkin; PCA, principal component analysis; SD, standard deviation.

4.3 The proposed experts' evaluation system

The decision-maker/expert plays a valuable role in the success of construction projects. The process of selecting a decision-maker needs to be helmed by a person or a team themselves having the requisite qualifications, because, otherwise, the result would be the choice of an unsuitable person to play the role of the decision-maker. So, in identifying this problem and establishing a means for its prevention or rectification, we are able to suitably address one of the main reasons underlying the failure of construction projects. It is proposed that the experts' evaluation system can be implemented to overcome this problem, and the following steps were performed in that regard:

(a) Identifying the main criteria and sub-criteria of selection of the decision-makers/experts in the construction projects by conducting face-to-face interviews with a group of experts;
(b) Developing the flowchart for the proposed evaluation system based on the rank and weight of the main criteria and the weight value of the sub-criteria;
(c) Building the proposed evaluation system program by using Visual Basic software.

Information about the criteria to be employed for selection of experts/decision-makers in construction projects was gathered by reviewing the related literature and visiting the related government directorates, as well as private and public construction companies. Then, to identify the main criteria and sub-criteria that would need to be applied for the selection and evaluation of the experts/decision-makers, face-to-face interviews were conducted with a group of experts possessing more than 15 years of experience in construction projects' management. After analysing the experts' opinions, a list of the main criteria and sub-criteria has been formulated. The arithmetic mean was used to rank and calculate the weight value of each main criterion, while using the expert-suggested weights values for the sub-criteria as presented in Table 6. Depending on the results presented in Table 6, the flowchart of the proposed experts' evaluation system was developed as shown in Figure 6. Then, the proposed evaluation system program was created by using Visual basic software; and, to enable the obtaining of the engineer's acceptance for taking on the role of an expert/decision-maker in construction projects, the final output degree of the proposed experts' evaluation system must be not less than a score of 50.

Finally, the present study stated that the sub-criterion for each expert should be evaluated by the company's top management based on the recorded history of the expert under consideration.

4.4 Applying the OPA method for selecting the contractor of the construction project

The multi-criteria attribute is regarded as a defining characteristic of the decision-making involved in the selection of a bidder/contractor for implementing the construction project; accordingly, the present study uses the developed proposed model to enhance decision-making with regard to the process involved in the selection of a contractor in the construction project, as illustrated in Figure 7.

A rest house construction project in Dhi Qar Governorate was selected as a case study for the proposed model's application, so as to ascertain its efficacy in enhancing the decision-making process involved in construction projects. This project is one of the projects of the Iraqi Ministry of Construction and Housing, which is subject to the instructions for implementing Iraqi government contracts. The owner aims to select the best contractor to implement this project from among four bidders. Three experts were assigned to participate in the model application in collaboration with the owner's crew. In order to rank, and ascertain the degree of suitability of, the selected experts concerning participation in the decision-making process, the proposed expert evaluation system was applied. According to the qualifications of each expert, shown in Table 7, the results of the proposed expert evaluation system showed that the rank and degree of each expert's evaluation are as follows:

(a) Exp. 1 with a score of (75.12)
(b) Exp. 2 with a score of (64.98)
(c) Exp. 3 with a score of (61.39)

Based on the evaluation results, all the appointed experts have been found suitable concerning the assumption of a role in the decision-making process, and the rank of each of them will be used when applying the OPA model. The bidder/contractor selection criteria that resulted from the Delphi survey and PCA were adopted in this case study. The appointed experts were then asked to rank these selection criteria for the best bidder/contractor. The final ranking of the selection criteria was collected, as shown in Table 8, and will used in applying the OPA model. The qualifications of the four competing contractors were collected, the experts were asked to rank the four contractors according to their criteria. The results of the competing contractors' ranking are summarised

Tab. 6: The main criteria and sub-criteria of selection and evaluation of experts/decision-makers and their weights.

The main criteria	AM	SD	Weight %	Sub-criteria	Weight value
(1) Years of practical experience in the field of specialisation	4.476	0.75	16.2362	– $10 \leq EX < 15$	0.25
				– $15 \leq EX < 20$	0.5
				– $20 \leq EX < 25$	0.75
				– $25 \leq EX$	1
(2) Personal relationships	4.142	0.91	15.0247	– Has a good relationship with the senior management?	0.25
				– Has not had discounts or problems with the work team?	0.25
				– Has acceptability and the ability to deal with different cultures?	0.25
				– Has good relations with other parties outside the organisation?	0.25
(3) Good conduct and confidence	4	1	14.5096	– Has not had an administrative penalty for the past 5 years?	0.25
				– Has had at least five certificates of thanks and appreciation during the past 5 years?	0.25
				– Has a good professional history characterised by integrity and impartiality?	0.25
				– Has a recommendation certificate from a previous job?	0.25
(4) The ability to communicate and coordinate between parties	3.857	0.91	13.9909	– Has had no communication and coordination problems in his last three projects?	0.25
				– Has the ability to use communication and coordination programs?	0.25
				– Has a high level of negotiation and persuasion skills?	0.25
				– Participation in previous committees in resolving and settling disputes?	0.25
(5) Capability for research and development in the field of specialisation	3.761	1.09	13.6426	– Participation in workshops or training courses in the specified field?	0.25
				– Has good experience from previous similar work?	0.25
				– Has knowledge and ability to use engineering programs?	0.25
				– Has published research in the selected field?	0.25
(6) Employment years	3.761	1.22	13.6426	– $10 \leq E < 15$	0.25
				– $15 \leq E < 20$	0.5
				– $20 \leq E < 25$	0.75
				– $25 \leq E$	1
(7) Academic degree (BSc., MSc., Ph.D.)	3.571	1.08	12.9534	– BSc.	0.25
				– High diploma	0.5
				– MSc.	0.75
				– Ph.D.	1

AM, Arithmetic Mean; SD, standard deviation.

in Table 9. As for formulation of the OPA mathematical model, MATLAB software was used for the realisation of the present study's proposal of a computerised program for formulating the OPA mathematical model; Figure 8 shows the interface of this computerised program. So, the research applied the proposed computerised program to formulate the OPA mathematical model for selecting the best bidder/contractor. Once the OPA mathematical model for selecting the best bidder/contractor was formulated, the research used the LINGO software to solve the mathematical model of this problem. Based on the results from the LINGO software, the research calculated the weight of each alternative, the weight of each criterion and the weight of each expert by solving Eqs (2), (3) and (4), respectively. The results showed that the weights of Exp. 1, Exp. 2 and Exp. 3 are (0.589), (0.262) and (0.148), respectively, as shown in Table 10; and the weight of each criterion has been calculated as illustrated in Table 11. Finally, the weights of the contractors 'R', 'F', 'A' and 'B' are (0.234803), (0.312379), (0.249111) and

