

SUPPLIER SELECTION IN THE REAL ESTATE INDUSTRY TO IMPLEMENT CIRCULAR ECONOMY: A CASE STUDY IN BANGLADESH PERSPECTIVE

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By

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A Project Submitted to

The Department of Industrial and Production Engineering,
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**DEPARTMENT OF INDUSTRIAL AND PRODUCTION ENGINEERING
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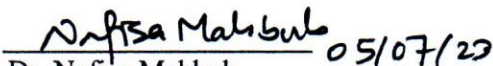
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It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.


.....
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Dedicated to

My parents Md. Zahedul Islam and Nilufar Islam,
and my friend Dr. Muztoba Ahmad Khan, without whose help I could not
be able to achieve this.

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Abstract

Supplier selection is one of the most important multi-criteria problems in supply chain management (SCM). Most of the existing decision-making frameworks for selecting suppliers in the construction industry have given priority to criteria such as cost, delivery, and quality. However, due to the current emphasis on achieving sustainability and reducing the impact on the environment, organizations are increasingly embracing circular economy (CE) principles. In this study, thereby, we proposed an integrated multiple-criteria decision-making (MCDM) framework, which comprises of fuzzy analytical hierarchy process (FAHP) and preference ranking organization method for enrichment of evaluations II (PROMETHEE II), for circular supplier selection in the construction industry from the perspective of the emerging economy countries. In the proposed framework, FAHP was used to identify the weight of each criterion and sub-criteria and later, PROMETHEE II was used to rank the suppliers from best to worst. Results showed that on time delivery, conformance to specifications, and rejection rate are the top three criteria for supplier selection. Additionally, the top three circular supplier selection criteria included pollution control initiatives, green packaging, and responses towards environmental regulations and standards. The result of this approach has been compared with another MCDM method, namely weighted aggregated sum product assessment (WASPAS) method, which validates the accuracy and efficiency of the proposed approach. Through the implementation of circular supplier selection, the proposed research is expected to reinforce circular supply chain, which can help managers of the construction sector to improve sustainability of their overall business.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Business environment is getting more competitive along with increasing environmental concern. Due to this reason business organizations are continuously trying to find new ways to make their operation more efficient and environment friendly. Although it differs from industry to industry, but in majority of cases, purchases can be associated with up to 70 percent cost for business organizations (Mirzaee et al., 2018; Mina et al., 2021). Suppliers are part of the upward most level of any supply chain and play a major role in increasing an organization's competitiveness and reducing environmental impact (Mina et al., 2021).

Suppliers are directly linked to the efficiency and profitability of a supply chain. For this reason, selecting an appropriate supplier can have positive effect on reducing cost and increasing efficiency of the supply chain, which ultimately increase the profitability of the organization by improving the ability of its supply chain to satisfy the customers (Chan and Kumar, 2007). Selecting an appropriate supplier for the supply chain requires considering various criteria (Karsak and Dursun, 2015). Due to the very nature of supplier selection process that involves consideration of various criteria, this is considered as a multiple-criteria decision-making (MCDM) problem. Since managing various suppliers can be quite difficult, the current trend in supplier selection and evaluation is to select a few numbers of suppliers with lasting relationship (Karsak and Dursun 2015).

There is also an increasing concern for preserving the environment and reducing the impact of business operations activities on the environment (Sehnem et al., 2022). This is encouraging many

industries to shift their focus towards developing new ways to mitigate the impact of their operations on the environment. For the past 150 years, supply chain management (SCM) principals have been developed mostly based on the general economic model that can be defined as take-make-use-destroy (Govindan and Hasanagic, 2018; Ghisellini et al., 2016). In this economic model, products are considered as waste materials at the end of their life cycle (Jawahir and Bradley, 2016). This economic model followed by the traditional methods of SCMs, greatly contribute to further the pollution of environment and the depletion of natural resources (Goyal et al., 2018). From the current data, researchers have predicted that by 2050 global population will reach around 9 billion and by 2100 it will become 10.1 billion (Govindan and Hasanagic, 2018). Due to this growth in population, the demand for natural resources will increase leading to growing pressure on the environment (Govindan and Hasanagic, 2018; Franklin-Johnson et al., 2016). The current generation rate of waste per year is 1.3 billion tons and by the year 2025, the number is anticipated to increase to 2.2 billion tons (Kawai and Tasaki, 2016).

To mitigate this increase in natural resources and to reduce waste generation, currently, organizations are leaning towards sustainable operation models. CE is one of the major efficient approaches for mitigating the environmental impacts (Lahane et al., 2020). Based on ecological economist Boulding's idea, Pearce and Turner presented the concept of the circular economic system in 1989 through their experimental framework (Govindan and Hasanagic, 2018). To consider both the environmental and socio-economic issues, CE is being seen as a new business strategy (Witjes and Lozano, 2016). By reusing wastes and resources, along with developing long-lasting and reusable products, CE can break the traditional production and consumption pattern of "take-make-use-dispose" (Norouzi et al., 2021; Ajayabi et al., 2019; Genc et al., 2020). CE can offer ways to minimize waste generation, landfill maintenance cost, transportation cost, etc. and

thus provide a comprehensive strategy for sustainable development (Shooshtarian et al., 2022).

Because of this advantage over traditional economic system, along with promoting both the environmental protection and social well-being, recently CE have gained substantial attention among researchers (Rodríguez-Espíndola et al., 2022). This CE based SCM, known as circular SCM, has the potential to increase the competitiveness of the organization and mitigate the environmental impact (Neves & Marques, 2022). Due to the current concern to reduce environmental impact and reduce consumption rate of the resources, many newly passed rules and regulations all over the world are propelling business organizations to integrate CE criteria as a major part of their decision-making process (Yu et al., 2022). For these reasons, organizations are increasingly incorporating CE criteria into their supplier selection process.

The building and construction sector is one of the largest consumers of energy, raw materials, and water and is also responsible for massive solid waste generation and environmental pollution (Eberhardt et al., 2022; Torres-Guevara et al., 2019; Genc, 2021). While consuming 50% of the total raw materials, and 36% of the global final energy, building and construction sector is also responsible for 37% of the global energy-related carbon dioxide (CO₂) emission (IEA., 2021; Pérez-Lombard et al., 2008). Furthermore, construction and demolition waste (C&DW) contributes up to 40% of the total amount of waste generated in some countries (Villoria-Sáez et al., 2020). To minimize these environmental impacts, in the Paris Agreement a target has been set for the global buildings and construction sector to completely decarbonize by 2050 (IEA., 2021). These environmentally contrasting features can be minimized with the active implementation of circular SCM (Fernando et al., 2022; Shooshtarian et al., 2021). Although, implementation of the basic CE concepts has already been proven to be successful in electrical equipment, furniture, and textiles sectors, the building and construction sector has not been able to implement this concept

at its fullest extent (Maury-Ramírez et al., 2022; Norouzi et al., 2021; Pomponi and Moncaster, 2017).

1.2 Research Questions

For supplier selection, various MCDM methods has been used in different industries (see Table 1 in section 2.2). However, there are very few research works that focuses on circular SCM and circular supplier selection methods (Behrouz et al., 2021; Kannan et al., 2020; Lo et al., 2018). Moreover, next to no research work has been conducted in context of building and construction industry located in the emerging economy countries. To address this gap, this study explores answers to the following research questions (RQs):

RQ1: What supplier selection criteria are considered important for the building and construction industry from the CE perspective?

RQ2: How can we best incorporate the identified supplier selection criteria into a supplier selection process in the emerging economies?

1.3 Objectives of the Study

Exploring the above RQs, this study develops a structured framework for evaluating and ranking prospective suppliers. In this research, we propose a MCDM framework based on fuzzy analytical hierarchy process (AHP) and preference ranking organization method for enrichment of evaluations II (PROMETHEE II) method to address the circular supplier selection problem in the construction industry of emerging economy. The study, thereby, intends achieve the following research objectives (Ros):

RO1: Identifying the supplier selection criteria relevant for the building and construction industry in the emerging economies.

RO2: Finding the weights of identified supplier selection criteria by using FAHP method.

RO3: Ranking the available suppliers by using PROMETHEE II method, from a CE perspective.

RO4: Finally, discussing the managerial implications of the proposed research.

