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A decision making support tool for selecting green building certification credits based on project delivery attributes

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ABSTRACT

The Green Building (GB) certification process embodies detailed requirements and specifications that lead to additional tasks for project teams, which increases complexity levels of the entire project delivery process. Previous studies show that if the GB certification credits to be fulfilled are selected without considering project team attributes, then elevated levels of time, money, and labor could get wasted while attempting to meet the additional requirements of GB certification. The aim of this study is to develop a multi-attribute decision making (MADM) support tool to be used by GB experts to select the appropriate GB certification credits based on the project team attributes. The developed framework with relative weights assigned via the Delphi method was used to perform the MADM analysis, which employs the hybrid use of the Multi Attribute Utility Technique (MAUT) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). This paper presents the developed MADM tool (i.e., GB-CS tool) and the relative weights of the attributes that were determined following expert opinions. To validate the tool, a case study was conducted at a LEED-registered residential project. The results show that the GB-CS Tool was successful in ranking the GB certification credits to be selected. This hybrid MADM tool can be used for preventing disruptions and bottlenecks in GB project delivery processes by assisting the owners/GB consultants in effectively selecting suitable GB certification credits based on the project team attributes. Thus, with the assistance of the GB-CS tool, root causes of waste can be mitigated in the GB project delivery process, decreasing associated hidden costs.

1. Introduction

A “green building” (GB) or a “sustainable building” is a high performance building that is designed and constructed in a resource-efficient manner to preserve energy, water, materials, and land throughout its life cycle while providing healthy environments for its occupants through the application of “environmental” principles [1,2]. GB projects require multiple technical disciplines to have elevated levels of interdependency and interconnectedness [3–5]. Basically, structural, mechanical, electrical, and architectural systems need to function together in systematic unity to form a project that is “green” [6]. This interconnected and interdependent nature of GB projects leads to certain complexities and results in additional management challenges [7–9].

The GB certification process embodies detailed requirements and specifications that lead to additional tasks for the project team (i.e., detailed documentation and advanced green system design and implementation) that elevate the level of complexity for the whole project delivery process [7,10]. This relatively novel concept results in some unique challenges for project teams and decrease productivity throughout design and construction phases of GB project delivery. This may prevent achievement of project objectives related to time, cost and sustainability [7,11–14].

To achieve GB certification for a project, the first step is to select appropriate credits to be met in the project from among a large set of credits categorized under the selected GB rating system. Selecting credits that qualify the project for GB certification is a pivotal decision to achieve the sustainability objectives of the project [15]. Former studies have shown that architecture, engineering and construction (AEC) professionals experience a great deal of difficulty in selecting the certification credits to be implemented in new construction projects because of several uncertainties in the selection process [8,16–22]. Once the credits are

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selected, the requirements of these chosen credits must be fulfilled throughout the project. Previous studies have shown that if the selected GB certification credits were not appropriate for the project team attributes, then increased levels of time, money, and labor could be wasted [7–10,23]. Therefore, selection of GB certification credits is a crucial process that determines the success of the project. To promoting the sustainability objectives throughout optimization of the GB certification credit selection process, several researchers recommended using a well-structured decision making support tool that aid in preventing various decision-making problem [9,15,16,19,24,25].

In the study explained in this paper, it is proposed that when selecting GB certification credits, attributes related to the project team (e.g., qualification of project teams) need to be considered, since they noticeably affect the project's success in terms of time, cost, and sustainability [5,7,9,11,12,14]. Moreover, according to the findings of the authors' previous study, the most critical factors that ensure the success of GB projects are related to project team attributes [26]. However, the studies that aimed to select appropriate credits in a GB project did not include the existing attributes of the project team in the selection criteria [15–18,20–22,27,28]. This study aims to fill this gap and the objective of this study is to develop a multi-attribute decision making (MADM) support tool that can be used by GB consultants/owners to effectively select the GB certification credits based on the project team attributes. This MADM tool, namely the Green Building-Credit Selection (GB-CS) Tool, is built on Leadership in Energy and Environmental Design – New Construction (LEED NC) within the Building Design and Construction (LEED BD + C) rating system. The MADM analysis is used to select the appropriate GB certification credits in a project based on relative weights of the project team attributes and scores assigned in the project to the project team attributes for each credit. A case study was performed showing how the developed tool can be used, and the credits and their rankings obtained from the GB-CS tool were compared with the credits that were actually selected by the LEED team in the case study.

2. Literature review

Previous studies developed models or tools to assist in selecting the appropriate GB credits (e.g., LEED, BREEAM). Some of those studies adopted case based reasoning (CBR) approach [17,18,20,24], a few of them employed Building Information Modelling (BIM) driven platforms [22,28], and some performed multi-criteria decision-making (MCDM) techniques such as Analytical Hierarchical Process (AHP) and ELECTRE [15,16] for selecting the appropriate GB certification credits.

One of the studies that adopted CBR approach focused on selection of LEED v3 Existing Buildings Rating System credits based on the project information (i.e., location, owner type, gross floor area and target level) and the surrounding climatic factor using data mining techniques [19]. Similarly, another CBR based study explored the credit bundles of LEED for Existing Building considering their correlation relationships [26]. Other two CBR based studies analyzed LEED v3 NC credit achievements in previous projects using data driven techniques [17,18]. While one of them adopted CBR approach to provide case studies of similar certified GB projects to select the target LEED credits [17], the other one studied on the achievement of individual credits using percentage of average score (PAS) and the achievement of the related credits using classification based on Multiple Association Rules (CMAR) [18].

The BIM driven studies conducted by Kasim et al. aimed at developing a BREEAM or LEED based approach for evaluating sustainable design alternatives [22,28]. Among the studies that used MCDM techniques for selecting LEED credits, Sulochana et al. [16] intended to develop a decision making model using AHP and Monte-Carlo simulation techniques based on multiple criteria such as project cost variation, the environmental impact, the impact on schedule and construction productivity. On the other hand, Attallah et al. [15] developed a MCDM methodology for ranking GB certification credits using ELECTRE III method. The selection criteria include project type and location, client type, experience and familiarity of architect/engineer.

Although Turkey is ranked ninth for LEED GB certification in the international arena [29], and many studies in sustainability was conducted ın Turkey [30–35], currently there is no study in Turkey that developed MADM tool for selecting the appropriate GB certification credits for a particular project. The other GB certification systems that are used in Turkey's construction industry are BREEAM, Deutsche Gesellschaft für Nachhaltiges Bauen/German Sustainable Building Council (DGNB), Comprehensive Assessment System for Built Environment Efficiency, Excellence in Design for Greater Efficiencies (EDGE), CEDBIK-Konut. (Çevre Dostu Yeşil Binalar Derneği/Turkish Green Building Council-Residence).

Review of the previous studies showed that none of the previous studies considered project team attributes [5,7,9,11,12,14], except one study [15]. In this study, Attallah et al. included a project team attribute, which is experience and familiarity of architect/engineer. However, other project team based attributes were excluded such as, "education and knowledge (i.e. accreditation on GB Rating System(s))", "involvement of project teams into the GB project delivery process". Besides, that study did not consider "integrated project team approach" which was strongly suggested as one the most considerable instruments for successful completion of a GB project [5,7,36].

When MADM analysis methods are investigated in the literature, it is identified that TOPSIS is strongly suggested for solving complex real life problems having numerous alternatives [37,38]. For this reason, it is actively employed in many disciplines such as design, engineering and manufacturing systems, supply chain management, health, safety and environment management, energy management and construction management [11,38,39]. TOPSIS is capable of detecting the best alternative(s) among numerous alternatives. However, if selection criteria (e.g., attributes) have varying relative weights for each alternative, it is suggested to combine TOPSIS with the Multi Attribute Utility Technique (MAUT) [40]. By using MAUT an overall utility value can be assigned to each alternative and rival alternatives (i.e., credits) can be evaluated based upon the attributes' weights, which can vary for each alternative [25,40]. However, such a hybrid decision making tool employing MAUT and TOPSIS were not developed in the previous studies.

