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Material Selection in Green Buildings: Optimization of Cost and CO_2 Emissions

Mehdi Ravanshadnia, Mohammad Bagher Nobakht, Niyousha Bahriyeh

***Abstract*—Material selection in green buildings is one of the important parts of construction of such buildings. It can be considered as a multi-criteria decision making problem; since not only are the environmental impacts of green buildings important, but also the invested budgets. This paper addresses this issue and aims at solving the material selection problem in the form of a multi-criteria decision making problem under two criteria: CO_2 and cost. The proposed method, integrates a very useful simulation method called fuzzy Monte Carlo simulation (FMCS) and fuzzy ordered weighted averaging (F-OWA) operator. The FMCS is utilized to evaluate the feasible alternatives under uncertainties. The F-OWA is a new method which is developed and proposed in this paper, selects the best and optimal alternative for a green building. The information of a case study is used to evaluate the workability and capabilities of the proposed method.**

Keywords—Greean buildings, Material selection, CO_2 emissions, Cost, Decision making, Fuzzy Monte Carlo Simulation

I. Introduction

Green building concept has been emerged to aid the construction industry move towards a healthier environment. Construction industry is one of the top rank contributors to the greenhouse gas emissions [1] which lead us to climate change, and consumes 50% of the total budget invested in energy [2]. Within the construction industry, buildings sector, mainly residential and commercial buildings is a sector to which the 35% of total greenhouse gas emissions is assigned, and moreover it consumes more cost and money than other sectors of the construction industry [3].

Knowing the point that costumers naturally are willing to pay as less as possible to buy a residential unit, construction of buildings which are environmentally-friendly are one of the challenges in today's societies. The reason is that implementation of green technologies and accomplishments of environmental goals in green buildings always entail high investments. This conflict has been addressed by some researchers to find solutions to this problem and create a balance between cost and environmental achievements (e.g. 2, 4-8).

Mehdi Ravanshadnia, Mohammad Bagher Nobakht, Niyousha Bahrieh
(Author)

Department of Civil Engineering, Science and Research Branch, Islamic Azad University
Tehran, Iran

In this paper, selection of building materials is considered as a significant part of the building construction to create the aforementioned balance. Materials demand 20~30% of the total cost of a building construction [9] and may have remarkable potentials to reduce the cost and environmental impacts. In this regard, this research proposes a framework to select the optimal materials. The proposed framework employs a risk assessment tool called fuzzy Monte Carlo simulation to incorporate uncertainty in measurements. The optimization procedure is done using a decision making tool which is developed in this paper and is an integration of OWA (ordered weighted averaging) operator and fuzzy sets theory.

II. The proposed framework

Every building consists of several elements and construction activities which could be done utilizing various resources and options. Combinations of these options make alternatives which can be considered as solutions to construct a building, namely a residential building. Every alternative brings a specific performance to the final product. In other words, it leads to specific CO_2 emissions and requires a particular budget depending on the characteristic of individual options. The main purpose of this research is to select the best alternative as the optimal solution to construct a building under two criteria: CO_2 emissions and cost.

A. *Objective functions*

As mentioned before, there are two criteria in this problem. It is assumed that there are two decision makers, each of which represents one of the two criteria. Thus, there are two objective functions that should be minimized:

- CO_2 emissions: The equivalent CO_2 emission of materials in their life cycle. The life cycle of the materials are summarized in five phases: 1) extraction of raw materials, 2) manufacturing and production, 3) transportation, 4) use, and 5) end of life. Therefore, the objective function for the CO_2 emissions are as follows:

$$CO_2 = \sum_{i}^{m} (E_i^{rm} + E_i^{mp} + E_i^{u} + E_i^{t} + E_i^{el}) \quad (1)$$

in which, E_i^{rm}, E_i^{mp}, E_i^{u}, E_i^{t}, and E_i^{el} are the total CO_2 emissions of the raw materials, manufacturing, transportation, use, and end of life phases, respectively, related to the material considered for activity *i*, and *m* is the total number of activities.

- Required cost: the total amount of cost that is required for 1) purchasing, 2) transportation, and 3) installation. Thus, the objective function for total cost is as follows:

$$Cost = \sum_{i}^{m}(C_i^p + C_i^t + C_i^{in}) \quad (2)$$

in which, C_i^p, C_i^t, and C_i^{in} are the total cost of purchasing, transportation, and installation phases, respectively, related to the material considered for activity *i*, and *m* is the total number of activities.