1.4 Arrangement of the Chapters

Rest of the chapters are structured as follows: Chapter 2 provides a brief review of the existing literature on CE, supplier selection methods, and supplier selection criteria. Chapter 3 explains the proposed methodology for circular supplier selection in the context of the building and construction industry. Chapter 4 presents the analysis process and the calculations. Chapter 5 presents the result of this study and compares the proposed method with another MCDM method from the literature. Chapter 6 discusses the implications of the proposed study. Finally, Chapter 7 concludes the study and discusses some future research directions.

CHAPTER 2

LITERATURE REVIEW

Based on the scope of the study, this section is divided into three parts. In the first part, the background and importance of CE has been discussed. The second part reviewed the existing supplier selection methods, followed by identification of supplier selection criteria from the literature.

2.1 Circular Economy (CE)

The concept of CE emerges from the idea of reducing the consumption of inputs for industrial production (Stahel, 2016). Although the concept of CE has been gaining popularity since the late 1970s, given the continuous development of the CE paradigm and its multidisciplinary nature, it is nearly impossible to define CE with a single definition (Hossain et al., 2020; Hart et al., 2019). Two things as central to CE, i) circular or closed flow of materials, and ii) the multi-phased use of raw materials and energy (Franklin-Johnson et al., 2016). CE can also be explained as an economy that reduce material, energy-consumption, and environmental deterioration without negatively impacting economic growth (Geng et al., 2009). Although CE addresses sustainability issues, there are significant differences present among sustainability and CE in the context of origins, goals, main motivations, institutionalization process, and perceptions of responsibilities (Geissdoerfer et al., 2017).

CE basically apply principles which are closely related to “3 Rs”: reduce, reuse, and recycle of materials and components to ideally eliminating all the inputs into and leakages out of the system (Geissdoerfer et al., 2017). To achieve this goal, CE applies different approaches. Designing products with versatile uses, extending product lifecycle to maximize uses, reuse of solid waste,

and systematic approaches to SCM are some of the activities that can encapsulate CE (Sharma et al., 2021; Genc, 2022). Due to the increasing popularity of CE among the policy makers, several countries are creating laws and policies to promote CE. Germany's "Closed Substance Cycle and Waste Management Act", Japan's "Basic Law for Establishing a Recycling-Based Society" and China's "CE Promotion Law of the People's Republic of China" are some of the examples of this trend (Su et al., 2013; Lieder and Rashid, 2016).

2.2 Supplier Selection Methods

Several supplier selection and evaluation methods have been developed and implemented successfully by researchers in recent years. Usually, because of its flexibility and simplicity, MCDM methods have been employed to address supplier selection problems in supply chain management before (Memari et al., 2019). For instance, MCDM methods like AHP (Etlanda and Sutawidjaya, 2022), fuzzy analytic network process (FANP) (Giannakis et al., 2020), fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS) (Cakar and Çavuş, 2021), data envelopment analysis (DEA) (Dobos and Vörösmarty, 2019), best worst method (BWM) (Amiri et al., 2021), fuzzy decision-making trial and evaluation laboratory (FDEMATEL) (Giri et al., 2022), multi-criteria optimization and compromise solution (VIKOR) (Gupta and Kumar, 2022), etc. have been used in the recent supplier selection and evaluation researches. Among those AHP is one of the most popular and commonly used supplier selection and evolution methods (Ebrahim Qazvini et al., 2021). The drawbacks of solving real-world problems with conventional AHP, which involves vagueness and uncertainty, can be overcome by applying Fuzzy AHP (FAHP) (Ecer, 2020; Gold and Awasthi, 2015). Another MCDM method, Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE II), is currently getting popularity in solving supplier selection and evaluation problems (Strantzali et al., 2019; Abdullah

et al., 2019) as well. First established by J.P. Bran in 1982, this ranking method has several different variations (Brans and Vincke, 1985; Isa et al., 2021).

To utilize the advantages and avoid the weakness of a particular MCDM method, researchers often integrate two or more MCDM methods into a hybrid method (Govindan et al., 2020; Abdel-Baset et al., 2019; Luthra et al., 2017). The available literature related to supplier selection problem-solving domain is dominated by hybrid MCDM approaches. A common trend in these hybrid MCDM methods is to calculate the weight of the supplier selection criteria and sub-criteria with one method and then use the calculated weight of the supplier selection criteria and sub-criteria to rank or evaluate the suppliers with another MCDM method. In this research, we followed a similar approach using FAHP and PROMETHEE II. Besides integrating two MCDM methods to address supplier selection and evaluation problems, researchers started to employ more than two MCDM methods. For example, a combination of fuzzy DEMATEL-FANP-FTOPSIS (Büyüközkan and Çifçi, 2011), ANP-DEMATEL-VIKOR (Kuo et al., 2015), and FAHP-FTOPSIS- Fuzzy inference systems (FIS) (Mina et al., 2021) has been proposed in recent years for supplier selection and evaluation problems. Table 2.1 shows some recent studies, which used various MCDM methods to select suppliers in various industrial sectors.

Table 2.1: Some recent studies on supplier selection using MCDM methods in various industrial sectors.

Author and year	Industry focused	Method used
Gupta and Kumar (2017)	Small and medium enterprises (SME)	BWM and FTOPSIS
Jain et al. (2018)	Automotive industry	FAHP and TOPSIS
Okwu & Tartibu (2020)	Retail industry	TOPSIS and ANFIS
Stević et al. (2020)	Healthcare industry	Measurement of alternatives and ranking according to compromise solution (MARCOS)
Fallahpour et al. (2021)	Textile industry	Fuzzy BWM and FIS
Cakar and Çavuş (2021)	Dairy industry	Fuzzy TOPSIS
Mina et al. (2021)	Petrochemical industry	FAHP, FTOPSIS, and FIS
Amiri et al. (2021)	Automobile industry	Fuzzy BWM
Kaushik et al. (2022)	Fashion retail industry	BWM and VIKOR
Liu et al. (2022)	Healthcare industry	Multi Criteria Group Decision-Making (MCGDM)
Nguyen et al. (2022)	Steel industry	DEA and Spherical FAHP
Thanh & Lan (2022)	Food processing industry	FAHP and Combined Compromise Solution (CoCoSo)
Tong et al. (2022)	Small and medium enterprises (SME)	Extended PROMETHEE II

2.3 Supplier Selection Criteria

Identifying appropriate and suitable criteria for the supplier selection process is considered as one of the major challenges of supplier selection and evaluation problems (Xue et al., 2018; Behrouz et al., 2021). MCDM problems are notable for their high complexity as many of the supplier selection criteria often contradicts between each other (Mina et al., 2021). Selecting the appropriate supplier selection criteria highly depend on the specific business context (Mina et al., 2021). Most of the criteria for selecting suppliers can be categorized into the three pillars of sustainability, i.e.,

economic, environmental, and social (Behrouz et al., 2021; Fallahpour et al., 2017). The most used economic criteria include cost, quality, flexibility, and service (Jain & Singh, 2020; Lo et al., 2018; Liu et al., 2019). Environmental criteria that are commonly used in supplier selection process are environmental management system, green technology, green packaging, and pollution control (Mishra et al., 2019; Ebrahim Qazvini et al., 2021; Haeri and Rezaei, 2019). In the context of sustainable supplier selection criteria, due to the increasing importance on social issues, social criteria are increasingly being considered (Behrouz et al., 2021; Luthra et al., 2017; Gurmu et al. 2022). Health and safety at work, information disclosure, and rights of employees are some of the common social supplier selection criteria that has been considered in recent studies (Khan et al., 2018; Durmić, 2019; Kannan et al., 2020).

One of the major differences between the conventional supply chain and the circular supply chain is their treatment towards end-of-life (EOL) products. In case of a conventional supply chain, EOL products produced from the production process are not considered a part of the supply chain and therefore conventional supply chain has no concern for EOL products (Behrouz et al., 2021). On the other hand, Circular supply chain or close-loop supply chain reuse EOL products in the production cycle through the self-sustaining production system design, which ultimately reduce the production waste (Genovese et al., 2017). Circular supply chain is also distinctive from both the green and socially responsible supply chain. The end goal of green and socially responsible supply chain is to achieve environmental and social gain through promoting cooperation by facilitating interconnection between the manufacturers and customers (Behrouz et al., 2021). In the recent green supplier selection studies, some of the criteria researchers have used are green image, resource consumption, pollution control, management commitment, recyclable package, green products (Haeri and Rezaei, 2019; Kannan, 2018; Gao et al., 2020; Liu et al., 2019; Ecer and

Pamucar, 2020).

