"Current state and barriers to circular economy in building sector: Proposal of an adoption framework"

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ABSTRACT

The circular economy (CE) paradigm offers a different perspective for industrial ecosystems where materials and products are fed back into supply chain as resources. Recently, there is an increase in number of research articles on CE due to improved awareness of CE paradigm. A research gap exist on assessment of current state and barriers to CE in building sector of developing countries, this research effort aims to bridge this gap in literature. A CE assessment scale was developed to identify current state of CE implementation in building sector, this scale comprised of 24 indicators from 7 dimensions of CE. Furthermore, Interpretive Structural Modeling (ISM), Matrice d'Impacts croises-multipication appliqué an classment (MICMAC) and influence matrix techniques were used to identify the key barriers to CE in building sector of developing countries. Finally, a CE barriers mitigation framework for building sector of developing countries is proposed, based on strategies suggested by experts of building sector. Further research can be conducted on extension of CE assessment for building sector through other methods.

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CHAPTER 1

INTRODUCTION

1.1 Study Background

Globally, the use of material resources increases with an increase in income and population (Behrens et al., 2007; Dobbs et al., 2011). If this scenario continues, many material resources will become scarce and expensive and even may vanish for the use of forthcoming generations (Benton and Hazell, 2013; Defra, 2012). It is envisaged that by adoption of CE there may have socio-economic benefits, including growth in gross domestic product (GDP), less use of virgin materials, employment opportunities, and reduction in risk of material supply and price unpredictability (Morgan and Mitchell, 2015). The concept of CE can be defined as an economic paradigm where maximum value can be extracted from material resources. (Jacobsen, 2006) "*The circular economy is not a new concept. It blends the principles of multiple schools of thought, some of which date back to the 1960s*" (BSI, 2017). The paradigm of CE has been evolved from industrial ecology, which emphasizes the perks of recycling the by-products and waste materials (Jacobsen, 2006).

The concept of CE is being recognized rapidly by experts from industry, academia and society (Merli et al., 2018). The idea of CE has already been successfully applied in a number of products like electronic goods and clothing (Ghisellini et al., 2016), but in case of building sector this concept is applied to a lesser extent (Minunno et al., 2018). There is a need to promote the concept of CE in building sector due to a large amount of material consumption and associated environmental impacts of this sector. The construction sector is known for its large amount of waste; moreover, construction and demolition waste (CDW) needs a lot of space. As with growing population, landfill spaces are severely limited therefore, CDW is a critical problem in several countries (Pappu et al., 2007). It is recorded that construction industry accounts for almost 40 % of industrial waste throughout the world (Kulatunga et al., 2006). Hence, calculating the amount of waste generated from construction industry, and developing approaches to minimize this waste are essential for sustainable development. Along with economic growth, for true emergence of CE concept it must compete economically with the traditional economic model, which is based on the model of take-make-dispose, otherwise implementation of CE will be an uphill task (Charonis, 2012).This research effort will identify barriers to circular economy implementation in building sector. Further, it will identify current state of circular economy in buildings sector. Finally, a framework for CE adoption in building sector is proposed.

1.2 Problem Statement

The building sector accounts for a large amount of waste, which is serious issue in many countries, furthermore, this sector also use a significant amount of energy and material resources. As material resources are finite, if material consumption continues at this pace the available material resources will become expensive and may even lost for future use. To overcome these issues, CE concept can be implemented. This research effort will identify the barriers, which impede implementation of CE in building sector, and will identify current state of circularity of building sector in developing countries. Finally, a framework for adoption of CE in building sector of developing countries will be proposed.

1.3 Research Objectives

1. To identify the current state of circular economy implementation in building sector.
2. To identify barriers to circular economy implementation in building sector.
3. To propose a framework for adoption of circular economy in building sector.

1.4 Overview of Study Approach

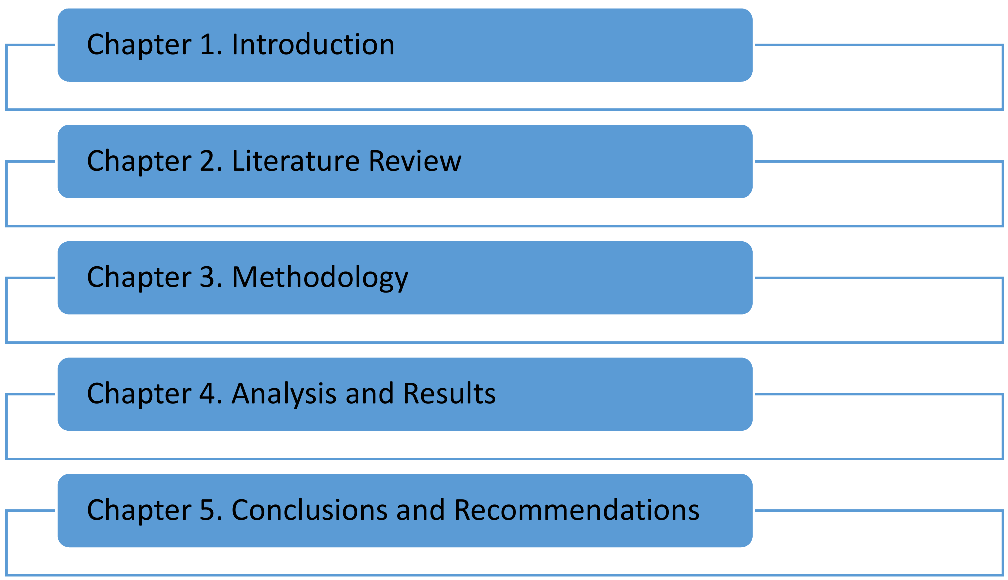
To fulfill the objectives set for this research, the subsequent research tasks are identified:

- Literature review of the previous relevant research works, and identifying the top barriers, which impede the implementation of CE in perspective of different industries. Using preliminary survey, barrier-impeding implementation of CE in building sector of developing countries has been shortlisted.
- To assess in detail the methodologies proposed in previous research, and to measure current state of CE with the help of literature review. The Indicators for assessment of CE in different perspectives has been identified from literature. Those indicators, which are relevant to building sector, are shortlisted using a preliminary survey.
- Obtaining feedback from the target audience with the help of questionnaire using shortlisted indicators and barriers.

- Analysis and discussions.
- Development of a framework for better adoption of CE in building sector.
- Conclusion and Recommendations.

1.5 Organization of thesis

This research is structured into five chapters, the order and brief description of these chapters is given below:



Chapter 1. Introduction

This chapter describes study background, problem statement, research objectives and over view of study approach and organization of thesis.

Chapter 2. Literature Review

This chapter covers thorough literature review comprising of different topics relevant to this research. It identifies major barriers to CE implementation in different perspectives including building sector; identifies different approaches used for measuring CE and extract indicators for assessment of current state of CE implementation.

Chapter 3. Methodology

This chapter covers tools, techniques, and methods used to answer the research objectives.

Chapter 4. Analysis and Results

In this chapter, analysis is performed using different statistical techniques, and results of this study has been presented and discussed.

Chapter 5. Conclusions and Recommendations

This chapter concludes the results of this study comprehensively, and recommendations for future research work are given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

CE can be described as an economy, which is based on closed flow of materials that is in contrast to linear economy (Wang et al., 2015). Fig 2-1 shows a comparison of linear versus circular economy. Linear economy due to its linearity generates many serious problems, like resource scarcity and environmental degradation (Su et al., 2013). CE can keep harmony between environment and humanity by using closed loop of materials (Tukker, 2015).The basic principles for CE are 3R's: Reduce, Reuse and Recycle (Su et al., 2013). Reduce implies to reduction of waste during production and usage phase of products; Reuse implies to use of by-products and waste of one product as resource for other product; and Recycle implies to recycling of products and materials for manufacturing of products, thus reducing virgin materials use for production chain. This literature review covers the evolution of CE, barriers to circular economy and indicators to assess CE in subsequent sections.

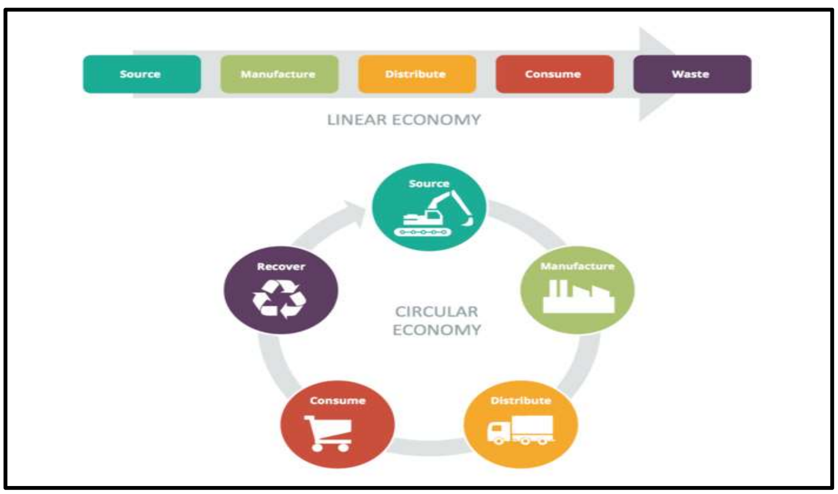


Figure 2- 1 Linear versus Circular Economy (Source: www.google.com)

An overview of existing definitions of CE is given in table 2-1.

Table 2- 1 An overview of existing definitions of CE (Source: Masi et al ., 2018)

Reference	Definition of Circular Economy
Ying and Li-jun (2012)	*"Circular economy is essentially an ecological economy, which requires human economic activities in line with 3R principle, namely Reduce, Reuse and Recycle"*
Geng and Doberstein (2008)	*"A circular economy approach encourages the organization of economic activities with feedback process which mimic natural ecosystems through a process of 'natural resources → transformation into manufacture products → by products of manufacturing used as resources for other industries.'(...) In essence, the circular economy approach is the same as the more familiar terms EID and industrial ecology"*
Gregson et al., (2015)	*"The circular economy (...) is a diverse bundle of ideas which have collectively taken hold, it is located in the allied but the distinctive fields of ecological and environmental economics"*
Sarkis and Zhu (2008)	*"CE was developed in China as a strategy for reducing its economy's demand for natural resources as well as ecological damage"*
Zhijun and Nailing (2007)	*"A mode of economic development based on ecological circulation of natural resources"*
Muray et al., (2017)	*"A true circular economy would demonstrate new concepts of system, economy , value, production and consumption, leading to sustainable development of the economy, environment and society"*
Glurco et al., (2014)	*"The concept of circular economy proposes new patterns of production, consumption and use, based on circular flows of resources"*
Ellen MacArthur Foundation (2013)	*"An industrial system (...) restorative by intention and design' that relies on renewable energy' and eliminates the use of toxic chemical aiming for the elimination of waste through the superior design of materials, products, systems, and (...) business models"*

2.2 Circular Economy and Building Sector

The new release of a range of durable and resilient materials in twentieth century affected the environmental impacts of construction industry (Shen and Qi, 2012).This sector in known as one of the main waste generating sector, and the least sustainable sector of economy because of its environmental impacts (Nuñez-Cacho et al., 2018). Many countries of the world are exerting pressure on this sector to find out a sustainable building model to lessen its environmental impacts (Lieder and Rashid, 2016). Building sector needs to promote eco-efficiency strategies to increase the economic returns and decrease its environmental impacts (Braungart et al., 2007). However, the contemporary state is different because waste generation is rapidly increasing in different life cycle phases of buildings and fewer efforts are made to minimize the waste. Moreover, resource scarcity is a major issue which needs to be addressed by recovery of materials form waste (Mulhall and Braungart, 2010; Van Dijk et al., 2014).

2.2.1 Research on Circular Economy in Built Environment Perspective

Within the context of whole system, the research work on circular economy application in perspective of built environment is limited. Across Europe, an end-of-pipe solution to manage waste generation has been focused by most research (Yuan and Shen, 2011). Though this approach improved management of CDW (Defra, 2015); however, most part of this recovered waste is down cycled, where the quality, value and functionality are lesser than the original product (Walsh, 2012).Table 1 depicts the fundamental aspects that can be applied to different lifecycle phases of buildings. These aspects, however, lack wide-scale acceptance and these are often applied only in isolation in a particular phase or project, with less thought of the economic aspects through a building's whole life cycle. UKCG (2014) identified a major challenge of an unproven business case supported by suitable business models such that manufacturers to be liable for their products, once products complete their life. While this model is evident in sectors, which have medium-lived consumer products, but in case of built environment it is largely absent (Pollard et al., 2016). Other barriers comprise the absence of a collective approach across the construction supply chain, the reduced worth of numerous construction materials and products at the end of their life (Schult et al., 2016).

Modern industries operate in a linear fashion such that raw materials are extracted, products are manufactured, used and finally materials are disposed of that are no longer necessary toward their life cycle (Stahel, 2016). Although in linear model of take–manufacture– use–dispose, maximum waste is produced in disposal phase but the waste generated in production phase is also significant, it should be considered as well. The waste in primary stage of production is produced due to inventory issues, delays, damage during transportation, and over-production, thus this results in scrap or defected materials (Fercoqet al., 2016) Due to these reasons, manufacturers are progressively concerned in enhancing the production chain on the way to material savings (Pearce and Turner, 1990). Amongst all the different methods to increase production efficacy, the incorporation of lean manufacture and parallel-line manufacturing was presented as the most superior methods to lessen waste during the manufacturing phases (Lin et al., 2012); by the incorporation of project management tools, like design for assembly, just-in-time (JIT) and supply management (Scherrer-Rathje et al., 2009). Most of the waste during production phase of buildings, comes from lack of accuracy in constructing concrete components, reinforcement steel-bar cut-offs, damaged or cut-off tiles and bricks, and sand loss during carriage (Formoso et al., 2002). The incorporation of lean manufacture and parallel-line manufacturing are highlighted as most viable solutions to reduce waste during the production period. These techniques can be applied to the built environment by the usage of Building Information Modeling (BIM), which has substantial potential to reduce waste (Sacks et al., 2010). However, the intricacy of traditional buildings (comprising their inconsistency in design and materials) does not always permit the use of BIM or additional lean-production-related tools (Yu et al., 2009). Moreover, traditional constructions are often considered as the merely building technology, thus acting as a barrier toward creative systems (Höök and Stehn, 2008). In order to improve the application of circular economy concept in building sector, the barriers impeding circular economy application should be studied and mitigated.

