Towards Group Fuzzy Analytical Hierarchy Process

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Abstract. Group decision making takes place in almost all domains. In building construction domain, a team of contractors with disparate specializations collaborate. Little research has been done to propose group decision making technique for this domain. As such, specific teams' competitiveness enhancements are minimal as it takes more time for individual evaluators to choose the right partners. Qualitative and quantitative methods were used. Themes and categorizations were based on deductive approach. Subsequently, Group Fuzzy Analytical Hierarchy Process (GFAHP), Multi-Criteria Decision Making (MCDM) algorithm, was designed and applied. It uses all evaluation criteria unlike Fuzzy AHP (FAHP) which excludes some criteria that are assigned zero weights. GFAHP reduces the number of pairwise comparisons required when a large number of attributes are to be compared. Validation of the technique carried out by five case studies, show that GFAHP is approximately 98.7% accurate in the selection of partners.

Keywords: Multi criteria decision making
Group Fuzzy Analytical Hierarchy Process
Partners evaluation and selection problem

1 Introduction

In almost all economic sectors globally, supply chains are composed of a complex sequence of processing stages, ranging from raw materials supplies, parts manufacturing, components and end-products assembling, to the delivery of end products [1]. In supply chain management (SCM), supplier selection decision is considered as one of the key issues faced by project managers to remain competitive. Supplier evaluation, selection and management can be applied to a variety of suppliers throughout a product's life cycle from initial raw material acquisition to end-of-life service providers. Thus, the breadth and diversity of suppliers make the process even more cumbersome [2]. In construction industry, apart from supply of physical materials, services are also supplied. In this case, the services supplied are key to the projects' completion.

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In the construction industry, a project is normally implemented by a team of professionals and an alliance of companies [3]. Alliance of companies is formed by consultants who evaluate contractors (or service suppliers) for specific project tasks. A client hires an architect/consultant who makes designs for the project and engages other consultants to carry out the various tasks. For example, in a building construction project, the main consultant who is normally the architect, contracts civil/structural, electrical, mechanical, plumbing, interior design and land-scaping engineers. They work as a team to accomplish the tasks. The main consultant selects the best engineer/engineering firm among many firms who might have similar or near similar required attributes for the project. These companies coordinate among each other.

Evaluation and selection of a candidate among many alternative contestants, like is done for building construction projects, is a multi-criteria decision-making (MCDM) process [4]. MCDM process has been widely used in various fields such as location selection, information project selection, material selection, management decisions, strategy selection, and problems relating to decision-making [5]. This study defines a multiple criteria decision making problem for construction projects as "Partner Evaluation and Selection Problem (PESP)" so that each prospective partner (service supplier) can be evaluated against each defined criterion. A multi criteria decision making technique is designed that can be applied to derive each partner's weight and determine the best partner that is eventually selected for each project task.

Partner Evaluation and Selection Problem (PESP) can be represented mathematically as:

$$\gamma(t) = f(Z(h), S(p), P(m), T) \tag{1}$$

where:

$\gamma(t)$: partner evaluation and selection problem.
$Z(h)$: a set of tasks of the project,

$$Z(h) = \{z_1, z_2, \ldots z_m\}_{,m \geq 1}.$$

$S(p)$: a set of selection criteria for assigning tasks to partner companies,

$$S(p) = \{s_1, s_2, \ldots s_n\}_{,n \geq 1}.$$

$P(m)$: a set of prospective partner companies that satisfies the selection criteria, s_p and project tasks, z_h.

$$P(m) = \{p_1, p_2, \ldots p_m\}_{,m \geq 1}.$$

T = expected completion time.

The PESP for the project is formulated as follows:

"Which partner companies $p_m(m > 1)$ are capable of performing the task $z_h(h > 1)$ according to the selection criteria $s_p(p > 1)$ for expected completion time T?" This requires the determination of the number of companies that are qualified to carry out tasks.

The same problem for a single task is formulated as follows:

"Which partner company p_m is capable of performing the task z_h according to the selection criteria s_p for expected completion time T?" This requires the determination of a company that is qualified to carry out a task.

In general, the PESP is a multi-criteria and multi-objective decision making problem [6]. With its need to trade-off multiple criteria exhibiting vagueness and imprecision, partner selection is a highly important multi-criteria decision making (MCDM) problem [8]. The classical MCDM methods that consider deterministic or random processes cannot effectively address decision problems incorporating imprecise and linguistic information. Fuzzy set theory is one of the effective tools to deal with uncertainty and vagueness.

The rest of the paper is organized as follows: The following section presents a brief literature review on supplier selection. In Sect. 3, methodology is presented. In Sects. 4 and 5, partner evaluation and selection factors, and Fuzzy Analytical Hierarchy Process approach are discussed respectively. Section 6 presents the proposed Group Fuzzy Analytical Hierarchy Process (GFAHP) and provides its stepwise representation. In Sect. 7, application of GFAHP is shown. Finally, concluding observations and directions for future research are given in the last section.

2 Literature Review

The partner selection process can be considered as a Multi-Criteria Decision-Making (MCDM) process, characterized by a substantial degree of uncertainty and subjectivity due to limited information about potential partners. Construction project partners are like suppliers to organizations [7]. In this regard, this review is based on suppliers in supply chain management which is applicable to construction domain. Supplier evaluation is a management decision-making process that addresses how organizations select strategic suppliers to enhance their competitive advantage [8].

According to the vast literature on supplier selection, the following properties need to be considered while resolving the supplier selection problem [9]. First, the supplier selection process requires considering multiple conflicting criteria. Second, several decision-makers are oftentimes involved in the decision process. Third, decision-making is often influenced by uncertainty in practice. Studies have shown that the classical MCDM methods which often consider deterministic or random processes have not been able to effectively address decision problems that incorporate imprecise and linguistic information [8].

Earlier studies on supplier selection focused on identifying the criteria used to select suppliers. Dickson [10] conducted one of the earliest works on supplier selection and identified 23 supplier attributes that managers consider when choosing a supplier. Among these criteria, quality, on time delivery, and performance history were noted as the most significant ones. Another study conducted by Lehmann and O'Shaughnessy [11] found that the key criteria generally claimed to affect supplier selection decisions were price, reputation of supplier, reliability, and delivery. Weber et al. [12] classified the articles published between 1966 and 1990 according to the considered criteria.

Based on 74 papers, they concluded that supplier selection is a multi-criteria problem, and price, delivery, quality, and production facility and location are the most frequently employed criteria.

In light of the multi-criteria nature of partner selection problem, it would appear that the application of multi-criteria decision making (MCDM) techniques to the problem is a fruitful area of research. Such techniques would allow project initiators to systematically examine the trade-offs among various criteria when selecting specific suppliers. As firms become involved in strategic partnerships with their suppliers, a new set of supplier selection criteria, termed as soft criteria, need to be considered in supplier selection decisions. These criteria are subjective factors that are difficult to quantify. Fuzzy set theory appears as an effective tool to deal with uncertainty inherent in supplier selection process. This section will briefly review the research works on supplier selection that employ fuzzy MCDM techniques.