B. *Evaluation of alternatives*

The evaluation process of the alternatives is considered to be plagued by uncertainty. It is assumed that there are always sources of risk and uncertainty in measurements and evaluations. For instance, the lack of comprehensive measurement systems, human judgment, and some other causes may make our evaluations uncertain. Therefore, it is not compatible with the real situations to use precise and deterministic values. Due to these uncertainties this paper employs FMCS to evaluate the alternatives.

Fuzzy Monte Carlo Simulation [10] is a tool to deal with uncertainty and risk analysis in problems consisting of fuzzy and random inputs. For a model with both kinds of variables (probabilistic distributions: R_1, R_2, … , R_n and fuzzy sets F_1, F_2, …, F_m), sample sets are generated from the probabilistic distributions and after this procedure the model will only contain fuzzy variables.

Definition: A triangular fuzzy number $\tilde{A}$ is defined by (a, b, c), and the membership function is as follows [11]:

$$\mu_A(x) = \begin{cases} \frac{x-a}{b-a} & when\ x \in [a, b) \\ \frac{x-c}{b-c} & when\ x \in [b, c) \\ 0 & otherwise \end{cases} \quad (3)$$

The triangular fuzzy number is based on a three-point estimation, where a is the minimum possible value, b is the most possible value, and c is the maximum possible value [11]. In this paper, triangular fuzzy numbers are used as commonly used fuzzy numbers.

In the FMCS framework, then, the fuzzy arithmetic is performed for each sample set to calculate the output in the form of fuzzy sets [10]. Thus, the final output in this framework can be represented by fuzzy sets. In other words, fuzziness in incorporated into cumulative distribution functions (CDF) and fuzzy CDFs are generated (for more details see [10]).

By using these fuzzy CDFs, a decision maker is able to estimate the probability of achieving an output which is less than an acceptable threshold or is able to estimate the output based on their perception of risk or probability [10].

III. The F-OWA method

There are many decision making methods, many of them are developed to deal with precise and determined information [12]. However, it is very important to include uncertainty in decision makings, especially in the construction activities. The method proposed here employs the ordered average weighting (OWA) operator to make the final optimal decision based on the out puts of the FMCS. The reason to use the OWA operator is that it offers an adaptable tool in comparison to other multi-criteria decision making methods. The procedure in the proposed MCDM method is described in the following sub sections.

A. *Scoring the alternatives*

If we assume that there are *n* alternatives, which are combination of material options to execute the whole project, and *j* criteria, then the scoring procedure will be as the following steps:

- Formation of the decision matrix:

$$\tilde{D} = [\tilde{x}_{ij}] \quad (4)$$

In which, $\tilde{D}$ is the decision matrix, $\tilde{x}_{ij}$ is the fuzzy performance of the alternative A_i under the criteria C_j.

- Normalization of the fuzzy decision matrices

In this section the fuzzy numbers are normalized and are transformed to the range of [0 1] [11].

$$\tilde{P} = [\tilde{p}_{ij}] \quad (5)$$

$$\tilde{p}_{ij} = \begin{cases} \left(\frac{x_{ij1}}{M}, \frac{x_{ij2}}{M}, \frac{x_{ij3}}{M}\right), M = \max_i x_{ij3} & C_j\ is\ benefit\ criterion \\ \left(\frac{N-x_{ij3}}{N}, \frac{N-x_{ij2}}{N}, \frac{N-x_{ij1}}{N}\right), N = \max_i x_{ij3} & C_j\ is\ cost\ criterion \end{cases} \quad (6)$$

In this decision making problem both of the existing criteria are cost criteria, this means the smaller the value of the criteria, the better. The values in the normalized fuzzy matrix represent the cardinal scores for each alternative from the view point of each decision maker.

B. *OWA-operator*

The OWA operator is developed and introduced by Yager [13], and is a soft aggregation operator [14]. This operator has been used to develop many multi-criteria decision making methods in many fields such as engineering, expert systems, mathematical programming and some other (e.g. [14-16]). OWA is an *n*-dimensional operator, which assigns a score, S, to each alternative *i* in a multi-criteria decision making problem, while satisfies the following condition:

$$S_i^{min}(p_{i1},p_{i2},\dots,p_{in}) \leq S_i^{OWA}(p_{i1},p_{i2},\dots,p_{in}) \leq S_i^{max}(p_{i1},p_{i2},\dots,p_{in}) \quad (7)$$

Where $S_i^{OWA}: I^n \to I$ as follows:

$$S_i^{OWA}(p_{i1},p_{i2},\dots,p_{in}) = \sum_{j=1}^{n} w_j g_{ij} = w_1 g_1 + w_2 g_2 + \dots + w_n g_n, (i = 1,2,\dots,m) \quad (8)$$

Where g_j is the *j*th largest element in the set of inputs $\{p_{ij}\}$ for alternative i , which belongs to a unit interval. In this study, p_{ij} represents the score or the normalized values of alternative *i* under criterion *j* calculated in subsection A. The coefficient $w_j \geq 0$, are the order weights such that $\sum_{j=1}^{n} w_j = 1.$ It should be noted that the components of the input vector are ordered before multiplying the order weights to them [16]. Obviously, these order weights are are related to an ordered position [14]. Because of these features, OWA is capable of providing optimal solution and brings proximate satisfaction to all decision makers.