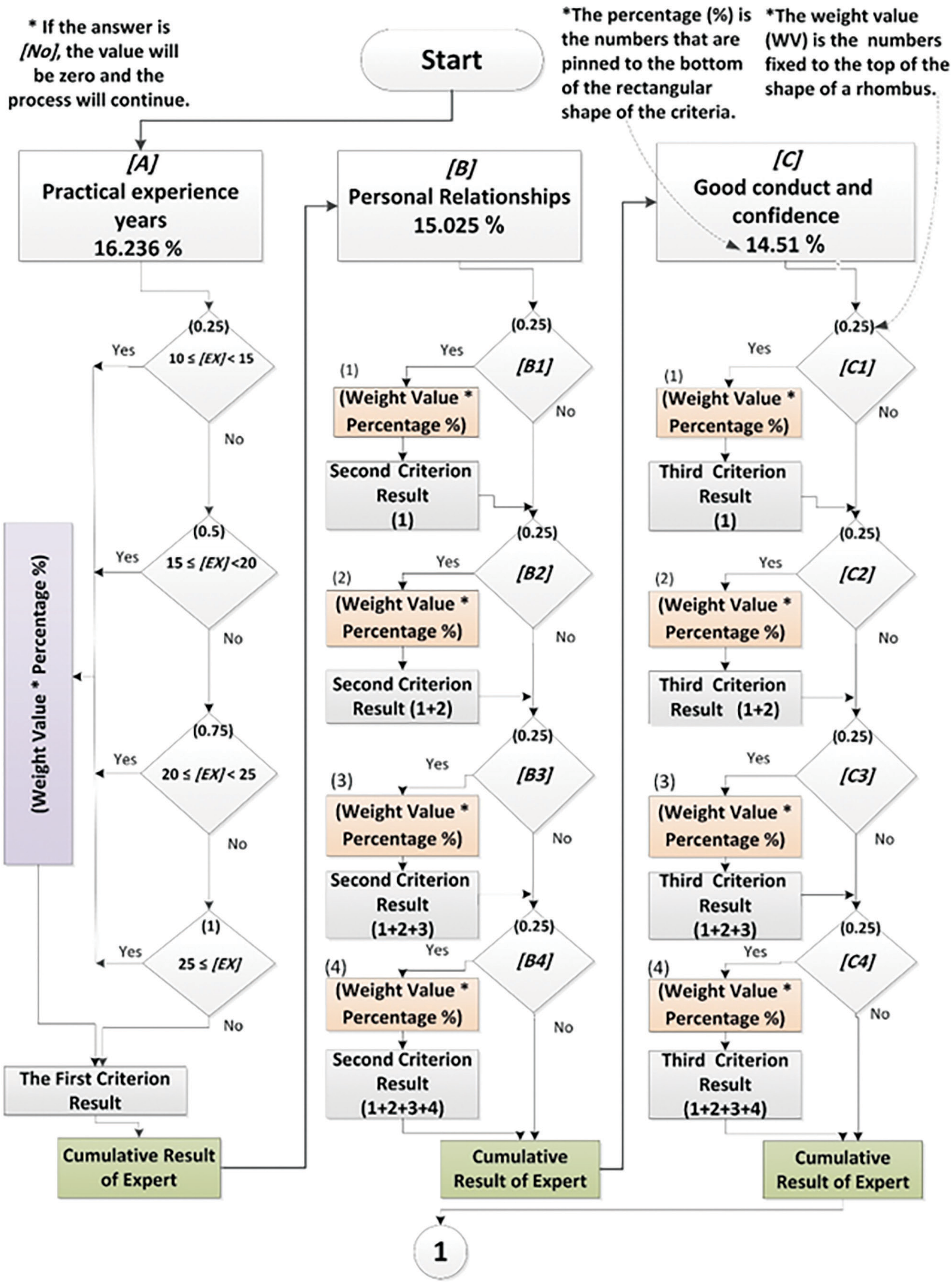

Fig. 6: Continued.

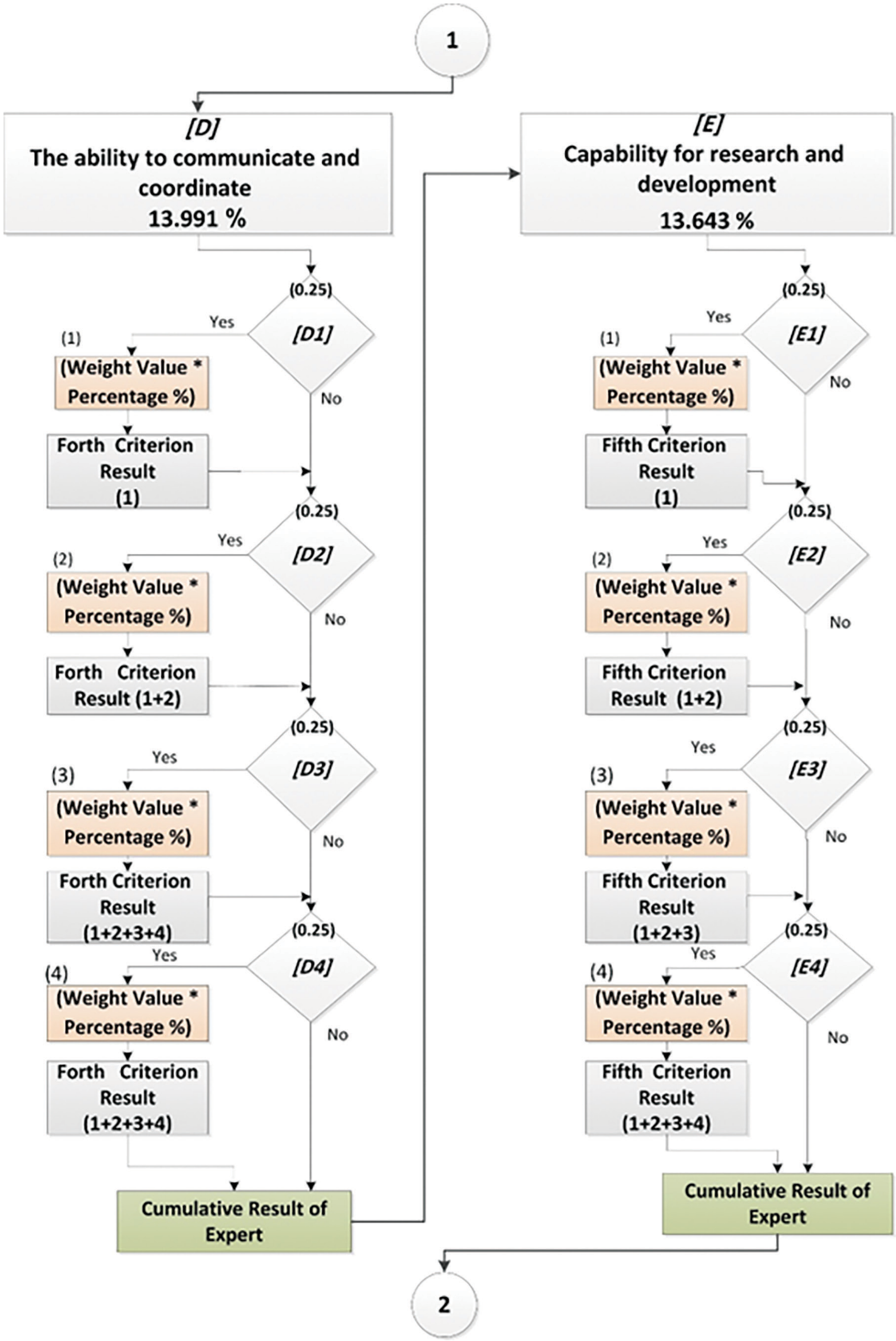

Fig. 6: Continued.