3. Research methodology

In this study, a novel hybrid approach, in which the TOPSIS was integrated with the MAUT), was used to represent varying relative weights (i.e., relative weights of the tertiary attributes) of GB project team attributes and to perform the MADM analysis. In addition, the Delphi method was used to collect data from the experts to determined relative weights based on expert opinion. The following steps were performed to develop the GB-CS tool (Fig. 1): (1) a three-tier hierarchical framework of the GB project team attributes was built [26]; (2) credits under the LEED BD + C rating system were integrated into the framework as alternatives, and relative weights of the attributes in the framework were determined by applying the integrated use of the Delphi method and the Top-down Direct Rating (TDR) method; and (3) the developed framework with relative weights was used to perform

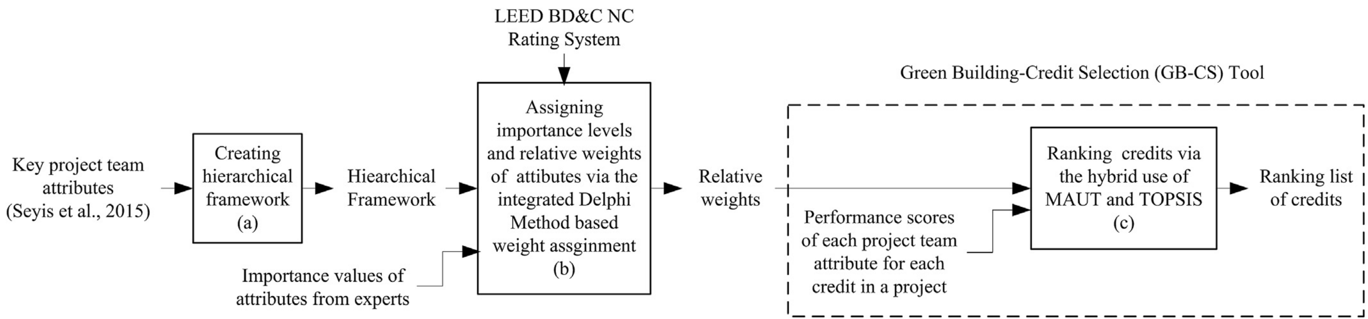

Fig. 1. Methodology of the study.

the MADM analysis, which integrates TOPSIS with MAUT.

In the first step, the findings of a previous study conducted by the authors were used when developing the hierarchical framework to be used in the MADM tool [26]. This prior study classified waste types and associated root causes for the GB project delivery process, described of their relationships and ranked waste types and primary and secondary root causes according to their negative impacts on time and cost both in design and construction phases of a GB project delivery process. The findings showed that the most critical root causes of wastes in the GB project delivery process were related to the project team: (1) lack of educated key project team members/subcontractors experienced in GB projects, and (2) late involvement of key project participants into the process. The present study built on the results of this previous study and developed the hierarchical framework based on these key project team attributes identified (Fig. 1a).

In the second step, credits under LEED NC under the BD + C Rating System were integrated into the framework as alternatives, since LEED is the most widely practiced GB rating system in the US and in the world [2]. To represent the project team-related attributes in the framework, importance levels and relative weights were determined (Fig. 1b). The weight assignment step is crucial in MADM tool development, since, if the outputs from the weight assignment process are sensitive and reliable, more accurate results will be obtained from the decision making analysis [41,42]. In this study, the Delphi method integrated with Top-Down Direct Rating (TDR) method was used to assign relative weights via expert opinion (Fig. 1b). The Delphi method is preferred in the literature to strengthen the weight elicitation procedure due to internal consistency and decreased vulnerabilities in data [43,44]. The first step of the Delphi method was defining criteria for experts' qualifications to ensure that they have sufficient knowledge and experience in the GBs and GB certification [45]. Six criteria were identified in this study, and 11 panel members were selected based on these predefined criteria. Nine questionnaires, which were based on the hierarchical framework, were distributed to these 11 experts via e-mail in two rounds. The details of the questionnaires can be found in Section 4.1. The experts scored the project team attributes based on their relative importance in meeting the GB credit requirements. Via Delphi method, an importance value was assigned to each secondary and primary attribute in the framework and to each tertiary attribute for each credit. The TDR method was applied to normalize the relative importance values [46]. At the end of this step, a relative weight of each attribute was calculated along with relative weights of tertiary attributes for each credit.

In the third step, MADM analysis was performed using the developed framework and assigned weights via hybrid use of TOPSIS and MAUT (Fig. 1c). There are over 50 alternatives (i.e., credits under LEED NC) to analyze with respect to the project team-related attributes. TOPSIS was selected for performing the MADM analysis due to its capability in detecting the best alternative(s) among numerous alternatives [37,41]. Also, extensibility of TOPSIS was another reason for selecting this method [37], since integration with the MAUT was necessary in this study. Preliminary interviews with two experts showed that the relative weights of the third level attributes might vary for each credit. To represent varying relative weights MAUT was integrated into TOPSIS. For the tertiary attributes, the relative importance levels were collected for each credit in the weight assignment process. On the other hand, for primary and secondary attributes, only one value that applies to all credits was retrieved.

The user of the GB-CS tool scores the project team attributes for each credit and the tool ranks the credits based on these scores. To evaluate the performance of the GB-CS tool, it was tested in a LEED-registered residential project case study.

3.1. Selected green building certification system

The GB-CS tool was developed for selecting the credits under the main categories of LEED NC, which consists of five main categories: (1) sustainability sites (SS), (2) water efficiency (WE), (3) energy & atmosphere (EA), (4) materials & resources (MR), and (5) indoor environmental quality (IEQ). Each category includes a number of credits whose points (i.e., environmental points) are allocated based on the relative importance of their building-related impacts, such as energy consumption, greenhouse gas emissions associated with the building systems, and the embodied energy of the building materials [36]. All the credits (i.e., 54 credits) under these categories were included in the MADM analysis, and they correspond to 100 base points. The credits from the bonus categories (i.e., “regional priorities” and “innovation in design”) were excluded in this study.

3.2. Building hierarchical framework of the project team attributes

The first step of the study was to develop a framework that represents the critical qualitative attributes [37], which were used in selecting appropriate credits via MADM analysis. According to the findings of the authors' previous study, the most critical factors that ensure the success of GB projects are related to project team attributes: qualifications of project teams (representing education and experience) and timing of project teams' involvement in GB projects [26]. Building on the findings of this study, the authors created a three-tier framework of these key project team attributes in the light of experts' comments and suggestions (Fig. 2).

The top level of the framework includes two project team-related attributes: “qualification of project teams in GB projects and features” and “timing of project teams' involvement in GB project delivery process”. This level represents major attributes and associated content. The former was identified to be a significant

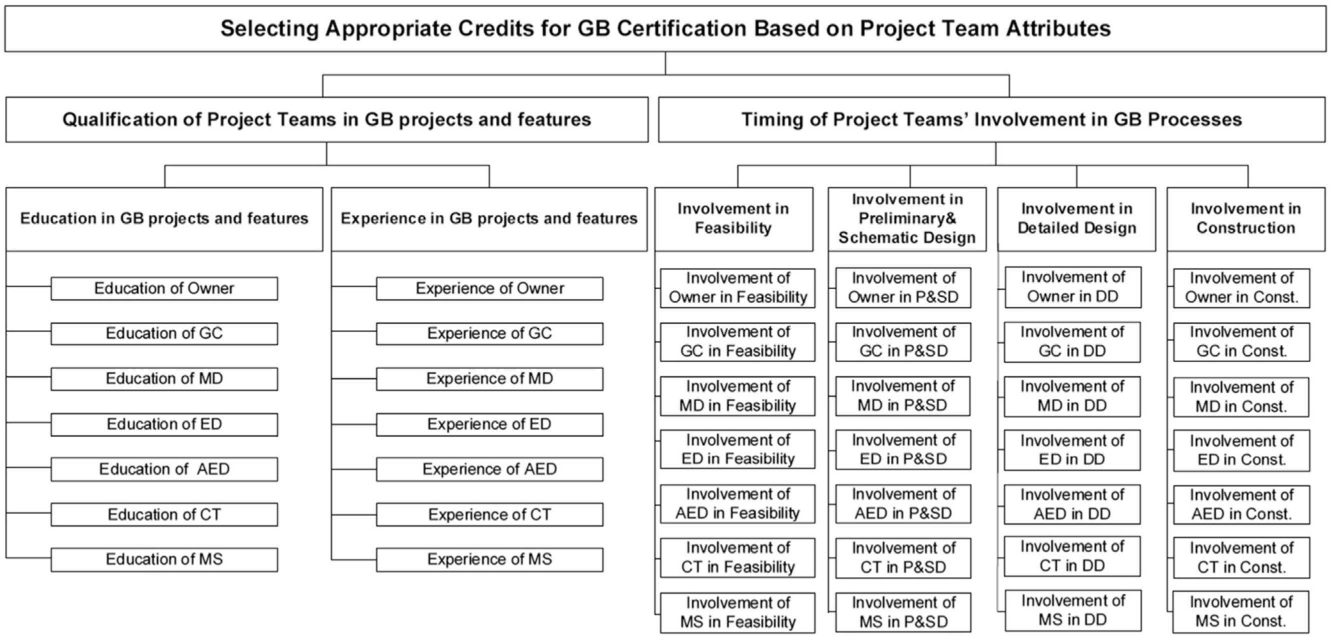

Fig. 2. Hierarchical framework of the project team-related attributes.