Several authors have used fuzzy MCDM techniques such as fuzzy analytic hierarchy process (F-AHP), fuzzy analytic network process (F-ANP), fuzzy technique for order preference by similarity to ideal solution (F-TOPSIS), fuzzy multi-criteria optimization and compromise solution (F-VIKOR), fuzzy preference-ranking-organization-method-for-enrichment-of-evaluation (F-PROMETHEE), fuzzy suitability index, 2-tuple fuzzy linguistic representation model, and grey approach. Bevilacqua and Petroni [13] proposed a methodology for supplier selection based on the use of fuzzy suitability index. Bottani and Rizzi [14] addressed the problem of supplier selection in an e-procurement environment. Fuzzy AHP was employed to determine the most viable supplier. Chen et al. [9] developed a methodology for solving supplier selection problems in fuzzy environment. This was based on TOPSIS. Chan and Kumar [15] identified the decision criteria including risk factors for the development of an efficient system for global supplier selection. Fuzzy extended AHP based methodology was used in the selection procedure.

Chan et al. [16] employed a fuzzy modified AHP approach to select the best global supplier. Wang [17] used 2-tuple fuzzy linguistic representation model to determine the overall supplier performance with dynamic supply behaviors. Chen and Wang [18] provided an integrated VIKOR framework under fuzzy environment for determining the most appropriate supplier and compromise solution from a number of potential suppliers in information system/information technology outsourcing project. Kavita and Kumar [19] extended TOPSIS for interval-valued intuitionistic fuzzy data. Wang [20] developed a model based on 2-tuple fuzzy linguistic representation model to evaluate the supplier performance.

Vinodh et al. [21] utilized fuzzy ANP for supplier selection process and presented a case study in an electronics switches manufacturing company. In their study, Baskaran et al. [22] evaluated the Indian textile and clothing industry suppliers employing grey approach. The sustainability criteria were considered in the evaluation process. Chu and Varma [23] suggested a hierarchical MCDM model under fuzzy environment to evaluate and select suppliers. Govindan et al. [24] employed fuzzy TOPSIS for supplier selection considering environmental, social, and economic aspects of supplier selection problem. Roshandel et al. [25] used fuzzy hierarchical TOPSIS for evaluating suppliers in detergent production industry. Application of fuzzy TOPSIS and fuzzy AHP to supplier selection problem is seen in [26] where the results obtained are compared.

Integrated MCDM techniques based approaches have also been developed to select the most appropriate supplier [8]. Haq and Kannan [27] proposed an integrated supplier selection and multi-echelon distribution inventory model utilizing fuzzy AHP and genetic algorithm (GA). Sevkli et al. [28] developed a supplier selection approach that integrates AHP and fuzzy linear programming. Yang et al. [29] introduced a fuzzy MCDM method for supplier selection problem. First, they used interpretive structural modeling to obtain the relationships among the sub-criteria. Then, they applied fuzzy AHP to compute the relative weights for each criterion. Finally, they employed fuzzy integral to obtain the fuzzy synthetic performance and determined the rank order of alternative suppliers.

Tseng et al. [30] presented a hierarchical supplier evaluation framework combining ANP and Choquet integral. Razmi et al. [31] proposed a hybrid model based on ANP to evaluate and select supplier under fuzzy environment. The proposed approach was enhanced with a non-linear programming model to elicit weights of comparisons from comparison matrices in the ANP structure. Ordoobadi [32] combined Taguchi loss function and AHP to develop a decision making model for the selection of the appropriate supplier. Ravindran et al. [33] introduced two-phase multi-criteria supplier selection models incorporating supplier risk. In phase 1, initial set of supplier alternatives was reduced to a smaller set employing AHP. In phase 2, order quantities are allocated among the suppliers using a multi-objective optimization model [34].

Chen and Yang [35] combined constrained fuzzy AHP and fuzzy TOPSIS for supplier selection. Liao and Kao [36] proposed an integrated fuzzy TOPSIS and multi-choice goal programming model to solve multi-sourcing supplier selection problems. Pitchipoo et al. [37] proposed a structured decision model for evaluating suppliers by integrating fuzzy AHP and grey relational analysis. Rodriguez et al. [38] proposed a combination of AHP and TOPSIS in fuzzy environment for the selection of customized equipment suppliers.

Shidpour et al. [39] integrated fuzzy AHP, TOPSIS and multi-objective linear programming to determine the most appropriate configuration product design, assembly process, and supplier of components in the new product development process. Singh [40] combined TOPSIS and mixed linear integer programming for supplier selection and order allocation problem. Hashemian et al. [41] integrated fuzzy AHP and fuzzy PROMETHEE for supplier evaluation. Fuzzy AHP was used to determine the weight of the criteria and fuzzy PROMETHEE was employed for obtaining the final ranking of suppliers.

Although previously reported studies developed approaches for supplier (and for this study partner) selection process, further studies are necessary to integrate imprecise information concerning the partner assessment criteria, and dependencies between partner assessment criteria into the analysis. This study concentrates on the partner assessment criteria, even as dependencies between partner assessment criteria is left for future work. A sound decision aid for partner selection should also aim to rectify the problem of loss of time when computing with linguistic variables for a large set of selection criteria. In this paper, a fuzzy multi-criteria group decision making approach based on fusion of fuzzy information is developed. The weights of partner selection criteria and the final ranking of partners are obtained benefiting from FAHP methodology using geometric mean prioritization technique. The proposed approach uses the AHP method in partners' weights prioritization of linguistic information. The subjective information provided by decision-makers is unified into a specific linguistic labels. The collective performance values that are also fuzzy sets are obtained by geometric mean operator. Then, the collective preference values are defuzzified.

These techniques are applicable in supplier selection and there is no available research that investigated their applicability in the construction projects' partner evaluation and selection. However, although most of these techniques may be used to rank all the available partners for construction projects, they are still unable to take into account the requirements of the construction projects as a whole that may require that partners' attributes are varied to take into account partner or project changes. Given a pool of partner companies, these methods rank the partners according to their satisfaction of the evaluation and selection criteria without considering the tendencies of the decision makers to be imprecise when making judgements about partner abilities to perform a task. To account for this impreciseness, there is need for incorporating techniques that can address the imprecise judgements from evaluators. Covella and Olsina [42] as cited by Nyongesa et al. [6] suggested the use of fuzzy logic to deal with impreciseness (subjectivity) of the evaluators.