Table 2- 2 CE Aspects Across a Building's Life Cycle (Source: Adams et al ., 2017)

Life Cycle Phases	Circular Economy Aspect
Design Phase	Design for adaptability and flexibility Design for standardization Minimize waste during design Specify the reclaimed materials Specify the recycled materials Promote modularity
Manufacture and supply Phase	Principles of Eco-design Optimize material use Use of less hazardous materials Increase in the lifespan Design for product disassembly Design for product standardization Promote use of secondary materials Take-back schemes Promote reverse logistics
Construction Phase	Minimize waste Maximize use of reused materials Maximize use of recycled materials Promote off-site construction
In use and refurbishment Phase	Minimize waste Maintenance to be minimized Ease in repair and upgradation Promote Flexibility Promote Adaptability
End of life Phase	Promote deconstruction Promote selective demolition Reuse components and products Open-loop recycling Closed-loop recycling

2.3 Barrier to circular economy implementation

The work on identification of barriers to CE has been started by research community since the propagation of CE concept by European Union (Smol et al., 2015).The work on barriers to CE has been done in different perspectives. This literature review has reviewed the barriers to CE implementation in existing literature. As to date, work on identification of barriers to CE implementation in building sector is limited therefore; a wide range of barriers to CE implementation has been reviewed in different perspective. The subsequent sections elaborate the barriers being reviewed in different perspectives.

2.3.1 Barrier to circular economy in supply chain perspective

Reviewing literature on barriers to CE in supply chain perspective, significant articles has been synthesized and presented in this work. Mangla et al (2016), identified barriers to Circular Supply Chain (CSC) for developing countries (in context of India), they identified 16 barriers by literature review and response from experts, among the identified barriers "*lack of environmental laws and regulations and lack of preferential tax policies for promoting the circular models"* were the major barriers in Indian context. The focus of research was to understand the contextual relation between identified barriers, and to prioritize barriers according to hierarchy. Govindan and Hasanagic (2018), identified 39 barriers, which impede the implementation of CE in supply chain context; these barriers were found by methodical literature review and content analysis. Results of this study showed that generally, the government has major role in implementation of CE in supply chain, because of the upfront cost involved. As private organizations are profit driven, they often consider profits and neglect environmental impacts, thus, it is important for governments to make regulations and policies, which should be complied by organizations. Furthermore, lack of adequate technology is another issue faced by private organizations, because to implement CE, products should be designed by environment friendly technologies. Finally, a multi-perspective framework, concerning stakeholders and their involvement in CE was developed; this framework needs to be empirically tested and investigated.

2.3.2 Barrier to circular economy in organization's perspective

In organizational perspective, barriers to CE has been identified by different researchers, work of a few researchers has been synthesized. Masi et al (2018), in their exploratory research, identified 23 barriers to CE at a firm level, among the identified barriers the major barriers are *"lack of awareness and sense of urgency, limited attention to end-of-life phase in current product designs and higher costs for management and planning".* According to their survey, 65.33 percent firms were aware of the concept of CE. They noted that CE practices are driven economically rather environmentally, as firms prefer to adopt those practices of CE, which give economic returns. Liu, Y., & Bai (2014), studied firms behavior and awareness for CE in China, by using a questionnaire based survey, the results showed that there is a good awareness of CE concept among firm but there is gap between awareness and actions by firms. They identified contextual, structural and cultural barriers to CE, and reported that to improve the implementation of CE, some incentives should be given to firms and at the same time, firms should be penalized for noncompliance to regulation.

2.3.3 Barrier to circular economy in SME's perspective

Reviewing literature on barriers to CE in SME's perspective, significant articles has been synthesized and presented in this work. Ormazabal et al (2018), identified barriers to CE for small and medium enterprises (SME's) in Spanish context. Based on survey, they noted that companies are concerned about their profits, they do not consider environmental impacts; therefore, they are not willing to pay upfront costs to close the loop. In their work, two types of barriers, hard and soft barriers were identified. The participants of survey considered "*lack of support from public institutions*" as one of the main barriers to CE. The data gathered for this research was only from 2 cities of Spain, therefore, for confirmation a replication of study in other geographical region is required. Tura et al (2019), proposed an integrative framework of barriers and drivers to CE with the help of insights from literature and four case organizations by conducting interviews. Their proposed framework consisted of seven distinct categories of "*environmental, economic, social, institutional, technological and informational, supply chain, and organizational* factors". This classification of factors is a contribution to body of knowledge on CE; however, this work did not show the relative influence of these individual factors on development of new solutions for CE. Rizos et al (2016), indicated that regardless of the numerous policy instruments to support the transition of SME's to green business, there exist barriers to adoption of CE by SME's. They identified barriers to CE by SME's, among the identified barriers *"Lack of support supply and demand network, Lack of capital and Lack of government support"* were ranked as the major three barriers. They acknowledged the support of EU and other members states to transition of SME's to green but they indicated a wide range of enablers are needed to improve the transition of SME's to green business.

2.3.4 Barrier to circular economy at Macro level

A number of researcher has been done to identify barriers to CE implementation at macro level. Xue et al (2010), used questionnaire-based survey to evaluate the awareness of CE in China, at country and municipal level, their survey was based on six cities. The results indicated that overall awareness of CE concept is good but still 16 percent of officials had just heard of word CE, they stated that awareness of officials can be raised by conducting works shops, newsletters and media promotions. Furthermore, they indicated that lack of public awareness and lack of financial are main barriers to CE, in addition, there is a gap between CE policies and practical situation in China, as their survey showed that 50 percent of respondents were not ready to pay additional money for green products. Kirchherr et al (2018), with the help of questionnaire survey and interviews, ranked cultural barriers as the major barriers to CE, the most pressing cultural barriers which they identified were "*Lacking consumer interest and awareness*" as well as "*Hesitant company culture*". According to them, these two barriers effect the CE transition or even may derail it. They reported that none of technological barriers is amongst the critical barriers to CE. Most importantly, they stated that CE is still a niche debate among professional of sustainable development, and to maintain the momentum of CE concept, serious effort is required.

2.3.5 Barrier to circular economy in industrial perspective

The barriers to CE in industrial perspective are also identified by different researchers. Oghazi and Mostaghel (2018), identified challenges to CE with an industrial perspective; they used six case studies and structured interviews to identify these challenges. They reported "*revenue model*" as one of the major challenges to circular business model (CBM). They suggested four propositions "*rethinking customer engagement, reconfiguring external linkages, reconfiguring the revenue model, and optimizing cost structure"* to transform these challenges to CBM into opportunities. De Jesus and Mendonça (2018) used academic and grey literature to identify both hard and soft barriers to CE development. They indicated that academic literature calls for technological innovations for transformation towards CE, while grey literature calls for systemic innovation; they concluded that an innovation system's view should always be considered for transition towards CE.

2.3.6 Barrier to circular economy in building sector's perspective

The main aim of this literature review was to synthesize barriers to CE in building sector's perspective, searching literature on barriers to CE in building sector perceptive, only a limited number of articles were found, which are presented here. Mahpour (2018), identified barriers that impede the transition to CE in construction and demolition waste (CDW), 22 barriers were identified, which were ranked in three categories "*legal, technical and behavioral"* with the help of six experts having experience in behavioral , technical and legal science. Further, they prioritized the identified barriers using fuzzy TOPSIS method. They indicated that from behavioral, legal and technical perspective the barrier *"ineffective C&D wastes dismantling, sorting transporting and recovering processes"* ranked first. Further, they concluded that from aggregate perspective, the barriers "*agency and ownership issues in C&D waste management, lack of integration of sustainable C&D waste management, and uncertain aftermaths of moving toward circular economy in C&D waste management"* are the major barriers, which must be removed for transition of CDW industry to CE. According to Adams et al (2017), the application of CE concept in construction perspective is still in its infancy, and little research on CE from a systems perspective has been done. They studied the awareness and challenges to CE, and stated that the awareness of CE concept at overall industry level is very low. The barriers "*lack of incentive to design for end-of-life issues, lack of market mechanisms to aid greater recovery,* and *an unclear financial case"* were recognized as the most significant barriers.

After review of literature on CE, hardly there is any research, focusing on barriers, which impede the adoption of CE at overall industry level for the building sector in the developing countries. This research aims to fill this gap in literature by identifying the barriers to CE at overall industry level for building sector. Subsequently, significant barriers that impede implementation of CE are extracted after detailed literature review from 2010-2019 period. After content analysis, 25 barriers were shortlisted, which were relevant to building sector. These barriers are presented in table 2.3 shown below, and are used for further analysis:

Table 2- 3 Barriers Shortlisted after Content Analysis

Author Reference	Barriers To Circular Economy	Normalized Literature score	Cumulative Normalized Literature score	Rank
Mangla et al., 2016; Govindan and Hasanagic, 2018 ; Masi et al.,2018 ; Ormazabal et al ., 2018 ; Tura et al ., 2019 ; Xue et al., 2010 ; Kirchherr et al ., 2018 ; Mahpour, 2018 ; Adams, K. et al ., 2017	Lack of customer/public awareness	0.087	0.087	1
Mangla et al., 2016 ; Ormazabal et al ., 2018 ; Xue et al., 2010 ; Oghazi and Mostaghel , 2018; Jesus and Mendonça, 2018	Lack of adequate technology	0.058	0.145	2
Govindan and Hasanagic, 2018; Masi et al .,2018 ; Tura et al ., 2019 ; Kirchherr et al ., 2018 ; Jesus and Mendonça, 2018	Major upfront investment costs in Supply Chain (SC) by implementing Circular Economy (CE)	0.048	0.193	3
Mangla et al., 2016; Masi et al .,2018 ; Ormazabal et al ., 2018 ; Tura et al ., 2019; Kirchherr et al ., 2018 ; Rizos et al .,2016 ; Jesus and Mendonça, 2018	Lack of an information exchange system between different stakeholders	0.040	0.233	4
Mangla et al., 2016 ; Xue et al., 2010; Kirchherr et al ., 2018; Oghazi and Mostaghel , 2018; Mahpour, 2018	Lack of environmental laws and regulations	0.035	0.268	5

Author Reference	Barriers To Circular Economy	Normalized Literature score	Cumulative Normalized Literature score	Rank
Govindan and Hasanagic, 2018; Masi et al .,2018; Kirchherr et al ., 2018 ;	High costs are related to recycled materials in SC therefore they are often more expensive than virgin materials	0.029	0.297	6
Mangla et al., 2016; Govindan and Hasanagic, 2018;Tura et al ., 2019; Rizos et al .,2016 ; Adams, K. et al ., 2017	Lack of CE skills by employees in SC.	0.029	0.326	7
Govindan and Hasanagic, 2018; Tura et al ., 2019; Adams, K. et al ., 2017	Challenges of take-back from other companies	0.029	0.355	8
Ormazabal et al ., 2018 ; Tura et al ., 2019; Xue et al., 2010; Rizos et al .,2016 ; Mahpour, 2018	Lack of support from public institutions	0.029	0.383	9
Govindan and Hasanagic, 2018; Masi et al .,2018 ; Oghazi and Mostaghel , 2018;	Lack of standard systems for performance indicators in terms of measurement of CE in SC	0.029	0.412	10
Masi et al .,2018 ; Tura et al ., 2019; Kirchherr et al ., 2018; Oghazi and Mostaghel , 2018	Linear technologies are deeply rooted	0.023	0.435	11
Ormazabal et al ., 2018 ; Rizos et al .,2016	Insufficient financial resources	0.019	0.455	12

Author Reference	Barriers To Circular Economy	Normalized Literature score	Cumulative Normalized Literature score	Rank
Jesus and Mendonça, 2018; Mangla et al., 2016	Lack of appropriate training and development programmes for Supply Chain (SC) members & HR	0.019	0.474	13
Rizos et al .,2016 ; Kirchherr et al ., 2018	Hesitant company culture	0.019	0.493	14
Liu and Bai , 2014; Mahpour, 2018	Strong risk aversion of managers	0.019	0.513	15
Oghazi and Mostaghel , 2018; Mangla et al., 2016	Lack of coordination and collaboration among SC members.	0.019	0.532	16
Mangla et al., 2016; Govindan and Hasanagic, 2018	Lack of effective planning and management for Circular Supply System Management CSSM concepts	0.019	0.551	17
Govindan and Hasanagic, 2018; Liu and Bai , 2014	Difficulties to get prices right of the product in SC	0.019	0.570	18

Author Reference	Barriers To Circular Economy	Normalized Literature score	Cumulative Normalized Literature score	Rank
Govindan and Hasanagic, 2018; Kirchherr et al ., 2018	Design challenges to re-use and recover products	0.019	0.590	19
Kirchherr et al ., 2018 ; Mahpour, 2018	Lacking standardization	0.019	0.609	20
Adams, K. et al ., 2017; Mahpour, 2018	Complexity of buildings	0.019	0.628	21
Masi et al .,2018; Kirchherr et al ., 2018	Financial governmental incentives support the linear economy	0.019	0.647	22
Masi et al .,2018 ; Kirchherr et al ., 2018 ; Oghazi and Mostaghel , 2018	Limited availability and quality of recycling material	0.019	0.667	23
Govindan and Hasanagic, 2018; Mahpour, 2018	Ownership issues for taking advantages of reuse opportunities of CE in Supply Chain	0.019	0.686	24
Masi et al .,2018; Oghazi and Mostaghel , 2018	Exchange of materials is limited by capacity of reverse logistics	0.019	0.705	25

2.4 Circular Economy assessment

The famous proverb of Management and Economics "*you can't manage what you can't measure*" is of importance, and is applicable in case of assessment of CE (Nuñez-Cacho et al., 2018). For the fruitful growth of CE, a system of indicators for its monitoring is essential. Using indicator system, decision makers can monitor the implementation of CE and this can help in policymaking. Consequently, scholars and governmental organizations have made efforts to develop indicators for assessment of CE (Su et al., 2013). Using Indicators system, the complexity of our dynamic environment can be summarized with the help of manageable indicators (Geoffrey and Todd 2001). According to Church and Rogers (2006), indicators are a "*means to measure change*", thus, these can be used for handling the transition to CE. However, Beratan et al. (2004) stated that indicators can only be used as tool to measure the transition to CE, indicators in themselves cannot successfully achieve transition to CE, thus decision making must be linked with indicators for successful transition to CE. Indicators focusing the measurement of CE are at an early stage of growth (Giurco et al. 2014). Many of the developed indicators to measure circularity are at macro level (Åkerman 2016). Banaité (2016), reviewed indicators to measure CE at macro, meso and micro level; he found a total of 153 indicators at macro level, 46 at meso level and 65 at micro level. According to Geng et al. (2013), the highest profile of indicators comes from, China, where their government uses well-known scales to measures performance of CE policies. Circular economy can be implemented at Macro (city, province, region, country) level, Meso (symbiosis association, industrial parks) level and Micro (single company, consumer and product) level. For the assessment of CE at all three levels, different indicators are required (Banaitė, 2016).The literature on indicators to assess the implementation of CE at all three levels has been reviewed. Table 2-3 shows the reviewed indicators for assessment of CE at different levels. A brief overview of indicators to assess CE performance at all three levels is given in subsequent sections.