attribute in GB projects because experience and education in GBs and costs related to GB certification requirements (e.g., documentation) are suggested to be inversely proportional to each other [47]. This attribute includes two secondary level project team attributes, which are (1) experience in the related GB certification credit, and (2) education/knowledge in the related GB certification credit. In this study, experience refers to the number of years of experience in GB projects, and education/knowledge is represented by: (1) accreditation by a widely accepted GB council (e.g., US or UK Green Building Council), (2) having professional degrees (i.e., Professional Engineer (PE), Building Engineering Modeling Professional (BEMP) or having BSc, MSc, or PhD degrees from departments related to the AEC industry). "Project teams" is introduced into the framework to embody the third level attributes. Project teams, listed under each secondary attribute, are represented by seven groups: owner, general contractor (GC), architectural and structural design team (AED), design team (MD), electrical design team (ED), construction team (CT), and material suppliers (MS). In the tertiary attributes, each team's "experience in GB projects and features" and "education/knowledge in GB projects and features" are represented, such as education level of the owner in GB projects and features.

The latter attribute, "Timing of project teams' involvement in GB processes", is another key criteria. The previous studies strongly recommended that GB projects follow the integrated project delivery (IPD) method, which requires early team involvement to ensure the successful completion of GB projects [5]. This attribute is divided into four secondary attributes: (1) involvement in the feasibility phase, (2) involvement in preliminary and schematic design (S&PD), (3) involvement in the detailed design (DD) phase consisting of design development and construction documentation, and (4) involvement in the construction phase. "Project teams" is the third level group of attributes, represented by the same teams that were defined for the tertiary level of attributes for "Qualification of project teams in GB projects and features". It describes the timing of involvement for each project team, such as timing of the GC's involvement in the feasibility phase.

4. Weight assignment

In the second step of the MADM tool development, relative importance levels were assigned to the project team attributes at each level in the framework via the Delphi method to represent the significance of each attribute in the successful completion of GB projects. The relative importance values were normalized and used as inputs in the MADM analysis. Preliminary interviews that were made with two GB experts revealed that the relative weights of third level attributes might vary for each credit. For example, the importance level of the "architectural team's experience in GB projects and features" for gaining credit in "light pollution reduction" is different than the importance level of "architectural team's experience in GB projects and features" for gaining credit in "optimize energy performance". Therefore, for the tertiary attributes, the relative importance levels were collected for each credit. On the other hand, for primary and secondary attributes, only one value that applies to all credits were retrieved. The normalized outputs were the relative weights of the attributes for each credit and the first-, second-, and third-level weights of the attributes in the framework (i.e., overall weights, global weights, and local weights, respectively).

4.1. Collection of relative importance values via the Delphi method

Before implementing the Delphi method, the criteria were defined for-determining experts' qualifications to ensure that they have sufficient knowledge and experience in the GBs and GB certification [45]. It was expected that experts meet at least one criterion from each of the following two groups: (1) education/knowledge level, and (2) experience level (Table 1). Eleven panel members were selected based on these predefined criteria. Of these panel participants, six are GB consultants, two are academicians, and five are professionals in the AEC industry (Table 2).

Seven of the panel participants have more than ten years of experiences in the construction industry and also have 5–10 years of experience in GB industry. The other four panel members have

Table 1
Criteria for experts' qualifications.

Knowledge/Education Level	Experience Level
At least a LEED Green Associate (GA), and/or BREEAM International Assessor	At least two years of professional experience in GBs seeking LEED and/or BREEAM
Education degree (at least M.Sc. or M.Arch. or M.Eng.) from the departments related to the AEC industry (e.g., architecture, civil eng., mechanical eng., electrical eng.)	At least five years of professional experience in AEC industry
Professional degree in their subjects, such as Building Engineering Modeling Professional (BEMP), Commissioning Process Management Professional (CPMP), Project Management Professional (PMP) or Professional Engineer (PE), Certified Commissioning Professional (CCP)	At least two years of professional experience in ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) standards and applications

Table 2
Panel members participating in the Delphi process.

Profession/title	Experience in		Education Degree	Professional Degree related to		
	Construct. Ind.	GBs		Specialized Title	Title in GB Rating Systems	
Industrial Engineer/GB Consultant	≥10	5–10	M.Sc.	BEMP, CPMP	LEED AP	BREEAM Int. Asses.
Civil Engineer/GB Consultant	>10	5–10	M.Sc.	PMP	LEED AP	BREEAM Int. Asses.
Mechanical Eng./GB Consultant	>10	>10	Bachelor	PE, *CCP*	LEED AP	–
Architect (academician)	>10	5–10	PhD	–	–	–
Architect/GB Consultant (academician)	5–10	5–10	PhD	–	–	BREEAM Int. Asses.
Architect/GB Consultant	>10	5–10	M.Arch.	–	LEED AP -	–
Civil Engineer/Project Manager	>10	5–10	M.Sc.	–	LEED AP	–
Mechanical Engineer/GB and Project Management Consultant	5–10	5–10	M.Sc.	PMP	LEED AP	–
Civil Engineer/Green and non-green building Project Planning	5–10	2–5	MBA	–	LEED AP	–
Civil Engineer/Assist. Finance Supervisor	5–10	2–5	PhD	–	LEED GA	–
Architect/Procurement Arch.	5–10	2–5	M.Arch.	–	LEED GA	–

5–10 years of experiences in the construction industry and have 2–5 years of experiences in GB industry. -Two of the GB consultants are LEED Accredited Professional (AP) and BREEAM International Assessor, four of them are LEED AP, and only one of them is a BREEAM International Assessor. One of the panel participants is an Industrial Engineer, four of them are Civil Engineers, two of them are Mechanical Engineer and four of them are Architect.

To determine the relative weights of the project team attributes in the developed framework for fulfilling each credit, nine questionnaires were distributed to the panel members via e-mail in two rounds. A two-rounded process was employed since it is strongly suggested to obtain more accurate outputs in Delphi method [43]. Out of nine questionnaires, one of them was designed to assign the importance level of the primary team attributes (i.e., "qualification of project teams" and "timing of project teams' involvement") to achieve GB certification. Two questionnaires (1×2 and 1×4 matrix) were prepared to designate the importance of the secondary team attributes, which are project team's education in GB projects and project team's experience in GB projects. The last type of questionnaire was more complicated, since relative importance levels that were assigned to tertiary attributes vary for each credit (i.e., 54 credits). Tertiary attributes (e.g., owner, general contractor, architectural team) representing project teams were collected via six 54×7 matrix questionnaires (i.e., 2268 scores), since the levels of importance for tertiary attributes would be determined for each of the 54 credits listed under LEED NC. Two of the questionnaires are used to determine the importance levels of each project team's (e.g., owner, general contractor, architectural team) experience and education in GB projects for each criterion under LEED v3 NC rating system. The remaining four questionnaires are used to identify the importance levels of each project team's involvement in feasibility, schematic design (i.e., preliminary design and schematic design), detailed design and construction phases for each criterion. Every GB expert was asked to give points to nine types of questionnaires in each round. Panel participants were given considerable time (four to six weeks) to fill out these nine questionnaires, since completing each questionnaire is a detail-oriented activity.

A nine-point scale was employed, where "1" indicates "without any importance" while "9" corresponds to "extreme importance". Mean values and standard deviations of the importance levels of each attribute were calculated at the end of the first round. The mean value was calculated to determine the central tendency of all feedbacks, and standard deviation represents the group consensus [48,49].