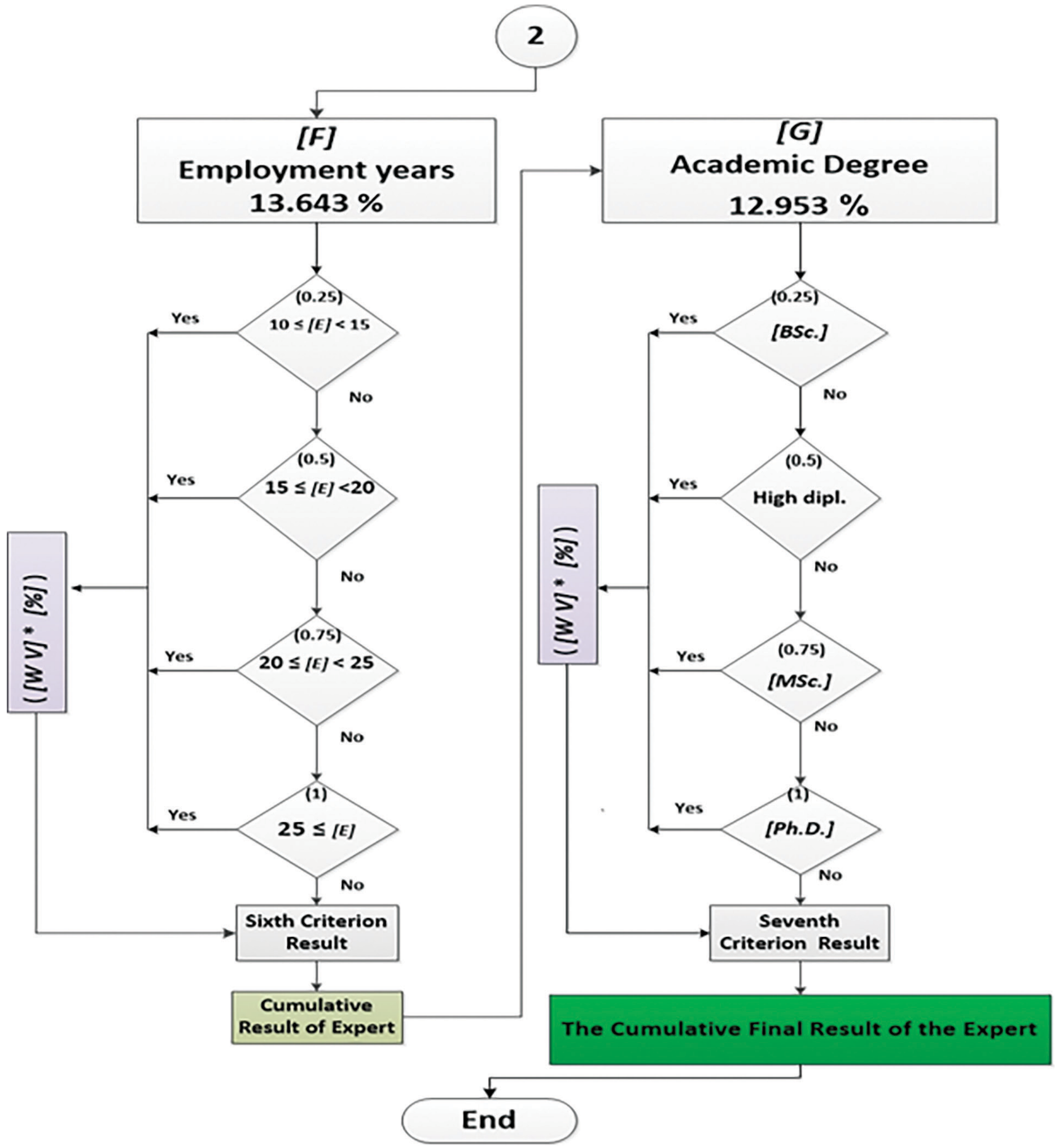

Fig. 6: The flowchart of the proposed experts' evaluation system.

(0.203858), respectively, as shown in Table 12. Further, all weights of alternatives are more than the *Z* value (0.0249) that resulted from solving the OPA mathematical model. According to the mentioned results, the best contractor for implementing the rest house building in Thi-Qar Governorate is the contractor 'F', followed by 'A', 'R' and 'B'.

For comparison, when the principle of the lowest bid was applied in the selection of the best contractor for the project of construction of the rest house building in Thi-Qar Governorate, together with the applicability of the bid amounts for each contractor as illustrated in Table 13, the results showed that the contractor 'B' was the best alternative, followed by 'A', 'F' and 'R'.

In the real world, the traditional method, involving the usage of the weighting form that is based on an averaging method (stated in the instructions for implementing Iraqi government contracts), was applied to select the best contractor for the project of construction of the rest house building in Thi-Qar Governorate, by a new group of the experts (not the same experts of the case study; and these experts were chosen without making an assessment of their attributes); the results showed that the contractor ‘F’ was the best alternative, followed by ‘R’, ‘A’ and ‘B’, and the scores of alternatives in this application are illustrated in Table 14. For this case study, the final rank of contractors from using the proposed framework for enhancing the decision-making process differs in the second rank from using the traditional method and differs in all ranks from using the principle of the lowest bid. The validity and usefulness of the proposed framework for enhancing the decision-making process are thus well indicated by these results.

