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2-Tuple Based VIKOR Methodology for Green Building Certification Selection

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Abstract—**Decision-making is a process encountered in everyday life and is used for evaluating different alternatives in the light of various criteria. Unfortunately, in this process, the data are not always accurate enough to obtain definite and optimum results. The uncertainty of data can quickly increase as information from different sources increases, leading decision makers to seek new approaches to reduce this uncertainty and create stable environments for decision-making. One of these approaches is linguistic decision making (LDM), where linguistic variables are used. The 2-Tuple linguistic model is an extension of these approaches. This study aims to propose a multi-criteria decision-making (MCDM) model with its 2-Tuple extension to overcome this imprecision. Also, to test the applicability of the proposed technique an application for a green building certification selection problem is provided.**

Index Terms—**2-Tuple linguistic representation, Green building certification selection, MCDM, VIKOR**

I. Introduction

In psychology, decision-making is a cognitive process where a selection of anything among other alternatives is sought. These processes are based on analyzing the alternatives and identifying their advantages over others by an individual to select the best one for him/herself.

We make selections in every part of our lives, and usually with different criteria. Decision making in this sense is an everyday practice. Making the right decision is very important at every level of these processes. Decision Makers (DMs) try to use their experience, knowledge, and sometimes intuition to decide which of the options is the best. The decision-making process in principle contains five consecutive essential steps. These are identifying the aim or describing the problem; investing problems and establishing priorities; generating alternatives; investing and evaluating options; detecting decision criteria and making a decision.

Nowadays, especially in business life, decision-making with multiple criteria (MCDM) has become excessively complicated. New challenges have been added to the evaluation, such as quickness and effectiveness of getting to the solution. In this environment, another goal of decision-making approaches has become the speed of modelings and simplicity of the algorithm to identify the most suitable answer faster and easier. To accomplish these goals, many different approaches have been developed, such as Analytical Hierarchical Process (AHP), Analytical Network Process (ANP), TOPSIS, ELECTRE, VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje) [1] etc.

These approaches are based upon scenarios where the input data are numerical and certain. However, in real life problems and solutions are not always that precise and numeric. Therefore, we need to use non-deterministic extensions of these approaches to handle the uncertainty in the data provided by the DMs. Non-deterministic methods are usually based on probabilistic approaches, but sometimes decision data could have a nonprobabilistic character that is related to uncertainty derived from DMs [2]. In such situations, the use of linguistic variables for DMs' assessments can be suitable. Linguistic variables are based on the fuzzy logic rather than probabilistic values, and they lead up to a linguistic decision making (LDM) approach. 2-Tuple linguistic representation, which is a tool for LDM, is a simple, robust and powerful method to work with semantic descriptions in decision-making. For that reason, 2-Tuple-based VIKOR method is employed in this study. Opricovic and Tzeng [3] first introduced this method for a selection problem. VIKOR method was chosen over other alternative methods due to its power to reflect the opinion of all DMs on the compromise solution [4]. Although VIKOR is a very widely used MCDM technique, it can only process numerical data and cannot reflect vague and subjective information [5]. For this reason, a2-Tuple extension of VIKOR is defined as MCDM method for uncertain environments for this study.

To test the applicability of the 2-Tuple, this integrated method is applied to a selection problem ina Turkish university. The primary objective of this application is to choose the most appropriate green building certification system for a retrofitting of the university building. Since Turkey does not have a national green building assessment system, the best option is to use one of the international ones that suit the university's requirements.

This study is organized as follows: The next part contains a literature review of the methodology and building assessment systems. Then, an application of the proposed method is provided with detailed steps. Next, results and

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discussions are given, and finally, conclusions and acknowledgments are provided.

II. LITERATURE REVIEW

In this study, the following literature research is crucial due to the following reasons:
A detailed literature review has been done to evaluate and identify those MCDM techniques that are used together with 2-Tuple extensions. Then, an elaborated literature review has been done about building certification schemes. Evaluation criteria are generated by this literature survey, university administration, and experts.