Table 2- 4 CE Assessment at different level

Circular Economy Evaluation Systems at Different Levels				
Level	**Author**	**Methodology**	**Categories**	**No. of Indicators**
Macro	Guo-gang et al (2011)	Specific indicator set	4	16
	Geng et al (2012)	Specific indicator set	4	22
	Wu et al (2014)	DEA window analysis method	N/A	N/A
Meso	Geng et al (2012)	Specific indicator set	4	12
	Li et al (2012)	Specific indicator set	5	18
	Nuñez-Cacho et al (2018)	Specific indicator set	7	44
Micro	Franklin-Johnson et al (2016)	Combination Matrix	N/A	N/A
	EMF (2016)	Specific single indicator	N/A	N/A

2.4.1 Circular Economy assessment at macro Level

At macro level, the indicators to assess CE are important for monitoring and promoting various programs and policies. The policy maker should have information about indicators to meet the goals of CE implementation (Banaitė, 2016). Different studies have been done on development of indicators for assessment of CE at macro level; Guo-gang et al (2011), developed an evaluation index system for assessment of CE at regional level. This evaluation index system contained 16 indicators classified into 4 groups "*Resources consumption, Environmental disturbance and Recycling and Social development*" this indicator system was used for assessment of CE for three provinces of China. This indicator system included indicators from 'reduce' and 'recycle' principles of CE; however, indicators from 'reuse' principle of CE lacked (Banaitė, 2016). Wu et al (2014), in their study for assessment of CE efficiency for 30 regions of China used DEA window analysis method, they measured efficiency of three sub systems of CE named as "*resource saving and pollutant reducing*

(RSPR), waste reusing and resource recycling (WRRR) and pollution controlling and waste disposing (PCWD)". This study concluded that relative efficiency of PCWD & WRRR is better than RSPR; therefore, to improve CE implementation, RSPR sub system should be focused in CE policy. Geng et al (2012) translated and explained the China's national CE evaluation index system in English, and stated that the overall purpose of this index system is to provide credible and objective information to decision makers on status of CE implementation. This evaluation index system contained 22 indicators classified into 4 groups "*Resource output rate, Resource consumption rate, Resource comprehensive utilization rate and Waste disposal and pollutant emission*". Although certain benefits can be gained using this evaluation index system but a revision is required to incorporate social and business indicators in this index system for better assessment of CE.

2.4.2 Circular Economy assessment at meso Level

The meso level comprises of industrial parks, businesses and symbiosis associations. The evaluation indicators of CE for this level help to control performance of these parks and plants; moreover, enable policy makers to take decisions**.** Different studies has been done on development of CE indicators for assessment at meso level, the number of indicators found in literature for meso level are less than macro and micro levels (Banaité,2016). China has launched evaluation index system based on the material flow analysis (MFA) for assessment of CE at macro and meso levels. For meso level, this evaluation index system contains 12 indicators being classified into 4 groups "*Resource output rate, Resource consumption rate, Resource comprehensive utilization rate, Waste disposal and pollutant emission"*. However, this evaluation index system lacked absolute energy and material reduction indicator (Geng et al., 2012). Furthermore, this indicator system was based on MFA indicators that are most applicable to macro level policy measures (Bringezu et al., 2003). Li et al (2012), proposed an indicator system for assessing CE performance of chemical industries, this indicator system consist of 18 indicators being classified into 5 groups "*Economic development, Economic development, Pollution reducing, Ecological efficiency and Developmental potential"*. They also evaluated CE performance of a chemical enterprise in China, based upon available data, the results showed that the enterprise was in transitional stage from traditional mode to circular mode. For proper assessment of CE using this evaluation index system, reliable data is mandatory and to have the required data in a developing country is an uphill task.

2.4.3 Circular Economy assessment at micro Level

The indicators at micro level are used for CE assessment of single enterprise or product, thus to set a generic indicator system for all enterprises may not be fit for use; therefore, customized indicators are required for CE assessment of micro level (Su et al., 2013). Franklin-Johnson et al (2016), proposed an indicator system for CE assessment at product design level, this indicator system is based on longevity, although this is simple and accessible method but this indicator system partially address CE principles (Cayzer et al., 2017). A more exhaustive approach has been proposed by Ellen MacArthur Foundation (EMF) as a circular design guide (EMF 2016).This approach is simple, comprehensive and speedy; however, potentially misleading results, hiding complexity and reliance on context specific assumptions are some limitation of this approach (Cayzer et al., 2017). The British Standards Institution has freshly launched a standard "*BS 8001:2017*" for CE. This standard includes quantitative indicators based on material flow analysis (MFA) and life cycle analysis (LCA) for assessment of CE in organizations. The authors of standard did not explained the relation between CE monitoring and already established quantitative tools LCA and MFA (Pauliuk, 2018).

2.4.4 Circular Economy Assessment in Building Sector

Buildings has been among the sustainable sectors since early times but with the advent of new construction materials having excellent strength and durability, the sustainability of this sector is compromised (Nuñez-Cacho et al., 2018) To overcome this problem of resource scarcity and environmental impacts of materials, CE model is useful for future sustainability of this sector. For the implementation of CE in building sector, indicator system is essential to monitor its implementation but literature review highlighted a challenge that the scales for assessment of CE of building sector are limited. By reviewing literature, only two scales for CE assessment of this industry were found. Nuñez-Cacho et al (2018), developed a scale based on Monte Carlo simulations for assessment of CE implementation by a construction firm; this scale is not only for contractor firm but also applicable for other project stakeholders. Their scale is based on scores from three sections "*Organization section, Process section and workgroup section"*, score for all three sections are integrated to get overall status of implementation of CE by a construction firm. Another scale for CE assessment of building industry was also developed by Nuñez-Cacho et al (2018), this scale is based on seven different weighted dimensions: one related to general CE indicators ; four related to resource management indicators ("*3Rs, Efficient Management of Energy, Water and Materials"*); and two related to environmental impacts ("*Emissions and Wastes"*).

After review of literature on CE, hardly there is any research, focusing on assessment of CE implementation at overall industry level for building sector in developing countries. This research targets to bridge this gap in literature by identifying the indicators to assess CE implementation at overall industry level for building sector of developing countries. Subsequently, significant indicators for CE assessment are extracted after detailed literature review from 2010-2019 periods. After content analysis, 24 indicators were shortlisted which are relevant to building sector. These indicators are presented in table 2.4 shown below and are used for further analysis:

Table 2- 5 Indicators Shortlisted after Content Analysis

Author Reference	Indicators for CE assessment	Frequency	Total Score (Normalized literature+ Normalized Industry score)	Cumulative normalized total score	Rank
Nuñez-et al., 2018; Bin et al; ChonQing, 2013; Zheng et al., 2012; Li & Su, 2012	Comprehensive utilization rate of industrial solid waste	5	0.029	0.029	1
Nuñez-et al., 2018; Geng et al., 2011; Bin et al., 2013 ; Zheng et al., 2012; Li & Su, 2012	Recycling rate of reclaimed wastewater	5	0.029	0.059	2
Geng et al., 2011; Bin et al., 2013; Zheng et al., 2012; Li & Su, 2012; Ma et al., 2014	Total amount of SO2 emissions	5	0.029	0.089	3
Geng et al., 2011; Bin et al., 2013; Zheng et al., 2012; Li & Su, 2012	Total amount of COD emissions	4	0.027	0.116	4
ChonQing ,2013; Zheng et al., 2012; Li & Su, 2012	Rate of Waste emissions	3	0.022	0.139	5
Nuñez-et al., 2018	Design in accordance with CE principles.	1	0.021	0.160	6
Geng et al., 2011; Bin et al., 2013; ChonQing ,2013;	Total amount of wastewater discharge	3	0.020	0.181	7

Author Reference	Indicators for CE assessment	Frequency	Total Score (Normalized literature+ Normalized Industry score)	Cumulative normalized total score	Rank
Geng et al., 2011;ChonQing ,2013; Li & Su, 2012	Water consumption per unit product in key industrial sectors	3	0.020	0.202	8
Nuñez-et al., 2018; Zheng et al., 2012	Environmental awareness in society	2	0.018	0.220	9
Nuñez-et al., 2018; Cayzer et al., 2016	Passing rate of used materials back into supply chain	2	0.018	0.238	10
Nuñez-et al., 2018; ChonQing ,2013	Comprehensive disposal rate of dangerous waste	2	0.018	0.256	11
Nuñez-et al., 2018; Cayzer et al., 2016	Resuing rate of products/materials	2	0.018	0.274	12
Zheng et al., 2012; Ma et al., 2014	Fresh water consumption	2	0.018	0.292	13
Nuñez-et al., 2018	Willingness for transformation to Circular Economy model	1	0.016	0.308	14
Nuñez-et al., 2018; Elia, et al., 2016	Percentage consumption of renewable or clean energy	2	0.016	0.325	15

Author Reference	Indicators for CE assessment	Frequency	Total Score (Normalized literature+ Normalized Industry score)	Cumulative normalized total score	Rank
Nuñez-et al., 2018	Energy saving amount	1	0.016	0.341	16
Nuñez-et al., 2018	Redesign of products/services	1	0.016	0.358	17
Nuñez-et al., 2018	Rate of carbon footprint	1	0.016	0.374	18
Nuñez-et al., 2018; Cayzer et al., 2016	Availability of complete bill of materials and substances for the product.	2	0.016	0.390	19
Nuñez-et al., 2018; Geng et al., 2011	Output of main mineral resource	2	0.016	0.407	20
Geng et al., 2011; Bin et al., 2013	Energy consumption	2	0.016	0.423	21
Geng et al., 2011; Bin et al., 2013	Total amount of industrial solid waste disposal	2	0.016	0.472	22
Nuñez-et al., 2018; Cayzer et al., 2016	Availability of complete bill of solid waste for the manufacturing process.	2	0.016	0.488	23
Geng et al., 2011	Recycling rate of industrial solid waste	1	0.016	0.504	24

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the research methodology being used in this study. The research strategy depicts how the researchers will perform their study to attain and answer research objectives (Saunders et al., 2009). It helps researcher to highlight the relevant tools and techniques to carry out the process with the limitation of time and resources. Therefore, this chapter discusses the tools and techniques utilized in the study. Multiple techniques were used during the research process i.e. literature review, questionnaire survey, Cronbach's alpha, Shapiro-Wilk test, RII, Pareto Analysis (80/20 rule), influence matrix and interpretive structural modeling.

3.2. Research strategy

Before proceeding to research design for this study, the research objectives are reproduced here:

1. To identify the current state of circular economy implementation in building sector.
2. To identify barriers to circular economy implementation in building sector.
3. To propose a framework for adoption of circular economy in building sector.

The research initiates through a literature review process for analysis of the status of research done on circular economy (CE) in building sector. Literature review presents the barriers to CE in different perspectives and assessment of CE at different levels. Afterwards, the research objectives are targeted using the appropriate techniques; where the selection of technique is determined by the relationship among the research objective, kind of data and analysis required on the data.

3.2. 1 Research strategy to achieve objective # 1

Key variables of circular economy were identified from literature review, and a questionnaire survey was conducted since it offers the advantage of covering a large population (Nkhata, 1997). Moreover, large sample sizes ensure generalization and interpretation of result for the entire population (Muya et al., 2013). This questionnaire was developed with few relevant indicators being able to give strong indication about the variables of circular economy. This survey instrument consists of seven variables of circular economy with few indicators from each. Five-point Likert scale was used for each indicator to provide flexibility to the respondents to select one option only that is best aligned with their thinking. The five-point scale used is "1= strongly disagree, 2 = disagree, 3 = neutral, 4= agree, 5 = strongly agree". The sample selected for this study was random chosen from architects, civil engineers, architectural engineers and building facility managers from the developing countries. All three major stakeholders (client, consultant and contractor) were included in the survey. The questionnaire was floated and submitted online. Out of 300 invitations, 157 completed responses were received, giving a response rate of 52.3%. Out of these 157 responses, 47 respondents had no understanding of CE concept, thus these 47 respondents were exempted for data analysis due to their low level of understanding of respondent about CE. Thus a total of 110 responses, were used for further data analysis, this sample size is larger than the minimum size of 96, ensuring representatives and significance (Shash and Abdul-Hadi, 1993; Dillman, 2011).

The answers to each statement were then used to compute RII, which ranged from 0 to 1. Data is evaluated using MS excel and SPSS-25, to have frequency analysis, reliability analysis and relative importance index (RII) analysis. The selection of these statistical methods will be introduced in relevant chapters.

3.2. 2 Research strategy to achieve objective # 2

From detailed literature review, a list of 79 barriers impeding implementation of CE in different perspectives, from 2010-2019 periods were extracted. Consequently, after calculating literature scores and normalized literature score for all barriers, top 25 barriers CE adoption were shortlisted. For further analysis, building sector experts were approached for review and shortlisting of these 25 barriers. Based on responses from 10 experts, relative importance index score was calculated and top 50% barriers from these 25 barriers were shortlisted for CE barriers interaction matrix and barrier-indicator influence matrix.

3.2. 3 Research strategy to achieve objective # 3

Two questionnaire surveys were developed to identify interaction among circular economy barriers and to study influence of CE barriers on indicators of CE. To identify interaction among barriers of CE, Interpretive Structural Modelling (ISM) approach was used. ISM is described in detail in data analysis portion of this research. To study influence of CE barriers on indicators of CE, an influence matrix was developed. The responses for interaction and influence matrix were collected from experts of academia and building industry from developing countries, having at least 10 years of experience. Methodology flow chart for this study is given in figure 3.1.