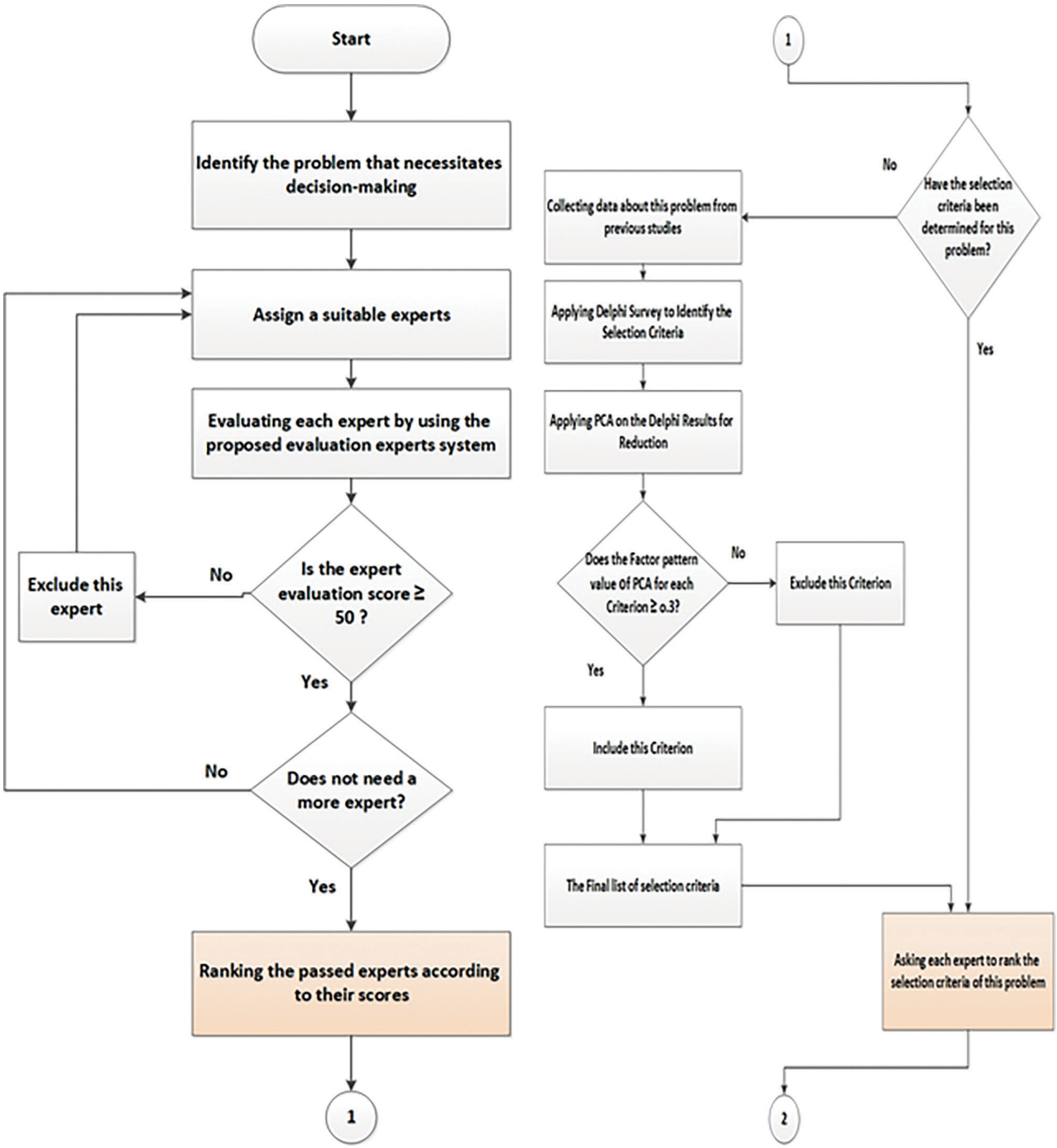

Fig. 7: Continued.

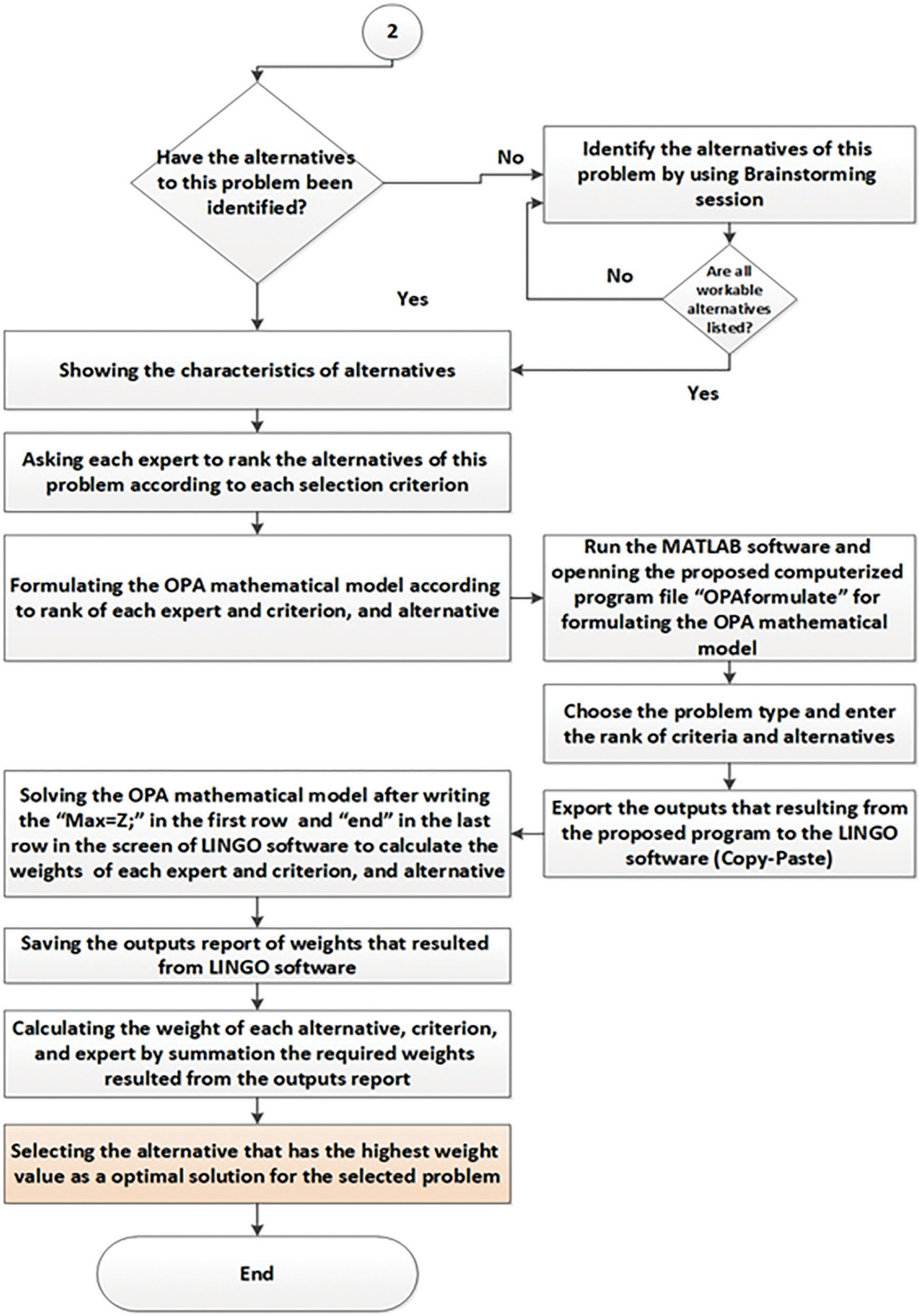

Fig. 7: The proposed framework flowchart for enhancing the decision-making in construction projects. OPA, ordinal priority approach; PCA, principal component analysis.