In the second round, along with the questionnaires, panel members were provided with the mean values and standard deviations of each attribute's importance level. The goal in the second round was to have panel participants re-evaluate their previous scores by using the findings of the first round and to reach a consensus among them if there were significant differences among the scores given by the panel members in the first round. At the end of the second round, the trimmed mean and standard deviation for each project team-related attribute were calculated based on the scores given by 10 panel members out of 11. One member's results were excluded because it included outliers. Calculating the trimmed mean value in the last round is a suggested method to eliminate biased responses that can alter mean values [50]. The standard deviation values were expected to decrease from one round to the other; otherwise, another round should be performed [43]. A 52%–82% decrease in the standard deviation values was observed in the second round, indicating a high consensus on the importance values of the attributes among GB experts.

Conducting interactive rounds and providing controlled feedbacks from the preselected group of experts allow researchers achieve higher reliability, consistency and quality in outputs [49,51]. This structured reasoning mechanism of Delphi method ensures that outputs attained from this qualitative procedure do not need to be tested-retested (e.g., via *t*-test, Kendall's tau-b, Scheffe test (post-hoc comparisons)) to control the reliability and consistency of data [52,53]. Its careful research design ensures researchers to achieve construct validity [53]. Hence, performing consistency analysis for the data gathered from the Delphi method based process and measuring its consistency and reliability is not required [44]. The relative importance values of each attribute that were assigned via the Delphi method were normalized via the TDR method before being input in the GB-CS tool to mitigate redundancies [46]. Normalization allows for deriving the relative weights of each attribute in the framework: overall weights for primary attributes, global weights for secondary attributes, and local weights for tertiary attributes. The sum of these weights is equal to one within that particular group. This procedure provides that the relative weight of the whole system equates to one.

These weights represent the importance of these project team attributes in selecting credits for GB projects. They are reported in Table 3. According to Table 3, overall weights refer to the relative weights of the first-level attributes that are (1) qualification of project teams (0.4891), and (2) timing of project teams' involvement (0.5109). Each overall weight is the sum of the related sub-attributes' global weights. As stated given in Table 3, global weights refer to the relative weights of second-level attributes that are (1.1) experience of project teams (0.2537); (1.2) education of project teams (0.2353); and project teams' involvement in (2.1) Feasibility (0.1138), (2.2) Schematic Design (0.1198), (2.3) Detailed Design (0.1497), and (2.4) Construction (0.1277). Each global weight is the sum of the related sub-attributes' local weights. Local weights represent the relative weights of third-level attributes (e.g., owner,

Table 3
Relative weights of GB project delivery team attributes.

No	Project Team Attributes and Sub-Attributes	Overall Weights (First Level Weights)	Global Weights (Second Level Weights)	Local Weights (Third Level Weights)
1.	Qualification of Project Teams in GB projects and features	0,4891		
1.1	Experience of Project Teams in GB projects and features		0,2537	
1.1.1	Owner			0,0457
1.1.2	General Contractor			0,0410
1.1.3	Mechanical Team			0,0348
1.1.4	Electrical Team			0,0270
1.1.5	Architectural Team			0,0411
1.1.6	Construction Team			0,0328
1.1.7	Material Suppliers			0,0313
1.2	Education of Project Teams in GB projects and features		0,2353	
1.2.1	Owner			0,0433
1.2.2	General Contractor			0,0375
1.2.3	Mechanical Team			0,0327
1.2.4	Electrical Team			0,0236
1.2.5	Architectural Team			0,0402
1.2.6	Construction Team			0,0296
1.2.7	Material Suppliers			0,0284
2.	Timing of Project Teams' Involvement in GB Processes	0,5109		
2.1	Project Teams' Involvement in Feasibility		0,1138	
2.1.1	Owner			0,0251
2.1.2	General Contractor			0,0175
2.1.3	Mechanical Team			0,0161
2.1.4	Electrical Team			0,0128
2.1.5	Architectural Team			0,0201
2.1.6	Construction Team			0,0104
2.1.7	Material Suppliers			0,0117
2.2	Project Teams' Involvement in Preliminary and Schematic Design		0,1198	
2.2.1	Owner			0,0247
2.2.2	General Contractor			0,0168
2.2.3	Mechanical Team			0,0173
2.2.4	Electrical Team			0,0135
2.2.5	Architectural Team			0,0231
2.2.6	Construction Team			0,0115
2.2.7	Material Suppliers			0,0128
2.3	Project Teams' Involvement in Detailed Design		0,1497	
2.3.1	Owner			0,0280
2.3.2	General Contractor			0,0227
2.4.3	Mechanical Team			0,0212
2.4.4	Electrical Team			0,0169
2.4.5	Architectural Team			0,0254
2.4.6	Construction Team			0,0160
2.3.7	Material Suppliers			0,0193
2.4	Project Teams' Involvement in Construction		0,1277	
2.4.1	Owner			0,0216
2.4.2	General Contractor			0,0193
2.4.3	Mechanical Team			0,0168
2.4.4	Electrical Team			0,0138
2.4.5	Architectural Team			0,0203
2.4.6	Construction Team			0,0196
2.4.7	Material Suppliers			0,0163

architectural team). For example, (1.1.1) owners' relative weight for experience is 0.0457, whereas (1.2.1) owners' relative weight for education is 0.0433.

It should be noted that the owner's and architectural team's qualification and timing of involvement attributes have the highest weights compared with the other teams' values; therefore, it can be stated that both teams significantly affect project outcomes in terms of time, cost, and sustainability. Another output of the normalization step is the list of relative weights of the tertiary attributes determined individually for each credit.

5. Development of the MADM tool

TOPSIS, which is a type of MADM method, was used to compare each alternative (i.e., credit) based on relative weights of project team attributes and their performance scores for each credit in a project of interest. The TOPSIS reasoning mechanism requires one constant weight for each attribute. However, the relative weights of third-level attributes might vary for each credit; hence, MAUT was integrated into the TOPSIS methodology to represent the varying relative weights of third-level attributes for each credit in the developed GB-CS tool. The reasoning mechanism of MAUT ensures evaluation of rival alternatives (i.e., credits) based upon the attributes' weights, which can vary for each alternative [40]. An aggregate utility function is calculated by the following formula:

$$rij = \frac{x_{ij}}{x_j^*}\text{ , where } i = 1,\ldots\text{m};\ j = 1,\ldots\text{n};\ x_j^* = max_i(x_{ij});\ = Wij = [0,1];\ \sum Wij\ =\ 1 \tag{3}$$

$$Uij(x)\ =\ \sum_{i=1}^{m} w_{ij}u_{ij}\ (x),\ \text{where } i = 1,\ldots m;\ j = 1,\ldots\text{n};\ wij = [0,1];\ \sum wij\ =\ 1 \tag{1}$$

In this formula, $u_{ij}(x)$ signifies a utility of a single attribute (x) for the selected alternative (y), while w_{ij} indicates the relative weight of that attribute for the selected alternative. In this study, w_{ij} represents the third-level attribute's relative weight for each credit, whereas u_{ij} represents the performance scores of third-level attributes for each credit (e.g., experience of the owner in brownfield development). The performance scores of the project team-related attributes for each credit will be entered by the decisions maker(s), who will use this tool in their project. Using this formula, the attributes' relative weights for each credit were integrated into the MADM analysis.

The other type of relative weights that were input in the MADM tool was the global weights (i.e., relative weights of secondary attributes), which, by definition, includes the overall weights (i.e., relative weights of primary attributes). TOPSIS ranks alternatives based on the shortest distance from the (positive) ideal solution (PIS) (i.e., the most appropriate credit) and the longest distances from the negative ideal solution (NIS) (i.e., the least appropriate credit). The best alternative refers to the PIS, while the worst alternative refers to the NIS [37].