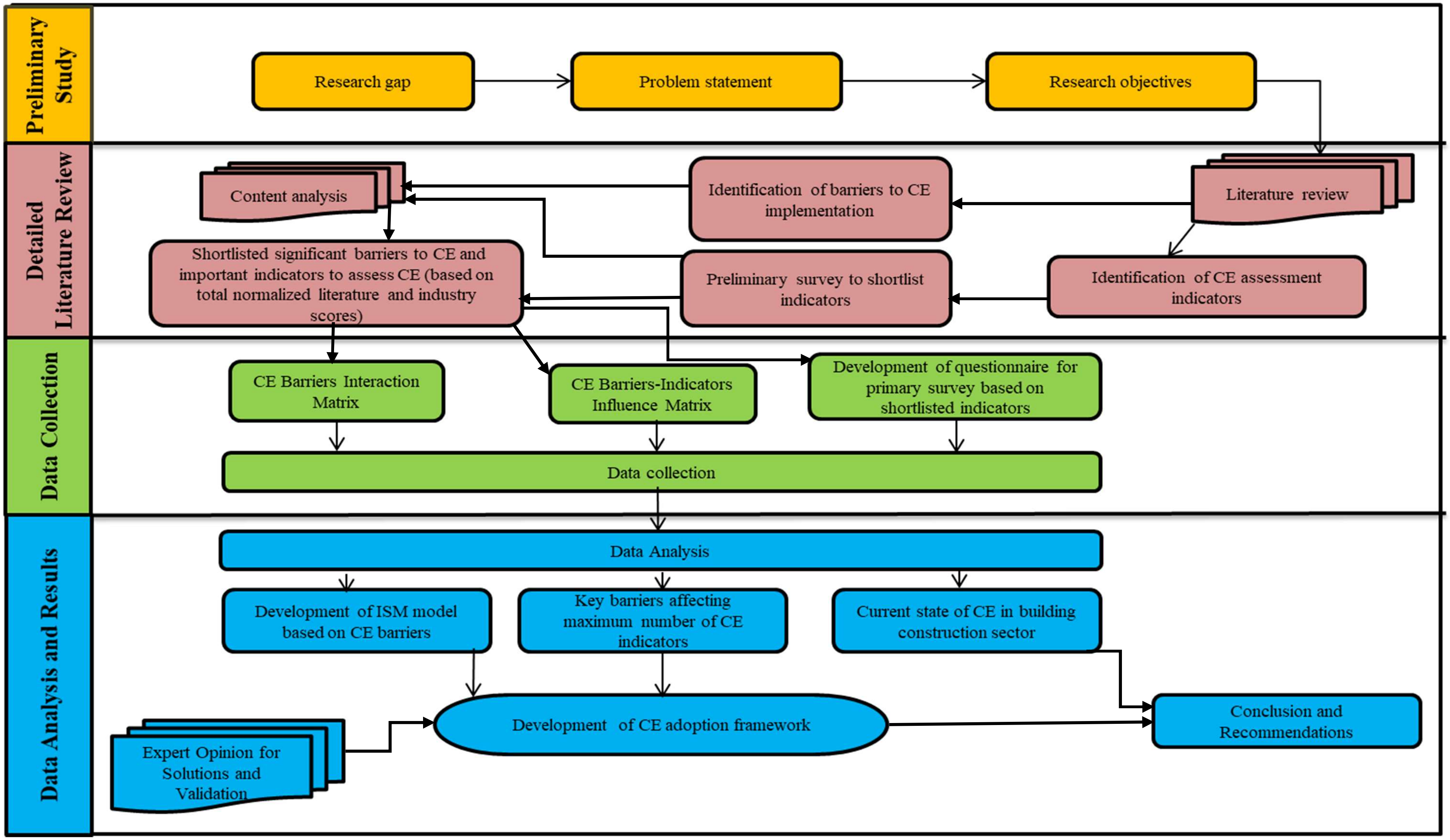


Figure 3- 1 Methodology Flow Chart

3.3. Preliminary survey

The purpose of conducting preliminary survey was to include the industry professionals input before performing content analysis for shortlisting of indicators for CE assessment. Preliminary survey questionnaires for shortlisting of indicators were circulated to 21 experts having field experience. Based on the feedback of experts, industry normalized score was calculated by using mode values obtained from survey. Against weightages, normalized industry and literature scores were combined. After content analysis, top 24 indicators for CE assessment were finalized for further analysis. Expert's demographics for preliminary survey are shown in table 3.1.

Table 3- 1 Respondents Demographics

Organization Type	No. of responses	Years of Experience	No. of responses	Education Level	No. of responses
Client	5	1-5 years	2	B Tech Hons	0
Contractor	7	6-10 years	3	B.Sc/B.Eng/B. Arch	2
Sub-Contractor	0	11-15 years	7	M.Sc/M.Eng/M.Arch/P.G.Dip	15
Consultant	7	16-20 years	4	PhD/D.Eng	4
Other	2	21 and above years	5		
Total Responses	**21**				

3.4 Data Analysis Methodology to Identify Current State of CE

Microsoft Excel and Statistical Package for Social Science (SPSS-25) were used to analyze the collected data to identify current state of CE. Following were the statistical techniques being used to analyze the collected data.

3.4.1 Tests for reliability and normality

For measuring the internal consistency and reliability of data, the value of Cronbach's alpha was 0.902. Values ranging from 0.70-0.95 are acceptable for further analysis (Tavakol and Dennick, 2011). Therefore, the data used for present study is valid and reliable. Further, to evaluate the normality of collected data, Shapiro-Wilk test was performed. The results highlighted a significance value of 0.000, which is less than 0.05, which indicates that the data is not normal.

3.4.2 Relative Importance Index

The different sections of the questionnaire were then analyzed using the technique Relative Importance Index (RII) to consider every respondent's feedback towards the inquiries asked in the survey. The technique, RII, analyses the responses to Likert Scale using following equation:

RII = Σ w / A*N, where

w = weights assigned in Likert Scale (for 5-point Likert Scale, w = {1, 2, 3, 4, 5}),

A = highest weight assigned in the scale (for 5-point Likert Scale, A = 5),

N = total number of respondents (i.e. 110 for this study), and

RII ranges from 0 to 1.

3.5 Data Analysis Methodology for Interpretive Structural Modeling (ISM) and Influence Matrix

This research aims to use ISM and Influence matrix techniques on the identified CE barriers to develop a CE adoption framework for building sector of developing countries.

3.5.1 Interpretive Structural Modeling

ISM is an interactive learning process; this technique comprehensively structure's various directly or indirectly elements into a well-organized and systematic model (Warfield, 1974). ISM identifies relationships among the specific items and portrays the patterns among items both graphically and by words (Raj et., 2008). The methodology for ISM is shown in figure 3-2.

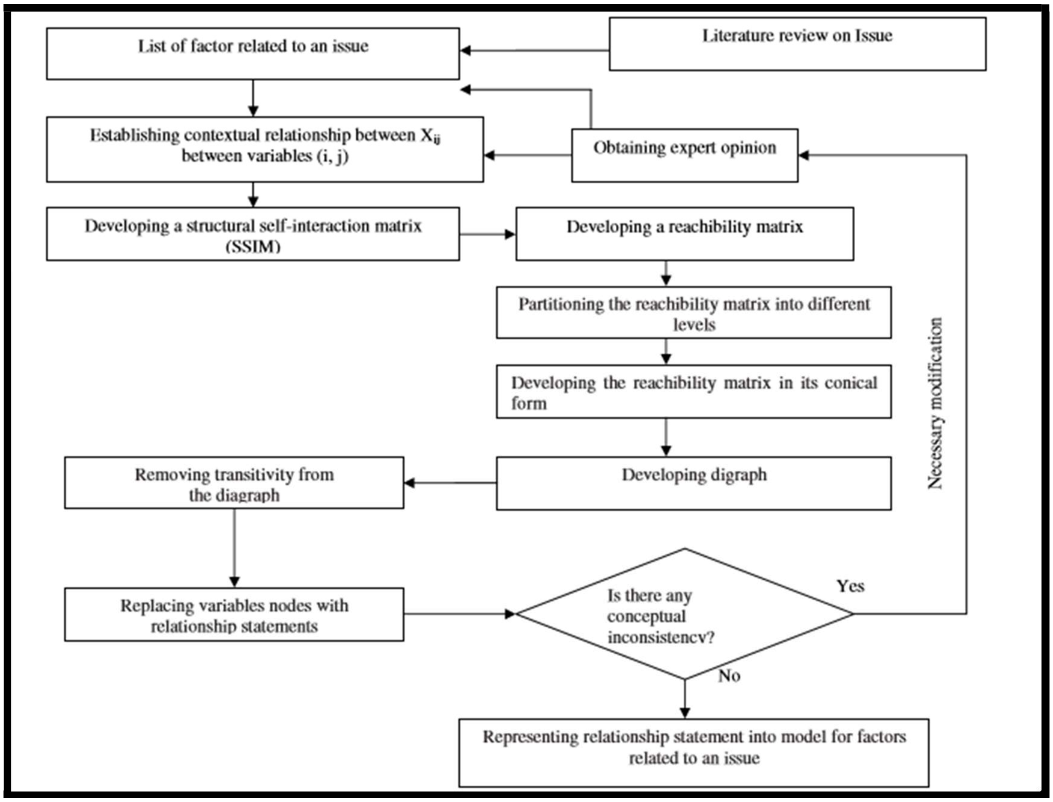


Figure 3- 2: ISM Methodology flow chart

3.5.2 Influence Matrix

To check the influence of CE barriers on the indicators of CE, an influence matrix is used in this study. The 25 identified barrier of CE are kept in rows, while identified 24 indicators of CE are kept in columns, experts were asked fill this matrix based upon the level of influence (1= low, 3= medium and 5= high) and relationship type (direct or inverse). The influence matrix is analyzed using Pareto analysis (80/20 rule) to identify most influencing barriers of CE.

3.6 Development of CE adoption framework

Based on the current state of CE implementation in the building sector and results of ISM and influence matrix, experts from building sector were contacted to propose the strategies, to alleviate the implementation level of CE in building sector by mitigation of the identified barriers of CE. This CE adoption framework was validated by review of experts from building sector.

3.7 Summary

This research used various research methods. In this chapter, the research methodology being used in this study was discussed in detail. Furthermore, discussion provides a lucid understanding of methodology used for development and validation of ISM and CE adoption framework.

CHAPTER 4

ANALYSIS AND RESULTS

4.1 Introduction

In this research study, different data analysis techniques were used in accordance with the research objectives, and type of data. To identify the current state of CE, a questionnaire survey was conducted and different analysis techniques were used for identification of implementation of circular economy in building sector of developing countries. Furthermore, Interpretive Structural Modeling (ISM) was used to study interaction among identified barriers of CE, and influence matrix was used to study influence of CE barriers on indicators of CE. These data analysis techniques and results for this study are presented one by one in detail in this chapter.

4.2 Characteristics of Respondents for Primary Survey

4.2.1 Grouping of the Respondents

There are total 157 responses out of 300, with a response rate of 52.3%. However, valid responses are 110, as 47 respondents had low level of understanding of CE concept. Response from clients is 10 %, consultants 46.3% and contractors 43.6 %. Grouping and frequency for respondents are presented in the Table 4.1 and Figure 4.1:

Table 4- 1: Grouping of Respondents

Respondents	No of Valid Questionnaires Returned	Percentage (%)	Cumulative Percentage (%)
Clients	11	10	10
Consultants	51	46.3	56.3
Contractors/Subcontractors	48	43.6	100
Total	110	100	-

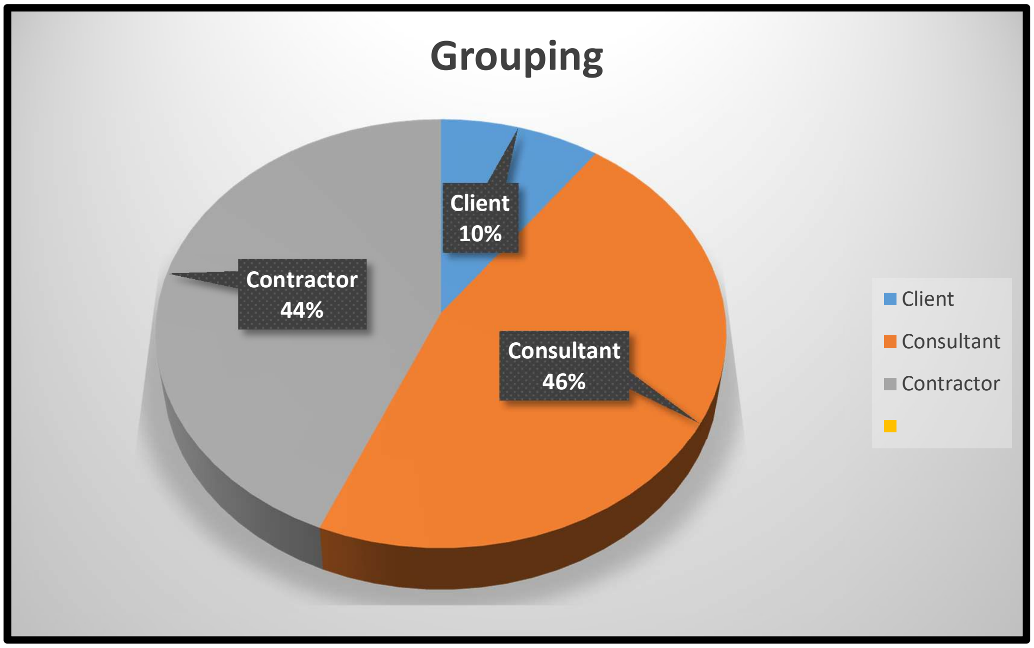


Figure 4- 1: Grouping of the Respondents

4.2.2 Experience of the Stakeholders in the Building Sector

Respondents are having diverse experience in the building sector, as presented in Table 4.2 and Figure 4.2. Almost 54.5% (60) of the respondents have overall above 10 years of experience in building sector, 27.2% (30) have 6 to 10 years of experience in building sector, whereas only 18.1% (20) have less than 5 years of experience in building sector. Therefore, this shows that the collected data can be considered as reliable and authentic.