Tab. 7: The qualifications of the selected experts in the case study.

No.	The element of evaluation	Experts' qualification		
		Exp.1	Exp. 2	Exp. 3
1.	10 ≤ EX < 15			
	15 ≤ EX < 20			√
	20 ≤ EX < 25	√	√	
	25 ≤ EX			
	The Experience Years	23	21	17
2.	Has a good relationship with the senior management?	√	√	√
	Not have discounts or problems with the work team?		√	√
	Has acceptability and the ability to deal with different cultures?	√		√
	Has good relations with other parties outside the organization?	√		√
3.	Has not had an administrative penalty for the past five years?	√	√	√
	Has at least five certificates of thanks and appreciation for the past five years?	√	√	√
	has a good professional history characterized by integrity, impartiality?	√	√	√
	Has a recommendation certificate from a previous job?	√	√	
4.	Has no communication and coordination problems in his last three projects?	√	√	√
	Has the ability to use communication and coordination programs?	√	√	√
	Has a high level of negotiation and persuasion skills?			
	participation in previous committees in resolving and settling disputes?		√	√
5.	participation in workshops or training courses in the building evaluation?	√	√	√
	Has good experience from previous similar work?		√	√
	Has knowledge and ability to use engineering programs?	√		
	Has published research in the selected field?			
6.	10 ≤ E < 15			
	15 ≤ E <20			√
	20 ≤ E <25	√		
	25 ≤ E		√	
	The Employment Years	25	23	18
7.	BSc.		√	√
	High diploma			
	MSc.	√		
	Ph.D.			

Tab. 8: The experts' answers on the rank of selection criteria employed for ascertaining the best bidder or contractor.

No.	Selection criteria of the design consultant	The experts		
		Exp. 1	Exp. 2	Exp. 3
		Rank		
C1.	The technical expertise of the contractor's current team	3	1	3
C2.	Previous experience in the project field (similar projects)	2	2	2
C3.	Contractor bid price	1	3	1
C4.	Contractor's cash flow	4	3	4
C5.	Collaboration with other designers and contractors	11	4	10
C6.	General experience of the contractor	3	5	3
C7.	History of legal disputes	3	8	4
C8.	Technical bid quality and organising	11	4	11
C9.	Number of failed projects in the contractor's record	2	6	2
C10.	Technical approach and work progress program	5	5	7
C11.	Number and status of the contractor's current projects (under construction)	2	2	5
C12.	Financial stability of the contractor	1	3	3
C13.	Complete projects within the specified time	2	1	2

(*continued*)

Tab. 8: Continued.

No.	Selection criteria of the design consultant	The experts		
		Exp. 1	Exp. 2	Exp. 3
		Rank		
C14.	Financial obligations and debts	4	4	8
C15.	Quality systems and cost control	7	7	9
C16.	Willingness to offer advice and suggest construction methods	8	9	12
C17.	Availability of construction equipment and tools	6	6	6
C18.	The occupational safety program	9	5	10
C19.	Relationship with the employer or his representative	6	10	7
C20.	Record of accidents during previous years	10	9	13

Tab. 9: The experts' answers on the rank of the competing contractors in the case study.

Exp.	Alter.	The selection criteria																			
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
		RANK																			
Exp. 1	**R**	2	1	2	2	2	3	1	3	2	4	2	2	4	1	2	2	2	2	4	4
	F	2	1	2	2	1	2	1	2	2	3	2	1	3	1	1	1	2	1	4	3
	A	1	2	2	2	3	1	1	1	1	1	3	3	1	2	2	4	1	3	4	2
	B	3	3	2	1	4	1	1	1	4	2	1	3	2	3	2	3	2	4	4	1
Exp. 2	**R**	2	1	3	2	2	3	1	3	1	1	2	1	3	1	2	2	2	2	4	4
	F	1	2	3	2	1	4	1	2	1	2	2	2	3	1	1	1	2	1	4	3
	A	3	3	3	2	3	2	1	1	2	4	3	3	2	3	2	4	1	3	4	2
	B	4	4	3	1	3	1	1	1	2	3	1	4	3	2	3	3	2	4	4	1
Exp. 3	**R**	3	1	3	3	2	2	1	4	3	4	2	2	3	2	2	2	3	2	4	4
	F	2	1	3	2	1	1	1	1	1	3	2	1	3	2	1	1	3	1	4	3
	A	1	2	3	4	3	4	1	2	2	1	3	3	1	1	2	4	2	3	4	2
	B	4	3	3	1	4	3	1	3	4	2	1	4	2	3	3	3	3	4	4	1

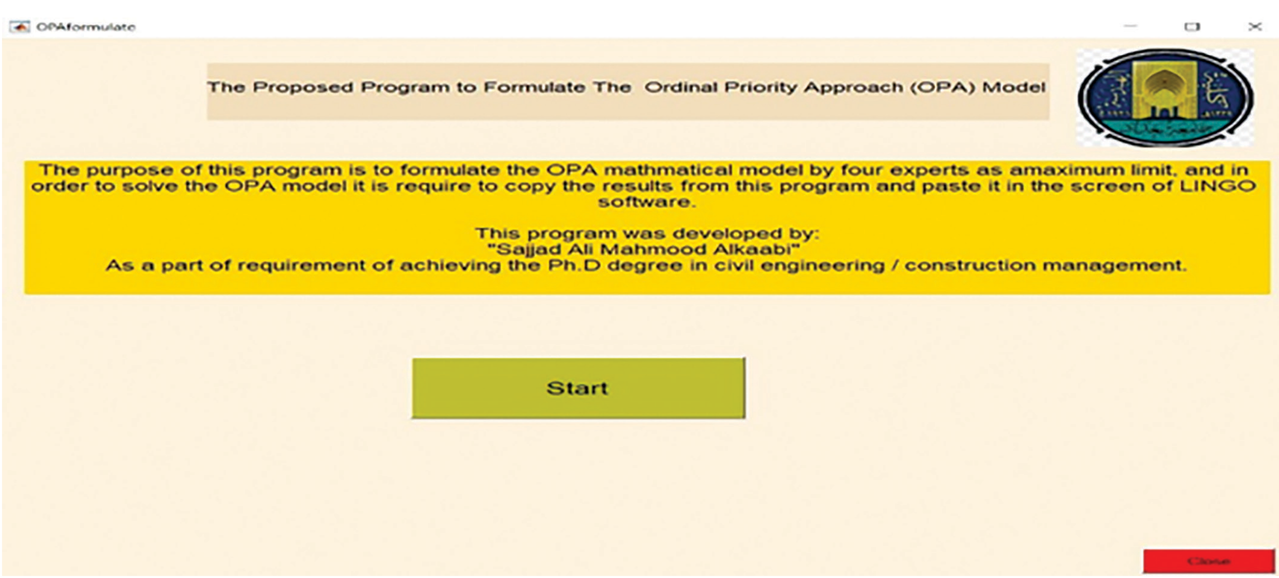

Fig. 8: The main interface of the program proposed in the present study for the formulation of the OPA model subject. OPA, ordinal priority approach.