The order weights are related to the degree of perception of risk by decision makers. According to [14], the relationship between optimism degree, β, and the order weights is as follows:

$$w_j = \left(\frac{j}{n}\right)^{\left(\frac{1}{\beta}\right)-1} - \left(\frac{j-1}{n}\right)^{\left(\frac{1}{\beta}\right)-1} \quad (9)$$

The value of β represents the decision maker's perception of risk towards the decision making problem. For instance, if it is intended to achieve a solution which satisfies all of the criteria, the amount of 0.001 should be adopted for β. As, in this study, the satisfaction of all decision makers is important, then, β is 0.001.

It should be mentioned that the outputs of the scoring procedure are fuzzy numbers and thus, the OWA scores will also be fuzzy scores. In order to determine which alternative is the best one, a diffuzification should be done. On of the most common difuzzifications method is centroid defuzzification. For the fuzzy number *A=(a,b,c)* defuzzification would be as follows:

$$d(A)=(a+b+c)/3 \quad (10)$$

As the larger value of p_j indicates that the *i*th alternative is closer to the ideal value of *j*th criterion, then the alternative with the largest OWA score is the optimal alternative for the decision making problem.

IV. Application

In this section, the applicability and workability of the proposed method is studied. The chosen case study is the floor covering, walls and ceilings of a 17-storey residential building complex project in Tabriz, located in northwestern Iran. This building consists of 102 residential units. The floor, wall, and ceiling categories are divided into four subsections: 1) bath and toilet, 2) kitchen, 3) bedrooms, and 4) dining rooms. Table I shows the details of the case study, material options, and the relevant information.

It is assumed that all of the data related to the kitchen are considered to be triangular probability distributions (random inputs) and the rest data are considered to be fuzzy numbers. CO_2 emissions of materials are obtained using the Building for Environmental and Economic Sustainability software (BEES) [17]. BEES is one of the wide-ranging and available tools to elicit the environmental properties of variety of construction materials and provides to some extent well-founded information. In this case study, the CO_2 emission of the transportation phase is considered to be zero.

TABLE I. DETAILS OF THE CASE STUDY

Category	Subcategory	Option	Materials	Quantity (m^2)	Cost (*1000 $)	CO_2 (tonne)
Floor	Bath and Toilet	1	Ceramic tiles	846	(6.1,8.1,10.9)	(1.5,2.0,2.6)
		2	Marble tiles	846	(12.2,16.2,20.3)	(2.5,3.3,4.1)
	Kitchen	1	Ceramic Tile	816	(5.8,7.8,9.7)	(1.5,1.9,2.5)
		2	Marble Tiles	816	(11.8,15.7,19.6)	(2.4,3.2,3.9)
		3	Vinyl Tile	816	(1.3,1.7,2.2)	(0.6,0.9,1.1)
		4	Natural Parquet Tile	816	(5.7,7.6,9.5)	(0.2,0.3,0.4)
	Bedrooms	1	Ceramic Tile	2676	(19.2,25.6,31.9)	(4.8,6.5,8.1)
		2	Natural Parquet Tile	2676	(18.8,25.0,31.3)	(0.6,0.9,1.1)
		3	Wool carpet	2676	(43.8,58.4,72.9)	(75.4,100.5,125.6)