Table 4- 2: Experience of Respondents in Building Sector

Experience of Respondents	Frequency of Respondents	Percentage of Respondents	Cumulative Percentage
0-5 years	20	18.18	18.18
6-10 years	30	27.27	45.45
11-15 years	37	33.64	78.09
16-20 years	9	8.18	87.27
20+ years	14	12.73	100
Total	110	100.0	-

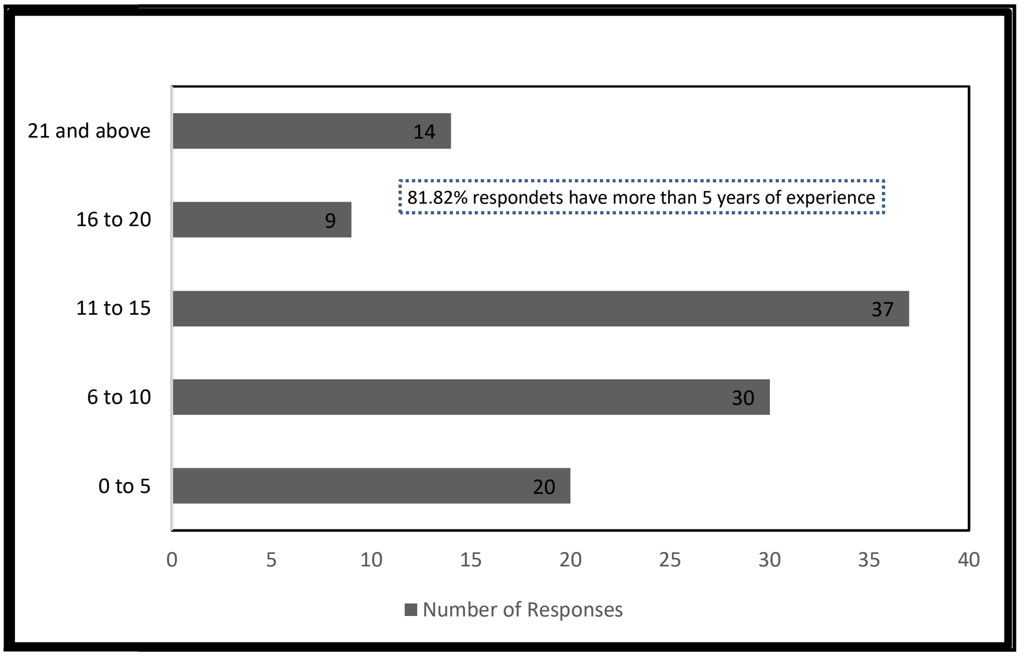


Figure 4- 2: Number of Respondents basing on Industry Experience

4.2.3 Qualification of the Respondents

Respondents are having varied qualification background as shown in Table 4.3 and Figure 4.3. Approximately 30.9 (34) of the respondents have B.sc/ B.Eng / B. Arch degree, 61.81% (68) M.sc/ M.Eng/ M.Arch/ PG.Dip degree, whereas 7.29% (8) have PhD/ D.Eng degree.

Table 4- 3: Qualification of Respondents

Qualification of Respondents	Frequency of Respondents	Percentage of Respondents	Cumulative Percentage
B.sc/ B.Eng / B. Arch	34	30.90	30.90
M.Eng/ M.Arch/PG.Dip	68	61.81	92.71
PhD/ D.Eng	8	7.29	100
Total	110	100.0	-

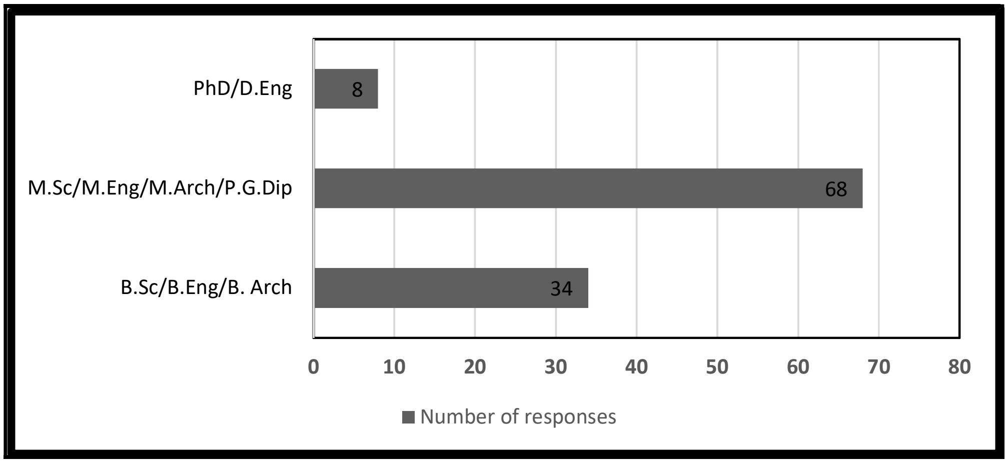


Figure 4- 3: Qualification of respondents

4.2.4 Positions of the Respondents in the Building Sector

Respondents for this survey are from different positions in the Building Sector. Table 4.4 and Figure 4.4; show the percentages of different positions holders, who responded to this survey. Approximately, 1.81% (2) of the respondents are general managers, 4.54 % (5) project directors, 33.63 % (37) project managers/construction managers, 5.45 % (6) facility managers, 0.9 % (1) contract manager, 0.9% (1) planning manager, 34.54 % (38) project engineers/site engineers, and 18.18 % (20) architects/designers.

Table 4- 4: Positions of the Respondents in Building Sector

Positions of the Respondents	Frequency of Respondents	Percentage of Respondents	Cumulative Percentage
General Manager	2	1.81	1.81
Project Director	5	4.54	6.35
Project Manager /Construction Manager	37	33.63	39.98
Facility Manager	6	5.45	45.43
Contract Manager	1	0.9	46.33
Planning Manager	1	0.9	47.23
Project Engineer/Site Engineer	38	34.54	81.77
Architect/ Designer	20	18.18	100
Total	110		

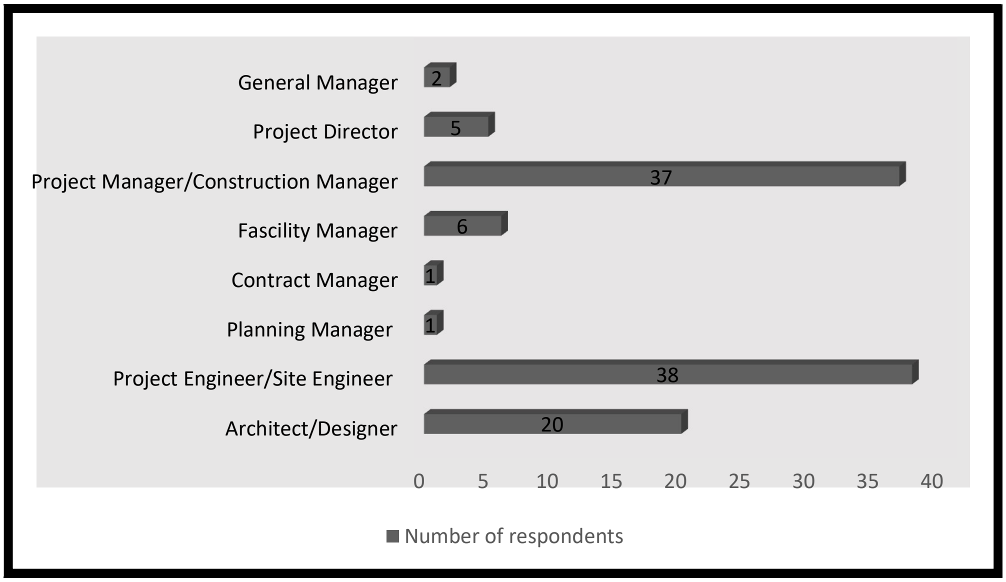


Figure 4- 4: Percentage of the Respondents basing on their Position

4.2.5 Location of the Respondents

Respondents to this survey are working in 16 developing countries of six continents. All the respondents were contacted through emails/ social websites projects. Table 4.5 shows the location along with the frequencies of respondents. Approximately, 19% of the respondents are national while 81% are from different developing countries.

Table 4- 5: Location of Respondents Included in the Survey

Location of Respondent	Frequency of Respondents
Pakistan	21
India	10
Malaysia	7
Turkey	5
Bangladesh	3
China	2
Ghana	13
Nigeria	8
South Africa	2
Kenya	2
Egypt	1
Serbia	16
Albania	9
Brazil	8
Mexico	2
Fiji	1
Total	**110**

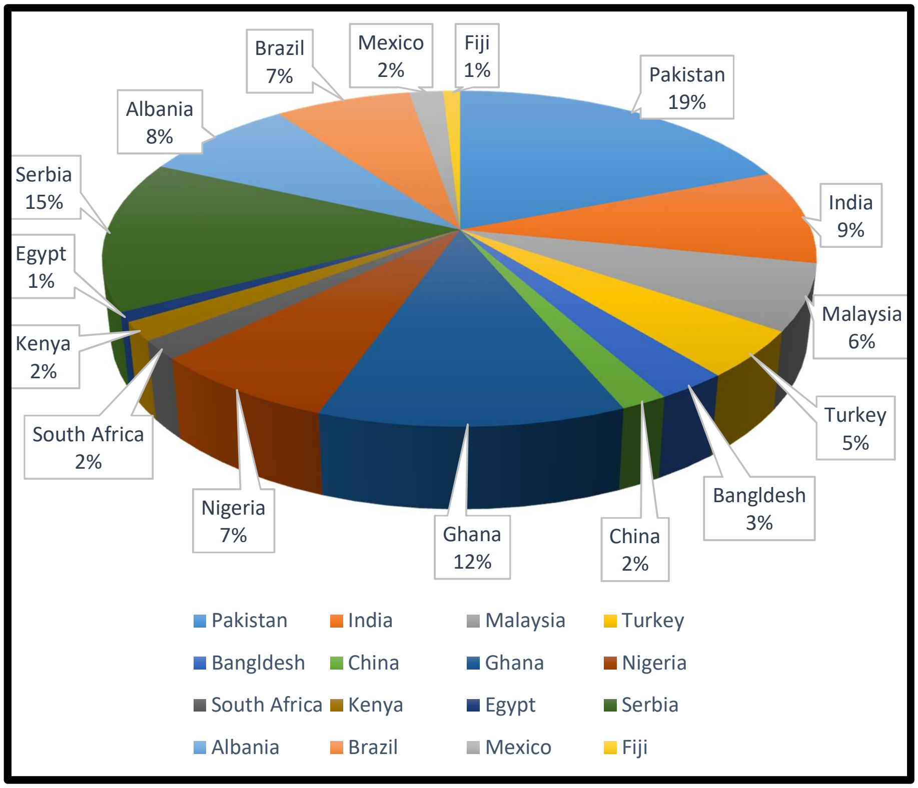


Figure 4- 5: Location of Respondents Included in the Survey

4.2.6 Respondents level of understanding of CE

Respondents for this research had different level of awareness of CE. A total of 157 responses were collected but respondents having 'no understanding' of CE were excluded. 47 respondents having 'no understanding' of CE were excluded; only 110 responses were considered for further analysis. This low level of awareness shows the newness of CE paradigm in building sector of developing countries. Out of 110 valid responses, 31% (34) respondents had slight understanding of CE, 22 % (24) had neutral understanding of CE, 40 % (44) had moderate understanding of CE, whereas only 7 % (8) had advanced level of understanding of CE. The respondent level of understanding of CE is shown in figure 4.6 and table 4.6 given below.

Table 4- 6: Respondents Level of Understanding of CE

Level of Understanding of CE	Frequency of Respondents	Percentage of Respondents	Cumulative Percentage
Slight	34	31	31
Neutral	24	22	53
Moderate	44	40	93
Advanced	8	7	100
Total Responses	110	100	-

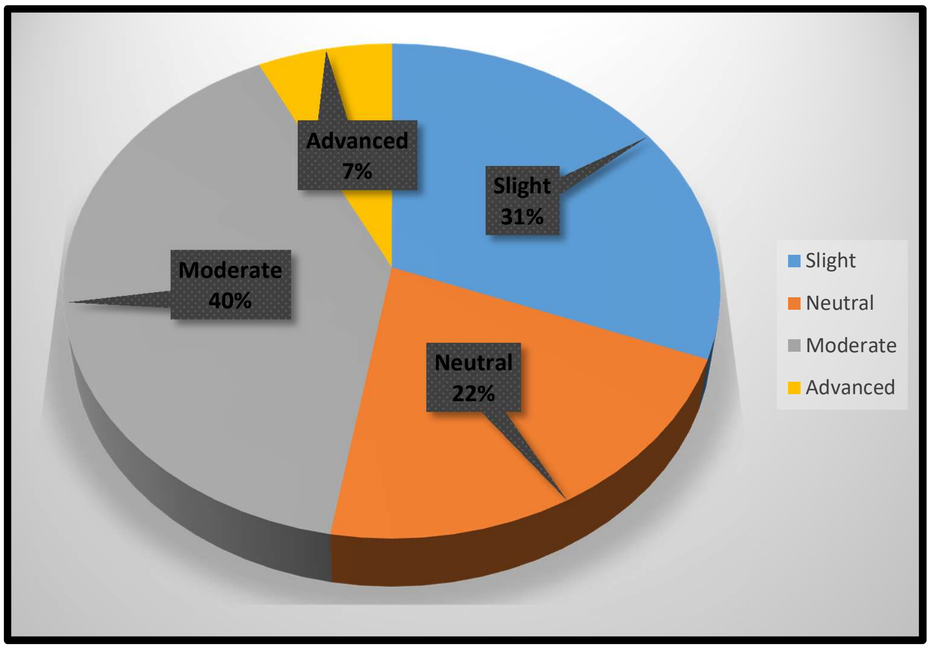


Figure 4- 6: Respondents Level of Understanding of CE

4.3 Characteristics of respondents for Interaction and Influence Matrix

In order to collect of data for CE barriers interaction matrix and CE barriers and indicators influence matrix, experts having at least 10 years of experience and good understanding of CE were contacted. A total of 15 experts were contacted but 10 experts from 4 countries participated in this survey. Experts were contacted through face-to-face interaction and through email. Demographics of respondents are shown in table 4.7.