Many research studies have analyzed and solved multi-criteria decision making problems using multi-level analysis of alternatives. Analytical Hierarchy Process (AHP) [43] is a MCDM algorithm that uses pairwise comparisons of alternatives to derive weights of importance from a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives depending on the problem. In cases where the comparisons are not perfectly consistent, AHP provides an uncomplicated method for improving the consistency of the comparisons, by using the eigenvalue method and consistency checking method [44].

The hierarchical structure fits well with the structure of partner evaluation and selection problem. Cheng et al. [45] identified the shortcomings of AHP as follows: (i) it is used in nearly crisp (exact) decision applications, (ii) does not take into account any uncertainty associated when mapping human judgement to a number scale, (iii) the subjective assessment of decision makers, and change of scale have great influence on the AHP outcome. Furthermore, Wang and Chin [46] found out that the increase in the number of characteristics geometrically increases the number of pairwise comparisons by $O(n^2/_2)$ which can lead to inconsistency or failure of the algorithm. Furthermore, AHP cannot solve non-linear models [45].

Another weakness of AHP identified by Mikhailov [47] is that it cannot be used when judgements are considered to be uncertain. In practice, human evaluation can sometimes be vague [6]. The factors that contribute to ambiguity/fuzzy/uncertainty of judgements are: (i) lack of sufficient information about the problem domain, (ii) incomplete information, (iii) lack of methods for data validation, (iv) changing nature of the problem, (v) lack of appropriate scale. Mikhailov [47] argues that the best way to solve uncertain judgement is to express it in terms of fuzzy sets or fuzzy numbers [47].

In an attempt to address the shortcomings of AHP, Mikhailov [47] introduced fuzzy logic in AHP. Fuzzy logic [48] deals with a continuum of variables and best addresses uncertainty and vagueness in input variables, in order to make rational decisions under such conditions. Fuzzy logic is derived from fuzzy set theory that has proven advantages within fuzzy, imprecise and uncertain decision situations and is an abstraction of human reasoning in its use of approximate information and uncertainty to generate decisions [49]. It implements grouping of data with boundaries that are not sharply defined. Fuzzy logic is considered the best method compared to deterministic approaches, algorithmic approaches, probabilistic approaches and machine learning [50] for problems that users are not certain of the value of parameters to use.

Fuzzy AHP [47] being an extension of conventional AHP, comprises the steps of conventional AHP, with fuzzy logic, namely: (i) structuring the problem into hierarchy; (ii) computing the pairwise comparison matrix to obtain the weight or priority vector and (iii) computing the global prioritization weight. Structuring of the problem into hierarchy involves decomposing the problem into objectives, sub-objectives and alternative solutions. AHP analyses how the alternative solutions satisfy the sub-objectives and how sub-objectives influence objectives of the problem. This is done by computing priority weights (PW) for alternatives in all levels of the hierarchy.

Wang et al. [51] describes FAHP challenges as follows; (a) Once a criteria is assigned a zero weight, it will not be considered in the decision making process, (b) This method may lose some useful information in the form of judgment ratios in the fuzzy comparison matrices as some of the criteria are assigned zero weight, (c) Weights calculated through this method may not represent the true relative importance of that criterion, and (d) This method might select the worst decision alternative as the best one and thus leads to wrong decision making. To handle weaknesses of FAHP, this study proposes Group FAHP (GFAHP). GFAHP can handle group fuzzy values of evaluation and is effective, that is it uses all evaluation criteria even if some are assigned zero values. It is also more accurate than FAHP.

3 Methodology

Steps followed in this study were as follows: Step 1: Literature review on decision making models and their application to the partner evaluation and selection problem to help identify MCDM technique that could be used for evaluation and selection of construction projects partners. Step 2: Design and Implementation of a MCDM technique for partner evaluation and selection problem. Step 3: Data collection from case study construction projects through interviews and evaluation tool (in the appendix). Focus group interviews and evaluation tools were used to collect data from participants. Step 4: Data analysis from case studies' data. The analysis of qualitative data was done by finding patterns in the collected data, as suggested by Seidel [52]. In analyzing the data and identifying patterns, themes and subcategories were developed. Sub categories were arrived at by analyzing the data further. Additionally, triangulation (interview questions and evaluation tools) was used to increase the reliability of research findings. Step 5: Categorization and themes based on deductive approach:- Selective coding for choosing partners' selection criteria; open coding for identifying selection sub-criteria; axial coding for making connections/relationships among sub criteria and between sub-criteria and criteria.

Representatives of construction companies based in Nairobi were invited for a focus group interview. These companies were selected by purposive sampling [53] from the National Construction Authority (NCA) database. NCA is the body mandated to regulate construction industry in Kenya. The purposive sampling procedure was used because of the difficulty in getting these participants. Results of the interview were used to design an evaluation tool. The applicability and validity of the evaluation tool for the collection of quantitative data was evaluated and discussed with experienced quantitative data analysis experts.

Data was collected between September 2016 and December 2016. Ten construction companies with ongoing construction projects within and in the environs Nairobi city were identified from the NCA database. Each organization was given twenty evaluation tools (the appendix). A total of 83 responses (response rate of 41.5%) were collected. Taking into consideration the length and complexity of the evaluation tool, this response rates compares well above other surveys such as Bailey et al. [54], and Culley et al. [55] that obtained 31%, and 23.6% response rate respectively. To corroborate results of the study, five case studies were conducted. Each case had ten construction companies selected from various sub counties in Nairobi County. However, some sub-counties did not have construction firms based in them. These respondents were given profiles of five companies, P1 to P5 as suggested by Musumba and Wario [56]. They used the companies' profiles information to evaluate each company according to how they satisfied a selection criterion for a particular task in the construction project [6]. Respondents of evaluation tool were required to indicate the level of importance of one selection criterion over another in implementing the task, the level of importance of a sub-criterion over another in satisfying a criterion and how preferable a company (partner) was over another in satisfying a sub-criterion.

The data from focus group interview was largely qualitative while data from evaluation tools were largely quantitative. Techniques to analyze both qualitative and quantitative data were employed. Analyzed data was used to evaluate and select partners. Merriam [57] and Creswell [58] recommend simultaneous data collection and analysis for generating categories. As data were being categorized, the responses were compared within categories and between categories (constant comparative analysis) [59]. Constant comparative analysis occurs as the data are compared and categories and their properties emerge or are integrated together. Data from focus group interviews was categorized into evaluation and selection criteria and sub-criteria.

4 Evaluation and Selection Criteria

To determine partner evaluation and selection criteria, data from focus group (experts) interviews were categorized. Categories include: Technical capability (TC), development speed (DS), cost of development (CD), Information Technology (IT), financial security (FS), business strength (BS), strategic position (SP), collaboration record (CR), cultural compatibility (CC) and management ability (MA). Specific categories were then put in general categories. Technical skills comprised TC, DS, CD and IT while FS, BS, SP and CR, CC, MB were categorized as Business Skills and Management Skills respectively. Constant comparative analysis aided in identifying patterns and categories.

