CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

APPLICATION OF FUZZY ANALYTICAL HIERARCHY PROCESS (FAHP) TO REDUCE CONCRETE WASTE ON CONSTRUCTION SITES

Mdallal, A [1] and Hammad, A [2, 3]
[1] Graduate M. Sc. Student, Engineering Management, University of Sharjah, UAE
[2] Associate Professor, Civil and Environmental Engineering, University of Alberta, Canada
[3] ahammad@ualberta.ca

Abstract: Achieving sustainability is a major global challenge pressing on construction industry to reduce the pollution caused by its activities. Hence, the industry has a mandate to change the traditional cost/benefit analysis, which focuses only on financial gains, to a multi-criteria decision-making model taking into consideration the three pillars of sustainability: economical, environmental and social aspects. Construction waste is considered to be one of the main barriers towards achieving sustainability in construction. As per previous studies, concrete waste is a major contributor to construction waste. This study is proposing a generic model to enable decision makers to select the most sustainable alternative to reduce concrete waste on construction sites. The study starts with a comprehensive literature review regarding construction waste, Multi Criteria Decision Making (MCDM) techniques and their application to solve the construction waste problem. After that, Fuzzy Analytic Hierarchy Process (FAHP) technique is selected to minimize concrete waste. The developed model defined selection criteria and compared applicable alternatives with respect to the three aspects of sustainability using pairwise comparison matrices. Technical criteria has been also considered in the decision-making model. A case study has been conducted with several experts from United Arab Emirates (UAE). The proposed model has been validated using the consistency test to eliminate inconsistency in the judgments of experts. Results show that Concrete Prefabrication is the most sustainable alternative to solve this problem according to experts' judgment. The developed model is generic and can be implemented on any construction site.

1 INTRODUCTION

Amounts of generated waste are increasing quickly, globally and becoming a major challenge facing urbanization. Around 1.3 billion tons per year of solid waste is generated among the world cities. It's expected that this volume would reach 2.2 billion tons by 2025 (Wahi et al 2016). Construction industry is considered as one of the main producers of waste (Al-Hajj et al 2011). The major sources of construction waste include materials such as soil, sand, concrete, bricks, blocks, wood, metal, plastic and packaging materials. (Begum et al 2006). In Canada, construction waste represents 35% of the material volume in landfill areas (Begum et al 2009).

On the other hand, United Arab Emirates (UAE) is considered amongst top waste generators per capita in the world due to vast economic growth (Al-Hajj et al 2012). As per their research, construction waste reduction is currently a critical issue and there is an urgent need to adopt other waste management applications instead of disposal in the landfills. Adoption of sustainability principles will have a major impact on addressing the above-mentioned challenge, since sustainability covers the three dimensions of economic, social, and environmental.

The construction industry is a major contributor to the gross domestic product (GDP) of UAE driven by oil & gas, transportation, residential and hospitality sectors. The industry has seen continuous growth during the last three decades. Hence, UAE is facing a major challenge in achieving the mission of sustainability. There is a significant need for a better solution to deal with the large amounts of construction waste related to the enormous amounts of urban development and construction sites in the country. Begum et al (2006) concluded in that concrete and aggregates have the largest portion of 65.8% of the total construction waste generation in UAE. The main objective of this research is to develop a tool to apply Multi Criteria Decision Making (MCDM) techniques to find the most suitable solution for reducing concrete waste taking into consideration the three pillars of sustainability.