Table 4- 7: Respondents Demographics for Interaction and Influence Matrix

Respondent	Years of Experience	Qualification	Type of Organization	Designation/ Trade	Country	Medium of Contact
Respondent 1	16	B.Eng. (Civil)	Consultant	Chief Civil Engineer	Nigeria	Email
Respondent 2	19	M.Eng. (Civil)	Contractor	Project Manager	Pakistan	Face to Face
Respondent 3	11	M.Eng. (Civil)	Client	Manager Property Development	Pakistan	Face to Face
Respondent 4	37	B.Eng. (Mechanical)	Client	Facility Manager	Pakistan	Face to Face
Respondent 5	15	Phd (Architecture)	Academia	Professor	Turkey	Email
Respondent 6	11	Phd Scholar (Civil Eng.)	Academia	Student	Pakistan	Face to Face
Respondent 7	10	M.Eng. (Civil)	Contractor	Project Manager	India	Email
Respondent 8	12	M.Eng. (Architectural)	Consultant	Resident Engineer	Pakistan	Face to Face
Respondent 9	35	M.Eng. (Environmental)	Client	Senior Resident Engineer	Pakistan	Face to Face
Respondent 10	32	M.Eng. (Civil)	Contractor	Contract Manager	Pakistan	Face to Face

4.4 Statistical Analysis to Identify Current State of CE

4.4.1 Reliability of the Sample

To check the internal consistency of developed scale, Cronbach's Coefficient Alpha method was used. This method is mostly used for assessment of reliability for Likert scales. If value of Cronbach's Coefficient Alpha is between 0.7-0.95, this indicates that the data is acceptable for further analysis (Tavakol and Dennick, 2011). For the collected data, its value was calculated as 0.902 using SPSS. The higher value of data showed that data was reliable and consistent for further analysis. The statistics of reliability test are shown in table 4.8 given below.

Table 4- 8: Reliability Statistics

<table>
<tr><th colspan="4">Case Processing Summary</th><td rowspan="3">Cronbach's Alpha</td><td rowspan="3">0.902</td></tr>
<tr><td colspan="2"></td><td>N</td><td>%</td></tr>
<tr><td rowspan="3">Cases</td><td>Valid</td><td>110</td><td>100.0</td></tr>
<tr><td>Excluded [a]</td><td>0</td><td>.0</td><td rowspan="3">Number of Items</td><td rowspan="3">24</td></tr>
<tr><td>Total</td><td>110</td><td>100.0</td></tr>
<tr><td colspan="4">a. List wise deletion based on all variables in the procedure.</td></tr>
</table>

4.4.2 Normality Test

For the assessment of normality of data, Shapiro-Wilk test was used; sample size being less than 2000. Significance values found for data were 0.000, which were less than 0.05. This indicated that collected data is not normally distributed. The statistics of normality test are shown in table 4.9 given below.

Table 4- 9: Tests of Normality- Shapiro Wilk Test

Circular Economy Indicators (CEI)	Shapiro-Wilk Test	
	Statistic	Sig.
CEI (01)	0.878	.000
CEI (02)	0.877	.000
CEI (03)	0.893	.000
CEI (04)	0.855	.000
CEI (05)	0.865	.000
CEI (06)	0.875	.000
CEI (07)	0.860	.000
CEI (08)	0.852	.000
CEI (09)	0.852	.000
CEI (10)	0.907	.000
CEI (11)	0.903	.000
CEI (12)	0.891	.000
CEI (13)	0.871	.000
CEI (14)	0.845	.000
CEI (15)	0.889	.000
CEI (16)	0.881	.000
CEI (17)	0.880	.000
CEI (18)	0.867	.000
CEI (19)	0.899	.000
CEI (20)	0.865	.000
CEI (21)	0.884	.000
CEI (22)	0.890	.000
CEI (23)	0.881	.000
CEI (24)	0.889	.000

4.5 Ranking of Circular Economy Variables by Mean and RII

The questionnaire comprised of 24 statements/questions to assess the implementation level of circular economy in building sector. These circular economy variables are further grouped in 7 variables. The data collected from 110 respondents is evaluated using SPSS-25 and MS excel. Means, Relative Importance Index (RII), percentages and ranking of 7 circular economy variables is calculated, which is given in Table 4.10. Mean value of circular economy implementation level in building sector of developing countries is assessed to be 2.936, which should ideally be closer to 5. Similarly, RII for current application of circular economy in building sector of developing countries is calculated as 0.5873. Out of 7 circular economy variables, the variable of 'Energy Indicators' has the maximum value of RII (0.6533), whereas 'Waste Indicators' has the minimum value of RII (0.5114). It implies that 'Waste indicators' is the most neglected aspect in building sector of developing countries, followed by '3R's (Reduce, Recycle, Reuse) Indicators' and 'Emission Indicators'.

Table 4- 10: Mean, Percentage, RII and Ranking of Circular Economy Variables

S. No	Circular Economy Variables (7)	Mean of Variables	Percentage (%) of Variables	RII of Variables	Overall Ranking of Variables
1	Material Indicators	2.9667	59.33	0.5933	**4**
2	Energy Indicators	3.2666	65.33	0.6533	**1**
3	Waste Indicators	2.5571	51.14	0.5114	**7**
4	3R's (Reduce, Recycle, Reuse) Indicators	2.7363	54.73	0.5473	**6**
5	Water Indicators	3.0818	61.64	0.6164	**3**
6	Emission Indicators	2.8045	56.09	0.5609	**5**
7	General Circular Economy Indicators	3.1424	62.85	0.6285	**2**
Average of Current State of CE of Building Sector of Developing Countries		**2.9365**	**58.73**	**0.5873**	
Note: Ranking score is based on the level of implementation of each circular economy variable.					

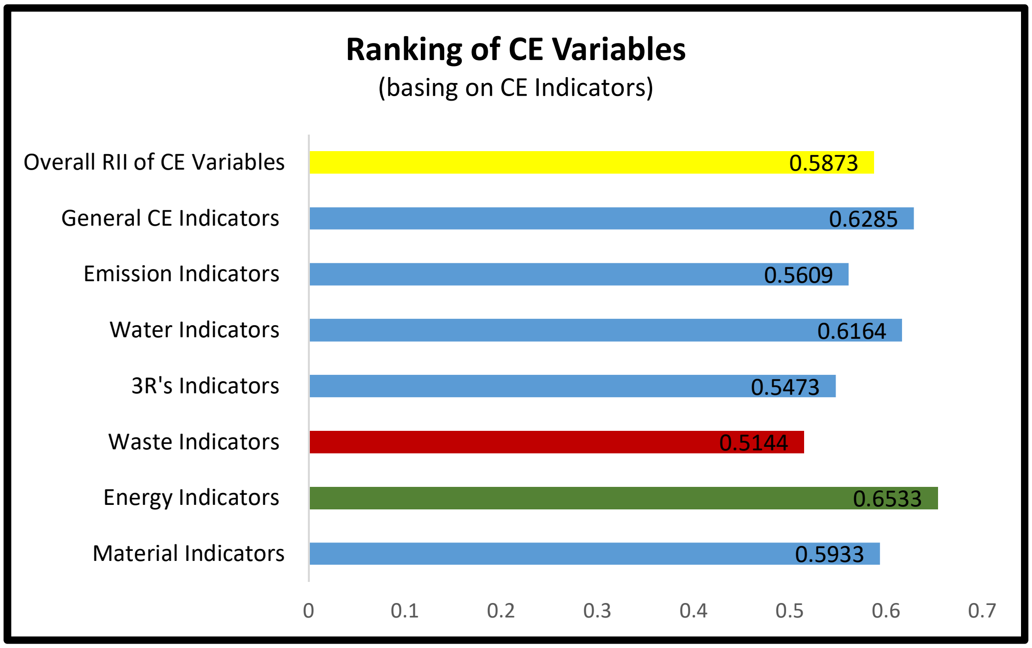


Figure 4- 7: shows the ranking of all 7 CE variables basing on RII.

4.6 Ranking of all CE Indicators by Mean and RII

The data collected through 110 respondents for twenty-four (24) CE indicators have been evaluated using SPSS-25 and MS excel. Furthermore, the percentages, means, RII and ranking of all CE indicators have been calculated. Table 4.11 shows the ranking of all CE variables within each variable and overall ranking. Mean value of all CE indicators is computed as 2.936, and in terms of percentage CE implementation level of building sector of developing countries is computed as 58.73%, which should ideally be nearer to 100. This warrants attention of all stakeholders to work for improvement of CE practices in the building sector of developing countries.

Table 4- 11: Mean, Percentage, RII and Ranking of 24 CE Indicators

7 CE Variables (24 Indicators)		Mean of CE Indicators	Percentage (%) of CE Indicators	RII of CE Indicators	Ranking of CE Indicators basing on RII	
					Within variable	Overall (1 to 24)
1. **Material Indicators**						
01	Passing rate of used materials back into supply chain.	2.8727	57.5	0.575	2	9
02	Availability of complete bill of materials and substances for the product.	3.3000	66	0.660	1	4
03	Output of main mineral resource.	2.7273	54.5	0.545	3	16
2. **Energy Indicators**						
01	Percentage consumption of renewable or clean energy.	3.4455	68.9	0.689	2	2
02	Energy saving amount.	3.5727	71.5	0.715	1	1
03	Energy consumption.	2.7818	55.6	0.556	3	13
3. **Waste Indicators**						
01	Comprehensive utilization rate of industrial solid waste.	2.3545	47.1	0.471	7	24
02	Recycling rate of reclaimed wastewater.	2.4182	48.4	0.484	6	23
03	Total amount of wastewater discharge.	2.5636	51.3	0.513	4	21
04	Comprehensive disposal rate of dangerous waste.	2.8091	56.2	0.562	1	11
05	Total amount of industrial solid waste disposal.	2.6818	53.6	0.536	2	18
06	Availability of complete bill of solid waste for the manufacturing process.	2.4273	48.5	0.485	5	22
07	Recycling rate of industrial solid waste.	2.6455	52.9	0.529	3	19

7 CE Variables (24 Indicators)		Mean of CE Indicators	Percentage (%) of CE Indicators	RII of CE Indicators	Ranking of CE Indicators basing on RII	
					Within variable	Overall (1 to 24)
4. **3R's (Reduce, Recycle, Reuse) Indicators**						
1	Reusing rate of products/materials.	2.8273	56.5	0.565	1	10
02	Redesign of products/services.	2.6455	52.9	0.529	2	20
5. **Water Indicators**						
1	Water consumption per unit product in key industrial sectors.	3.2455	64.9	0.649	1	5
02	Fresh water consumption.	2.9182	58.4	0.584	2	8
6. **Emission Indicators**						
1	Total amount of SO2 emissions.	2.7818	55.6	0.556	2	14
02	Total amount of COD emissions.	2.7545	55.1	0.551	3	15
03	Rate of Waste emissions.	2.6909	53.8	0.538	4	17
04	Rate of carbon footprint.	2.9909	59.8	0.598	1	7
7. **General Circular Economy Indicators**						
1	Design in accordance with CE principles.	2.7909	55.8	0.558	3	12
02	Environmental awareness in society.	3.4364	68.7	0.687	1	3
03	Willingness for transformation to Circular Economy model.	3.2000	64	0.640	2	6

4.6.1 Five (5) Better Circular Economy Indicators

Although, perfection is needed in all the CE indicators; however, five (5) indicators having better performance in the building sector of developing countries are shown in figure 4.8.

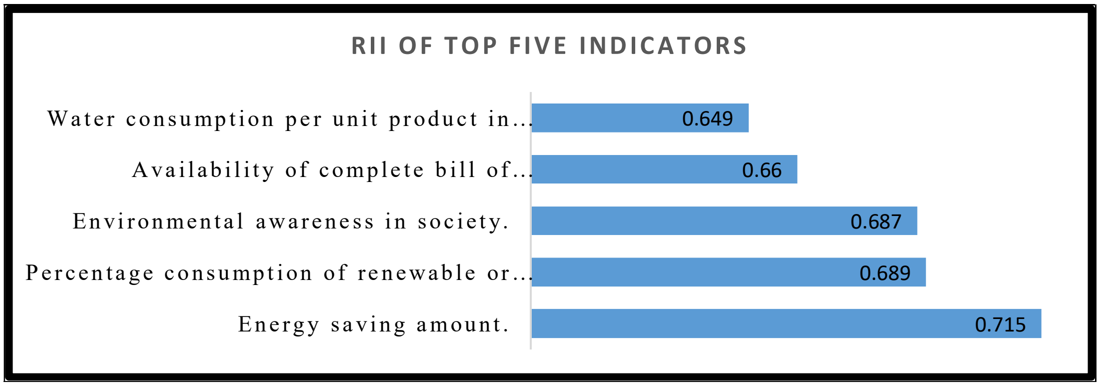


Figure 4- 8: Five (5) Better CE Indicators of Building Sector

4.6.2 Five (5) Most Neglected CE Indicators

The five (5) most neglected CE indicators in building sector of developing countries are shown in figure 4.9. These require special attention to enhance the CE implementation level:

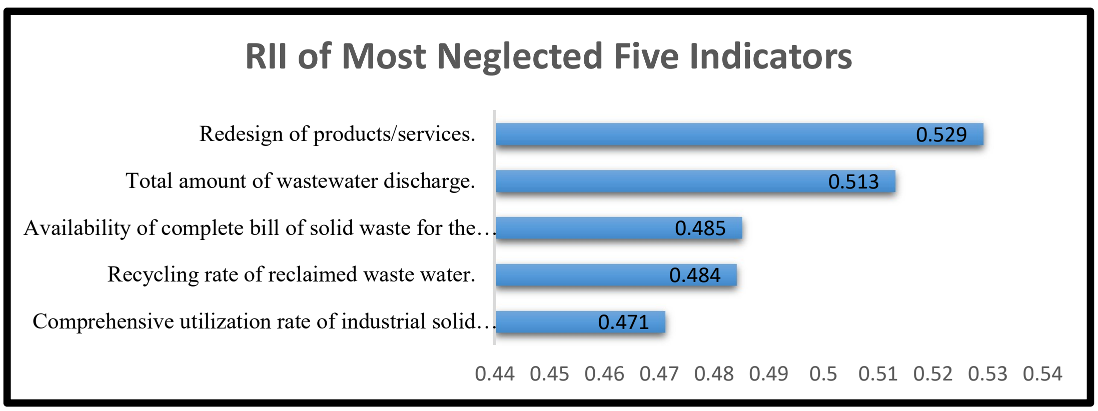


Figure 4- 9: Five (5) Most Neglected CE Indicators of Building Sector

4.7Analysis of CE Variables

CE indicators, which are ranked closer to 1, indicate that their implementation level is better, whereas the CE indicators which are ranked closer to 24 specify that their implementation level is very poor.

4.7.1 Material Indicators

Level of implementation of CE for material dimension in building sector is analyzed through three questions. Ranking of these indicators is given below in Table 4.12. Results shows that there is availability of information about materials and substances for the product manufacturing but output of main mineral resources is increasing, thus serious steps are required by building sector to reduce the consumption of main mineral resources.