Although supplier selection criteria often differ from industry to industry, from the literature review it is visible that, criteria related to delivery, quality, and price are commonly considered across industries. Additionally, often the criteria that are used in the selection process of green suppliers, can also be found in some of the studies for selecting a circular supplier.

In the identification process of all the circular supplier selection criteria and sub-criteria, in this study related literatures are used as the primary sources for the identification of the initial supplier selection criteria and then feedback from industry experts of building and construction sector have been utilized for validation of the initial criteria and as secondary sources of new selection criteria. After extracting sub-criteria from related literature, with the experts help, sub-criteria are categorized into seven different criteria, which include material cost, delivery, quality, circular, reputation, flexibility, and capability. All the identified supplier selection and evaluation criteria and sub-criteria for building and construction industry are presented in Table 2.2.

Table 2.2: List of identified criteria and sub-criteria.

Criteria	Sub-Criteria	Criteria Type	References
Cost (C)	Cost of Information (C1)	Cost	Expert Feedback
	Cost of Material (C2)	Cost	Expert Feedback
	Logistics costs (C3)	Cost	Feng and Gong, (2020)
	Inspection cost (C4)	Cost	Feng and Gong, (2020)
Delivery (D)	On time delivery (D1)	Benefit	Ebrahim Qazvini et al. (2021), Govindan et al. (2020)
	Reliability of Delivery (D2)	Benefit	Cavalcante et al. (2019)
	Delivery Accuracy (D3)	Benefit	Expert Feedback
	Distribution network quality (D4)	Benefit	Parkouhi and Ghadikolaei (2017), Parkouhi et al. (2019)
Quality (Q)	Conformance to Specifications (Q1)	Benefit	Expert Feedback
	Rejection rate (Q2)	Cost	Feng and Gong (2020)
	After-sale services (Q3)	Benefit	Mina et al. (2021), Wu et al. (2019),

			Kannan et al. (2015)
	Quality Certification (Q4)	Benefit	Hou and Xie (2019)
	Quality management system (Q5)	Benefit	Hou and Xie (2019)
Environmental and Circular (ECR)	Use of green technology (CR1)	Benefit	Banaeian et al. (2018), Gören (2018), Ecer and Pamucar (2020)
	Green Packaging (CR2)	Benefit	Mina et al. (2021), Ebrahim Qazvini, Mina (2021)
	Response towards environmental regulations and standards (CR3)	Benefit	Govindan et al. (2020), Kannan et al. (2020)
	Use of environment-friendly and recyclable raw materials (CR4)	Benefit	Govindan et al. (2020), Gupta and Barua (2017)
	Green research and development (CR5)	Benefit	Lee et al. (2009)
	Environmental certification (CR6)	Benefit	Feng and Gong (2020)
	Pollution control initiatives (CR7)	Benefit	Awasthi et al. (2010), Feng and Gong (2020)
Reputation (R)	Corporate reputation (R1)	Benefit	Hou and Xie (2019)
	Past performance (R2)	Benefit	Cengiz et al. (2017)
	Financial History (R3)	Benefit	Cengiz et al. (2017)
Flexibility (F)	Timeliness (F1)	Benefit	Expert Feedback
	Order Quantity (F2)	Benefit	Feng and Gong, (2020)
	Return of Goods (F3)	Benefit	Industry Expert Opinion
	Responsiveness (F4)	Benefit	Hou and Xie (2019)
	Product diversity (F5)	Benefit	Feng and Gong (2020)
Capability (CA)	Technical Capability (CA1)	Benefit	Haeri and Rezaei (2019), Gao et al. (2020)
	Research and Development Capability (CA2)	Benefit	Kannan (2018), Stević et al. (2020)
	Robust financial Capability (CA3)	Benefit	Yazdani et al. (2017), Mishra et al. (2019)
	Flexible production and recycling capability (CA4)	Benefit	Gören (2018)
	Executive capability (CA5)	Benefit	Kannan (2018)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview of Research Methodology

In this study, data has been collected from two different sources, literature review and expert opinion of building and construction sector. First, all the supplier selection criteria and sub-criteria has been identified from the existing literature. Second, all the pairwise comparison of supplier selection criteria and sub-criteria has conducted through industry expert opinion. Also, expert opinions have been implemented to calculate the final ranking value of the suppliers.

Bangladesh is projected to become a developed country by 2041 (Saleh, 2022). Given this goal, Bangladesh government has started to invest heavily on infrastructure development. Among those infrastructures there are roads, bridges, administrative building complex, river development structures, and dams. Beside the government construction projects, many private and self-owned land and residential building projects are currently under development. Many government and private organizations are involved with the work of developing the infrastructures. With the continuous change of technologies, increasing safety measures, and concern for environmental impact, selecting an appropriate supplier for construction materials has never been as complicated and crucial as now. In this study four suppliers of cement, one of the major materials extensively used in civil construction work has been selected and through the suggested method ranked from best to worst based on the weight of the selected criteria.

In the selection process of suitable industry experts, non-probability sampling of purposive or judgmental sampling method has been applied (Bari et al., 2022b; Palit et al., 2022). Purposive sampling is one of the non-probabilistic sampling methods in which the experts are chosen based on the judgment of the investigators (Black, 2019). In total 10 industry experts' responses have

been collected and utilized in this study. The selection criteria for the industry experts have includes- having minimum educational qualification of a bachelor's degree in civil engineering, architecture, or business studies, having at least five years of working experience, having knowledge of building and construction material supplier selection process, operations, and project management, having knowledge on sustainability and CE, and so on. Table 3.1 presents an overview of the ten participating experts. Designation

Table 3.1: Overview of the participating experts

Expert no.	Company Age (In Years)	Department	Designation	Experience (In Years)	Education level
1	10	Supply Chain	Manager	8	Postgraduate
2	10	Supply Chain	Deputy Manager	18	Bachelor
3	23	Purchase And Procurement	Deputy Manager	14	Bachelor
4	23	Purchase And Procurement	Assistant Manager	6	Bachelor
5	10	Operations	General Manager	22	Postgraduate
6	12	Operations	Manager	8	Postgraduate
7	10	Operations	Manager	11	Postgraduate
8	10	Supply Chain	Supply Chain	7	Bachelor
9	15	Supply Chain	Deputy Manager	15	Postgraduate
10	34	Supply Chain	Manager	9	Bachelor

3.2 FAHP method

AHP method evaluate relative importance or weight of multiple criteria by structuring them into a hierarchy (Gegovska et al., 2020). To determine the rank of the criteria, AHP makes pairwise comparisons of alternatives of the criteria (Gegovska et al., 2020). Although, conventional AHP is easier to use it has several downsides (Kabir and Hasin, 2011). One major weakness of conventional AHP is that it is incapable to proceed with vague or imprecise information (Wang and Chen, 2008). But, in real-world decision-making problems, often nature of the criteria and

human opinions are qualitative in nature and may not be represented in numerical exact values (Chan and Kumar, 2007). In order to counter uncertainty and vagueness in a decision maker's opinion, Chang (Chang, 1996) proposed the Fuzzy AHP (FAHP) approach. With FAHP, it is possible to control uncertainty and vagueness attributes through fuzzy set theory (Gegovska et al., 2020). This approach of using fuzzy numbers, makes FAHP more effective and appropriate over standard AHP approach (Petkovic et al., 2012).

In this research, global weight of each of the sub-criteria are determine by applying FAHP method. Several steps are used to calculate the final global weight of all the sub-criteria. To obtain the final global weight Buckley's method has been used (Buckley, 1985). The detail of the steps followed to obtain the global weights for each of the sub-criteria are provided in the *Supplementary Material* file.

3.3 PROMETHEE II method

Among the MCDM methods, PROMETHEE is often considered simple, due to its straightforward conception and computation (Abdullah et al., 2019). This ranking method ranks each of the alternatives by mutually comparing them with each pair relative to each selected criterion (Ozsahin et al., 2017; Bari et al., 2022a). Among the different versions of PROMETHEE, PROMETHEE II is referred by most of the researchers, as it provides a complete ranking of the alternatives (Brans, 1982). Weight and preference function is two of the additional inputs required to implement PROMETHEE II (Behzadian et al., 2010). In this study, PROMETHEE II method is used to determine the final ranking of the circular suppliers. The steps followed for this have been provided in the *Supplementary Material* file.