The first step of TOPSIS is to construct a decision matrix [D]. The decision matrix refers to the m alternatives (Y_i) evaluated in terms of n attributes (X_j). In this study, Yi values are represented by 54 credits categorized under LEED NC, while Xj values are represented by second-level attributes, which are (1) education, (2) experience, (3) involvement in the feasibility phase, (4) involvement in the SD phase, (5) involvement in the DD phase, and (6) involvement in the construction phase. The decision matrix was created by x_{ij}, which equals U_{ij}, which denotes the aggregate utility function that was calculated based on relative weights and performance scores of each third-level attribute for each credit (Eq. (2)).

$$D = \begin{array}{cc} & \begin{array}{ccccc} X_1 & \cdots & X_j & \cdots & X_n \end{array} \\ \begin{array}{c} Y_1 \\ \vdots \\ Y_i \\ \vdots \\ Y_m \end{array} & \begin{bmatrix} (x_{11}) & \cdots & (x_{1j}) & \cdots & (x_{1n}) \\ \vdots & & \vdots & & \vdots \\ (x_{i1}) & \cdots & (x_{ij}) & \cdots & (x_{in}) \\ \vdots & & \vdots & & \vdots \\ (x_{m1}) & \cdots & (x_{mj}) & \cdots & (x_{mn}) \end{bmatrix} \end{array} \tag{2}$$

The next step is to construct a normalized decision matrix [D] by applying linear normalization. r_{ij}, denoted as an element of the normalized matrix, is calculated using Eq. (3). To establish the weighted normalized matrix (V), a set of relative weights (i.e., global weights), denoted as $W = (w_{ij,\ldots,}w_{in})$, were multiplied by the normalized matrix to acquire a weighted normalized matrix (V) (Eq. (4)).

$$V = \begin{bmatrix} w_{11}r_{11} & w_{12}r_{12} & \cdots & w_{1j}r_{1j} & \cdots & w_{1n}\,r_{1n} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ w_{i1}\,r_{i1} & w_{i2}\,r_{i2} & \cdots & w_{ij}\,r_{ij} & \cdots & w_{in}\,r_{in} \\ \vdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ w_{m1}r_{m1} & w_{m2}r_{m2} & \cdots & w_{mj}r_{mj} & \cdots & w_{mn}r_{mn} \end{bmatrix} \tag{4}$$

The third step is to determine the (positive) ideal solutions (PIS) and the negative ideal solutions (NIS). PIS (A^+) is the optimal solution where all the attributes have the optimum performance (Eq. (5)). On the contrary, NIS (A^-) is the solution (i.e., decision) where all the attributes have the worst performance (Eq. (6)) [37]. To identify the distance from the ideal solutions, separation measures were calculated by applying Eqs. (7) and (8). S_i^+ refers to the distance from the ideal solution, while S_i^- refers to the distance from the negative ideal solution.

$$A_j^+\ =\ \left\{\left(\max_i v_{ij}\right) j{\in}J \mid i{\in}n\right\} = \left[v_1^+, v_2^+\ldots, v_m^+\right] \tag{5}$$

$$A_j^-\ =\ \left\{\left(\min_i v_{ij}\right) j{\in}J \mid i{\in}n\right\} = \left[v_1^-, v_2^-\ldots, v_m^-\right] \tag{6}$$

$$S_i^+\ =\ \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2},\ i = 1,\ldots,m \tag{7}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2},\ i = 1, \dots, m \quad (8)$$

The attributes' separation measures are aggregated within *PIS* (S_i^+), and *NIS* (S_i^-) by calculating the relative closeness (closeness coefficient) (C_i^+) to the ideal solution (Eq. (9)). In this study, $(m) = 6$ since the framework consists of six secondary attributes, and $(n)= 54$ since the framework consists of 54 alternatives.

$$C_i^+ = S_i^- \Big/ S_i^+ + S_i^-,\ 0 \le C_i^+ \le 1,\ i = 1, \dots, m \quad (9)$$

If $A_i = A^+$, $C_i^+ = 1$, and if $A_i = A^-$, $C_i^+ = 0$. In other words, if A_i equals to A^+, C_i^+ of an alternative is equal to 1; this alternative refers to the best alternative. On the contrary, if A_i equals A^-, C_i^+ of an alternative is equal to 0; this corresponds to the worst alternative (Eq. (9)).

The last step of the TOPSIS procedure is to rank the preference order (i.e., ranking list) of the credits according to C_i^+ *values*. The largest C_i^+, which has the shortest distance to the ideal solution, indicates the best alternative(s), which corresponds to the most appropriate credit to be selected based on the GB project team attributes [37].

Three performance scoring systems, based on a nine-point scale, were developed and used in this study. Two of the scoring systems were for "qualification level" (i.e., education and experience levels) and one was for "timing of involvement". Table 4 and Table 6 report scoring systems that represent "education of project teams" and "experience of project teams" in the related credit topic, respectively. For example, according to Table 4, if any project team (e.g., Mechanical Team) has no formal education/knowledge in the credit topic (e.g., Brownfield Development), 1 point is given to that team. Besides, Table 5 presents the corresponding education levels that were defined for representing professional degrees of the team members. If any project team member is LEED AP, his/her education level corresponds to four years of education (Table 4) in every credit topic; and accordingly, performance score of this person is six points. If this team member has another 2 years of education in the related field, performance score will equal to eight. Similar to Table 4, in Table 6, if any project team (e.g., Mechanical Team) has no experience in the credit topic (e.g., Brownfield Development), 1 point is given to that team. In the scoring system that is used for timing of involvement, if the "team has not been involved yet", "1" point is given. In this scoring system, "2" refers to "late involvement in the related phase", while "9" corresponds to "early involvement in the related phase. Scores between "2" and "9" indicate the intermediate values. Scores of "3","4″, and "5″ were given if the project team was involved in the second half of the related phase, while "6","7″, and "8″ were given if the project team was involved in the first half of the related phase.

Table 4
Scoring system representing "education of project teams" in the related credit topic.

Performance Scores	Corresponding education level of project teams (in years)
1	No education/knowledge
2	0 ≤ years of education < 1
3	1 ≤ years of education < 2
4	2 ≤ years of education < 3
5	3 ≤ years of education < 4
6	4 ≤ years of education < 5
7	5 ≤ years of education < 6
8	6 ≤ years of education < 7
9	7 ≤ years of education

Table 5
Corresponding education levels for degrees.

Degree	Associated education level
LEED GA	2 years of education
LEED AP	4 years of education
LEED Faculty	6 years of education
Professional degree (e.g. Building Engineering Modeling Professional (BEMP), PE)	2 years of education

Table 6
Scoring system representing "experience of project teams" in the related credit topic.

Performance Scores	Corresponding experience level of project teams (in years)
1	No experience
2	0 ≤ year of experience < 1
3	1 ≤ years of experience < 2
4	2 ≤ years of experience < 4
5	4 ≤ years of experience < 6
6	6 ≤ years of experience < 8
7	8 ≤ years of experience < 10
8	10 ≤ years of experience < 12
9	12 ≤ years of experience

5.1. Case study

In order to test the GB-CS tool, a case study was conducted at a LEED-registered residential project with a total area of 410,000 m^2. The project was developed based on the "Revenue Sharing Model", a Design-Build-Sell concept [54]. In this model, the Contractor's Executive Board carries the entire owner's authority and decision making rights/responsibilities; hence, it is denoted as the owner. Mechanical, electrical, architectural, structural, and construction teams were responsible for both design and build. Preliminary design and quantity take-off (QTO) studies were performed in-house by the "owner" early in the feasibility phase. The LEED team in this project consisted of owner, GC, Sustainable Projects Coordinator, Construction Manager, Commissioning Agent (CxA), architects, a landscape architect, and design engineers (i.e., structural engineers, mechanical engineers, and electrical engineers).

To build the decision matrixes (*D*), the Sustainable Projects Coordinator scored the performance of each project team (i.e., third-level attributes) using Tables 4 and 5 in terms of their related education and experiences under each credit topic and the timing of their involvement at each phase in the project. The ranking of the credits obtained from the GB-CS tool were compared with the credits that were actually selected by the LEED team in the case study, and similarities and differences were discussed.

5.2. Results of the case study

The output from the GB-CS tool is presented in Table 7. In this table, rankings of the credits, the separation measure of each credit ($S_i^*$and $S_i^'$), relative closeness (i.e. closeness coefficient (Ci*)) of project team attributes, ranking list of credits (i.e, preference order) according to Ci* and credits' points in LEED v3 BD + C are given. The table also includes the actual checklist (i.e. credits classified as "YES", "MAYBE" or "NO") that was created by the LEED team to be used as a roadmap during the GB project delivery process. In the LEED checklist, the credits marked as "YES" refer to the credits that were selected to be fulfilled by project teams, while the credits marked as "MAYBE" correspond to the credits that may be fulfilled if some improvements are made to collect the required environmental points from that credit. The credits marked as "NO" indicate

Table 7
Output from the GB-CS tool.