Tab. 10: The final weights of each expert in the case study.

Expert name	Weight
Exp. 1	0.589135
Exp. 2	0.262262
Exp. 3	0.148754

Tab. 11: The final weights of the selection criteria in the case study.

Selection criteria	Weight
C1	0.092762
C2	0.10515
C3	0.0666
C4	0.039449
C5	0.022768
C6	0.061125
C7	0.0478
C8	0.029022
C9	0.0685
C10	0.034672
C11	0.077974
C12	0.110802
C13	0.08656
C14	0.044946
C15	0.021029
C16	0.020759
C17	0.021233
C18	0.024357
C19	0.006592
C20	0.018051

Tab. 12: The final weight of each alternative in the case study.

Contractor name	Weight
R	0.234803
F	0.312379
A	0.249111
B	0.203858

4.5 Sensitivity analysis for the proposed framework in the case study

Every decision-making process can benefit from a sensitivity analysis. The consequences of any modifications to the input data are often of interest to project managers and decision-makers. So, another approach to assess the effectiveness of the OPA model will be executed using a sensitivity analysis, by adjusting the priority of experts, criteria and alternatives. Three scenarios for sensitivity analysis will be applied as follows:

(a) First scenario: The ranks of experts that are used in this scenario are the same ranks that are obtained from applying the proposed experts' evaluation system, as mentioned in the case study, and as follow: (Exp.1 > Exp.2 > Exp.3); this scenario is called 'Basic or Original'.
(b) Second scenario: The ranks of experts that are used in this scenario are equal, as follow: (Exp.1 = Exp.2 = Exp.3).
(c) Third scenario: The ranks of experts that are used in this scenario are opposite to the first scenario, as follow: (Exp.1 < Exp.2 < Exp.3).

After formulation of the OPA mathematical model for each scenario in the construction project under study and solving them with the use of LINGO software, the results showed that the weight of each alternative was affected in each scenario as shown in Figure 9. Moreover, the weight of alternative 'F' is the highest and followed by the weight of alternative 'A' in the first and second scenarios, while in the third scenario the weight of alternative 'F' stayed the highest but was followed by the weight of alternative 'R'. The sensitivity analysis result indicates a possibility for there being an effect on the final decision resultant

Tab. 13: The rank of each alternative in the case study according to bid amount.

The rank		
Contractor name	**Bid amount (ID)**	**Rank**
R	2,908,346,500	4
F	2,563,811,500	3
A	2,022,069,000	2
B	2,001,704,000	1

Tab. 14: The scores of each alternative from applying the traditional method in the case study.

The traditional method (weighted form)	
Contractor name	**Score**
R	80.56
F	83.36
A	77.6
B	68.61

to changes taking place in the rank of experts. Also, the weight of each criterion was affected in each scenario, as shown in Figure 10, where the weight of criterion ‘C12’ was the highest weight and followed by the weight of criterion ‘C2’ in the first and second scenarios, while in the third scenario the weight of criterion ‘C2’ was the highest and followed by the weight of criterion ‘C1’. So, this result indicates the possibility for there being an effect on the final decision resultant to changes taking place in the rank of experts.

Finally, the proposed computerised programs were sent to experts with the questionnaire form and the flowchart of the proposed framework, to evaluate their performance. The evaluation process was conducted through 14 experts, all of them possessing greater than 20 years’ experience in planning, consulting and construction management. According to the experts’ answers, as shown in Table 15, the research concluded that the proposed framework and the computerised program have a high applicability in construction projects and provide a high contribution in enhancing the decision-making process. Moreover, it has a high degree in the organisation, suitability and easily in use, and accuracy in outputs.

5 Conclusion

The literature review showed that there are many problems that may arise when using traditional MCDM methods in the decision-making process, and thus there is a need to use a modern method, such as the OPA method, to overcome these problems. To apply the OPA method, 20 major selection criteria for selecting the best contractor on a construction project were determined using a Delphi survey

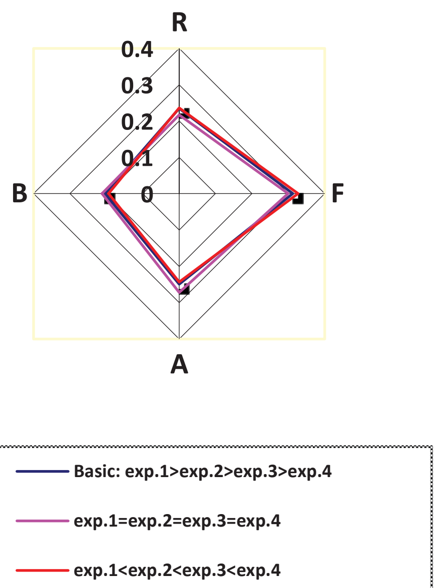

Fig. 9: The weights of alternatives of case study from each scenario.

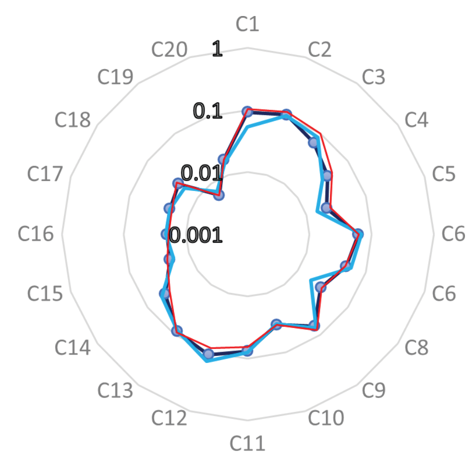

Fig. 10: The weights of criteria of case study from each scenario.

Tab. 15: The evaluation questions and their answers.