At the lowest level, TC comprised the following factors: capacity, customer services, value-adding capabilities, skills, experience, complementation in core capabilities; DS comprised delivery time, development speed, task completion probability; CD comprised price/cost, task price; IT comprised design capabilities, communication techniques while FS comprised financial position, credit worthiness, risk, uncertainty, caution price; BS comprised commitment to quality, partner flexibility, reputation, communication mechanism, market position, size of company, reliability, partner resources, security; SP comprised partner performance, location, strategic goals; CR comprised previous collaboration experience, ability to work as a team, relationship between staff; CC comprised matching of corporate cultures, trust, confidentiality. Finally, MA comprised management style and openness.

The following section explains the sub criteria considered. Technical capabilities, requires that partners should have relevant types of skills and experience for the task. Development speed, assesses the capability of a partner to complete tasks within project timelines. Financial security, is important because it reveals the financial strength of the partner. The partner deposits some amount of money before project commencement. Collaborative record, determines the ability of the partner to work in a team. This is done by examining the successful projects the partner has been part of. Business strength, examines the necessary equipment and qualified staff of the partner. Cost of development, determines the ability of the partner to implement a task within the project budget. Corporate cultural compatibility, examines staff management style in the previous projects and corporate culture of the partner. In determining the strategic position, examination of the partnerships with other firms like financiers during previous projects is done. Management ability, indicates how the partner relates with staff and handles staff issues. Use of Information Technology, determines the partner's ability to use software for designs, finance and staff related issue management.

These categorizations of evaluation and selection factors can be represented in a hierarchical structure. The hierarchy proposed by Nyongesa et al. [6], shown in Fig. 1 represents a decision problem for a specific task. This hierarchy is composed of four levels: objective (the problem), criteria, sub-criteria and partners (alternatives). The overall objective of the problem is the task of partner evaluation and selection, the criteria for evaluating and selecting partners are technical, management and business, sub-criteria for each criterion are defined and the partners to be considered. The process was simplified into finding the best partner for a structural engineering works of a building. This could be replicated to find best partners for other tasks like electrical, mechanical and plumbing, interior design and landscaping works.

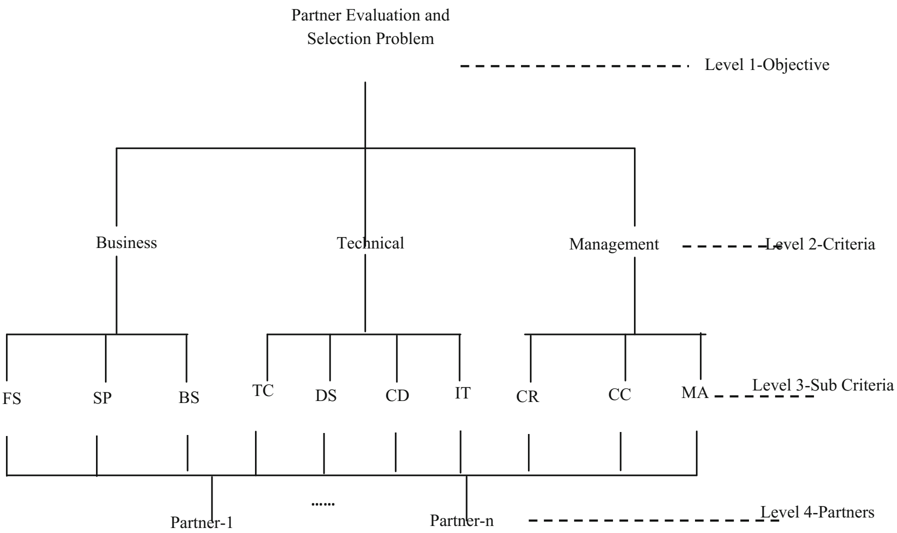

Fig. 1. A task specific decision problem representation [4]

5 Fuzzy Analytical Hierarchy Process Approach

Fuzzy theory has proven advantages for dealing with imprecise and uncertain decision situations and models human reasoning in its use of approximate information [48]. Fuzzy set theory implements grouping of data with boundaries that are not distinctly defined. In conventional AHP, the pairwise comparison is established using a nine-point scale which indicates the human preferences between alternatives [45]. The discrete scale of AHP has the advantage of ease of use but, it cannot handle the uncertainty associated with the mapping of evaluators' preferences to a number [60]. The evaluators' judgements are normally vague and difficult to represent in terms of exact numbers but could best be given as interval judgements than fixed value judgements. Different types of fuzzy numbers (triangular or trapezoidal) are used to decide the priority of one decision variable over other [61, 62]. A triangular fuzzy number (TFN), $\tilde{N}$ is given by $a \leq b \leq c$ where b, a, and c are the most likely, the lower bounds and upper bounds decision values, respectively [61, 62]. The triangular fuzzy numbers (TFNs), $\tilde{N}$ are linear piece-wise membership functions, $\mu_n(x)$ of the form;

$$\mu_n(x) = \begin{pmatrix} (x-a)/(b-a), & a \leq x \leq b \\ (c-x)/(c-b), & b \leq x \leq c \\ 0, & \text{Otherwise} \end{pmatrix}$$
$$\text{where } \infty < a \leq b \leq x \leq c < \infty$$

When Saaty's nine scale values are converted into fuzzy numbers and the values used in AHP, the resulting algorithm is Fuzzy AHP (FAHP). First, obtain preference values/level of importance of alternatives. This is done by choosing the linguistic attributes e.g. the statement "Indicate how important each of the following criterion is when your company is selecting partners for structural engineering works in a building construction project" needs an evaluator to choose one answer from (extremely important, very important, important, weakly important and not at all important) to answer.

Secondly, the chosen linguistic attributes are converted into numerical crisp values [6]. In the partner evaluation tool (in the appendix), alphabetical symbols $(\mathrm{A}, \mathrm{B}, \mathrm{C}, \mathrm{D}, \mathrm{E})$ with matching nominal scales (extremely important, very important, important, weakly important and not at all important) are provided. These are converted to Saaty scale [43]. Thirdly, once the linguistic opinions are converted to numerical values, the crisp values are converted to fuzzy scale using Table 1.

Table 1. Conversion of nominal or crisp to fuzzy scale

Alphabetical symbol	A	B	C	D	E
Nominal scale	Extremely important	Very important	Important	Weakly important	Not at all important
Crisp number	1	3	5	7	9
Fuzzy membership function	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)

Notes: According to Akadiri et al. [76] as cited by Nyongesa et al. [6], in crisp AHP, a scale of one to nine is used to decide the priority of one decision variable over another whereas in fuzzy AHP fuzzy numbers or linguistic variables are used.