A. 2-Tuple Linguistic Model and MCDM

Herrera and Martinez first presented this model in 2000 [6]. Later on, many other studies discussed the approach. In 2015, Kahraman et al. [7] made an extensive literature review about fuzzy MCDM and recent studies about 2-Tuple-based techniques, which are discussed next.
The 2-tuple linguistic model and its extensions have been applied to a wide variety of topics, mainly for decision-making and decision analysis problems [8]. These applications range from evaluation processes for different aims such as industrial processes, resource management, internet-based purposes, human resources and so on. Various analytical techniques are used with 2-Tuple to study these subjects.
The 2-Tuple model is a useful way to deal with various forms of linguistic information. For this purpose, in 2001 Herrera and Martinez presented its advantages and computational steps to deal with multi-granular linguisticinformation[9]. Its strengths and computational steps to deal with non-homogenous information are given in [8]. Later, Martinez and Herrera extend the application area of the2-Tuple model to engineering evaluations [10], safety and cost analysis [11] and sensory evaluations.
These applications led to novel studies in the evaluation literature, such as evaluation model for intellectual capital of enterprise [12], and supplier evaluation [13][14]. On the other side, fuzzy linguistic is a very widely used methodology with the 2-Tuple method. Different subjects are studied with fuzzy linguistic integrating the2-Tuple model.
The 2-Tuple is also used with different analytical MCDM methods, such as VIKOR in human resource (HR) evaluation methodology [15]. VIKOR method is one of the most preferred ways with the 2-Tuple in the literature in selection problems. It has been applied to material selection problem [16], and site selection for waste management [17]. Another preferred 2-Tuple-based MCDM method is TOPSIS. It has been used for robot evaluation and selection [18] and personnel selection[19].
Other 2-Tuple-integrated MCDM methods have also been applied, such as DEMATEL for calculating the CO_2 capture in iron and steel industry with Delphi method [20] and for health-care waste treatment with MULTIMOORA [21]. MULTIMOORA has also been combined with the 2-Tuple in SERVQUAL-SICTQUAL for quality service in ICT sector [22].

VIKOR method is a highly preferred method for selection problems due to its power to reflect the opinion of all DMs on the compromise solution [23]. In this study, 2-Tuple-based VIKOR is applied to create a flexible linguistic environment enabling DMs to better express their judgments and to form a robust compromise solution.

B. Green Building Certification Systems

The construction sector is a vital industry for many economies. It has a significant role in combatting climate change due to its effects on its environment. This role should be considered with a view to the global effort to reduce after-effects of human traces on the planet. The construction sector, therefore, comes up with innovative solutions to decrease its environmental footprint. These “green building” solutions help buildings to reduce their effects on the environment. Sustainable building systems and architectural approaches can be coupled with sustainable design criteria to achieve these goals.
At the beginning of the 1970s when the northern countries started to seek the path for new policies for developments, the environmental concept of the events have been accentuated. Then with the United Nation’s Environment and Development in Stockholm, this ecological component of the development policies has expanded through the world politics [24]. Amid these speeches about ecological concepts, sustainable development policies have been generated. As a result, the new architectural point of view about sustainable building design has grown by the end of the 70s.
Then in the80s, the notion “green” became more popular as consumption and production patterns got increasingly unsustainable, with their direct and indirect environmental impacts becoming more visible. Healthy, organic and environmentally friendly building designs took a prominent place in building models and human consciousness.
Nowadays, there exist several different building rating systems to construct healthy environments. Many of these systems are built upon each other[25]. Their development path and detailed information are given in Table I.