2 LITERATURE REVIEW

2.1 Construction Waste Minimization

In 1978, The Building Research Establishment (BRE) defined construction waste as ‘the difference between materials ordered and those placed for fixing on building projects’. In 1981, another definition emerged from BRE stating that waste is ‘any material apart from earth materials, which needed to be transported elsewhere from the construction site or used on the site itself other than the intended specific purpose of the project’. In Hong Kong, the definition by HK Polytechnic made it clear what construction waste is defining it as: ‘The by-products generated and removed from construction, renovation and demolition workplaces or sites of building and civil engineering structures’ (Al-Hajj et al 2011). Construction wastes originate from various sources in the whole process of implementing a construction project. Existing studies provide various classifications on construction waste sources (Shen et al 2004). Generally, wastages of building materials can be divided into two types; one is direct waste and the other is indirect waste. Direct waste is the loss of those materials, which were damaged and could not be repaired and subsequently used, or which were lost during the building process. Indirect waste is distinguished from direct waste because it normally represents only a monetary loss and the materials are not physically lost.

Causes of material wastage on building construction projects can be classified into nine groups. These groups are: design and documentations, site management and practices, procurement, materials handling, storage, transportation, operation, and environmental and other conditions (Muhwezi et al 2012). Nagapan et al (2011) found 63 causes of construction waste grouped into seven categories: design, handling, worker, management, site condition, procurement and external. Shen at al (2002) stated that material wastage includes concrete, steel reinforcement, wood and bricks.

According to Begum et al (2006), concrete and aggregates have the largest waste generation portion on construction site where it reached 65.8% of the total waste generated. The wastage results mainly from the mismatch between the quantity of concrete ordered and that required in the case of ready mix concrete supply. The contractor may not know the exact quantity because of imperfect planning and poor quantity surveying leading to over-ordering. For big projects, concrete wash areas, where the concrete mixers and pumps are washed, are considered to be major source of concrete waste.

Often, some waste of concrete is also generated during the transportation, operation and handling on site. At a few sites, due to uncertainty related to material consumption, engineers often order an extra allowance of concrete in order to avoid any interruptions during concrete placement process. Sometimes this results in a surplus of concrete that is not used. (Carlos et al 2002).

The most commonly used method to deal with waste in construction sites is disposal in landfills. Jaillon et al (2009) mentioned that in 2005, around 21.5 million tonnes of construction waste is generated in Hong Kong and 11% of this waste is landfilled. Other method to reduce construction waste is to use the prefabrication elements in construction. The use of prefabrication techniques in construction leads to major reduction of on-site activities, increased productivity, less safety incidents and reduced waste. Tam et al (2007) reported that the reduction in waste could reach up to 84.7% with prefabrication when compared to conventional construction.

Other researchers proposed a probable method to treat and reuse construction waste as aggregates for new concrete. This practice is usually utilized for lower level applications such as road bases and non-structural concrete elements. Shahidan et al (2017) discussed in their proposal that recycled aggregates obtained from the construction wastes can make good quality concrete for lower level application which called recycled aggregates concrete (RCA). Senaratne et al (2017) reported that using of recycled aggregates (RA) has major potential to lead the future of sustainability because it provides an alternative for the traditional concrete. They also mentioned that for the construction industry to be sustainable, recycled aggregates should be widely used to replace the use of natural aggregates. In addition to its positive environmental impact, the use of construction waste as recycled aggregates in concrete has also useful economical benefits to the construction industry. (Wagih et al 2013). The researchers also suggested in their study that there is a possibility to replace the natural coarse aggregates with the recycled aggregates for structural concrete application. Recently, UAE has applied such concept by establishing multiple factories to recycle the construction wastes in Abu Dhabi and Dubai (Al-Zarouni 2015).

2.2 Multiple Criteria Decision-Making (MCDM) Techniques

MCDM refers to making decisions in the presence of multiple, usually conflicting, criteria (Shim et al 2002). These techniques are used in a wide variety of application domains. As per Karmperis et al (2015), the basic model of MCDM involves establishing the decision domain, identify alternatives, define decision making criteria and score each alternative in light of the defined criteria. Grilliams et al (2005) addressed in their paper that alternatives represent the different choices of action available to the decision makers. Usually, the set of alternatives is assumed to be finite, ranging from a few to hundreds, and this set is screened, prioritized, and eventually ranked. Multiple attributes represent the lowest level of decision criteria and some methods allow hierarchies of criteria. Different attributes may conflict with each other, and may be expressed in different units. Hence, decision weights are assigned to the attributes. Usually, these weights are normalized to add up to one.