The linguistic symbols obtained from individual evaluators can be converted directly to TFNs [6]. TFN values are divided in three parts. That is lower bound, middle and upper bound triangular fuzzy values. In the fourth step, compute the pairwise comparisons matrices of the values of alternatives. This step gives the fuzzy pairwise comparison matrix in form of triangular fuzzy number (l, m, u). The pairwise comparison judgement matrix gives the preference of one alternative (A_i) over the other (A_j), and is given by

$$A_{ij} = \frac{Ai}{Aj} for\, i, j = 1, 2, 3, \ldots n. \tag{4}$$

In the fifth step, apply the fuzzy extent analysis to the pairwise comparison matrix. The basic procedures for fuzzy extent are adopted from Zhu et al. [39] thus, Let $\mathrm{X} = \{\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3 \ldots \mathrm{x}_\mathrm{n}\}$ be an object set (for this study object set is either the objective, criteria, or sub-criteria) and $\mathrm{G} = \{\mathrm{g}_1, \mathrm{g}_2, \mathrm{g}_3, \ldots \mathrm{g}_\mathrm{n}\}$ be a goal defined for each level in the hierarchical structure. Thus, G can change depending on the level of the hierarchy.

M extent analysis on each object is taken

$$\acute{M}^1_{gi}, \acute{M}^2_{gi}, \acute{M}^3_{gi}, \ldots\ldots \acute{M}^m_{gi}, \quad i = 1, 2, 3, \ldots\ldots, n$$

where $\acute{M}^j_{gi}(\mathrm{j} = 1, 2, 3, \ldots., \mathrm{m})$ are triangular fuzzy numbers (TFNs).

6 Proposed Group Fuzzy AHP

This section outlines the Group Fuzzy AHP which is a multi-criteria decision making algorithm that builds on Fuzzy AHP. The proposed decision making approach uses the geometric mean operator to aggregate decision makers' preferences. This algorithm has both features for AHP and FAHP. First, obtain evaluation comparison judgements of different alternatives in crisp values, as it is done in AHP. Then crisp values are fuzzified using triangular fuzzy number as it is done in FAHP. The arithmetic average of the fuzzified evaluators' opinions is found and a fuzzy pairwise comparison matrix is formed. From literature, this is based on Group Decision Making Algorithm [63]. The steps of the GFAHP are illustrated in Fig. 2.

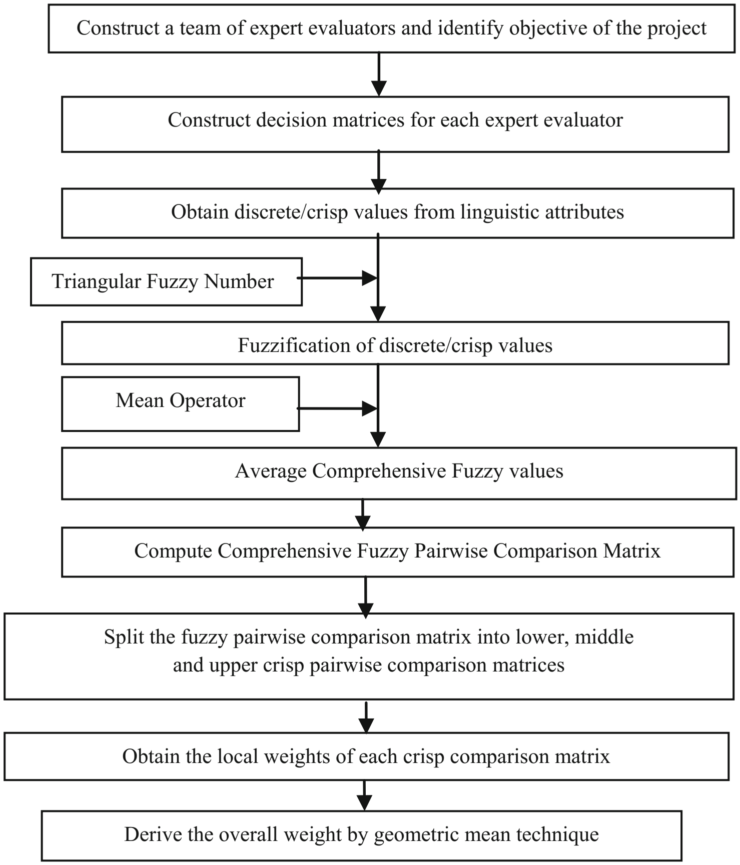

Fig. 2. Group Fuzzy AHP for PESP

Detailed stepwise representation of the proposed Group Fuzzy AHP algorithm is given below.

Step 1. Put in place a team of expert evaluators $\mathrm{E}(\mathrm{e} = 1, 2, \ldots \mathrm{E})$ and identify the requirements (objective) of the project in order to meet the client's needs and the criteria (CRs) and sub criteria (SCRs) relevant to partner assessment
Step 2. Construct the decision matrices for each decision-maker that denote the fuzzy assessment to determine the relative importance of CRs, SCRs, and the overall evaluation scores of each considered partner.
Step 3. Obtain preference values/level of importance of alternatives (appendix) as done in FAHP.
Step 4. The chosen linguistic attributes are converted into numerical crisp values using Table 1 as done in FAHP.
Step 5. Once the linguistic opinions are converted to numerical values, computation of the arithmetic mean of the numerical values is done and the average of crisp values, are converted to fuzzy using Table 1. The linguistic symbols obtained from evaluators can also be converted directly to TFNs and their arithmetic mean computed. The use of weight mean operator helps to get the collective opinion of all participants. This is done to all lower bound, middle and upper bound triangular fuzzy values. The outcomes of this step are comprehensive fuzzy opinions.
Step 6. Compute the pairwise comparisons matrices of the values of alternatives. This step gives the fuzzy pairwise comparison matrix in form of triangular fuzzy number (l, m, u). The pairwise comparison judgement matrix gives the preference of one alternative (A_i) over the other $\left(A_j\right)$, and is given by $A_{ij} = Ai/Aj$ for $\mathrm{i}, \mathrm{j} = 1, 2, 3, \ldots \mathrm{n}$.
Step 7. The fuzzy comparison matrix is split into three parts. The lower bound values are used to form lower pairwise comparison matrix (PCM), middle values are used to form middle PCM while upper bound values form upper PCM. These PCMs have crisp values, therefore, AHP approach is used to derive priority vectors after confirming the evaluators' consistency using Saaty and Kearns [64]'s method. Priority vector of lower PCM, middle and upper PCM are combined using geometric mean.
Step 8. Computing global weights. This is the step whereby the relative importance of each element within the level (local weights) is merged/multiplied with the relative importance of each element in the parent level. This gives the global weights for each alternative.