TABLE I
BUILDING CERTIFICATION SYSTEMS

Assessment System	Origin	Based-on
BREEAM (Building Research Establishment Great Britain Environment Assessment Method)	England	First assessment system
HQE (Haute Qualité Environnementale)	France	BREEAM
LEED (Leadership in Energy and Environmental Design)	USA	BREEAM
GreenGlobe	Canada	BREEAM
CASBEE	Japan	BREEAM. LEED
Green Star	Australia	BREEAM. LEED
GBAS (Green Building Assessment System)	China	BREEAM. LEED. CASBEE
DGNB	German	LEED. BREEAM. CASBEE. HQE. Green Star
Protocollo Italia	Italy	SB Tool
TQ (Total Quality)	Austria	SB Tool
SBTool Portugal	Portugal	SB Tool
SBTool CZ	Czech Republic	SB Tool
VERDE	Spain	SB Tool

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1) Selecting Building Assessment Systems for Case Study

As shown in Table I, BREEAM is the origin of most of these systems. So, in this study, the first alternative for the university will be the BREEAM(A1) system. Other systems that are identified as alternatives are LEED (A2), GreenStar (A3), DGNB(A4) and CASBEE(A5).For this application, the selection will be made between these five green building evaluations systems. Since Turkey does not have its own national retrofitting building assessment system, choosing the most suitable one to use is the best solution.

III. CASE STUDY: GREEN BUILDING CERTIFICATION SYSTEM SELECTION

The defined problem for the case study is the building certification system selection. Considering that Turkey is an emerging country, sustainability has its special place in the future of the country. However, there is no national building assessment system. ABC University in Turkey wants to choose the most appropriate certification system according to certain selection criteria to retrofit its buildings. The main steps of the application are as follows:

1. Identifying university's criteria for certification,
2. Analysing certification systems,
3. Choosing the most appropriate building certification system according to university's criteria with 2-Tuple-based VIKOR

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Step 1: Identifying university's criteria with the help of a literature review and expert opinions. The criteria list is provided in Table II.

TABLE II
UNIVERSITY CRITERIA FOR A CERTIFICATION SYSTEM

Evaluation Criteria	Context
Applicability (R1)	It is the ability to apply the system to the different conditions of the various environment such as Turkey. In addition, it is related to the size of the data needed for the assessment.
Social (R2)	The system can think of the local area and the building's occupants.
Energy efficiency (R3)	It is about the environmental concerns and the energy reduction power of the assessment system.
Economic evaluation (R4)	It is the economic assessment power of the system.
Flexibility (R5)	It is the potential of the assessment system to handle the innovations in structures.
Management (R6)	The power of managerial aspects of the assessment system.

Step 2: Assessing certification systems according to criteria by experts.

At this step, the critical point is the aggregation of experts' evaluations. Two experts are chosen as advisors in this selection problem, and different scales are assigned to them due to the difference of their experience about the subject. Their hierarchical scales are provided in Fig. 1. The first expert is given a five-scaled linguistic variable set, and the second expert is given a nine-scaled linguistic variable set. They are then aggregated with the 2-Tuple linguistic model. In the 2-Tuple linguistic model, a transformation equation is used for normalization of label sets with different granularity. The relations are given by the following equation [2]:

$$TF_{t'}^{t}(S_i^{n(t)},\alpha^{n(t)}) = \Delta\left(\frac{\Delta^{-1}(S_i^{n(t)},\alpha^{n(t)})\cdot(n(t')-1)}{n(t)-1}\right) \quad (1)$$

Here, TF is the transformation function for linguistic hierarchies (LH), and the transformation of LH is from t^{th}level to t'^{th} level.

First, the definition of the 2-Tuple representation is necessary to evaluate the assessments [1]:

Definition 1: The 2-Tuple fuzzy linguistic representation model represents the linguistic information using a 2-Tuple (S, α), where S is a linguistic label and α is a numerical value that represents the value of the symbolic translation. The function is defined as:

$$\Delta_s:[0,g]\rightarrow \overline{S}$$
$$\Delta_s(\beta)=(S_i,\alpha), with\begin{cases} i = round(\beta) \\ \alpha=\beta-i \end{cases} \quad (2)$$

And the reverse function is defined as follows:

$$\Delta_s^{-1}:\overline{S}\rightarrow[0,g]$$
$$\Delta_s^{-1}(\beta)=i+\alpha \quad (3)$$