Rank	Separation Measures		Closeness Coefficient (Ci*)	Ranking List Of Credits according to Ci*	Credits' Points in LEED BD + C	Credits decided as "YES", "MAYBE" or "NO"
	S_i^+ (distance from the positive ideal solution)	S_i^- (distance from the negative ideal solution)	Ci* = Si/(Si' + Si*) 0 < Ci*<1, i= 1,2, …,m			
1	0,0456104230	0,7584279154	0,9432733231	Site Development—Protect or Restore Habitat	1	YES
2	0,1165025894	0,6875357490	0,8551031912	Alternative Transportation—Bicycle Storage and Changing Rooms	1	YES
3	0,1232018300	0,6808365084	0,8467711997	Development Density and Community Connectivity	5	YES
4	0,1465527643	0,6574855741	0,8177291339	Site Selection	1	YES
5	0,1487507624	0,6552875760	0,8149954358	Alternative Transportation—Public Transportation Access	6	YES
6	0,1993567887	0,6046815498	0,7520556183	Controllability of Systems—Thermal Comfort	1	YES
7	0,2022222484	0,6018160901	0,7484917836	Environmental Tobacco Smoke (ETS) Control	Prerequisite	YES
8	0,2129769386	0,5910613999	0,7351159412	Storage and Collection of Recyclables	Prerequisite	YES
9	0,2244227546	0,5796155838	0,7208805303	Construction Activity Pollution Prevention	Prerequisite	YES
10	0,2312715986	0,5727667398	0,7123624738	Minimum Indoor Air Quality Performance	Prerequisite	YES
11	0,2336482284	0,5703901100	0,7094066076	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3	YES
12	0,2336721529	0,5703661855	0,7093768521	Rapidly Renewable Materials	1	MAYBE
13	0,2386012632	0,5654370753	0,7032464103	Increased Ventilation	1	YES
14	0,2585053350	0,5455330034	0,6784912825	Construction IAQ Management Plan—During Construction	1	YES
15	0,2613887035	0,5426496349	0,6749051743	Daylight and Views—Views	1	YES
16	0,2644194936	0,5396188448	0,6711357146	Daylight and Views—Daylight	1	YES
17	0,2690004018	0,5350379366	0,6654383393	Controllability of Systems—Lighting	1	YES
18	0,2720285477	0,5320097907	0,6616721682	Water Use Reduction	2 to 4	YES
19	0,2720682672	0,5319700713	0,6616227682	Regional Materials	1 to 2	YES
20	0,2722583397	0,5317799987	0,6613863709	Construction Waste Management	1 to 2	YES
21	0,2725360227	0,5315023158	0,6610410105	Water Use Reduction—20% Reduction	Prerequisite	YES
22	0,2779911537	0,5260471847	0,6542563452	Water Efficient Landscaping	2 to 4	YES
23	0,2795415870	0,5244967514	0,6523280376	Minimum Energy Performance	Prerequisite	YES
24	0,2797603503	0,5242779881	0,6520559568	Fundamental Refrigerant Management	Prerequisite	YES
25	0,2906368545	0,5134014840	0,6385286117	Innovative Wastewater Technologies	2	YES
26	0,2914133830	0,5126249554	0,6375628262	Enhanced Refrigerant Management	2	YES
27	0,2946537125	0,5093846259	0,6335327578	Fundamental Commissioning of Building Energy Systems	Prerequisite	YES
28	0,2954511502	0,5085871882	0,6325409671	Materials Reuse	1 to 2	MAYBE
29	0,2989925003	0,5050458381	0,6281365129	Heat Island Effect—Non-roof	1	YES
30	0,3015967388	0,5024415996	0,6248975647	Recycled Content	1 to 2	MAYBE
31	0,3039114631	0,5001268754	0,6220186917	Optimize Energy Performance	1 to 19	YES
32	0,3053316990	0,4987066394	0,6202523133	Heat Island Effect—Roof	1	YES
33	0,3118441977	0,4921941408	0,6121525768	Thermal Comfort—Design	1	YES
34	0,3174784650	0,4865598734	0,6051451158	Low-Emitting Materials—Paints and Coatings	1	YES
35	0,3205236021	0,4835147364	0,6013578125	Low-Emitting Materials—Flooring Systems	1	YES
36	0,3232782788	0,4807600597	0,5979317611	Construction IAQ Management Plan—Before Occupancy	1	MAYBE
37	0,3238034540	0,4802348844	0,5972785892	Low-Emitting Materials—Adhesives and Sealants	1	YES
38	0,3631070668	0,4409312716	0,5483958296	Thermal Comfort—Verification	1	YES
39	0,3750428644	0,4289954741	0,5335510181	Certified Wood	1	NO
40	0,4279612611	0,3760770773	0,4677352551	Indoor Chemical and Pollutant Source Control	1	NO
41	0,4515651973	0,3524731412	0,4383785254	Site Development—Maximize Open Space	1	NO
42	0,4550013487	0,3490369898	0,4341049090	Alternative Transportation—Parking Capacity	2	NO
43	0,4598798097	0,3441585288	0,4280374608	Measurement and Verification	3	NO
44	0,4818539265	0,3221844119	0,4007077729	Outdoor Air Delivery Monitoring	1	NO
45	0,5021427780	0,3018955604	0,3754740863	Stormwater Design—Quantity Control	1	NO

(*continued on next page*)

Table 7 (*continued*)

Rank	Separation Measures		Closeness Coefficient (Ci*)	Ranking List Of Credits according to Ci*	Credits' Points in LEED BD + C	Credits decided as "YES", "MAYBE" or "NO"
	S_i^+ (distance from the positive ideal solution)	S_i^- (distance from the negative ideal solution)	Ci* = Si/(Si' + Si*) 0 < Ci* <1, i= 1,2, …m			
46	0,5029114304	0,3011269080	0,3745180965	Stormwater Design—Quality Control	1	NO
47	0,5058835255	0,2981548129	0,3708216371	Low-Emitting Materials—Composite Wood and Agrifiber Products	1	NO
48	0,5102526377	0,2937857008	0,3653876771	Light Pollution Reduction	1	NO
49	0,5413454481	0,2626928903	0,3267168713	Green Power	2	NO
50	0,5670082585	0,2370300799	0,2947994748	Enhanced Commissioning	2	NO
51	0,6117550155	0,1922833229	0,2391469582	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3	NO
52	0,6144883147	0,1895500237	0,2357474944	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1	NO
53	0,7146205963	0,0894177421	0,1112107941	On-Site Renewable Energy	1 to 7	NO
54	0,7330859457	0,0709523928	0,0882450368	Brownfield Redevelopment	1	NO

the credits that are out of scope of the project. To validate the GB-CS tool, the credits ranked by the GB-CS tool and the credits selected in the actual checklist were compared. For example, credit called "Site Development—Protect or Restore Habitat" was marked as "YES" in the original LEED checklist in the case study and it ranks first according to its closeness coefficient (0,9432733231) retrieved from the GB-CS tool. This credit provides one point for the project based on the LEED checklist. On the other hand, "Brownfield Development" already marked as "NO" in the LEED checklist ranks the 54th credit according to its closeness coefficient (0,0882450368).

The 16 credits that the LEED team marked as "NO" in the checklist gained the lowest relative closeness (C_i^+) values, and were successfully ranked last in the GB-CS tool. Identifying these 16 credits shows that the hybrid GB-CS tool was successfully able to determine the credits that are out of the scope of a project and are not to be implemented by the project teams. The ranking of credits that were marked as "YES" and "MAYBE" shows that four credits that were marked as "MAYBE" were ranked higher than they were supposed to be. These credits were "Rapidly Renewable Materials", "Recycled Content", "Material Reuse", and "Construction IAQ Management Plan-Before Occupation", and they were in the 12th, 28th, 30th, and 36th credits in the ranking, respectively. The feedback from the LEED team indicated that the reason they marked three of these credits (i.e., Rapidly Renewable Materials, Recycled Content, and Material Reuse) as "MAYBE" was related to material unavailability. A relatively higher cost was also another factor for not selecting these four credits in the first place. These results show that the developed hybrid MADM tool successfully ranked the GB certification credits that are more likely to be obtained in an efficient and effective manner considering the significant project team-related attributes.