3.4 Proposed Approach

The hybrid MCDM approach based on FAHP and PROMETHEE II applied to selecting and

ranking potential supplier in building and construction industry has been presented here. In this 3-stage approach, all the circular supplier selection criteria and sub-criteria has been determined through literature reviews and expert opinions. In stage 2, FAHP has been used here to weight the supplier selection criteria and sub-criteria. And finally in stage 3, rank of all the potential suppliers has been calculated with the help of PROMETHEE II. Figure 3.1 illustrates the proposed research framework.

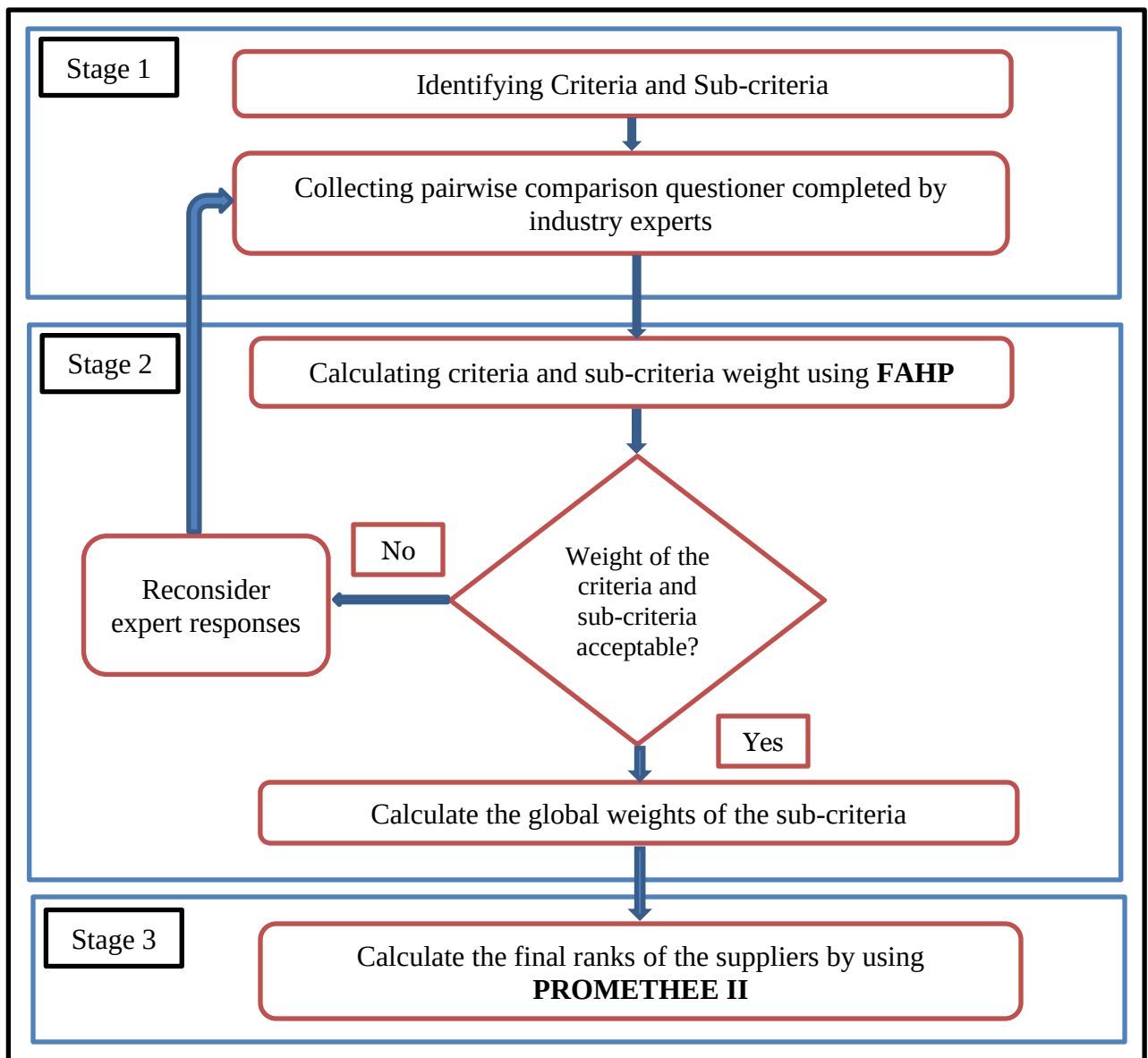


Figure 3.1: Proposed research framework

CHAPTER 4

CALCULATIONS

From the literature and from the industry expert, criteria, and sub-criteria for selecting supplier in perspective of CE has been collected. All the sub-criteria have been classified and grouped into seven major criteria with the help of industry experts. The nature of the identified sub-criteria, whether they fall into ‘cost’ or ‘benefit’ category, have also been identified in this step with the help of the industry experts. The identified criteria and sub criteria have been presented earlier in Table 2.2 in section 2.3.

4.1 Steps of FAHP

After collecting the expert response through filled up questioners, those linguistic response were converted into triangular fuzzy number using Table 4.1. The following steps explain how the global weights for each of the sub-criteria are calculated using FAHP (Ho et al., 2021). The detail on the Consistency Test for FAHP has been discussed in step 6.

Step 1

In this step, pair-wise comparison matrices for the criteria are generated using experts’ feedback on the criteria and sub-criteria. Experts have given their responses following a linguistic scale, based on Triangular Fuzzy Number (l, m, u), as shown in (Table 4.1). To compare between two criteria, the following method has been followed,

Comparison between Criteria C1 to C2	(l, m, u)
Comparison between Criteria C2 to C1	$(1/u, 1/m, 1/l)$

Here “ l ” is the lower fuzzy triangular value, “ m ” is the middle fuzzy triangular value and “ u ” is upper fuzzy triangular value.

Table 4.1: Linguistic scale for importance

Linguistic variable	Fuzzy Triangular Scale
Equally important	(1, 1, 1)
Weakly important	(2, 3, 4)
Fairly important	(4, 5, 6)
Strongly important	(6, 7, 8)
Absolutely important	(9, 9, 9)
The intermittent values between two adjacent scales	(1, 2, 3)
	(3, 4, 5)
	(5, 6, 7)
	(7, 8, 9)

Step 2

In this step, consistency of comparison has been checked following the rules of FAHP (Saaty, 2008; Alonso and Lamata, 2006). Consistency ratio has been maintained less than 0.1 for each of the pair-wise comparison matrix. Equations (1A) and (2A) have been used to calculate consistency index (CI) and consistency ratio (CR) value.

$$CI = \frac{\lambda_{max} - m}{m - 1} \quad (1A)$$

$$CR = \frac{CI}{RI} \quad (2A)$$

In Table 4.2, the pairwise comparison by one of the experts of criteria ‘Delivery (D)’ is presented as a sample.

Table 4.2: Pairwise comparison matrix of criteria ‘Delivery (D)’

	D1	D2	D3	D4
D1	(1, 1, 1)	(2, 3, 4)	(6, 7, 8)	(4, 5, 6)
D2	(0.25, 0.33, 0.50)	(1, 1, 1)	(4, 5, 6)	(2, 3, 4)
D3	(0.13, 0.14, 0.17)	(0.17, 0.20, 0.25)	(1, 1, 1)	(1, 1, 1)
D4	(0.17, 0.20, 0.25)	(0.25, 0.33, 0.50)	(1, 1, 1)	(1, 1, 1)

A sample consistency check for the expert feedback used in FAHP has been presented in Table 4.3-4.6, using equations 1A and 2A.