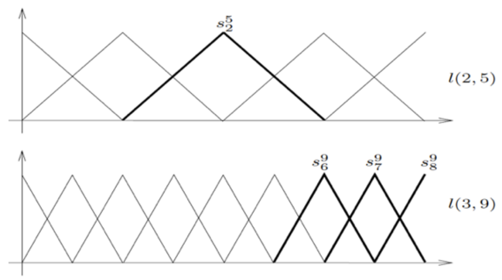

Fig. 1. Second level five-scaled (None-Low-Medium-High-Perfect) and the third level nine-scaled (None-Very Low-Low-Almost Medium-Medium-Almost High-High-Very High-Perfect) hierarchy of letters [1]

Definition 2: Let $F(S_T)$ be a fuzzy set in the basic linguistic term set (BLTS), χ a function that transforms such a fuzzy set into a 2-tuple linguistic value as:

$$\chi: F(s_T)\rightarrow \overline{S_T}$$
$$\chi(F(s_T))=\Delta\left(\frac{\sum_{j=0}^{g} j.\gamma_j}{\sum_{j=0}^{g}\gamma_j}\right)=\Delta(\beta)=(s,\alpha) \quad (4)$$

where γ_i is the membership function of the fuzzy sets related to the linguistic terms S_T, g is the granularity of the linguistic term set $F(S_T)$.

Definition 3: The linguistic term set S could be converted into the 2-Tuple form by adding a zero value, as in the following relation:

$$S_i \in S \rightarrow (S_i, 0) \quad (5)$$

Definition 4: Let (S_i, α_i) and (S_j, α_j) be two linguistic 2-Tuples, each representing a linguistic assessment [2]:

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1. If $i<j$ then (Si, α_i) is smaller than (S_j, α_j).
2. If $i = j$ then
3. If $\alpha_i = \alpha_j$ then (Si, α_i) and (S_j, α_j) represent the same information. (6)
4. If $\alpha_i<\alpha_j$ then (Si, α_i) is smaller than (S_j, α_j).
5. If $\alpha_i>\alpha_j$ then (Si, α_i) is bigger than (S_j, α_j).

Different granulated assessments of experts have shown in Table III.

Step 3: Applying the 2-Tuple-based VIKOR to choose the most appropriate certification system.

In VIKOR, every alternative is assessed with different criteria, and its proximity to the ideal solution is the primary parameter to rank them. The basis of ranking alternatives is coming from L_p criteria which are shown in the following formula:

$$L_{pj} = \left\{ \sum_{i=1}^{n} \left[\frac{W_i(f_i^* - f_{ij})}{f_i^* - f_i^-} \right]^p \right\}^{1/p} ,1 \le p \le \infty, j = 1,2...m \quad (7)$$

where W_i is the weights assigned to the selection criteria.

TABLE III
ASSESSMENTS OF EACH EXPERT FOR ALTERNATIVES

IMP.	R1 AH		R2 VH		R3 P		R4 P		R5 VH		R6 VH	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
A1	P	P	L	L	M	M	L	VL	M	AM	L	L
A2	L	L	L	VL	P	P	N	N	H	VH	L	L
A3	M	M	L	L	H	VH	N	N	P	P	P	P
A4	H	VH	P	P	M	AM	P	P	M	M	H	VH
A5	L	VL	M	M	H	VH	N	N	N	N	M	AM

Next, obtain the common decision matrix and continue with the VIKOR steps. First, the decision matrix should be aggregated under the same granularity. For that purpose, five-scaled linguistic variables should be transformed into nine-scaled, since nine is the highest granularity of the term sets [22]. Initially, the linguistic terms set is transformed into the 2-Tuple form with (5); then LH is applied with (1) for the transformation from the second level to the third level. As an example; the relation between A1-R1 is given below:

A1-R1 is assessed Perfect(P) by the first expert in S^5.Using (5); it could be represented as $(P,0)$ in S^5. Then by applying (1):

$$TF_3^2(S_4^5,0) = \Delta(\frac{\Delta^{-1}(S_4^5,0).(9-1)}{5-1}) = \Delta(8) = (S_8^9,0)$$

The 2-Tuple values under the nine-scaled terms sets are obtained. Later, the aggregation of normalized values is accomplished with *OWA* operator using (7):

$$\bar{x} = \left(\frac{\sum_{i=1}^{n} \Delta^{-1}(r_i,\alpha_i) \times \Delta^{-1}(w_i,\alpha_i)}{\sum_{i=1}^{n} \Delta^{-1}(w_i,\alpha_i)} \right) \quad (8)$$

where, (r_i,α_i) is the nine-scaled assessment of each alternative and criteria pair, (w_i,α_i) stands for the weights of experts and n represents the number of experts (2 for this case study). The aggregated decision matrix is presented in Table IV.