6. Discussions

The GB-CS tool can be used to prevent disruptions and bottlenecks in the GB project delivery process by assisting the owners/GB consultants in selection of suitable credits that can be efficiently met in the project. In the LEED Rating System, the required thresholds for LEED Platinum, Gold, Silver, and Certified are 80, 60, 50, and 40 points, respectively. The decision makers can use these relative closeness values and the ranking list to integrate each credit's environmental points to select appropriate credits and meet LEED requirements. Thus, with the assistance of the GB-CS tool, the root causes of waste can be mitigated in the GB project delivery process, decreasing associated hidden costs. The GB-CS tool can also assist GB consultants/owners in determining which level of certification can be achieved under existing circumstances by taking into consideration of the credits with higher C_i^+ values.

The outputs of the GB-CS tool can be used by the owner to assess the competency of existing projects and project teams before deciding to follow a GB certification system. If the relative closeness values (C_i^+) that are retrieved from the GB-CS tool are low, this indicates that selected project teams might not be qualified to meet the unique requirements of these credits and/or the project teams were not involved in the process in a timely fashion. If these credits are to be selected, the project managers need to improve the project team's qualifications or involvement level. For example, the most important credit in promoting energy efficiency in buildings is "optimize energy performance", since up to 19 points can be obtained. However, its *relative closeness value* is 0.6220 in the case study. If the owner prefers to choose this credit, s/he can hire an Energy Modeling expert, who is a LEED AP and BEMP, and who has sufficient experience (i.e., 10 years of experience) in LEED Rating Systems. If this specialist is involved in the early Schematic Design, his/her qualifications would drastically increase the design efficiency and prevent accumulation of excessive time and costs in subsequent phases of the project. Moreover, if the GB-CS tool is utilized before project teams are selected, it can be employed as a guideline in team building and in properly timing project teams' involvement.

7. Conclusions

This paper presented a MADM tool to aid GB consultants/owners in the selection of appropriate GB certification credits that are more likely to be fulfilled efficiently in a residential project. The attributes that were used in this tool were based on the project team attributes that are identified to be crucial in the GB certification process. When developing the GB-CS tool, a novel hybrid approach was used: the TOPSIS was integrated with MAUT to represent varying relative weights. The developed tool ranked the GB certification credits based on the project team attributes, which were hierarchically defined under "qualifications of project team" and "timing of project teams' involvement". The performance scores of the attributes are to be entered for each credit by decision makers, and the tool will provide the preference order of the credits (i.e., ranking list) according to the credits' relative closeness (C_i^+) values.

The findings of the study include the relative weights of hierarchically created project team attributes, which were determined via the Delphi method based on expert opinion. The results demonstrate that the owner's and architectural team's qualifications and timing of involvement attributes have the highest weights compared with the other teams' values; therefore, it can be stated that both teams significantly affect project outcomes in terms of time, cost and sustainability.

A case study was conducted to determine if the developed tool can be effectively used for selecting the appropriate GB certification credits. The ranking of credits obtained from the GB-CS tool were compared with the credits that were actually selected by the Sustainable Projects Coordinator in the case study, and the similarities and differences between the two were determined and discussed. The results demonstrated that the developed hybrid MADM tool successfully ranked the GB certification credits that are more likely to be obtained in an effective manner considering the significant project team-related attributes.

The practitioners can use the GB-CS tool to (1) rank the LEED credits based on based the project team attributes, (2) select the most appropriate credits by combining this ranked list with the cost of each credit for the project of interest. The GB-CS tool can be used by owners/GB consultants to prevent disruptions and bottlenecks in the GB project delivery process by selecting the appropriate credits. This selection can mitigate root causes of waste in the GB project delivery process, thereby decreasing associated hidden costs. This tool can also be used by the owner to assess the competency of existing projects and project teams before deciding to follow a GB certification system. Similarly, it will provide proactive guidance for more efficient team building and timely involvement of project teams to successfully deliver GB projects. Moreover, this integrated tool can assist owners/GB consultants in determining which level of certification can be achieved under existing circumstances. The GB-CS tool was developed for owners/GB consultants, but a similar methodology can be also adapted for designers or design-builders. By using this tool, the time spent on selecting LEED credits for implementation will be reduced, and some negative aspects of GB certification on project's success will be minimized.

By following the MADM tool development methodology that is described in this paper, this hybrid methodology can be adapted to solve other complex decision making problems which intend to rank alternatives using a large set of attributes and alternatives with varying relative weights. Furthermore, the same tool integrated methodology can be adapted for the other versions of the LEED BD + C rating system or for different GB certification programs after reassessing relative weights of the credits of the selected LEED rating system or the selected certification program. Previous studies focused on the comparison of international and/or national GB certification programs (e.g., Green Building Evaluation Label (GBEL), Italian National Rating System (ITACA), Turkish Green Building Council (CEDBIK) - Housing Certification, BREEAM, DGNB, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) and Green Star) showed that their main categories are similar (i.e. energy, water, materials, site and indoor environmental quality) [2,15,30,32,55,56]. Due to the similarities among the GB rating systems' main categories, implications of the GB-CS tool in the countries not using LEED rating system could be feasible.

A limitation of this study is that the GB-CS tool does not consider the cost of fulfilling each credit, although that is a decision factor in selecting the credits. The reason for this limitation is that cost information regarding each credit in a LEED rating system is limited in GB literature [31,33,57,58]. The practitioners can use this tool to rank the credits and integrate with their internal cost data in the next step before making a final decision. A future direction would be advancing this hybrid tool by integration of cost information regarding each credit.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.buildenv.2017.09.028.

References

[1] D. Riley, M. Magent, M. Horman, Sustainable metrics: a design process model for high performance buildings, in: Building for the Future: the 16th CIB World Building Congress, CIB World Building Congress, Rotterdam, Netherlands, 2004.
[2] C.J. Kibert,). Sustainable Construction. Green Building Design and Delivery, John Wiley & Sons, Inc, 2016.
[3] W. Reed, E. Gordon, Integrated design and building process: needed research and methodologies, Build. Res. Inf. 28 (5/6) (2000) 325–337.
[4] BHKR., Achieving Architectural and Engineering Collaboration in Building Design. (White Paper) Butler, PA: Burt Hill Kosar Rittelmann Associates, 2003.
[5] S. Korkmaz, D.R. Riley, M. Horman, Piloting evaluation metrics for sustainable high-performance building project delivery, J. Constr. Eng. Manage. 136 (8) (2010) 877–885.
[6] H. Rohracher, Managing the technological transition to sustainable construction of buildings: a socio-technical perspective, Technol. Analysis Strategic Manag. 13 (1) (2001) 137–150.
[7] L.B. Robichaud, V. Anantatmula, Greening project management practices for sustainable construction, J. Manage. Eng. 27 (1) (2011) 48–57.
[8] A. Ofori-Boadu, D. Owusu-Manu, D. Edwards, G. Holt, Exploration of management practices for LEED projects: lessons from successful green building contractors, Struct. Surv. 30 (2) (2012) 145–162. https://doi.org/10.1108/02630801211228743.
[9] N. Singhaputtangkul, A decision support tool to mitigate decision making problems faced by a building design team, Smart Sustain. Built Environ. (2012). https://doi.org/10.1108/SASBE-06-2016-0009. ISSN: 2046-6099.
[10] P. Gultekin, S. Mollaoglu-Korkmaz, D. Riley, R. Leicht, Process indicators to track effectiveness of high-performance green building projects, J. Constr. Eng. Manage. 139 (12) (2013).
[11] A.A. Banawi, Improving Construction Processes by Integrating Lean, Green, and Six-sigma (Ph.D. Dissertation), Department of Civil and Environmental Engineering. University of Pittsburgh, 2013.
[12] M.G. "Matt" Syal, S. Mago, S, D. Moody, Impact of LEED-NC credits on