6.1 Time Complexity of GFAHP

Time complexity refers to time in which the algorithm runs. It is determined by finding the upper bound on the execution time [65]. In AHP, the computational time is affected by the size of a matrix with bigger matrices requiring more time [69]. Considering a prioritization of n elements stated as $T_1, T_2, \ldots, T_n$, the intensity of preference element T_i over element T_j which represent a judgment is indicated as $\mathrm{a_{ij}}$ for $i, j = 1, 2, \ldots, n$ [66]. If element T_i is preferred to T_j, then $\mathrm{a_{ij}} > 1$ or otherwise $\mathrm{a_{ij}} < 1$ and $\mathrm{a_{ij}} = 1$ (for all $i, j = 1, 2, \ldots, n$) when the two elements is of the same importance. Hence, the reciprocal property $a_{ji} = 1/a_{ij}$ by assumption will always hold, with $a_{ij} = 1$ (for all $i = 1, 2, \ldots, n$) [67, 68]. Finally, a positive reciprocal matrix of pairwise comparison with the property $A = a_{ij}$ is constructed by having a dimension of $n \times n$ [69].

Consider an AHP reciprocal matrix A with weights,

$$A = \begin{matrix} & \begin{matrix} T_1 & T_2 & \ldots\ldots & T_n \end{matrix} \\ \begin{matrix} T_1 \\ T_2 \\ \ldots \\ T_n \end{matrix} & \begin{pmatrix} a_{11} & a_{12} & \ldots\ldots & a_{1n} \\ a_{21} & a_{22} & \ldots\ldots & a_{2n} \\ \ldots & \ldots & \ldots\ldots & \ldots \\ a_{n1} & a_{n2} & \ldots\ldots & a_{nn} \end{pmatrix} \end{matrix}, \quad \text{Weights} = \begin{pmatrix} W_1 \\ W_2 \\ \ldots \\ W_n \end{pmatrix}$$

where n is the number of elements and T are the objects while W is the derived weights from the reciprocal matrix. For the elements of the main diagonal in matrix A which are a_{ii}, ..., a_{nn}, the elements will always be equal to 1. Due to the reciprocal nature of AHP matrix, judgments are only required to the upper diagonal of the matrix and only need $n(n - 1)/2$ of the judgments to generate a matrix for prioritization while the symmetrical elements are communally reciprocal [67]. This means that the elements below the diagonal elements are satisfying the equation which is $a_{ji} = 1/a_{ij}$.

If there are n selection criteria and m candidates, the evaluators would have to make $n(n-1)/2 + n(m(m-1)/2)$ pairwise comparisons, a substantial number even for a small n and m (<8). Chang [65] found FAHP (for n criteria) has the time complexity of $n(n + 6)$ and AHP has a time complexity equal to $\frac{n(n-1)}{2}$. The number of comparisons in GFAHP is thrice that of AHP. This is due to the fact that once linguistic evaluations are converted to fuzzy values, three matrices are formed. One matrix is formed using lower bound elements, another one formed using middle elements and the other matrix is formed using the upper bound elements. Pairwise comparisons for each matrix are computed using AHP approach. One matrix of n criteria will take $p = \frac{n(n-1)}{2}$ comparisons. For the three matrices, the number of comparisons is thrice p comparisons, $3\,x\frac{n(n-1)}{2} = \frac{3n(n-1)}{2}$. Therefore, using these illustrations, GFAHP has a time complexity of $\frac{3n(n-1)}{2}$.

7 Application of the Proposed Group Fuzzy AHP

Data collected from evaluators was converted from crisp values to fuzzy/continuous values. It was done for all levels of the hierarchy. The arithmetic mean values for business (CR_1), technical (CR_2) and management (CR_3) criteria by evaluators were (9, 7, 7) respectively. These crisp values were fuzzified using TFNs to get (7, 9, 9) for CR_1, (5, 7, 9) for CR_2 and (5, 7, 9) for CR_3. A fuzzy pairwise comparison matrix was formed as shown in Table 2.

Table 2. Fuzzy pairwise comparison matrix for partner selection criteria

Criteria	CR_1	CR_2	CR_3
CR_1	1, 1, 3	7/5, 9/7, 9/9	7/5, 9/7, 9/9
CR_2		1, 1, 3	1, 1, 3
CR_3			1, 1, 3

Then the fuzzy pairwise comparison matrix is divided into three matrices consisting of lower, middle and upper bound elements as shown in Tables 3, 4 and 5.

Table 3. Lower bound PCM for selection criteria

Criteria	CR_1	CR_2	CR_3
CR_1	1.00	1.40	1.40
CR_2	0.714	1.00	1.00
CR_3	0.714	1.00	1.00

Table 4. Middle PCM for selection criteria

Criteria	CR_1	CR_2	CR_3
CR_1	1.00	1.29	1.29
CR_2	0.778	1.00	1.00
CR_3	0.778	1.00	1.00

Table 5. Upper bound PCM for selection criteria

Criteria	CR_1	CR_2	CR_3
CR_1	3.00	1.00	1.00
CR_2	1.00	3.00	3.00
CR_3	1.00	0.33	3.00

After that the local weight of each pairwise comparison matrix is done like in the conventional AHP. Table 6 shows the local weights for the lower and upper bound elements.

Table 6. Local and global weights for selection criteria

Criteria	Lower local weight	Middle local weight	Upper local weight	Overall weight (Geometric mean)
CR_1	0.412	0.386	0.325	0.372
CR_2	0.294	0.324	0.401	0.337
CR_3	0.294	0.361	0.228	0.289

After obtaining the results for the local weights of the lower and upper elements then the final step is to combine three respective local weights (for the lower, middle and upper element) in order to get the overall weights for alternatives. The same procedure was applied to all levels of hierarchy. It should be noted business criterion sub-criteria were denoted as $SCR_{1,1}$ to $SCR_{1,3}$ for FS, Sp and BS respectively.

Likewise, technical criterion sub-criteria were denoted as $SCR_{2,1}$ to $SCR_{2,4}$ for TC, DS, CD and IT respectively. Finally, management criterion sub-criteria were denoted as $SCR_{3,1}$ to $SCR_{3,3}$ for CR, CC and MA respectively. Table 7 shows the overall outcome of the GFAHP.