Table 4- 12: Material Indicators-Ranking

Material Indicators	Ranking within Variable	Overall Ranking
Passing rate of used materials back into supply chain.	2	9
Availability of complete bill of materials and substances for the product.	1	4
Output of main mineral resource.	3	16

4.7.2 Energy Indicators

Level of implementation of CE for energy dimension in building sector is analyzed through three questions. Ranking of these indicators is given below in Table 4.13. Overall energy dimension ranked at number 1, and top 2 indicators among 24 indicators are from energy dimension. This is good to know that energy saving amount and percentage consumption of renewable or clean energy is increasing but overall energy consumption is still increasing by building sector. Thus, building sector has to reduce its energy consumption by using energy efficient appliances and equipment during all phases of a building lifecycle.

Table 4- 13: Energy Indicators-Ranking

Energy Indicators	Ranking within Variable	Overall Ranking
Percentage consumption of renewable or clean energy	2	2
Energy saving amount	1	1
Energy consumption	3	13

4.7.3 Waste Indicators

Level of implementation of CE for waste dimension in building sector is analyzed through seven questions; ranking for these indicators is given in Table 4.14. This is alarming that waste dimension of CE ranked at lowest for building sector. The poorest results for current state of CE for building sector require serious attention from all the stakeholders of building sector to reduce waste in all phases of building lifecycle.

Table 4- 14: Waste Indicators-Ranking

Waste Indicators	Ranking within Variable	Overall Ranking
Comprehensive utilization rate of industrial solid waste	7	24
Recycling rate of reclaimed wastewater	6	23
Total amount of wastewater discharge	4	21
Comprehensive disposal rate of dangerous waste	1	11
Total amount of industrial solid waste disposal	2	18
Availability of complete bill of solid waste for the manufacturing process.	5	22
Recycling rate of industrial solid waste	3	19

4.7.4 3R's (Reduce, Recycle, Reuse) Indicators

Level of implementation of CE for 3R's dimension in building sector is analyzed through two questions. Ranking of these indicators is given below in Table 4.15. As 3R's is the main component of CE paradigm, the results for CE assessment of building sector showed poor results for this dimension of CE. As current level of implementation of CE for 3R's dimensions ranked at sixth number, this requires serious attention of all the stakeholders of this industry to improve the implementation of 3R's among all phase of buildings lifecycle.

Table 4- 15: 3R's (Reduce, Recycle, Reuse) Indicators-Ranking

3R's (Reduce, Recycle, Reuse) Indicators	Ranking within Variable	Overall Ranking
Reusing rate of products/materials	1	10
Redesign of products/services	2	20

4.7.5 Water Indicators

Level of implementation of CE for water dimension in building sector is analyzed through two questions. Ranking of these indicators is given below in Table 4.16. The results for current assessment of water dimension of CE showed a good ranking among other dimensions but RII and mean of this dimension depicts that to improve the CE of building sector and to move towards perfection this dimension needs improvement as well.

Table 4- 16: Water Indicators-Ranking

Water Indicators	Ranking within Variable	Overall Ranking
Water consumption per unit product in key industrial sectors	1	5
Fresh water consumption	2	8

4.7.6 Emission Indicators

Level of implementation of CE for emission dimension in building sector is analyzed through four questions. Ranking of these indicators is given below in Table 4.17. The results of current assessment of CE of building sector shows poor results for current state of emission dimension. This calls for serious attention of this sector to play its role to cut short the associated environmental impacts of buildings.

Table 4- 17: Emission Indicators-Ranking

Emission Indicators	Ranking within Variable	Overall Ranking
Total amount of SO2 emissions	2	14
Total amount of COD emissions	3	15
Rate of Waste emissions	4	17
Rate of carbon footprint	1	7

4.7.7 General Circular Economy Indicators

Level of implementation of CE for general CE dimension in building sector is analyzed through three questions. Ranking of these indicators is given below in Table 4.18. The results for current assessment of general CE dimension showed a good ranking among other dimensions but RII and mean of this dimension depicts that to improve the CE of building sector and to move towards perfection, this dimension needs further improvement as well.

Table 4- 18: General CE Indicators-Ranking

General CE Indicators	Ranking within Variable	Overall Ranking
Design in accordance with CE principles.	3	12
Environmental awareness in society	1	3
Willingness for transformation to Circular Economy model	2	6

4.8 Model development for CE barriers using ISM

This section describes the analysis of CE barriers using ISM technique being used in this research.

4.8.1 Identifying barriers to CE in building sector

After detailed literature review, a list of 25 barriers to CE implementation was identified. Expert of building sector-having awareness of CE, were contacted for shortlisting of these barriers in perspective of building sector. 15 experts were approached for this survey, whereas, 10 experts took part in the survey, the details of experts are given in table 4-4. Based on the ranking of experts, top 12 barriers were shortlisted, based on RII score for further analysis. The shortlisted 12 barriers to CE are given in table 4-19 below:

Table 4- 19: RII score for shortlisted Barriers

Sr. No	CE Barriers	RII	Rank
1	Lack of environmental laws and regulations	0.940	1
2	Lack of support from public institutions	0.920	2
3	Lack of customer/public awareness	0.900	3
4	Insufficient financial resources	0.860	4
5	Major upfront investment costs in Supply Chain (SC) by implementing Circular Economy (CE)	0.800	5
6	Lack of appropriate training and development programs for Supply Chain (SC) members and HR	0.800	6
7	Lack of adequate technology	0.760	7
8	Challenges of take-back from other companies	0.740	8
9	Lack of an information exchange system between different stakeholders	0.720	9
10	High costs are related to recycled materials in Supply Chain therefore they are often more expensive than virgin materials	0.720	10
11	Lack of Circular Economy skills by employees in Supply Chain.	0.700	11
12	Lack of standard systems for performance indicators in terms of measurement of Circular Economy in Supply Chain	0.700	12

4.8.2 Developing SSIM for CE Barriers

The respondents were asked to identify pair-wise relationships between CE barriers. To identify the relationship between any two barriers (i and j) of CE, four symbols were used, which are given as below:

1) V: barrier i influence barrier j ;
2) A: barrier j influence barrier i ;
3) X: barriers i and j will influence each other;
4) O: barrier i and j are not related.

Table 4.19 shows the SSIM matrix developed with the above-mentioned four symbols

Table 4- 20: SSIM for CE barriers

Barriers	12	11	10	9	8	7	6	5	4	3	2
1	O	O	O	O	O	X	O	A	O	O	O
2	O	A	O	O	O	A	O	O	O	A	
3	O	A	O	O	O	A	A	A	A		
4	A	O	O	V	O	A	X	O			
5	V	O	V	O	O	O	O				
6	A	A	V	V	O	A					
7	V	V	V	O	O						
8	O	A	O	X							
9	O	O	O								
10	O	O									
11	V										

4.8.3 Developing RM from SSIM

The SSIM was converted into RM by substituting 1 and 0 in place of symbols V, A, X, and O as per the rules given below:

1) For symbol V in the (i, j) entry in the SSIM, the (i, j) entry in reachability matrix is substituted as 1 and the (j, i) entry is substituted as 0.
2) For symbol A in the (i, j) entry in the SSIM, the (i, j) entry in reachability matrix is substituted as 0 and the (j, i) entry is substituted as 1.
3) For symbol X in the (i, j) entry in the SSIM, the (i, j) entry in reachability matrix is substituted as 1 and the (j, i) entry is substituted as 1.
4) For symbol O in the (i, j) entry in the SSIM, the (i, j) entry in reachability matrix is substituted as 0 and the (j, i) entry is substituted as 0.

Following the above-mentioned rules, the initial RM for the CE barriers is shown in Table 4.20.After transitivity check, RM is converted into final RM by removal of transitivity, as given in table 4.21.

Table 4- 21: Initial RM for CE barriers

Barriers	1	2	3	4	5	6	7	8	9	10	11	12
1	1	0	O	O	0	0	1	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	0	0
3	0	1	1	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	1	0	0	1	0	0	0
5	1	0	0	0	1	0	0	0	0	1	0	1
6	0	0	0	1	0	1	0	0	1	1	0	0
7	1	1	0	1	0	1	1	0	0	1	1	1
8	0	0	0	0	0	0	0	1	1	0	0	0
9	0	0	0	0	0	0	0	1	1	0	0	0
10	0	0	0	0	0	0	0	0	0	1	0	0
11	0	1	1	0	0	1	0	1	0	0	1	1
12	0	0	0	1	0	1	0	0	0	0	0	1

Table 4- 22: Final RM for CE barriers

Barriers	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1*	1*	1*	0	1*	1	1*	1*	1*	1*	1*
2	0	1	0	0	0	0	0	0	0	0	0	0
3	0	1	1	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	1	0	1*	1	1*	0	0
5	1	1*	1*	1*	1	1*	1*	1*	1*	1	1*	1
6	0	0	0	1	0	1	0	1*	1	1	0	0
7	1	1	1*	1	0	1	1	1*	1*	1	1	1
8	0	0	0	0	0	0	0	1	1	0	0	0
9	0	0	0	0	0	0	0	1	1	0	0	0
10	0	0	0	0	0	0	0	0	0	1	0	0
11	0	1	1	1*	0	1	0	1	1*	1*	1	1
12	0	0	0	1	0	1	0	1*	1*	1*	0	1

4.8.4 Partitioning the RM into different levels

The reachability and antecedent sets were derived for each barrier from the final RM, as shown in Table 4.22. The level for barriers having the same reachability and intersection set were decided in the first step; as barrier 2, 8, 9 and 10 had the same reachability and intersection, thus these were placed at level 1. Once level of any barrier is decided, it is discarded from the list. The same procedure is repeated until level for each barrier is decided. The iterations are given in subsequent tables 4.23 to 4.28. These levels of barriers helped in development of final ISM model.

Table 4- 23: Level-partitioning iteration 1

Iteration-1				
CE Barrier	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,2,3,4,6,7,8,9,10,11,12	1,5,7	1,7	
2	2	1,2,3,5,7,11	2	**1**
3	2,3	1,3,5,7,11	3	
4	4,6,8,9,10	1,4,5,6,7,11,12	4,6	
5	1,2,3,4,5,6,7,8,9,10,11,12	5	5	
6	4,6,8,9,10	1,4,5,6,7,11,12	4,6	
7	1,2,3,4,6,7,8,9,10,11,12	1,5,7	1,7	
8	8,9	1,4,5,6,7,8,9,11,12	8,9	**1**
9	8,9	1,4,5,6,7,8,9,11,12	8,9	**1**
10	10	1,4,5,6,7,10,11,12	10	**1**
11	2,3,4,6,8,9,10,11,12	1,5,7,11	11	
12	4,6,8,9,10,12	1,5,7,11,12	12	

Table 4- 24: Level-partitioning iteration 2

Iteration-2				
CE Barrier	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,3,4,6,7,11,12	1,5,7	1,7	
3	3	1,3,5,7,11	3	**2**
4	4,6	1,4,5,6,7,11,12	4,6	**2**
5	1,3,4,5,6,7,11,12	5	5	
6	4,6	1,4,5,6,7,11,12	4,6	**2**
7	1,3,4,6,7,11,12	1,5,7	1,7	
11	3,4,6,11,12	1,5,7,11	11	
12	4,6,12	1,5,7,11,12	12	

Table 4- 25: Level-partitioning iteration 3

Iteration-3				
CE Barrier	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,7,11,12	1,5,7	1,7	
5	1,5,7,11,12	5	5	
7	1,7,11,12	1,5,7	1,7	
11	11,12	1,5,7,11	11	
12	12	1,5,7,11,12	12	**3**

Table 4- 26: Level-partitioning iteration 4

Iteration-4				
CE Barrier	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,7,11	1,5,7	1,7	
5	1,5,7,11	5	5	
7	1,7,11	1,5,7	1,7	
11	11	1,5,7,11	11	**4**

Table 4- 27: Level-partitioning iteration 5

Iteration-5				
CE Barrier	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,7	1,5,7	1,7	**5**
5	1,5,7	5	5	
7	1,7	1,5,7	1,7	**5**

Table 4- 28: Level-partitioning iteration 6

Iteration-6				
CE Barrier	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
5	5	5	5	**6**

4.8.5 Developing the ISM model for CE barriers

Based on the level portioning, a diagraph for CE barriers is developed, as shown in figure 4.10. As barriers 2, 8, 9 and 10 were at the level 1 in level partition, thus these were placed at top of diagraph. This depicts that these barriers have less influence on other barriers, while these barriers are more affected by other barriers. The arrows in the diagraph shows the type of relationship which exist between different barriers.

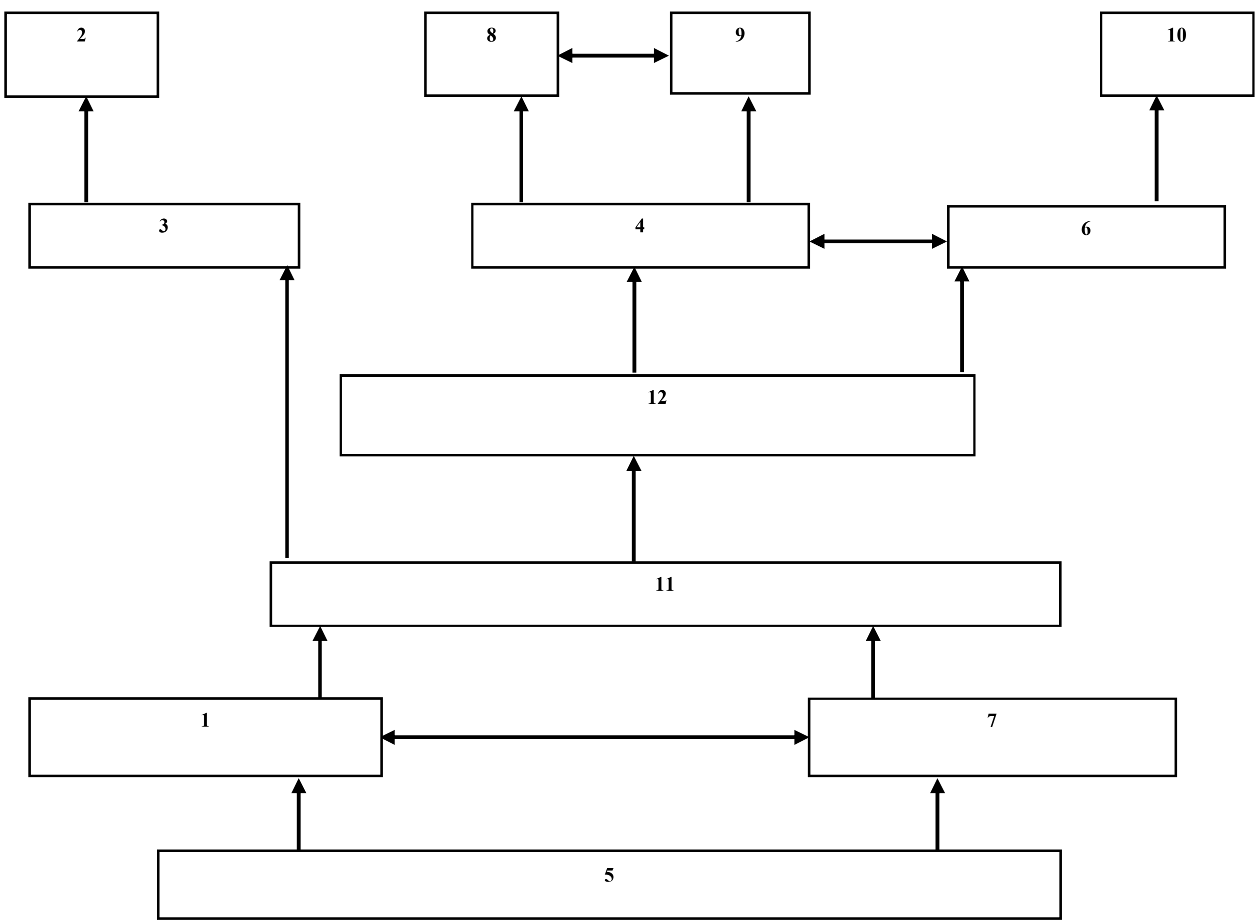


Figure 4- 10: Diagraph for CE barriers

4.8.6 Developing the ISM model for CE barriers

The diagraph was again checked for transitivity, as there was no transitivity, thus diagraph was converted into final ISM model, as shown in figure 4.11.