The widely-used methods are analytical hierarchy process (AHP), elimination etchoix traduisant la realite´ (ELECTRE) and technique for order of preference by similarity to ideal solution (TOPSIS) (Aruldoss et al 2013). AHP breaks down difficult MCDM problem into a systematic hierarchy procedure and applies pair-wise comparison to rank decision alternatives. Meanwhile, ELECTRE allows decision makers to choose the best action among a given set of actions and has several varieties such as ELECTRE I, II, III and IV. TOPSIS uses Euclidean distance to select the alternative that has the shortest distance from the positive ideal solution (PIS) and farthest distance from the negative ideal solution (NIS).

2.3 Construction Waste Reduction using MDCM

Mirakovski et al (2013) used AHP to select the optimum location for construction landfill. ELECTRE III technique is utilized to select the optimal location and method for construction and demolition waste management (Banias et al 2010). Several researchers combined other techniques with MCDM as a hybrid approach to maximize validity of developed solutions. Kharat et al, (2016) combined AHP with Delphi technique to select the optimum disposal technology for municipal solid waste. Another application for municipal solid waste applied fuzzy TOPSIS and fuzzy AHP (Al-Anbari et al 2014). Geographic Information System (GIS) was combined with MCDM to select the optimum location for landfill sites in in Jeddah, KSA (Al-Anbari et al 2014). Roussat et al (2009) presented an application of the ELECTRE III decision-aid method in the context of choosing a sustainable demolition waste management strategy.

In summary, reducing construction waste is a major problem hindering achieving sustainability in construction industry. Several researchers have addressed this problem using variety of techniques. Based on our literature review, hybrid MCDM techniques represent a powerful research approach to search for optimum solutions to the problem of reducing construction waste.

3 RESEARCH METHODOLGY

3.1 Selection of Fuzzy AHP

AHP is one of the most widely used MCDM techniques for solving complex decision-making problems. AHP allows defining weight for each criteria in a scientific way based on expert opinions, finds a complete ranking of each alternative and provides an overview of the complex relationships between decision elements (Saaty 1980). The AHP method relies on pair-wise comparison performed by decision experts to form the relative weighting matrix for decision criteria and construction of an evaluation matrix for all alternatives in light of each criterion. Each comparison is based on a verbal scale (very low, low, medium, high, very high) or numerical scale (ranging from 1 to 9 as defined by Saaty). Theses comparison matrices contain the value of one on the diagonal, comparison values on one-half of the matrix and inverse of each value on the other half. These matrices are then transferred to a priority vector showing the rank of decision alternatives.

Fuzzy sets theory has been introduced to handle uncertainties and vagueness that are observed in the data of the problems (Zadeh 1965). By adding the fuzzy set theory to AHP, the hybrid approach represents a more reliable, applicable and effective solution for decision-making problems in the real world (Rezaei et al 2013). As suggested by other researchers, ELECTRE process and outcome can be difficult to explain in non-technical language and its outranking does not identify the strengths and weaknesses of each alternative. Moreover, PROMETHE does not provide a clear method by which to assign weights to decision criteria. While TOPSIS use Euclidean Distance, which does not consider the correlation of decision attributes and it’s difficult to weight and keep consistency of judgement (Velasquezet al 2013). For these reasons, Fuzzy AHP (FAHP) hybrid approach is used in this research.

3.2 FAHP Steps

In this research, the standard FAHP model is followed to solve the decision-making problem under investigation (Rezaei et al 2013). The model provides practical steps to implement FAHP as presented in Figure 1. Each of these steps is explained in detail in the following sections of this research methodology.