Table 7. Results of evaluations using GFAHP

Criteria	CR_1			CR_2				CR_3			
CR LW	0.372			0.337				0.289			
SCR	$SCR_{1,1}$	$SCR_{1,2}$	$SCR_{1,3}$	$SCR_{2,1}$	$SCR_{2,2}$	$SCR_{2,3}$	$SCR_{2,4}$	$SCR_{3,1}$	$SCR_{3,2}$	$SCR_{3,3}$	
SCR LW	0.417	0.302	0.253	0.312	0.211	0.126	0.351	0.449	0.298	0.254	
GW	0.155	0.112	0.094	0.105	0.071	0.042	0.118	0.13	0.086	0.073	
											Priority weights
P1	0.203	0.263	0.215	0.128	0.109	0.21	0.103	0.267	0.12	0.06	0.218
P2	0.137	0.157	0.113	0.22	0.245	0.12	0.237	0.313	0.09	0.24	0.242
P3	0.213	0.101	0.313	0.147	0.105	0.348	0.237	0.201	0.046	0.255	0.222
P4	0.112	0.101	0.154	0.274	0.122	0.211	0.194	0.022	0.289	0.179	0.157
P5	0.155	0.188	0.085	0.121	0.259	0.021	0.139	0.067	0.345	0.006	0.152
										Total	0.991
										Error	0.009

Note: CR LW denotes criteria local weight
SCR denotes sub criteria
SCR LW denotes sub criteria local weight
GW denotes global weight

To calculate the priority weight (PW) of partners, the global weights for each sub-criterion in each criterion is multiplied by the local weights of each partner according to a sub-criterion. After this, the sum of the products (partner local weights multiplied by sub-criterion global weights) of each partner is computed. This is illustrated in the following section.

$$\begin{bmatrix} 0.203 & \cdots & 0.155 \\ \vdots & \ddots & \vdots \\ 0.060 & \cdots & 0.006 \end{bmatrix} \times \begin{Vmatrix} 0.155 \\ \vdots \\ 0.006 \end{Vmatrix} = \begin{Vmatrix} 0.218 \\ \vdots \\ 0.152 \end{Vmatrix}$$

The global weight (GW) for $SCR_{1,3}$ (BS) is derived by multiplying local weight of business criterion by local weight of $SCR_{1,3}$, which is $0.372 \times 0.253 = 0.094$, GW for $SCR_{2,3}$ (DS) is $0.337 \times 0.211 = 0.071$. Likewise the GW for $SCR_{3,1}$ (CR) is $0.289 \times 0.449 = 0.130$. Finally PW for partners is derived by finding the sum of products of global weights of each sub criterion and the local weight of the partner in the sub criterion. For instance PW for partner 1 is $0.155 \times 0.203 + 0.112 \times 0.263 + 0.094 \times 0.215 + 0.105$ $0.128 + 0.071 \times 0.109 + 0.042 \times 0.210 + 0.118 \times 0.103 + 0.130 \times 0.267 + 0.086$ $0.120 + 0.073 \times 0.060 = 0.218$. PWs for partners 2, 3 to 5 are derived in the same way. If all was perfect the sum of the weights for partners should be 1. From Table 7 the sum is

0.991 with an error of 0.009. The PWs of Partners 1 through 5 was 0.218, 0.242, 0.222, 0.157 and 0.152 respectively. Partner 2 has the highest weight value and is consequently selected.

Ideally, in any algorithm that ranks alternatives, the sum of the PWs of alternatives should be 1. If this is not the case, then the algorithm has not performed optimally therefore resulting in errors. The higher the error the worse the algorithm's performance. Since the consistency ratio correlate to the judgemental errors in pairwise comparisons [70, 50], it can be concluded that these mean errors correspond to the consistency ratio [19]. GFAHP algorithm ranked all the partners in the following order, P2, P1, P3, P4 and P5 with P2 with the highest weight and P5 having the lowest weight. GFAHP has an error of 0.009. In order to verify the results of the algorithm, sources of data was varied from additional five cases of evaluators and projects. However, evaluation tool and company profiles were not varied. Table 8 shows the results of the five cases.

Table 8. Results of all cases

	P1	P2	P3	P4	P5	Total	Error
Case 1	0.251	0.232	0.206	0.145	0.154	0.988	0.012
Case 2	0.253	0.223	0.206	0.145	0.154	0.981	0.019
Case 3	0.251	0.232	0.206	0.154	0.143	0.986	0.014
Case 4	0.253	0.234	0.202	0.152	0.149	0.990	0.010
Case 5	0.251	0.252	0.206	0.134	0.145	0.988	0.012
Mean						0.987	0.013

According to the results of the analysis for cases 1 and 2, partners P1 is determined as the most suitable supplier, which is followed by P2, P3, P5 and P4 in that order. For cases 3 and 4, partners P1, P2, P3, P4 and P5 had priority weights in that order with P1 with the highest and P5 with the least. For case 5, P2, P1, P3, P4 and P5 had priority weights in that order with P2 with the highest and P5 with the least. The arithmetic mean total and error of the algorithm are 0.987 and 0.013 respectively. P1 averagely had the best types of skills and relevant experience; was best placed to complete the project task within reasonable time; had more financial strength than the rest; had shown better previous team collaborations; had better necessary equipment; better staff management capability among others. In the converse P5 had the reverse competencies to P1. Prior to this analysis, the cases had been working with P1, P2 and P3 using their own evaluation and selection system. The results obtained from the proposed decision making approach are similar to the findings from real life selection of partners in then cases, which demonstrates the robustness of the methodology and promotes its use as a decision aid for further partner evaluation and selection situations faced by project initiators.

Over the past decade, several researchers have used various fuzzy MCDM techniques for supplier selection process. While fuzzy MCDM techniques enable consideration of imprecision and vagueness inherent in partner evaluation, they also incorporate several shortcomings. Defuzzification has been commonly employed in a number of fuzzy MCDM methods. Freeling [71] revealed that by reducing the whole analysis to a single number, much of the information which has been intentionally kept throughout calculations is lost. Thus, defuzzification might essentially contradict with the key objective of minimizing the loss of information throughout the analysis [8].

Moreover, obtaining pairwise comparisons in AHP and ANP may become quite complex especially when the number of attributes and/or alternatives increases. Apart from this, Saaty and Tran [72] claimed that uncertainty in the AHP was successfully remedied by using intermediate values in the 1–9 scale combined with the verbal scale and that seemed to work better to obtain accurate results than using fuzzy AHP. The lack of a precise justification for the values chosen for concordance and discordance thresholds in fuzzy ELECTRE as well as the absence of a clear methodology for the weight assignment in fuzzy PROMETHEE may pose limitations for their use in partner selection. To the best of researchers' knowledge, an earlier study, which is apt to account for the impreciseness of human judgments in the partners evaluation and selection when information available about partners is either inadequate or uncertain in a decision setting with multiple information sources, does not exist in the partner evaluation and selection literature. In here, the partner selection and evaluation methodology which has made use of fuzzy logic is designed and employed. However, this methodology has neither considered the inner dependencies among partner attributes nor enabled the use of different semantic types by decision-makers.

8 Discussions

Considering the inherent challenges in the construction sector, project initiators have to select the right partners to work with in order to remain competitive. To reach this aim, firms must device better ways to get the right partners to improve on their overall performance. Selecting the right partners significantly reduces the project management cost and improves corporate competitiveness. Partner evaluation and selection problem, which requires the consideration of multiple selection criteria incorporating vagueness and imprecision with the involvement of a group of experts, is an important multi-criteria group decision making problem. The classical MCDM methods that consider deterministic or random processes cannot effectively address partner evaluation and selection problems since fuzziness and imprecision coexist in real-world. In this study, a fuzzy multi-criteria group decision making algorithm is presented to rectify the problems encountered when using classical decision making methods in partner evaluation and selection.