The questions	Answers					AM	Degree of importance
	V. high (5)	High (4)	Medium (3)	Low (2)	V. low (1)		
(1) Is the proposed framework applicable to construction projects?	3	8	3	-	-	4	High
(2) Is the sequence of issues in the proposed framework suitable?	2	11	1	-	-	4.07	High
(3) Based on your opinion, does the proposed framework contribute towards enhancing decision-making in construction projects?	1	7	6	-	-	3.64	High
(4) What do you think about the importance of the proposed framework for your workplace?	1	6	3	4	-	3.28	Medium
(5) Does the proposed framework deal well with changes and updates?	3	4	5	2	-	3.57	High

AM, Arithmetic Mean.

and verified with the use of PCA. These selection criteria will assist decision-makers in future projects.

Most of the previous studies relied on two or three components in the expert assessment process while the present study suggested seven components for the construction expert assessment system program, and the results showed a more comprehensive and accurate assessment process with validity for use in the construction sector. The process of formulating the OPA mathematical model in the previous studies was performed manually, which required a long time, while the results of applying the proposed program to formulate the OPA model in the construction project showed high applicability with simple operating procedures and high accuracy while saving time. The proposed model for enhancing decision-making has shown a high sensitivity to changes in the ranks of alternatives, criteria and experts, and this fact, seeing that its discovery serves as a potential benefit of research conducted along these lines, requires consideration when using a larger number of scenarios in future studies. Finally, since the core of the proposed OPA model focusses on rank, the proposed model can help decision-makers to enhance decision-making in all construction planning decisions in public procurement and not just for contractor selection.

Statements and declarations

Acknowledgement

This work was produced in cooperation with the Ministry of Housing and Construction/Directorate of Buildings and the Department of Civil Engineering, University of Baghdad.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Al-Agele, H. K. B., & Al-Kaabi, S. A. M. (2016). Identification of key factors affecting waste management in life cycle of the construction project by using Delphi technique. *Journal of Engineering, 22*(7), pp. 19-34, Available at https://joe.uobaghdad.edu.iq/index.php/main/article/view/187 [accessed 23 November, 2021].

Al-farra, W. A. K. (2009). *Analysis of Questionnaire Data by Using the Statistical Program SPSS*. World Assembly of Muslim Youth, (Retrieved at: November, 2019).

Alkaabi, S. A. M., & Mahjoob, A. M. R. (2022). Identifying the selection criteria of design consultant for Iraqi construction projects. *Journal of the Mechanical Behavior of Materials, 31*, pp. 290-297. doi: 10.1515/jmbm-2022-0036.

Alkaabi, S. A. M., & Mahjoob, A. M. R. (2023). Identification of key criteria of selecting the delivery system and type of contract in construction projects. In: Yang, X. S., Alkaabi, S. A. M., & Mahjoob, A. M. R. (eds.), *Proceedings of Seventh International Congress on Information and Communication Technology*, *Lecture Notes in Networks and Systems 464*. doi: 10.1007/978-981-19-2394-4_14.

Ataei, Y., Mahmoudi, A., Feylizadeh, M. R., & Li, D. (2020). Ordinal priority approach (OPA) in multiple attribute decision-making. *Applied Soft Computing Journal, 86*, p. 105893.

Brauers, W. K. M., Zavadskas, E. K., Zenonas Turskis, Z., & Vilutiene, T. (2008). Multi-objective contractor's ranking by applying the MOORA method. *Journal of Business Economics and Management, 9*(4), pp. 245-255. doi: 10.3846/1611-1699.2008.9.245-255.

Cheng, E. W. L., & Li, H. (2004). Contractor selection using the analytic network process. *Construction Management and Economics, 22*(10), pp. 1021-1032. doi: 10.1080/0144619042000202852.

CITB. (2015). Industry Guidance for Contractors. The Construction (Design and Management) Regulations. https://www.citb.co.uk/about-citb/partnerships-and-initiatives/construction-design-and-management-regulations-2015/cdm-regulations/

Crane, D., Henderson, E. J., & Chadwick, D. R. (2017). Exploring the acceptability of a 'limited patient consent procedure' for a proposed blood-borne virus screening programme: A Delphi consensus building technique. *BMJ Open, 7*, p. e015373. doi: 10.1136/bmjopen-2016-015373.

Elazouni, A. M. (2006). Classifying construction contractors using unsupervised-learning neural networks. *Journal of Construction Engineering and Management, 132*(12), pp. 1242-1253. doi: 10.1061/(ASCE)07339364(2006)132:12(1242).

El-Sayeg, S. M. (2009). Multi-criteria decision support model for selecting the appropriate construction management at risk firm. *Construction Management and Economics, 27*(4), pp. 385-398. doi: 10.1080/01446190902759009.

Fong, S. P., & Choi, S. K. (2000). Final contractor selection using the analytical hierarchy process. *Construction Management and Economics, 18*, pp. 547-557.

Ginevičius, R., & Vaitkūnaitė, V. (2006). Analysis of organizational culture dimensions impacting performance. *Journal of Business Economics and Management, 7*(4), pp. 201-211.

Grisham, T. (2009). The Delphi technique: A method for testing complex and multifaceted topics. *International Journal for Managing Projects in Business, 2*, pp. 112-130.

Hasson, F., & Keeney, S. (2011). Enhancing rigour in the Delphi technique research. *Technological Forecasting & Social Change, 78*, pp. 1695-1704. doi: 10.1007/s12652-020-02395 -z.

Jahan, A., & Edwards, K. L. (2013). VIKOR method for material selection problems with interval numbers and target-based criteria. *Materials & Design, 47*, p. 759765.