contractors, J. Archit. Eng. 13 (4) (2007) 174–179.
[13] R.J. Yang, P.X.W. Zou, Stakeholder-associated risks and their interactions in complex green building projects: a social network model, Build. Environ. 73 (2014) 208–222.
[14] L. Swarup, S. Korkmaz, D. Riley, Project delivery metrics for sustainable, high performance buildings, J. Constr. Eng. Manage. 137 (12) (2011) 1043–1051.
[15] S.O. Attallah, A. Kandil, A. Senouci, H. Al-Derham, Multicriteria decision-making methodology for credit selection in building sustainability rating systems, J. Archit. Eng. 23 (2) (2017) 04017004.
[16] H.L. Sulochana, P. Madanayake, J.Y. Ruwanpura, Multi-crıterıa decision making to improve performance in construction projects with LEED certification, in: Construction Research Congress 2012, Construction Challenges in a Flat World, ASCE, 2012, pp. 1899–1909.
[17] J.C.P. Cheng, L.J. Ma, A non-linear case-based reasoning approach for retrieval of similar cases and selection of target credits in LEED projects, Build. Environ. 93 (2) (2015) 349–361.
[18] J. Ma, J.C.P. Cheng, Data-driven study on the achievement of LEED credits using percentage of average score and association rule analysis, Build. Environ. 98 (2016) 121–132.
[19] J.O. Choi, A. Bhatla, C.M. Stoppel, J.S. Shane, LEED credit review system and optimization model for pursuing LEED certification, Sustainability 7 (2015) 13351–13377.
[20] M.A. Jun, J.C.P. Cheng, Selection of target LEED credits based on project information and climatic factors using data mining techniques, Adv. Eng. Inf. 32 (2017) 224–236.
[21] J.C.P. Cheng, L.J. Ma, A data-driven study of important climate factors on the achievement of LEED-EB credits, Build. Environ. 90 (2015) 232–244.
[22] S. Azhar, W.A. Carlton, D. Olsen, I. Ahmad, Building information modeling for sustainable design and LEED® rating analysis, Autom. Constr. 20 (2011) 217–224.
[23] S. Banihashemi, M.R. Hosseini, H. Golizadeh, S. Sankaran, Critical success factors (CSFs) for integration of sustainability into construction project management practices in developing countries, Int. J. Proj. Manag. 35 (2017) 1103–1119. https://doi.org/10.1016/j.ijproman.2017.01.014.
[24] F.K.T. Cheung, J.L.F. Kuen, R.M. Skitmore, Multicriteria evaluation model for selection of architectural consultants, Constr. Manag. Econ. 20 (7) (2002) 569–580.
[25] E. Turban, J.E. Aronson, T.P. Laing, R. Sharda, Decision Support and Business Intelligence Systems, eighth ed., Prentice Hall, New Jersey, 2007.
[26] S. Seyis, E. Ergen, E. Pizzi, Identification of waste types and their root causes in green-building project delivery process, J. Constr. Eng. Manage. 142 (2) (2015), https://doi.org/10.1061/(ASCE)CO.1943-7862.0001038.
[27] J.C. Cheng, L.J. Ma, A study of the relationship between credits in the LEED EB& OM green building rating system, IACSIT Int. J. Eng. Technol. 5 (2013) 438–442.
[28] T. Kasim, H. Li, Y. Rezgui, BREEAM: based dynamic sustainable building design assessment, in: 19th EG-ICE International Workshop on Intelligent Computing in Engineering, 2012.
[29] US Green Building Council (USGBC), 2015. https://www.usgbc.org/articles/usgbc-announces-international-rankings-top-10-countries-leed-green-building. (Accessed 9 September 2017).
[30] S. Mollaoglu, C. Chergia, C.E. Ergen, M. Syal, Diffusion of green building guidelines as innovation in developing countries, Constr. Innov. 16 (1) (2016) 11–29. https://doi.org/10.1108/CI-09-2014-0045.
[31] L.O. Ugur, N. Leblebici, An examination of the LEED green building certification system in terms of Construction costs, in: Renewable and Sustainable Energy Reviews, Article in Press, June 2017. Available online 7.
[32] O. Suzer, A comparative review of environmental concern prioritization: LEED vs other major certification systems, J. Environ. Manage. 154 (2015) 266–283.
[33] A.P. Gurgun, D. Arditi, P.C. Vilar, Impacts of construction risks on costs in leed-certified projects, J. Green Build. Fall 11 (4) (2016) 163–181.
[34] B. Aktas, B. Ozorhon, Green building certification process of existing buildings in developing countries: cases from Turkey, ASCE J. Manag. Eng. (2015), https://doi.org/10.1061/(ASCE)ME, 1943-5479.0000358, 05015002.
[35] B.I. Dincer, C.O. Colpan, F. Kadioglu (Eds.), Causes, Impacts and Solutions to Global Warming, Springer, NY Heidelberg Dordrecht London, 2013.
[36] US Green Building Council (USGBC), LEED 2009 for New Construction and Major Renovations Rating System, 2009.
[37] E. Triantaphyllou, Multi-criteria Decision Making Methods: a Comparative Study, Kluwer Academic Publishers, The Netherlands, 2000.
[38] M. Behzadian, S.K. Otaghsara, M. Yazdani, J. Ignatius, A state-of the-art survey of TOPSIS applications, Expert Syst. Appl. 39 (17) (2012) 13051–13069.
[39] M. Velasquez, P.T. Hester, An analysis of multi-criteria decision making methods, Int. J. Operations Res. (IJOR) 10 (2) (2013) 56–66.
[40] K. Kabassi, M. Virvou, A knowledge-based software life-cycle framework for the incorporation of multicriteria analysis in intelligent user interfaces, IEEE Trans. Knowl. Data Eng. 18 (9) (2006) 1265–1277.
[41] P. Nijkamp, P. Rietvelt, H. Voogd, Multi-criteria Evaluation in Physical Planning' Amsterdam: North-Holland, Elsevier Science Publishers, B.V., Amsterdam, The Netherlands, 1990.
[42] M. Weber, K. Borcherding, Behavioral influences on weight judgments in multi-attribute decision making, Eur. J. Operational Res. 67 (1993) 1–12.
[43] N.C. Dalkey, D.L. Rourke, R. Lewis, D. Synder, Studies in the Quality of Life, Lexington Books, Lexington, MA, 1972, pp. 55–83.
[44] F. Hasson, S. Keeney, Enhancing rigour in the Delphi technique research, Technol. Forecast. Soc. Change 78 (9) (2011) 1695–1704.
[45] M.R. Hallowell, J.A. Gambatese, Qualitative research: application of the Delphi method to CEM research, J. Constr. Eng. Manage. 136 (1) (2010) 99–107.
[46] H.-S. Shih, H.-J. Shyur, E.S. Lee, An extension of TOPSIS for group decision making, Math. Comput. Model. 45 (2007) 801–813.
[47] C. Mapp, M.E.E. Nobe, B. Dunbar, The Cost of LEED - an analysis of the construction costs of LEED and non-LEED banks, JOSRE 3 (1) (2011) 254–273.
[48] I.A. Curtis, Valuing ecosystem goods and services: a new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes, Ecol. Econ. 50 (3–4) (2004) 163–194.
[49] V.W. Mitchell, The Delphi technique: an exposition and application, Tech. Anal. Strat. Manage. 3 (4) (1991) 333–358.
[50] H.S. Cha, J.T. O'Connor, Optimizing implementation of value management processes for capital projects, J. Constr. Eng. Manage. 131 (2) (2005) 239–251.
[51] G. Rowe, G. Wrigt, Expert opinions in forecasting: the role of the Delphi technique, Princ. Forecast. Int. Ser. Operations Res. Manag. Sci. 30 (2001) 125–144.
[52] M.F. Teisl, K.J. Boyle, D. McCollum, S.D. Reiling, Test–retest reliability of contingent valuation with independent sample pretest and posttest control groups, Am. J. Agric. Econ. 77 (3) (1995) 613–619.
[53] C. Okoli, S.D. Pawlowski, The Delphi Method as a research tool: an example, design considerations and applications, Inf. Manag. 42 (1) (2004) 15–29.
[54] TOKI. (2014). http://www.toki.gov.tr/en/housing-programs.html, (accessed 15 September 2015).
[55] Retrieved from, CEDBIK (Turkish Green Building Council), 2016, http://www.cedbik.org/imagess/file/CEDBIK-KONUTSERTIFIKAKILAVUZU-Haziran-2016.PDF.
[56] F. Asdrubali, G. Baldinelli, F. Bianchi, S. Sambuco, A comparison between environmental sustainability rating systems LEED and ITACA for residential buildings, Build. Environ. 86 (2015) 98–108.
[57] N. Stegall, Cost Implications of LEED Silver Certification for New House Residence Hall at Carnegie Mellon University, (Senior Honors Research Project). Carnegie Institute of Technology, Department of Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA, 2004.
[58] GSA., LEED Cost Study Final Report, Retrieved from, 2004, October, https://archive.epa.gov/greenbuilding/web/pdf/gsaleed.pdf.