TABLE I. *(Continued)* DETAILS OF THE CASE STUDY

		4	Nylon Carpet Tile	2676	(16.1,21.5,26.9)	(10.0,13.4,16.8)
		5	Cushion	2676	(10.4,13.9,17.3)	(4.1,5.5,6.9)
	Dining rooms	1	Ceramic Tile	3851	(27.6,36.8,45.9)	(6.9,9.3,11.7)
		2	Natural Parquet Tile	3851	(27.03,36.0,45.0)	(1.0,1.3,1.7)
		3	Wool carpet	3851	(62.9,83.9,104.9)	(108.5,144.6,180.7)
		4	Nylon Carpet	3851	(23.2,30.9,38.7)	(14.5,19.3,24.2)
		5	Cushion	3851	(14.9,19.9,24.9)	(5.9,7.9,9.9)
Wall	Bath and Toilet	1	Ceramic Tile	7475	(53.5,71.4,89.2)	(13.6,18.1,22.6)
		2	Composite Panels (I)	7475	(110.5,147.3,184.2)	(25.8,34.4,42.9)
		3	Athlon Panels	7475	(78.9,105.2,131.6)	(25.5,34.0,42.5)
		4	Marble Tiles	7475	(107.6,143.5,179.4)	(21.8,20.1,36.4)
	Kitchen	1	Composite Panels (II)	4718	(69.7,92.9,116.2)	(16.3,21.7,27.1)
		2	Ceramic Tile	4718	(33.8,45.1,56.3)	(8.6,11.4,14.3)
		3	Marble Tiles	4718	(67.9,90.6,113.2)	(13.8,18.4,22.9)
		4	Athlon Panels	4718	(49.8,66.4,83.0)	(16.1,21.5,26.8)
	Bedrooms	1	Gypsum Board	13547	(7.3,9.8,12.2)	(19.5,25.9,32.5)
		2	Athlon Panels	13547	(143.0,190.7,238.4)	(46.2,61.6,77.0)
		3	Composite Panels(I)	13547	(200.25,267.0,333.8)	(6.1,8.1,10.1)
	Dining rooms	1	Gypsum Board	10827	(5.8,7.7,9.7)	(15.6,20.7,25.9)
		2	Athlon Panels	10827	(114.3,152.5,190.6)	(36.9,49.3,61.6)
		3	Composite Panels (I)	10827	(160.1,213.4,266.7)	(37.3,49.8,62.2)
Ceiling	Bath and Toilet	1	Composite Panels (II)	846	(8.9,11.9,14.9)	(2.9,3.8,4.8)
		2	Composite Panels (I)	846	(12.5,16.7,20.8)	(2.9,3.8,4.9)
	Kitchen	1	Composite Panels (II)	816	(8.9,11.4,14.4)	(2.8,3.7,4.6)
		2	Composite Panels (I)	816	(12.1,16.1,20.1)	(2.8,3.8,4.7)
	Bedrooms	1	Composite Panels (II)	2676	(28.3,37.7,47.1)	(9.1,12.2,15.2)
		2	Composite Panels (I)	2676	(39.6,52.7,65.9)	(9.2,12.3,15.4)
	Dining rooms	1	Composite Panels (II)	3851	(40.7,54.2,67.8)	(13.1,17.5,21.9)
		2	Composite Panels (I)	3851	(56.9,75.9,94.9)	(13.3,17.7,22.1)

In order to incorporate the risk attitude of the decision makers (CO_2 and cost) in the optimization process, three scenarios are assumed. In the first scenario all of the decision makers have the risk attitude of 80%. In the second and third scenarios the decision makers have the risk attitudes of 50% and 20%, respectively. The results and the outputs of the proposed framework for the case study are shown in Table II. It is obvious from the results that as the uncertainty increase the values of CO_2 and cost decreases.

TABLE II. UOTPUTS OF THE PROPOSED FRAMWORK

Scenario	Outputs	
1	Resource combination	1, 4, 2 ,2, 1, 2, 3, 1, 1, 1, 1, 1
	Cost	(456.04, 585.83, 715.62)
	CO_2	(79.68, 100.88, 122.08)
2	Resource combination	1, 3, 2, 2, 1, 2, 3, 1, 1, 1, 1, 1
	Cost	(451.57, 581.36, 711.15)
	CO_2	(79.02, 100.02, 121.42)
3	Resource combination	1, 4, 2, 2, 1, 2, 3, 1, 2, 2, 1, 1
	Cost	(457.67, 588.65, 719.63)
	CO_2	(77.47, 98.67, 119.89)

The results show that, ceramic tiles are preferred to other types of materials for the bath and toilet in all scenarios. For the Floor covering of the other parts (kitchens, bedrooms and dining rooms) where the parquet tiles are available, the proposed framework proposes this option (except kitchens in Scenario 2). In the wall category, ceramic is suggested for bath and toilet and kitchens, while composite panels (I) is proposed for bedrooms and gypsum boards for dining rooms in all scenarios. For the ceiling category there are differences among the three scenarios.

All in all, this paper proposes a flexible tool which can catch different risk perceptions and ideas of the decision makers and based on them is able to adopt the optimal decision. This framework also considers risk assessment and the existing uncertainty in measurements.