Javed, S. A., Mahmoudi, A., & Liu, S. (2020). Grey absolute decision analysis (GADA) method for multiple criteria group decision making under uncertainty. *International Journal of Fuzzy System, 22*, pp. 1073-1090.
Jeleva, A., Pacalo, V., & Dodu-Gugea, L. (2017). The features of decision-making process in international companies. Are companies in control of their own decisions? CSEI Working Paper Series, Issue 5.
Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika, 39*(1), pp. 31-36.
Kashiwagi, D., & Byfield, R. (2002). Selecting the best contractor to get performance: On time, on budget, meeting quality expectations. *Journal of Facilities Management, 1*. doi: 10.1108/14725960310807872.
Lam, K. C., Hu, T. S., & Ng, S. T. (2005). Using the principal component analysis method as a tool in contractor pre-qualification. *Construction Management and Economics, 23*(7), pp. 673-684. doi: 10.1080/01446190500041263.
Lam, K. C., Hu, T. S., Ng, S. T., Skitmore, M., & Cheung, S. O. (2010). A fuzzy neural network approach for contractor prequalification. *Construction Management and Economics, 19*(2), pp. 175-188. doi: 10.1080/01446190150505108.
Lever, J., Krzywinski, M., & Altman, N. (2017). Points of significance: Principal component analysis. *Nature Methods, 14*(7), pp. 641-642.
Mahmoudi, A., Deng, X., Javed, S. A., & Yuan, J. (2020). Large-scale multiple criteria decision-making with missing values: Project selection through TOPSIS.OPA. *Journal of Ambient Intelligence and Humanized Computing*. doi: 10.1007/s12652-020-02649-w.
Mahmoudi, A., & Javed, S. A. (2021). Performance evaluation of construction sub-contractors using ordinal priority approach. *Evaluation and Program Planning*. doi: 10.1016/j.evalprogplan.2021.102022.
Mahmoudi, A., Javed, S. A., & Mardani, A. (2021a). Gresilient supplier selection through fuzzy ordinal priority approach: Decision-making in post-COVID era. *Operations Management Research*. doi: 10.1007/s12063-021-00178-z.
Mahmoudi, A., Deng, X., Javed, S. A., & Zhang, N. (2021b). Sustainable supplier selection in megaprojects: Grey ordinal priority approach. *Business Strategy and the Environment, 30*(1), pp. 318-339.
Malone, D. C., Abarca, J., Hansten, P. D., Grizzle, A. J., Armstrong, E. P., & Van Bergen, R. C, et al. (2005). Identification of serious drug-drug interactions: Results of the partnership to prevent drug-drug interactions. *The American Journal of Geriatric Pharmacotherapy, 3*(2), pp. 65-76.
Mitkus, S., & Trinkūnienė, E. (2008). Reasoned decisions in construction contracts evaluation. *Technological and Economic Development of Economy, 14*(3), pp. 402-416.
Mohammed, S. R., & Jasim, A. J. (2018). Examining the values and principles of agile construction management in Iraqi construction projects. *Journal of Engineering, 24*(7), pp. 114-133. doi: 10.31026/j.eng.2018.07.08.
Mohamed, S. R., & Majeed, R. A. (2016). Pre-qualification of contractors in Iraq. *Applied Research Journal, 2*(2), pp. 77-87.
Naghizadeh Vardin, A., Ansari, R., Khalilzadeh, M., Antucheviciene, J., & Bausys, R. (2021). An integrated decision support model based on BWM and fuzzy-VIKOR techniques for contractor selection in construction projects. *Sustainability, 13*, p. 6933. doi: 10.3390/su13126933.
Ogbeifun, E., Agwa-Ejon, J., Mbohwa, C., & Pretorius, J. H. C. (2016). The Delphi technique: A credible research methodology. In: *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Kuala Lumpur*, Malaysia, March 8–10.
Othoman, E., Gupta, N., Zhang, B., & Wamuziri, S. (2013). Contractor selection using an integrated AHP and TOPSIS Model. *International Journal of Civil and Environmental Engineering, 3*(1), pp. 1116-1126.
Plebankiewicz, E. (2014). Modelling decision-making processes in bidding procedures with the use of the fuzzy sets theory. *International Journal of Strategic Property Management, 18*(3), pp. 307-316. doi: 10.3846/1648715X.2014.943332.
Preetha, R., & Vinila, J. S. (2020). Early diagnose breast cancer with PCA-LDA based FER and neuro-fuzzy classification system. *Journal of Ambient Intelligence and Humanized Computing, 12*, pp. 7195-7204. doi: 10.1007/s12652-020-02395-z.
Quartey-Papafio, T. K., Shajedul, I., & Dehaghani, A. R. (2021). Evaluating suppliers for healthcare centre using ordinal priority approach. *Management Science and Business Decisions, 1*(1), pp. 5-11. doi: 10.52812/msbd.12.
Ralitsa, B., Tolson, H., & Cole, B. R. (2005). Stability of response characteristics of a Delphi panel: Application of bootstrap data expansion. *BMC Medical Research Methodology, 5*(37). doi: 10.1186/1471-2288-5-37.
Razi, P. Z., Ramli, N. I., Ali, M. I., & Ramadhansyah, P. J. (2019). Selection of contractor by using analytical hierarchy process (AHP). *IOP Conference Series: Materials Science and Engineering, 712*(2020), p. 012014. IOP Publishing. doi: 10.1088/1757-899X/712/1/012014, (NCWE & ISSCE).
Ringnér, M. (2008). What is principal component analysis. *Nature Biotechnology, 26*(3), pp. 303-304.
Sadeghi, M., Mahmoudi, A., & Deng, X. (2021). Adopting distributed ledger technology for the sustainable construction industry: Evaluating the barriers using ordinal priority approach. *Environmental Science and Pollution Research*. doi: 10.1007/s11356-021-16376-y.
Shajedul, I. (2021). Evaluation of low-carbon sustainable technologies in agriculture sector through grey ordinal priority approach. *International Journal of Grey Systems, 1*(1), pp. 5-26. doi: 10.52812/ijgs.3.
Sönmez, M., Yang, J. B., & Holt, G. D. (2001). Addressing the contractor selection problem using an evidential reasoning approach. *Engineering. Construction and Architectural Management, 8*(3), pp. 198-210.
Wainwright, P., Gallagher, A., Tompsett, H., & Atkins, C. (2010). The use of vignettes within a Delphi exercise: A useful approach in empirical ethics? *Journal of Medical Ethics, 36*, pp. 656-660.
Welding, A. K. (2013). Project evaluation: Lessons learned vs. Delphi method. Thesis of 6 ECTS credits submitted to the School of Science and Engineering at Reykjavík University in partial fulfillment of the requirements for the degree of Master of Project Management in MPM.
Yongtao, T. (2008). Contractor's competitiveness and competitive strategy in Hong Kong. The Hong Kong Polytechnic University Department of Building and Real Estate.

Zagorskas, J., & Turskis, Z. (2006). Multi-attribute model for estimation of retail centres influence on the city structure. Kaunas city case study. *Technological and Economic Development of Economy, 12*(4), pp. 347-352.
Zavadskas, E. K., & Kaklauskas, A. (1996). Determination of an efficient contractor by using the new method of multicriteria assessment. In: Langford, D. A., & Retik, A., CIB W 65, (eds.), *International Symposium for the Organisation and Management of Construction. Shaping Theory and Practice. Vol. 2: Managing the Construction Project and Managing Risk*. London, Weinheim, New York, Tokyo, Melbourne, Madras. E and FN SPON 2, London, pp. 94-104.
Zavadskas, E. K., Kaklauskas, A., Turskis, Z., & Tamošaitienÿe, J. (2009). Multi-attribute decision-making model by applying grey numbers. *Informatica, 20*(2), pp. 305-320.
Zavadskas, E. K., & Vilutiene, T. (2006). A multiple criteria evaluation of multi-family apartment block's maintenance contractors: I – Model for maintenance contractor evaluation and the determination of its selection criteria. *Building and Environment, 41*(5), pp. 621-632.
Zavadskas, E. K., Vilutiene, T., Turskis, Z., & Tamosaitiene, J. (2010). Contractor selection for construction works by applying SAW-G and TOPSIS Grey techniques. *Journal of Business Economics and Management, 11*(1), pp. 34-55.