Table 4.3: Fuzzified Sample Response from Expert 1 For Pair-Wise Comparison of supplier selection criteria

Criteria	Cost			Delivery			Quality			Circular			Reputation			Flexibility			Capability		
Cost	1.000	1.000	1.000	0.167	0.200	0.250	0.250	0.333	0.500	2.000	3.000	4.000	0.250	0.333	0.500	0.250	0.333	0.500	0.250	0.333	0.500
Delivery	4.000	5.000	6.000	1.000	1.000	1.000	1.000	1.000	1.000	9.000	9.000	9.000	4.000	5.000	6.000	4.000	5.000	6.000	4.000	5.000	6.000
Quality	2.000	3.000	4.000	1.000	1.000	1.000	1.000	1.000	1.000	9.000	9.000	9.000	2.000	3.000	4.000	2.000	3.000	4.000	2.000	3.000	4.000
Circular	0.250	0.333	0.500	0.111	0.111	0.111	0.111	0.111	0.111	1.000	1.000	1.000	0.125	0.143	0.167	0.167	0.200	0.250	0.125	0.143	0.167
Reputation	2.000	3.000	4.000	0.167	0.200	0.250	0.250	0.333	0.500	6.000	7.000	8.000	1.000	1.000	1.000	2.000	3.000	4.000	0.125	0.143	0.167
Flexibility	2.000	3.000	4.000	0.167	0.200	0.250	0.250	0.333	0.500	4.000	5.000	6.000	0.250	0.333	0.500	1.000	1.000	1.000	1.000	1.000	1.000
Capability	2.000	3.000	4.000	0.167	0.200	0.250	0.250	0.333	0.500	6.000	7.000	8.000	0.250	0.333	0.500	1.000	1.000	1.000	1.000	1.000	1.000

Table 4.4: Non-Fuzzified Sample Response from Expert 1 For Pair-Wise Comparison

Criteria	Cost	Delivery	Quality	Circular	Reputation	Flexibility	Capability
Cost	1.000	0.200	0.333	3.000	0.333	0.333	0.333
Delivery	5.000	1.000	1.000	9.000	5.000	5.000	5.000
Quality	3.000	1.000	1.000	9.000	3.000	3.000	3.000
Circular	0.333	0.111	0.111	1.000	0.143	0.200	0.143
Reputation	3.000	0.200	0.333	7.000	1.000	3.000	0.143
Flexibility	3.000	0.200	0.333	5.000	0.333	1.000	1.000
Capability	3.000	0.200	0.333	7.000	0.333	1.000	1.000
Sum	18.333	2.911	3.444	41.000	10.143	13.533	10.619

Table 4.5: Normalized Matrix

Criteria	Cost	Delivery	Quality	Circular	Reputation	Flexibility	Capability	Weights
Cost	0.055	0.069	0.097	0.073	0.033	0.025	0.031	0.055
Delivery	0.273	0.344	0.290	0.220	0.493	0.369	0.471	0.351
Quality	0.164	0.344	0.290	0.220	0.296	0.222	0.283	0.260
Circular	0.018	0.038	0.032	0.024	0.014	0.015	0.013	0.022
Reputation	0.164	0.069	0.097	0.171	0.099	0.222	0.013	0.119
Flexibility	0.164	0.069	0.097	0.122	0.033	0.074	0.094	0.093
Capability	0.164	0.069	0.097	0.171	0.033	0.074	0.094	0.100

Table 4.6: Weighted Matrix

Criteria	Cost	Delivery	Quality	Circular	Reputation	Flexibility	Capability	Weighted Sum Value	$\lambda_{\max}$	
Cost	0.055	0.070	0.087	0.067	0.040	0.031	0.033	0.382	6.999	7.243
Delivery	0.273	0.351	0.260	0.200	0.595	0.466	0.501	2.645	7.529	
Quality	0.164	0.351	0.260	0.200	0.357	0.279	0.300	1.911	7.364	
Circular	0.018	0.039	0.029	0.022	0.017	0.019	0.014	0.158	7.130	
Reputation	0.164	0.070	0.087	0.155	0.119	0.279	0.014	0.889	7.463	
Flexibility	0.164	0.070	0.087	0.111	0.040	0.093	0.100	0.664	7.133	
Capability	0.164	0.070	0.087	0.155	0.040	0.093	0.100	0.709	7.080	

For expert 1, the calculated CI and CR values are 0.0404 and 0.0301 respectively. Hence, the calculated CR value for expert 1 is less than 0.1, which is acceptable according to the FAHP protocol (Alonso and Lamata, 2006). CR values of all 10 experts have been calculated by following the similar process to make sure none of them exceeds 0.1. According to Alonso and Lamata (2006), if CR value for any particular expert exceeds 0.1, the pairwise comparison process have to be repeated until a CR value below 0.1 is obtained.

Step 3

In this step, all the fuzzy pair-wise comparison matrices have been aggregated into a single fuzzy pair-wise comparison matrix. A geometric mean approach has been used for that.

Step 4

Fuzzy local weight of criteria and sub-criteria is determined in this step using geometric mean method and fuzzy operations.

Step 5

In this step the de-fuzzified local weight of criteria and sub-criteria is determined. De-fuzzification has been done with the simple centroid formula.

Step 6

The global weight of sub-criteria is obtained by multiplying the sub-criteria weight with the corresponding criteria weight following Buckley's method (Buckley, 1985). Table 4.7 represents the final global weight of all the sub-criteria.

Table 4.7: Global weight of sub-criteria

Criteria	Criteria Weight	Sub-Criteria	Sub-Criteria Weight	Global Weight	Rank
Cost (C)	0.053	C1	0.049	0.003	30
	0.053	C2	0.589	0.031	12
	0.053	C3	0.261	0.014	19
	0.053	C4	0.101	0.005	26
Delivery (D)	0.251	D1	0.589	0.148	1
	0.251	D2	0.264	0.066	5
	0.251	D3	0.067	0.017	16
	0.251	D4	0.079	0.020	14
Quality (Q)	0.276	Q1	0.386	0.107	2
	0.276	Q2	0.071	0.019	15
	0.276	Q3	0.153	0.042	8
	0.276	Q4	0.051	0.014	18
	0.276	Q5	0.339	0.094	3
Environmental and Circular (ECR)	0.024	CR1	0.135	0.003	29
	0.024	CR2	0.223	0.005	27
	0.024	CR3	0.185	0.004	28
	0.024	CR4	0.028	0.001	33
	0.024	CR5	0.100	0.002	32
	0.024	CR6	0.101	0.002	31
	0.024	CR7	0.228	0.005	25
Reputation (R)	0.132	R1	0.640	0.084	4
	0.132	R2	0.259	0.034	11
	0.132	R3	0.102	0.013	20
Flexibility (F)	0.158	F1	0.358	0.056	6
	0.158	F2	0.066	0.010	21
	0.158	F3	0.158	0.025	13
	0.158	F4	0.062	0.010	22
	0.158	F5	0.356	0.056	7
Capability (CA)	0.107	CA1	0.372	0.040	9
	0.107	CA2	0.057	0.006	24
	0.107	CA3	0.154	0.016	17
	0.107	CA4	0.060	0.006	23
	0.107	CA5	0.357	0.038	10

4.2 PROMETHEE II

The final ranking of the considered circular suppliers is determined by implementing PROMETHEE II method. Weight of the sub-criteria calculated using FAHP method was used for the final ranking. Expert scored the alternative suppliers (A1, A2, A3, A4 and A5) in terms of the weighted sub-criteria following the linguistic preferences scale given in Table 4.8. Following steps has been followed for PROMETHEE II in this research (Agrawal,2021)

Step 1

In this step, all the sub-criteria were classified into beneficial and non-beneficial criteria. For Beneficial criteria, higher values and for non-beneficial criteria lower values are preferred. Also, evaluation matrix of all the alternative suppliers with respect to the sub-criteria was developed based on industry expert's opinion according to the linguistic preferences given in Table 2.2.

Table 4.8: Linguistic scale for importance

Weight of importance	Scale
Very Poor	1
Poor	2
Fair	3
Good	4
Very Good	5

Step 2

To make the sub-criteria values dimensionless and comparable, it is essential to normalize the sub-criteria values. Hence, the evaluation matrix constructed in the previous stage was normalized.

Step 3

Deference between i th supplier's importance with respect to other alternative suppliers' importance was calculated in this step.

Step 4

Preference function was calculated by adopting following simplified preference functions,

$$P_j(a, b) = 0 \text{ if } R_{aj} \leq R_{bj}$$

$$P_j(a, b) = (R_{aj} - R_{bj}) \text{ if } R_{aj} > R_{bj}$$

Here, $P_j(a, b)$ = Preference function between two alternative supplier “a” and “b”. Due to difficulties involving identifying and allocating each of the sub-criteria a specific form of preference function among six types of generalized preference functions by the industry experts, this simplified form of preference functions is adopted (Mareschal et al., 1984).