TABLE IV
AGGREGATED DECISION MATRIX

Imp.	(AH,0) R1	(VH,0) R2	(P,0) R3	(P,0) R4	(VH,0) R5	(VH,0) R6
A1	(VH,0.31)	(VL,0)	(M,0.34)	(VL,0.34)	(AM, 0)	(L,0)
A2	(L,0)	(VL, 0.34)	(VH, 0.31)	(N,0.34)	(H, 0.31)	(L,0)
A3	(AM,0.34)	(L,0)	(H, 0.31)	(N,0.34)	(H, 0.31)	(H, 0.31)
A4	(H, 0.31)	(VH, 0.31)	(AM, 0)	(VH, 0.31)	(AM,0.34)	(H, 0.31)
A5	(L, 0.34)	(M,0.34)	(H, 0.31)	(N,0.34)	(N,0.34)	(AM, 0)

As a result, the weighted and aggregated decision matrix is obtained by computing with the 2-Tuple-based VIKOR steps to achieve the most appropriate selection. Its steps are as follows:

1. Find the best (f^*_i,α_i) and the worst values (f_i^-,α_i).For the criteria that have the best utility values are the maxima of each column, and the worst values are the minima of each column. However, for criteria that have a cost property, the best values are the minima and the worst values are the maxima of each column. The 2-Tuple values in the decision matrix are compared with (6).

2.Normalize the decision matrix.

3. Determine the (R_j,α_i) and (S_j,α_i)values from the following formulations:

$$(S_i,\alpha_i) = \sum \frac{\Delta^{-1}(v_i,\alpha_i) \times (\Delta^{-1}(f_i^*,\alpha_i) - \Delta^{-1}(f_{ij},\alpha_i))}{\sum_{j=1}^{t} \Delta^{-1}(v_i,\alpha_i) \times (\Delta^{-1}(f_i^*,\alpha_i) - \Delta^{-1}(f_i^-,\alpha_i))}$$
$$(R_j,\alpha_j) = \max_j \left[(S_i,\alpha_i) \right] \quad (11)$$

where $(v_i, \alpha_i)$are the weights assigned by experts for the i^{th} criteria, t is the number of criteria.

4. Calculating (Q_j, α_j) values for each alternative with the following relation:

$$(Q_j,\alpha_j) = \Delta \left(\left(\frac{q \times \Delta^{-1}(S_i,\alpha_i) - \Delta^{-1}(S^*,\alpha^*)}{\Delta^{-1}(S^-,\alpha^-) - \Delta^{-1}(S^*,\alpha^*)} \right) + \left(\frac{(1+q) \times \Delta^{-1}(R_i,\alpha_i) - \Delta^{-1}(R^*,\alpha^*)}{\Delta^{-1}(R^-,\alpha^-) - \Delta^{-1}(R^*,\alpha^*)} \right) \right) \quad (12)$$

where (S^*, α^*) is the minimum value, (S^-, α^-) is the maximum value of(S_i, α_i) values and (R^*, α^*) is the minimum value, (R^-,α^-) is the maximum value of(R_j ,α_j)values;q is the weight of the strategy that provides the highest group utility and $(1-q)$ represents the weight of the minimum regret of the opposite direction.

There are different levels of a compromise that can be achieved in VIKOR. The compromise can be achieved with “majority” $(q > 0{,}5)$, with “consensus” $(q = 0{,}5)$ or with “veto” $(q < 0{,}5)$. In this study, the q value is taken as 0,5 (“consensus” option),as consensus is the essential aim in this case.