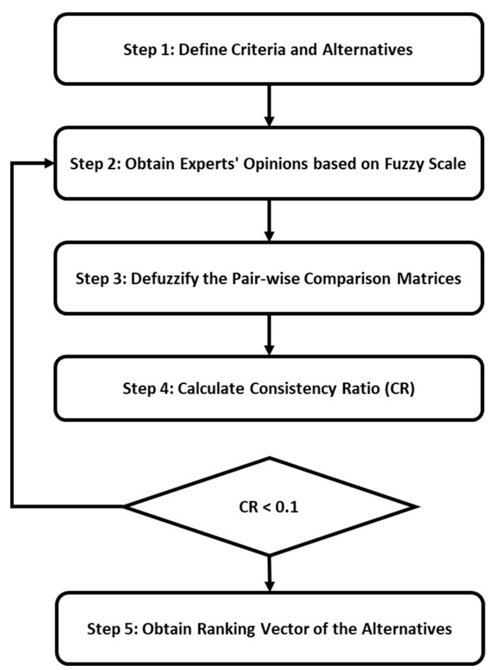

Figure 1: Research Methodology based on FAHP

Step 1, Defining Criteria and Alternatives

The main objective of this research is to implement a multiple-criteria approach that takes into consideration the three pillars of sustainability to address the problem of reducing concrete waste. Hence the decision-making criteria included environmental (C1) with two sub-criteria, economical (C2) with two sub-criteria and social (C3). However, since the problem of finding optimum alternative for reducing concrete waste is of technical nature, the technical criteria (C4) is also taken into consideration. The complete hierarchy for the decision-making criteria is shown in Table 1.

Table 1: Summery of Selected Criteria

Table 1: Summery of Selected Criteria **Type of Criteria**	**Sub-Criteria**	**Mark**
Environmental (C1)	Impact to environment: Air Pollution	C11
	Impact to environment: Ground Pollution	C12
Economical (C2)	Initial Investments	C21
	Savings	C22
Social (C3)	Social Acceptance	C31
Technical (C4)	Applicability of the technique	C41

On the other hand, three alternatives are considered for the study. These alternatives are: Landfill (A1), Prefabrication (Precast Concrete) (A2) and Recycled Aggregates Concrete (RCA) (A3) as shown in Table 2. Alternative A1 (Landfill) represents the traditional approach currently used in most construction sites, meanwhile A2 and A3 represent the most common more sustainable approaches found in the literature review.

The selection of decision-making criteria, sub-criteria and alternatives is verified after extensive discussions with industry experts. The industry experts confirmed that the selected criteria reflects a comprehensive multi-dimensional approach to address the problem. They also confirmed that the selected alternatives are available in UAE and represent feasible options to reduce construction waste.

Table 2: Selected Alternatives for Reducing Concrete Waste

Alternative	**Mark**
Landfill	**A1**
Prefabrication (Precast Concrete)	**A2**
Recycled Aggregates Concrete (RCA)	**A3**

3.3 Step 2: Obtain Expert Opinion based on Fuzzy Scale

In this research, six experts is selected to represent the construction industry in UAE. Two of the them represented construction owners, another two represented engineering consultants and the last two represented construction contractors. The proposed decision-making criteria and alternatives were finalized and approved during the first meeting with the experts. Second meeting was held to reach agreed-upon opinions and weights to be assigned to the proposed criteria and alternatives.

In this research, experts opinions and judgements will be presented as Triangular Fuzzy Numbers (TFN). Fuzzy numbers are more useful in describing the subjective measurement as a range rather than an exact number (Chen et al 2008). TFN come in the format of $\tilde{A} = (l, m, u)$, where $l \leq m \leq u$. TFN values presented by Ayhan (2013) are used in this research and are shown in Table 3.