Step 5

Global weights of sub-criteria calculated with FAHP method on the 2nd stage was incorporated and Aggregated preference function, $\pi(a, b)$ was determined using equation (3A)

$$\pi(a, b) = [\sum_{j=1}^n W_j P_j(a, b)] / \sum_{j=1}^n W_j \quad (3A)$$

Step 6

The leaving (positive) and the entering (negative) outranking flows of the alternative suppliers were calculated in this step using equation (4A) and (5A)

$$\varphi^+ = \frac{1}{m-1} \sum_{b=1}^m \pi(a, b) \quad (4A)$$

$$\varphi^- = \frac{1}{m-1} \sum_{b=1}^m \pi(b, a) \quad (5A)$$

Here, φ^+ = Leaving flow for ath supplier and φ^- = Entering flow for ath supplier.

Step 7

Net outranking flow value of all the suppliers are determined according to equation (6A)

$$\varphi(a) = \varphi^+(a) - \varphi^-(a) \quad (6A)$$

Here, $\varphi(a)$ = Net outranking flow value of supplier a.

Step 8

In this final step, the ranking of all the considered alternative suppliers is determined depending on their net outranking flow value $\varphi(a)$. The supplier with the higher value of $\varphi(a)$ ranks higher and vice versa. Best supplier has the highest value of $\varphi(a)$ among all the considered suppliers. Weight of the sub-criteria calculated using FAHP method was used for the final ranking. Expert scored the alternative suppliers (A1, A2, A3, A4 and A5) in terms of the weighted sub-criteria following the linguistic preferences scale given in Table 4.8. Table 4.9 shows the supplier evaluation matrix, which shows the scoring done by the experts under each sub criteria.

Aggregated preference function, $\pi(a,b)$ was determined using equation 3A given in *supplementary materials*. Leaving (positive) and entering (negative) and net outranking flow is calculated using equation 4A, 5A and 6A respectively. Table 4.10 shows the calculation of leaving and entering flow for each supplier and Table 4.11 presents the final ranking of the suppliers.

Table 4.9: Supplier evaluation matrix

S/L	Sub-Criteria	Category	Alternative suppliers				
			A1	A2	A3	A4	A5
1	Cost of Information	Cost	4	1	5	5	2
2	Cost of the Product	Cost	2	3	5	2	3
3	Transportation Cost	Cost	4	2	4	5	4
4	Material Handling Cost	Cost	3	3	4	3	2
5	On time delivery	Benefit	2	1	3	5	3
6	Reliability of Delivery	Benefit	4	1	4	5	4
7	Delivery Accuracy	Benefit	5	4	3	5	4
8	Distribution network quality	Benefit	5	4	2	3	2
9	Rejection rate	Cost	4	4	5	3	3
10	Conformance to Specifications	Benefit	4	4	3	3	3
11	After-sale services	Benefit	4	2	2	5	3
12	Quality Certification	Benefit	5	2	2	3	3
13	Quality management system	Benefit	4	2	2	3	3
14	Clean technology	Benefit	5	4	3	4	4
15	Green Packaging	Benefit	4	2	3	3	2
16	Responses towards environmental regulations and standards	Benefit	5	4	3	3	2
17	Eco-friendly and recyclable raw material	Benefit	5	5	3	5	2
18	Green research and development	Benefit	5	5	3	3	3
19	Environmental certification	Benefit	5	5	3	5	3
20	Pollution control initiatives	Benefit	2	2	2	5	3
21	Corporate reputation	Benefit	4	4	2	5	3
22	Past performance	Benefit	5	2	4	5	2
23	Financial History	Benefit	5	1	1	5	3
24	Timeliness	Benefit	5	1	4	5	3
25	Order Quantity	Benefit	5	4	4	2	3
26	Return of Goods	Benefit	5	1	1	3	2
27	Responsiveness	Benefit	4	4	4	5	4
28	Product diversity	Benefit	3	3	3	4	3
29	Technical Capability	Benefit	3	2	2	5	2
30	Research and Development Capability	Benefit	3	1	2	4	2
31	Financial Capability	Benefit	5	1	2	5	2
32	production facilities and capacity	Benefit	5	2	3	4	2
33	Executive capability	Benefit	1	1	5	5	2

Table 4.10: Leveling and entering flow calculation matrix

Supplier	A1	A2	A3	A4	A5	Leaving Flow, $\varphi^+(a)$
A1		0.429	0.449	0.129	0.302	0.327
A2	0.011		0.195	0.053	0.083	0.085505
A3	0.075	0.238		0.012	0.075	0.099847
A4	0.361	0.703	0.618		0.441	0.530591
A5	0.106	0.304	0.253	0.013		0.168906
Entering Flow, $\varphi^-(a)$	0.138	0.418	0.379	0.052	0.225	

Table 4.11: Final ranking of the suppliers based on net outranking flow

Supplier	Leaving Flow, $\varphi^+(a)$	Entering Flow, $\varphi^-(a)$	Net Outranking Flow, $\varphi(a)$	Rank
A1	0.327	0.138	0.189	2
A2	0.086	0.418	-0.333	5
A3	0.100	0.379	-0.279	4
A4	0.531	0.052	0.479	1
A5	0.169	0.225	-0.056	3

CHAPTER 5

RESULTS AND DISCUSSION

From the criteria ranking by the FAHP method, the top five sub-criteria include- on time delivery (D1), conformance to specifications (Q1), rejection rate (Q5), corporate reputation (R1), and reliability of delivery (D2). Although in this study the objective is to evaluate circular supplier, none of the top five supplier selection sub-criteria are circular in nature. This is an important indication that for industrial sector in an emerging economy, where profitability is the main concern, the sub-criteria related to environment or circularity may not get a lot of attention from the area experts or the management.

On time delivery (D1) with the global weight of 0.148, ranks first among all the supplier selection sub-criteria and considered as the most critical sub-criteria for selecting a circular supplier in building and construction industry. According to experts, on time delivery (D1) is the most important supplier selection sub-criteria due to several reasons. First, in most of the building and construction projects, each task is usually prescheduled, and appropriate personnel (specialist, engineers, daily labors) are to be deployed at the project site accordingly. If scheduled materials do not arrive at site on time, it may increase the cost of the project significantly. Secondly, suppliers' failure to deliver materials on time increase the overall project completion time. For example, if a supplier fails to deliver a material on scheduled date, project work might come to a halt due to the unavailability of that material. This halt often costs organization a lot of money and wastes valuable time. Finally, due to the delay in project completion, organization might face serious reputation loss as well as monetary penalties.

Among the circular supplier selection sub-criteria, the top three circular sub-criteria are- pollution control initiatives (CR7), green packaging (CR2) and responses towards environmental regulations

and standards (CR3). As a circular sub-criterion, pollution control initiatives (CR7) are the most important because organization feel more confident to use materials from a supplier, who has better pollution control system, since it will lessen the regulatory activities from government environmental agencies. Green packaging (CR2) is the second most important circular supplier selection sub-criteria because it often reduces overall cost of the material, by reducing the relevant disposal costs. Finally, purchasing and using materials from a supplier who conforms to the environmental regulations and standards (CR3), increases the reputation of the building and construction organization. Customers and project inspectors respond positively if they see materials being used in their project are supplied by a supplier who have respect and compliance towards environmental regulations and standards.

Among the lowest five ranked sub-criteria, four of them are from the circular category. Table 5.1 represents both the local and global weight and rank of the circular sub-criteria. This again is an important indicator that environmental or circular issues are not getting much attention from the area experts or the top management of the emerging economy countries. This is a serious challenge towards the implementation of CE in the emerging economy countries, which need to be dealt with utmost important, since it has serious implications toward achieving sustainable development.