5. Ranking of the alternatives according to the following conditions:

The building certification system alternatives are ranked according to their $(S_i,\alpha_i), (R_j,\alpha_j)$ *and* (Q_i,α_i) values in

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decreasing order. The building certification system with the minimum value of (Q_i, α_i) is the most appropriate alternative, if it satisfies the conditions below:

Condition 1: Acceptable Advantage:

$$\Delta^{-1}(Q(A^2), \alpha(A^2)) - \Delta^{-1}(Q(A^1), \alpha(A^1)) \geq DQ \quad (13)$$

where, A^1 is the best alternative with the minimum Q value, and A^2 is the second best one the second smallest Q value.

Condition 2: Acceptable Stability:

Alternative A^1 needs also to be the best ranked in the ranking of S and R. If A^1 is best ranked for all, it is possible to say that the situation is stable for the compromising process.If one of the conditions is not satisfied:

If only Condition 2 is unsatisfied, then
Alternatives A^1 with the minimum Q value and $A^2$with the second minimum Q value are the best solutions.

If only Condition 1 is unsatisfied, then alternatives from $A^1$with the minimum Q value to mth alternativefound with (14) are the best solutions for the problem.

$$\Delta^{-1}\big(Q(A^m), \alpha(A^m)\big) - \Delta^{-1}\big(Q(A^1), \alpha(A^1)\big) < DQ \quad (14)$$

IV. Results and Discussions

The alternative which has the minimum Q value (Table V) is the most appropriate one for satisfying VIKOR's solution conditions. The first condition of VIKOR (Acceptable advantage) is not held. Therefore, the second condition (Acceptable stability in decision-making) is checked for the solution, and three alternatives are found to be appropriate. These alternatives are BREEAM, DGNB, and GreenStar.
As seen from the importance of the requirements given by university directory, Energy efficiency (R3) and Economic evaluations (R4) are the most critical requirements for the university.

TABLE V
S, R and Q Valued For Each Alternative

Alt.	S_j	R_j	Q_i
A1	31.20	7.00	0.48
A2	27.46	8.00	0.88
A3	19.15	8.00	0.65
A4	13.83	8.00	0.50
A5	31.83	8.00	1.00

The DGNB alternative is the one, which contains both of the criteria highly as reported by experts. However, the other two appropriate alternatives have low economic evaluations but high qualifications. Therefore, the university can choose the most appropriate tool for itself between these three systems according to its strategy.
Three alternatives are likely to be suitable for the university's requirements according to VIKOR method. LEED, which is mostly strong in environmental issues, is not in the solution. This can be associated with the high importance of economic, social and managerial requirements of the university management.

V. Conclusions

The proposed 2-Tuple-based VIKOR methodology is applied to a university in Turkey to choose its building assessment system to renovate its buildings. As a result, BREEAM, DGNB and the GreenStar systems are found to be appropriate for the university.
In this application, the main idea was to generate an international building assessment system for a university retrofit in Turkey. Since Turkey does not have its own certification scheme, making a selection of existing systems is the best solution.
This selection problem is approached as an MCDM problem, and it contains more than one decision maker. In these types of decision-making problems, the main challenge is to provide a flexible environment for decision makers to evaluate the alternatives. At this point, in this study the 2-Tuple method is chosen due to its advantageous properties as stated in the Introduction and Methodology sections. The use of different scales for linguistic evaluations enabled the experts to assess easily with their knowledge. VIKOR provided a very convenient means of application due to its easy computational steps and proposition of the solution which is closest to the ideal.
When VIKOR is combined with the 2-Tuple, the method can handle imprecise, non-deterministic values, which contributes to a flexible decision-making process with multi-criteria.
At this point, this tool is proposed for building assessment system selection. Nevertheless, it can also be applicable to other selection problems where linguistic data present bottlenecks. The extension of this tool can also be used with more than two decision makers and even with incomplete information.
In the future, this 2-Tuple method can also be combined with other MCDM tools, such as TOPSIS, ANP, and AHP for similar problems, and other industries alike.

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