V. Conclusions

This paper considers material selection in green buildings. As green buildings employ expensive materials and technologies to fulfill the environmental goals, they demand high amounts of money. This leads the green buildings to be less attractive for customers. Thus, this paper tried to consider both environmental concerns and budgetary issues in selection of materials in green buildings. For this purpose this research proposed a decision making tool which optimizes materials options under two criteria: cost and CO_2 emissions as the representative of environmental issues. The developed decision making adopts fuzzy Monte Carlo simulation to account for uncertainty, and also a decision making tool which is suggested in this paper. This decision making has the capability to handle fuzzy inputs and utilizes OWA operator – called F-OWA – to select the optimal decision.

Finally, a case study was chosen to evaluate the workability of the proposed method and the example solved for different risk levels.

References

[1] EPA. Potential for reducing greenhouse gas emissions in the construction sector. Washington, D.C. Environmental Protection Agency; 2009. In: Liu S, Tao R, and Tam C M. Optimizing cost and CO_2 emission for construction projects using particle swarm optimization. Habitat International; 37: 155-162, 2013.

[2] M. J. González, J. G. Navarro, "Assessment of the decrease of CO_2 emissions in the construction field through the selection of materials: practical case study of three houses of low environmental impact," Build Environt, vol. 41(7), p 902-909, 2006.

[3] E. Vine, "Opportunities for promoting energy efficiency in buildings as an air quality compliance approach." Energy (Oxf), vol. 28(4), p. 319-341, 2003.

[4] L. Florez, and D. Castro-Lacouture "Optimization model for sustainable materials selection using objective and subjective factors," Mater Des; 2012.

[5] D. Castro-Lacouture, J. A. Sefair, L. Flórez, A. L. Medaglia, "Optimization model for the selection of materials using a LEED-based green building rating system in Colombia," Build Environ, vol. 44(6), p. 1162-1170, 2009.

[6] M. Hamd, A. Hasan, K. Siren, "Applying a multi-objective optimization approach for Design of low emission cost effective dwellings," Build Environ, vol. 46(1), p. 109-123, 2011.

[7] P. O. Akadiri, P. O. Olomolaiye, E. A. Chinyio, "Multi-criteria evaluation model for the selection of sustainable materials for building projects," Autom Constr, vol. 30, p. 113-125, 2013.

[8] S. Liu, R.Tao, C. M. Tam, "Optimizing cost and CO_2 emission for construction projects using particle swarm optimization," Habitat Int, vol. 37, p. 155-162, 2013.

[9] B. Ross, M. Lopez-Alcala, A. A. Small III, "Modeling the private financial returns from green building investments," J Green Build, vol. 2(1), p. 97-105, 2006. in: D. Castro-Lacouture, J. A. Sefair, L. Flórez, A. L. Medaglia, "Optimization model for the selection of materials using a LEED-based green building rating system in Colombia, Build Environ, vol. 44(6), p. 1162-1170, 2009.

[10] N. Sadeghi, A. R. Fayek, W. Pedrycz, "Fuzzy Monte Carlo Simulation and Risk Assessment in Construction," Computer-Aided Civ Infrastruct Eng,vol. 25(4), p. 238-252, 2010

[11] N. Fenton, and W. Wang, (2006). "Risk and confidence analysis for multi-criteria decision making," Knowl. Base. Syst., 19(6), 430–437, 2006.

[12] E. K. Zavadskas, A. Kaklauskas, Z. Turskis, and J. Tamošaitienė, "Multi-attribute decision-making model by applying grey numbers," Inform, vol. 20(2), p. 305-320, 2009.

[13] R. R. Yager, "On ordered weighted averaging aggregation operators in multicriteria decision making," *IEEE Transactions on Systems, Man and Cybernetics* 18 (1) 183–190, 1988.

[14] Zarghami M. (2011). Soft computing of the Borda count by fuzzy linguistic quantifiers. Applied Soft Computing; 11(1): 1067-1073, 2011.

[15] Heravi G, Nezhad S. A group decision making for stochastic optimization of time-cost-quality in construction projects. Journal of Computing in Civil Engineering; doi: 10.1061/(ASCE)CP.1943-5487.0000264, 2012.

[16] Zarghami M, Szidarovszky F. Revision the operator for multi criteria decision making problems under uncertainty. Eur J Oper Res, vol. 198(1), p. 259-265, 2009.

[17] B. C. Lippiatt. BEESRG 4.0: Building for Environmental and Economic Sustainability. Technical Manual and User Guide, 2007.

About Author (s):

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