Table 5.1: Global and local weight and rank of Circular Sub-Criteria

S/N	Circular Sub-Criteria	Local Weight	Local Rank	Global Weight	Global Rank
1	Use of green technology (CR1)	0.135	4	0.003	29
2	Green Packaging (CR2)	0.223	2	0.005	27
3	Responses towards environmental regulations and standards (CR3)	0.185	3	0.004	28
4	Use of environment-friendly and recyclable raw materials (CR4)	0.028	7	0.001	33
5	Green research and development (CR5)	0.100	6	0.002	32
6	Environmental certification (CR6)	0.101	5	0.002	31
7	Pollution control initiatives (CR7)	0.228	1	0.005	25

From the final ranking of the suppliers, shown in Table 4.11, Supplier A4 is rated as the best supplier with a net outranking flow value of 0.479; and with the lowest net outranking flow value of -0.333, supplier A2 is the worst supplier. Both of the top two best suppliers, A4 and A1, have got relatively better scores in the top five weighted sub-criteria. On the other hand, supplier A2 and A3, both of whom ranked the lowest, have a low relative score in the top five weighted sub-criteria. This is a very important and interesting observation from this study.

Table 5.2: Final ranking of the suppliers using WASPAS method

Suppliers	Weighted Sum Model (Q_1^1)	Weighted Product Model (Q_1^2)	WASPAS (Q_i) With $\lambda=0.5$	Rank from WASPAS	Rank from PROMETHEE II
A1	3.63	3.40	3.52	2	2
A2	2.29	1.95	2.12	5	5
A3	3.16	2.93	3.04	3	4
A4	4.21	4.07	4.14	1	1
A5	2.91	2.85	2.88	4	3

In this study, an additional analysis has been carried out by using another MCDM method-weighted aggregated sum product assessment (WASPAS), to check the consistency of the obtained

supplier ranking by PROMETHEE II (Mukhametzhanov and Pamucar, 2018). Table 5.2 shows the comparison of supplier ranking by using both PROMETHEE II and WASPAS.

From Figure 5.1, it is visible that a slight ranking variation exists. In both PROMETHEE II and WASPAS, supplier A4, A1, and A2 ranked first, second and fifth respectively. However, in the ranking of suppliers using PROMETHEE II method, supplier A5 and A3 ranks consecutively as third and fourth, while in the ranking using WASPAS, supplier A3 ranks as third and supplier A5 ranks as fourth. In both ranking methods, the first and the lowest ranked supplier is unchanged.

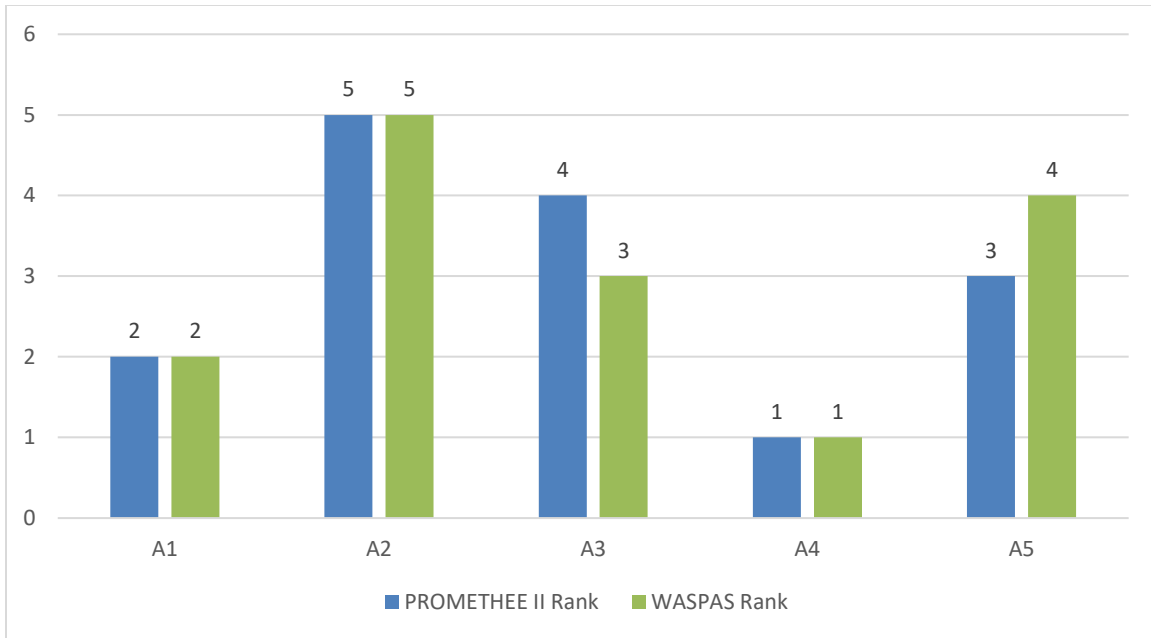


Figure 5.1: Ranking of Suppliers using PROMETHEE II and WASPAS methods.

We have compared our study findings with other recent relevant studies. For instance, we found that Cost or Economic criteria ranks first and Circular criteria ranks last in sustainable circular supplier selection in wire-and-cable production industry (Kannan et al., 2020). In another study, Quality ranks first among all other supplier selection criteria in packaging industry (Lin and Chiang, 2020). Additionally, in a supplier selection study of Turkish construction industry suggests

that cost ranks first followed closely by Quality and Delivery criteria (Cengiz et al. (2017). This indicates that the rank of the supplier selection criteria differs depending on type of industry and the economic stance of the country.

5.1 Competitive Advantages of Implementing Circular Elements

The top five supplier selection sub-criteria identified in this study contains no sub-criteria from Environmental and Circular (ECR) criteria. At the same time, among the bottom five ranked sub-criteria of this study, four of them are from the circular category. This finding reflects that, the building and construction companies in Bangladesh do give emphasis when select their suppliers. But recent studies (Rodríguez-González et al., 2022) have indicated that, implementing CE policies in supplier selection process can provide an organization advantage in different ways. Tax subsidies, grants, and different preferential policies from government organizations can be utilized by an organization by throw implementation of CE policies in supplier selection process. Give emphasis towards CE criteria also can help an organization achieve desired level of sustainability in the long run (Yadav et al., 2020). Although, implementing CE policies in SC does not provide any comparative advantage directly, but due to the increasing emphasis towards environmental concerns and sustainability, in the long run it will provide comparative edge over other organizations (Manavalan and Jayakrishna, 2019).

Most of the top five supplier selection sub-criteria identified in this study are economic in nature. That indicates that industry experts are more concern about reducing economic costs over selecting circular and environment friendly suppliers. But, by implementing CE policies in the SC it is possible to reduce and reintroduce the waste in the supply chain, which in the long run ultimately reduce the cost of the production.

By implementing CE policies in the SC, an organization indicates its emphasis towards sustainability, pollution and waste reduction, and environmental concern. This positively effect on sales volume and increase the profitability. Studies in different industries has shown that, benefits of implementing CE in SC outweigh the negative aspects (Rodríguez-González et al., 2022).

5.2 Research Implications

This study has several significant theoretical and managerial implications. Since no previous studies have been conducted for circular supplier selection for the building and construction industry, the research is expected to contribute to filling the gap in the relevant literature. Managers can benefit from this research in various ways. The proposed study can be used to architecture the overall supply chain action plans to achieve or boost the circular approach in the building and construction sector of emerging economies such as Bangladesh. It can also aid in overcoming the challenges towards achieving circular supply chain in various industries. For instance, the circular supplier selection criteria identified in this study can provide building and construction organizations of emerging economies with valuable insights and indicators on implementation of CE in that sector. Another challenge that hinders the implementation of circular supply chain is the inability of the organization's decision makers to make the most efficient decision in the right time to improve the implementation potential of CE in their supply chain (Pan et al., 2015, Govindan & Hasanagic, 2018). The proposed method provides both the weight of the selected supplier selection criteria and the ranking of the selected suppliers, which will be able to help the managers and other decision makers to make efficient strategies to incorporate circularity and sustainability in their business to minimize their detrimental impacts on society, economy, and environment.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

By reducing and reusing waste, CE can effectively reduce adverse effect on environment and can be an excellent tool to reduce environmental and social concern (Feng & Gong, 2020). Due to being in the most upstream stage of the supply chain, supplier selection holds special importance, especially in the building and construction industry to reduce overall cost and achieve competitive edge.