Using GFAHP, it has been shown how preference and consensus can be attained if a group decision-making process is used in the partner evaluation and selection problem. It resembles the traditional AHP method, which uses preferences and consensus generated from crisp values to evaluate and select partners. The level of accuracy of the prioritization outcome when GFAHP was 98.7%. It can be stated that GFAHP can be incorporated in the design and development of new techniques for the partner evaluation and selection. GFAHP have those advantages of conventional AHP [73], which are: It is flexible, integrates deductive approaches, acknowledge interdependence of alternatives (selection criteria and sub-criteria), has hierarchical structure, measure intangibles, track logical consistency, give an overall estimation, consider relative weights and improves judgements. It also has advantages for FAHP which are: It is applied in evaluation and selection when imprecise values are used.

PESP is solvable if pragmatic scientific approaches were employed with appropriate mathematical models. This paper proposed an GFAHP algorithmic paradigm for evaluating and selecting right partners for building construction projects. The algorithm was used to demonstrate the choice of the most preferred partner based on business, technical and management skills among five potential partners. The consistency of the selected partner was tested using some mathematical tools. It was observed that the selected partner falls within the acceptable limit of the error margin. Precisely, we can say that the requirement of consistency is the most critical issue in the practical application of GFAHP. The use of the balanced scale improves consistency, but it would be most helpful to have well defined, theoretically founded cut-off limits, independent from scales and priority derivation methods. GFAHP employed FAHP process. PCM were divided into three, lower, middle and upper because Triangular Fuzzy Numbers were used. This could be applied to Trapezoidal Fuzzy Numbers where the PCM would be divided into four.

The procedure used in this paper considers the GFAHP as a fuzzy multi-criteria group decision tool and constructs three matrices to compute the weights of partner selection criteria and the ratings of partners. It utilizes the geometric mean of TFN, which enables decision-makers to tackle the problems of multi-criteria decision making impreciseness. The proposed methodology possesses two merits compared to some other MCDM techniques presented in the literature for partner selection. First, the developed method is a group decision making process which enables the group to identify and better appreciate the differences and similarities of their judgments. Second, the proposed approach is apt to incorporate imprecise data into the analysis using fuzzy set theory.

Finally, This study examines multi-criteria decision-making (MCDM) "under uncertainties", in particular the linguistic uncertainties and proposes the incorporation of fuzzy logic in AHP algorithm thus addressing issues of partner evaluation and selection while information available about partners is subjective. This study sought to evaluate and select partners for tasks in the construction projects. Research has shown the importance of using multiple evaluators in the evaluation and selection of partners. This is important for the project sustainability in terms of the evaluators being able to work as a team.

9 Further Work

Future research will focus on implementation of the decision technique presented in here for real-world group decision making problems in diverse disciplines. That research should be carried out to determine the applicability of this technique to other industries and other research fields. The limitations of GFAHP should probably be addressed in future research. Examples of limitations are: (i) checking if GFAHP preserve the consistency of the evaluator's judgement; and (ii) whether GFAHP ignore the dependence between the elements at the same level of the hierarchy, as is the case with AHP. A study should be done to determine how the incorporation of the Analytical Network Process (ANP) in this algorithm can address its weaknesses.

Moreover, as pointed out in several recent works [74, 75], supplier segmentation which in this study means, partner segmentation has an important role in supply chain management. Partner segmentation that succeeds partner evaluation and selection is the process of classifying the partners on the basis of their similarities. This classification or segmentation enables to choose the most suitable strategies for handling different segments of selected partners. Therefore, further development of the proposed method for partner segmentation may also be considered as a direction for future research.

Appendix: Partner Evaluation Tool

Collaboration of Construction Projects

Indicate your choice with a tick (✓) on the label provided. For the purpose of this study the term "collaboration" is defined as participation in a project between organizations that operate under a different management.

Section A-Partners Evaluation and Selection Criteria

1. Indicate how important each of the following criterion is when your company is selecting partners for a task in a building construction project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice

Criterion	Extremely important	Very important	Important	Weakly important	Not at all important
Business Skills	A	B	C	D	E
Technical Skills	A	B	C	D	E
Management Skills	A	B	C	D	E

2. Considering Business Skills Criterion; indicate how important each of the following sub-criteria is when your company is selecting partners for a task in a building construction project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice

Sub-Criteria	Extremely important	Very important	Important	Weakly important	Not at all important
Business Strength (BS)	A	B	C	D	E
Financial Security (FS)	A	B	C	D	E
Strategic Position (SP)	A	B	C	D	E

3. Considering Technical Skills Criterion; indicate how important each of the following sub-criteria is when your company is selecting partners for a task in a building construction project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice

Sub-Criteria	Extremely important	Very important	Important	Weakly important	Not at all important
Technical Capabilities (TC)	A	B	C	D	E
Development Speed (DS)	A	B	C	D	E
Cost of Development (CD)	A	B	C	D	E
Information Technology (IT)	A	B	C	D	E

4. Considering Management Skills Criterion; indicate how important each of the following sub-criteria is when your company is selecting partners for a task in a building construction project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice

Sub-Criteria	Extremely important	Very important	Important	Weakly important	Not at all important
Collaboration Record (CR)	A	B	C	D	E
Cultural Compatibility (CC)	A	B	C	D	E
Management Ability (MA)	A	B	C	D	E

Section B-Partner Selection

Use the company profiles of companies P1, P2, …, P5 provided at the end of this questionnaire. Indicate how preferable is each company against each other according to partner selection sub-criterion to perform a task in a building construction project. Use the symbols "A to E" with A being "Extremely preferable" and E being "Not at all preferable". Choose the symbol which best indicates your choice

Sub-Criteria	Extremely preferable	Strongly preferable	Preferable	Weakly preferable	Not at all preferable
	P1 P2 P3 P4 P5	P1 P2 P3 P4 P5	P1 P2 P3 P4 P5	P1 P2 P3 P4 P5	P1 P2 P3 P4 P5
Technical capabilities (Have relevant types of skills)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Development speed (Can complete tasks within project timelines)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Financial security (Amount of money deposited before project commencement)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E

Collaborative record (Have been part of large projects)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Business strength (Have necessary equipment and qualified staff)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Cost of development (The projected task cost within the project budget)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Corporate cultural compatibility (Staff management style in the previous projects)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Strategic position (Partnership with other firms like financiers)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Management ability (Handles staff issues amicably)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E
Use of Information Technology (Use software for designs, finance and staff issues management)	A A A A A	B B B B B	C C C C C	D D D D D	E E E E E

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