Table 3: Linguistic Terms and the Corresponding Triangular Fuzzy Numbers

Scale	Definition	TFN
1	Equally important (Eq. Imp.)	(1,1,1)
3	Weakly important (W. Imp.)	(2,3,4)
5	Fairly important (F. Imp.)	(4,5,6)
7	Strongly important (S. Imp.)	(6,7,8)
9	Absolutely important (A. Imp.)	(9,9,9)
2	The intermittent values between two adjacent scales	(1, 2, 3)
4		(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

As per Table 3, when experts decide Criterion 1 (C1) is Fairly Important than Criterion 2 (C2), then it takes the corresponding TFN as (4, 5, 6). On the contrary, the comparison of C2 to C1 will take the TFN in the pair wise comparison matrix as (1/6, 1/5, 1/4). The same approach is used to compare decision alternatives in light of each criterion. The generated pair-wise comparison matrix for the decision-making criteria is represented at Table 4 as an example of the obtained matrices. Similar matrices were obtained from the experts after performing pair-wise comparison of alternatives in light of each criterion.

Table 4: Pairwise Comparison Matrix for Decision-Making Criteria

Criteria	C1	C2	C3	C4
C1	(1,1,1)	(2,3,4)	(4,5,6)	(4,5,6)
C3	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(4,5,6)
C3	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)
C4	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)

3.4 Step 3: Defuzzification of the Obtained Matrices

As per Chang et al (2011), the TFN, which are presented as ranges, will be defuzzified back to crisp numbers using the formula:

[1] $A_{crisp} = (l + m4, u) / 6$

Table 5 presents the defuzzified matrix for decision-making criteria as an example of the obtained defuzzified matrices.

Table 5: the Defuzzified Matrix for Decision-Making Criteria

Criteria	C1	C2	C3	C4
C1	1.00	3.00	5.00	5.00
C2	0.35	1.00	3.00	5.00
C3	0.20	0.35	1.00	3.00
C4	0.20	0.20	0.35	1.00
Total	**1.75**	**4.55**	**9.35**	**14.00**

3.5 Step 4: Checking the Consistency Ration (CR)

The standard steps described by Saaty (1980) is followed to check the Consistency Ration (CR) for the obtained defuzzified matrices. CR is used to make sure the experts represent their opinions in a systematic, logical and consistent manner. CR is obtained via calculating Consistency index (CI) as per following equations and comparing it a set of predefined values provided by Saaty. The CI and CR for a pair wise comparison matrix are calculated based on the following equations Eq. 2 and Eq. 3:

[2] $CI = (\lambda_{max} - n) / (n - 1)$

[3] $CR = CI / RI$

Where (λ_{max}) is the largest eigenvalue of the comparison matrix, (n) is the dimension of the matrix and (RI) is the random index that depends on (n) as shown in Table 6:

Table 6: Random Indices (RI) of Different Sizes of Matrices

N	1-2	3	4	5	6	7	8	9
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

One of the difficulties we faced during the second meeting with the experts is that when filling the matrices, the consistency results showed a failure in the test because of the experts did not fully understand the method of comparing the criteria and alternatives using linguistic terms. The FAHP method was further explained to the experts and a third meeting was held to revise the obtained matrices. The revised matrices passed the consistency tests and an example of the test results is presented in Table 7.

Table 7: An Example of Consistency Test for one of the Pairwise Comparison Matrices

No. of Comparison	N = 4
λmax	4.23
CI	0.08
RI	0.90
CR	0.09 < 0.1
Consistent	Yes

3.6 Step 5: Obtaining Priority Vector

Table 8 shows a summary of the obtained pairwise comparison matrices. These matrices are transferred to a priority vector using the standard calculations presented by Saaty (1980).