The objective of this paper was to identify, analyze and weight the circular supplier selection criteria for the building and construction industry and finally, to rank the best suppliers from emerging economy perspective. In the proposed framework, the weight of the supplier selection criteria is determined using FAHP method and by those weights, the final ranking of the suppliers has been determined by using PROMETHEE II method. Five suppliers have been evaluated in the study and ten industry experts have provided their responses for the evaluation process. After the final ranking of the suppliers using PROMETHEE II, a consistency and a sensitivity analysis have also been performed to test the stability and accuracy of the proposed framework. Both tests ensure that the proposed framework is stable enough to be used in the area under consideration as well as in supplier selection in the other industrial sectors. The proposed research is expected to provide the decision makers in the building and construction industry with necessary insights, to successfully overcome the barriers towards achieving a circular and sustainable supply chain in their industry.

7.2 Recommendations

The proposed study has some limitations as well, which can be overcome in the future research attempts. For instance, identified circular supplier selection criteria and the final ranking of the suppliers identified in this study is based on the subjective judgement of the industry experts. Therefore, there is always some possibility to some subjective bias in the obtained results. A total of 33 supplier selection criteria were identified in this study, which is not an exhaustive list. There could more such important selection criteria, which can be explored in future research. Again, these criteria are relevant to the specific context of the construction industry and their supplier selection policies. They might need to be revised, if this framework is to be used in some other industrial sector. Moreover, due to the continuously evolving nature of the technology, policy, and overall status of the building and construction sector, the findings of this study might not stay relevant over a long period of time. Finally, future researchers can use other MCDM methods and compare the outcome of the different MCDM approaches to optimize this circular supplier selection process. It is also advised to conduct this future study with a larger sample size to reduce opinion bias in the obtained results to a greater extent. Researchers can also implement the same approach to the other relevant industries and for the countries with different economic standing with necessary modifications.

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Appendix A

Questionnaire to Collect Experts Opinion for Determining Criteria Weights with FAHP (Sample

Response from an Expert)

	Equally	Between Equal and Weakly	Weakly	Between Weakly and Fairly	Fairly	Between Fairly and Strongly	Strongly	Between Strongly and Absolutely	Absolutely
How much important do you think Cost over Delivery?		Y							
How much important do you think Cost over Quality?							Y		
How much important do you think Cost over Environmental and Circular?					Y				
How much important do you think Cost over Reputation?			Y						
.....	...								
How much important do you think Capability over Reputation?				Y					
How much important do you think Capability over Time Flexibility?			Y						

Appendix B

Collected Experts Opinion for Determining supplier evolution

S/L	Sub-Criteria	A1	A2	A3	A4	A5
1	C1	Good	Very Poor	Very Good	Very Good	Poor
2	C2	Poor	Fair	Very Good	Poor	Fair
3	C3	Good	Poor	Good	Very Good	Good
4	C4	Fair	Fair	Good	Fair	Poor
5	D1	Poor	Very Poor	Fair	Very Good	Fair
6	D2	Good	Very Poor	Good	Very Good	Good
7	D3	Very Good	Good	Fair	Very Good	Good
8	D4	Very Good	Good	Poor	Fair	Poor
9	Q1	Good	Good	Very Good	Fair	Fair
10	Q2	Good	Good	Fair	Fair	Fair
11	Q3	Good	Poor	Poor	Very Good	Fair
12	Q4	Very Good	Poor	Poor	Fair	Fair
13	Q5	Good	Poor	Poor	Fair	Fair
14	CR1	Very Good	Good	Fair	Good	Good
15	CR2	Good	Poor	Fair	Fair	Poor
16	CR3	Very Good	Good	Fair	Fair	Poor
17	CR4	Very Good	Very Good	Fair	Very Good	Poor
18	CR5	Very Good	Very Good	Fair	Fair	Fair
19	CR6	Very Good	Very Good	Fair	Very Good	Fair
20	CR7	Poor	Poor	Poor	Very Good	Fair
21	R1	Good	Good	Poor	Very Good	Fair
22	R2	Very Good	Poor	Good	Very Good	Poor
23	R3	Very Good	Very Poor	Very Poor	Very Good	Fair
24	F1	Very Good	Very Poor	Good	Very Good	Fair
25	F2	Very Good	Good	Good	Poor	Fair
26	F3	Very Good	Very Poor	Very Poor	Fair	Poor
27	F4	Good	Good	Good	Very Good	Good
28	F5	Fair	Fair	Fair	Good	Fair
29	CA1	Fair	Poor	Poor	Very Good	Poor
30	CA2	Fair	Very Poor	Poor	Good	Poor
31	CA3	Very Good	Very Poor	Poor	Very Good	Poor
32	CA4	Very Good	Poor	Fair	Good	Poor
33	CA5	Very Poor	Very Poor	Very Good	Very Good	Poor

Appendix C

Final ranking of the suppliers using WASPAS method (calculation)

Weightage	S/L	Sub-Criteria	Type	A1	A2	A3	A4	A5	WSM	WPM	WASPAS Lambda	Rank
0.003	1	C1	Cost	4	1	5	5	2	0.045	1.014	0.530	0.985
0.031	2	C2	Cost	2	3	5	2	3	0.472	1.178	0.825	3.584
0.014	3	C3	Cost	4	2	4	5	4	0.265	1.094	0.679	2.092
0.005	4	C4	Cost	3	3	4	3	2	0.081	1.029	0.555	3.078
0.148	5	D1	Benefit	2	1	3	5	3	2.070	1.945	2.007	-7.572
0.066	6	D2	Benefit	4	1	4	5	4	1.193	1.466	1.329	1.707
0.017	7	D3	Benefit	5	4	3	5	4	0.353	1.127	0.740	-3.716
0.020	8	D4	Benefit	5	4	2	3	2	0.319	1.115	0.717	-3.621
0.107	9	Q1	Cost	4	4	5	3	3	2.026	2.017	2.022	-214.701
0.019	10	Q2	Benefit	4	4	3	3	3	0.331	1.125	0.728	-3.618
0.042	11	Q3	Benefit	4	2	2	5	3	0.674	1.260	0.967	-1.264
0.014	12	Q4	Benefit	5	2	2	3	3	0.212	1.076	0.644	-1.069
0.094	13	Q5	Benefit	4	2	2	3	3	1.311	1.592	1.452	-1.446
0.003	14	CR1	Benefit	5	4	3	4	4	0.064	1.022	0.543	-3.108
0.005	15	CR2	Benefit	4	2	3	3	2	0.075	1.027	0.551	-1.022
0.004	16	CR3	Benefit	5	4	3	3	2	0.075	1.026	0.551	-3.126
0.001	17	CR4	Benefit	5	5	3	5	2	0.013	1.004	0.509	-4.032
0.002	18	CR5	Benefit	5	5	3	3	3	0.045	1.016	0.531	-4.107
0.002	19	CR6	Benefit	5	5	3	5	3	0.051	1.017	0.534	-4.121
0.005	20	CR7	Benefit	2	2	2	5	3	0.077	1.027	0.552	-1.025
0.084	21	R1	Benefit	4	4	2	5	3	1.516	1.682	1.599	-13.952
0.034	22	R2	Benefit	5	2	4	5	2	0.613	1.226	0.920	-1.261
0.013	23	R3	Benefit	5	1	1	5	3	0.201	1.060	0.630	0.069
0.056	24	F1	Benefit	5	1	4	5	3	1.014	1.379	1.196	1.038
0.010	25	F2	Benefit	5	4	4	2	3	0.188	1.066	0.627	-3.338
0.025	26	F3	Benefit	5	1	1	3	2	0.298	1.088	0.693	0.112
0.010	27	F4	Benefit	4	4	4	5	4	0.206	1.073	0.639	-3.377
0.056	28	F5	Benefit	3	3	3	4	3	0.897	1.383	1.140	-3.330
0.040	29	CA1	Benefit	3	2	2	5	2	0.555	1.209	0.882	-1.210
0.006	30	CA2	Benefit	3	1	2	4	2	0.073	1.024	0.548	0.025
0.016	31	CA3	Benefit	5	1	2	5	2	0.246	1.079	0.662	0.094
0.006	32	CA4	Benefit	5	2	3	4	2	0.102	1.035	0.568	-1.033
0.038	33	CA5	Benefit	1	1	5	5	2	0.533	1.160	0.847	0.256
1			WSM(Qi1)	3.635	2.287	3.156	4.210	2.906				
			WPM (Qi2)	3.404	1.952	2.927	4.070	2.851				
			WASPAS Lambda	3.520	2.120	3.041	4.140	2.879				
			Rank	2	5	3	1	4				