Table 8: Summary of the Obtained FAHP Matrices

Criteria	Global Weight	Sub-criteria	Sub-Criteria Weight	Final Weight	Scores of Alternatives with Respect to Related Criterion		
					A1	**A2**	**A3**
C1	0.53	C11	0.74	0.40	0.05	0.65	0.30
		C12	0.26	0.14	0.05	0.30	0.65
C2	0.28	C21	0.26	0.07	0.63	0.11	0.26
		C22	0.74	0.21	0.11	0.63	0.26
C3	0.12	C31	1.00	0.12	0.05	0.65	0.30
C4	0.06	C41	1.00	0.06	0.73	0.19	0.08
Total					**0.15**	**0.53**	**0.32**

The results show that using Precast Concrete is the best alternative to reduce concrete waste on construction sites in UAE as per experts' opinion.

A fourth meeting was held with the experts to validate the obtained ranking vector. All experts agreed that the presented priority vector properly reflects their opinions regarding presented alternatives in light of selected criteria.

Table 9: The Priority Vector for Ranking Decision Alternatives

Alternative	Rank
Landfill	**0.15**
Prefabrication (Precast Concrete)	**0.53**
Recycled Aggregates Concrete (RCA)	**0.32**

4 CONCLUSION

In this research, a holistic Fuzzy AHP approach is used as a multi-criteria decision-making tool for evaluating and selecting the optimum alternative to reduce concrete waste in construction sites. Fuzzy sets theory is applied to translate ambiguities and uncertainties inherited in experts' opinions to understandable linguistic terms. Environmental, economical, social and technical aspects are considered as the criteria. Landfill, prefabrication and recycled concrete aggregates represented alternatives for reducing concrete waste. A case study is applied on UAE construction sites to validate the developed model. Pairwise comparison matrices are generated using judgments of six experts who have vast experience on UAE construction sites. As a result of the research study, we found that prefabrication is most sustainable solution for reducing concrete waste. We also concluded that the Fuzzy AHP is practical and holistic approach for ranking alternatives in terms of their overall performance regarding multiple criteria.

The developed model is generic and can be implemented on any construction site. Defining the decision criteria and alternatives is very useful to support construction experts making informed-decisions for reducing waste. However, there is no one perfect solution to reduce the concrete waste on all construction sites, since the decision makers have different priorities, opinions, concerns and points of view. This study is expected to encourage future studies to utilize more hybrid approaches. Hence, combining different methodologies to benefit from strong sides of multiple techniques to solve complex multi-dimensional sustainability problems.

5 References

Alanbari, M., Al-Ansari, N. and Jasim, H. (2014). GIS and Multicriteria Decision Analysis for Landfill Site Selection in Al-Hashimyah Qadaa. Natural Science, 6, 282-304.

Al-Hajj, A. and Hamani, K. (2011). Material Waste in the UAE Construction Industry: Main Causes and Minimisation Practices. Architectural Engineering and Design Management, 221-235.

Al-Hajj, A., and Iskandarani, T. (2012). Reducing Waste Generation on the UAE Construction Sites. 7th International Conference on Innovation in Architecture, Engineering & Construction, São Paulo, Brazil.

Al-Zarouni, T. (2015). Impact of Using Recycled Materials in the Construction Industry of the United Arab Emirates. Dubai.

Aruldoss, M., Lakshmi, T. M., and Venkatesan, V. P. (2013). A survey on multi criteria decision making methods and its applications. American Journal of Information Systems, 1, 31-43.

Ayhan, M. B. (2013). A Fuzzy AHP approach for supplier selection problem: a case study in a gear motor company. International Journal of Managing Value and Supply Chains (IJMVSC), 4.
Banias, G., Achillas, C., Vlachokostas, C., Moussiopoulos, N. and Tarsenis, S. (2010). Assessing multiple criteria for the optimal location of a construction and demolition waste management facility. Building andEnvironment, 45, 2317-2326.
Begum, R. A., Siwar, C., Pereira, J. J., and Jaafar, A. H. (2006). A benefit–cost analysis on the economic feasibility of construction waste minimisation: the case of Malaysia. Resources, Conservation and Recycling, 1, 86-98.
Begum, R. A., Siwar, C., Pereira, J. J., and Jaafar, A. H. (2009). Attitude and behavioral factors in waste management in the construction industry of Malaysia. Resources, Conservation and Recycling, 6, 321-328.
Building Research Establishment (1978). Concrete: Practical Studies from the Building Research Establishment. Lancaster, Eng.: Construction Press.
Carlos, T., Lucio, S., Claudian, D. and Eduardo, L. (2002). Material Waste in Building Industry: Main Causes and Prevention. Journal of Construction Egineering and Management, 4, 316-325.
Gilliams, S., Raymaekers, D., Muys, B., and Van Orshoven, J. (2005). Comparing multiple criteria decision methods to extend a geographical information system on afforestation. Computers and electronics in agriculture, 1, 142-158.
Jaillon, L., Poon, C. S., and Chiang, Y. H. (2009). Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong. Waste management, 1, 309-320.
Karmperis, A. C., Aravossis, K., Tatsiopoulos, I. P., and Sotirchos, A. (2015). Decision support models for solid waste management: Review and game-theoretic approaches. Waste management, 5, 1290-1301.
Kharat, M., Raut, R., Kamble, S. and Kamble, S. (2016). The application of Delphi and AHP method in environmentally conscious solid waste treatment and disposal technology selection. Management of Environmental Quality: An International Journal, 27, 427-440.
Mirakovski, D. P. (2013). Selection of an optimal Landfill Location using Multi-Criteria Decision Analysis Methods. International Journal of Civil Engineering and Building Materials, 3, 27-36.
Muhwezi, L., Chamuriho, L. and Lema N. (2012). An Investigation Into Materials Wastes on Building Construction Projects in Kampala-Uganda. Scholarly Journal of Engineering Research, 11-18.
Nagapan, S., Rahman, I. and Asmi, A. (2011). A Review of Construction Waste Cause Factors. Asian Conference of Real Estate: Sustainable Growth Managing Challenges (ACRE 2011). Malaysia.
Rezaei, P., Rezaie, K., Nazari-Shirkouhi, S., & Tajabadi, M. R. J. (2013). Application of fuzzy multi-criteria decision making analysis for evaluating and selecting the best location for construction of underground dam. Acta Polytechnica Hungarica, 7, 187-205.
Roussat, N., Dujet, C. and Méhu, J. (2009). Choosing a sustainable demolition waste management strategy using multicriteria decision analysis. Waste Management, 29, 12-20.
Saaty, T.L. (1980). The Analytical Hierarchy Process. New York: McGrow-Hill.
Senaratne, S., Lambrousis, G., Mirza, O., Tam, V., and Kang, W. H. (2017). Recycled concrete in structural applications for sustainable. Procedia Engineering, 180, 751-758.
Shahidan, S., Azmi, M., Kupusamy, K., Zuki, S., and Ali, N. (2017). Utilizing Construction and Demolition (C&D) Waste as Recycled Aggregates (RA) in Concrete. Procedia Engineering, 174, 1028-1035.
Shen, L., Tam, W., Tam, M. and Drew D. (2004). Mapping Approach for Examining Waste Management on Construction Sites. Journal of Construction Engineering and Management, 472-481.
Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., and Carlsson, C. (2002). Past, present, and future of decision support technology. Decision support systems, 2, 111-126.
Tam, V. W., Tam, C. M., Zeng, S. X., and Ng, W. C. (2007). Towards adoption of prefabrication in construction. Building and environment, 10, 3642-3654.
Velasquez, M., and Hester, P. T. (2013). An analysis of multi-criteria decision making methods. International Journal of Operations Research., 2, 56-66.
Wahi, N., Joseph, C., Tawie, R., and Ikau, R. (2016). Critical Review on Construction Waste Control Practices: Legislative and Waste Management Perspective. Procedia-Social and Behavioral Sciences, 224, 276-283.
Zadeh, L. (1965). Fuzzy Sets. Information and Control., 8: 338–353.