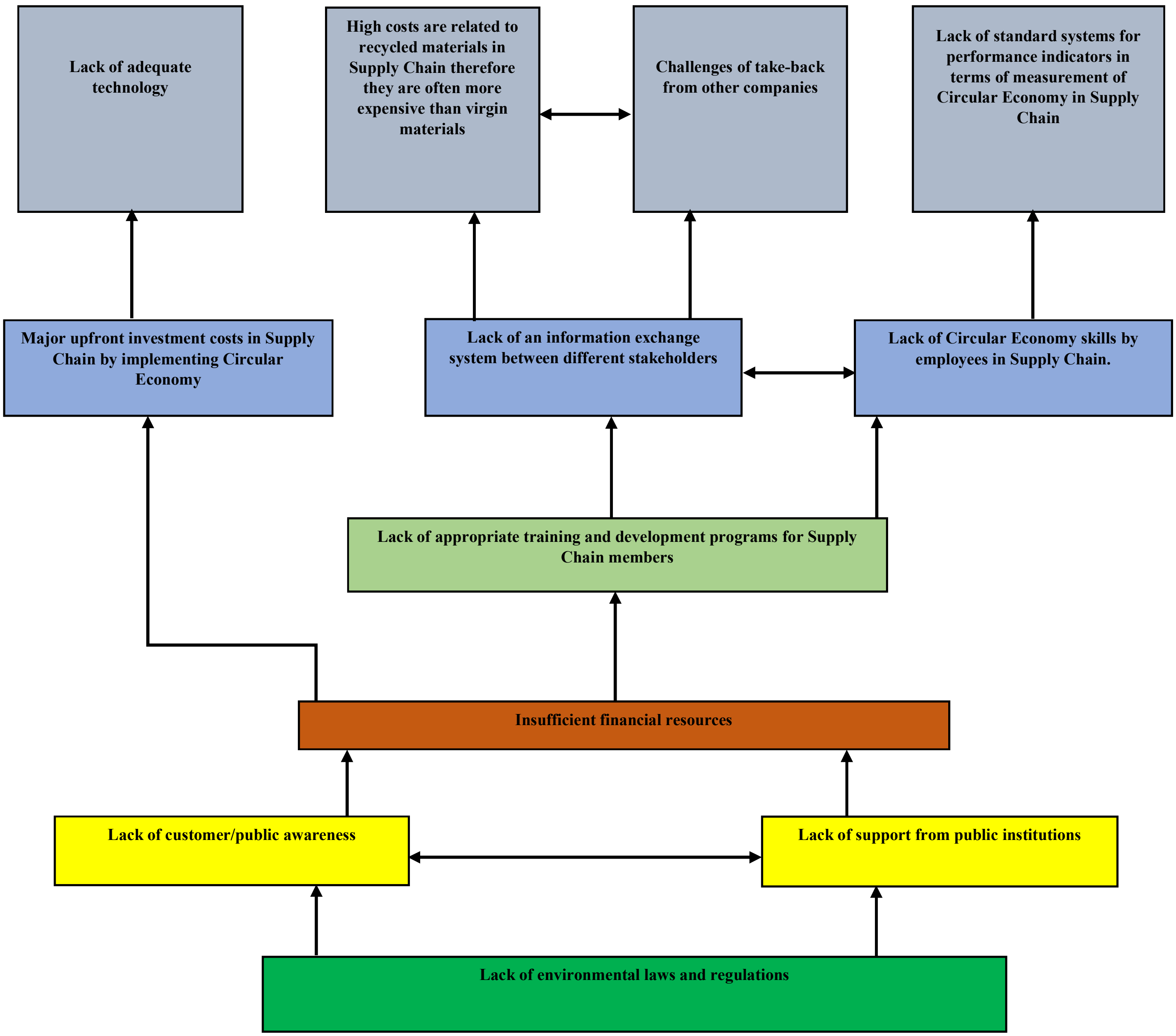


Figure 4- 11: ISM Model for CE barriers

4.8.7 Classifying CE barriers – MICMAC analysis

The CE barriers were classified into four cluster based on dependence and driving power, as given in table 4-29. The key findings of this classification (Fig. 4.12) were as follows:

The barriers 2, 3 and 12 have both weak driving and dependence power, thus these come in cluster of autonomous barriers. Autonomous barriers are comparatively disconnected from the rest of system.

The barriers 4, 6, 8, 9 and 10 have week driving power, nonetheless a strong dependence, thus these are classified into cluster of dependent variables. The barriers in dependent variables require removal of other driving barriers for their removal.

There is not any barrier in cluster of linkage barriers. The barriers in this cluster have both strong dependence and driving power, thus barriers in this cluster are unstable.

The barriers 1, 5, 7 and 11 have strong driving power but less dependence, thus these are classified in cluster of independent barriers. The barriers in this cluster are key barriers, and removal of these barriers will mitigate other barriers as well.

Table 4- 29: CE barriers driving and dependence power

Barriers	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Driving Power**	**Rank**
1	1	1	1	1	0	1	1	1	1	1	1	1	**11**	**2**
2	0	1	0	0	0	0	0	0	0	0	0	0	**1**	**7**
3	0	1	1	0	0	0	0	0	0	0	0	0	**2**	**6**
4	0	0	0	1	0	1	0	1	1	1	0	0	**5**	**5**
5	1	1	1	1	1	1	1	1	1	1	1	1	**12**	**1**
6	0	0	0	1	0	1	0	1	1	1	0	0	**5**	**5**
7	1	1	1	1	0	1	1	1	1	1	1	1	**11**	**2**
8	0	0	0	0	0	0	0	1	1	0	0	0	**2**	**6**
9	0	0	0	0	0	0	0	1	1	0	0	0	**2**	**6**
10	0	0	0	0	0	0	0	0	0	1	0	0	**1**	**7**
11	0	1	1	1	0	1	0	1	1	1	1	1	**9**	**3**
12	0	0	0	1	0	1	0	1	1	1	0	1	**6**	**4**
Dependence	**3**	**6**	**5**	**7**	**1**	**7**	**3**	**9**	**9**	**8**	**4**	**5**		
Rank	**7**	**4**	**5**	**3**	**8**	**3**	**7**	**1**	**1**	**2**	**6**	**5**		

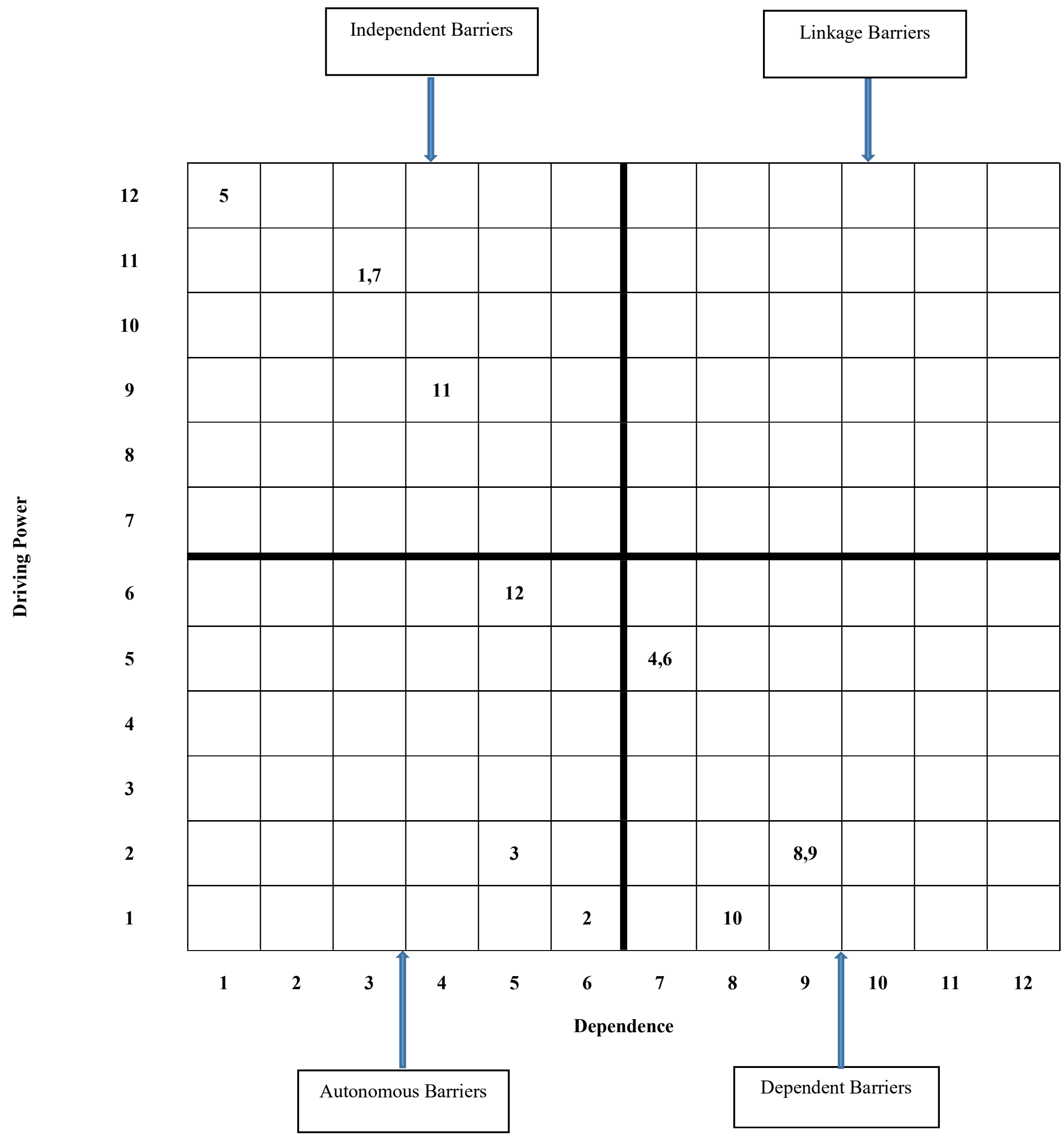


Figure 4- 12: MICMAC diagram for CE barriers

4.9 Analysis of CE Influence matrix

In the previous section, ISM approach used to identify the influence among CE barriers was discussed. In this section, influence matrix, being developed to identify the influence of CE barriers on indicators of CE is explained.

4.9.1 Development of Influence Matrix

The experts as shown in table 4-7, were asked to fill the CE barriers-indicators influence matrix. This matrix consisted of 288 entries, which were to be filled by experts. There was a difference in opinion of experts, to overcome difference in opinion, all entries of matrix was filled based on maximum number of votes by experts for that particular entry. For the finalized influence matrix, RII was calculated and following "80/20" rule most influencing barriers of CE were identified. RII for the barriers were calculated as given in table 4-29.The barrier "lack of environmental laws and regulations", "Lack of customer/public awareness" and "Lack of support from public institutions" affects the maximum number of indicators. Following "80/20" rule, which states that 20 percent variables account for 80 percent of results (Basile, 1996), it is envisaged mitigation of these 20 percent barriers can improve the implementation of CE.

Table 4- 30: RII for CE barriers influencing CE indicators

RII of Influence Matrix (CE Barriers Influencing CE Indicators)					
CE Barriers	**No. of CE Indicators effected by CE Barriers**			**RII**	**Rank**
	High	**Medium**	**Low**		
	1	**3**	**5**		
Lack of environmental laws and regulations	0	3	21	0.95	1
Lack of customer/public awareness	1	4	19	0.90	2
Lack of support from public institutions	0	6	18	0.90	2
Insufficient financial resources	4	6	14	0.77	3
Lack of adequate technology	5	9	10	0.68	4
Major upfront investment costs in Supply Chain by implementing Circular Economy	3	11	9	0.68	4
Lack of appropriate training and development programs for Supply members	2	15	6	0.64	5
Lack of an information exchange system between different stakeholders	3	15	5	0.61	6
Challenges of take-back from other companies	9	5	9	0.58	7
Lack of Circular Economy skills by employees in Supply Chain.	4	19	1	0.55	8
Lack of standard systems for performance indicators in terms of measurement of Circular Economy in Supply Chain	3	19	1	0.54	9
High costs are related to recycled materials in Supply Chain therefore they are often more expensive than virgin materials	11	4	4	0.36	10

4.10 CE barriers mitigation framework

Based on ISM model, and CE barriers-indicators influence matrix, it has been found that the key barriers to CE are those shown in dependent cluster of figure 4.12. This means that these key barriers influence the maximum number of barriers and indicators of CE, thus the mitigation of these barriers will improve the implementation of CE in building sector. Therefore, to mitigate these key barriers, experts from building sector of developing countries were contacted to propose mitigation strategies. Based on the proposed strategies, CE barriers mitigation framework for building sector of developing countries is proposed. This framework was validated through expert opinion. The CE barriers mitigation framework is as shown in figure 4-13.

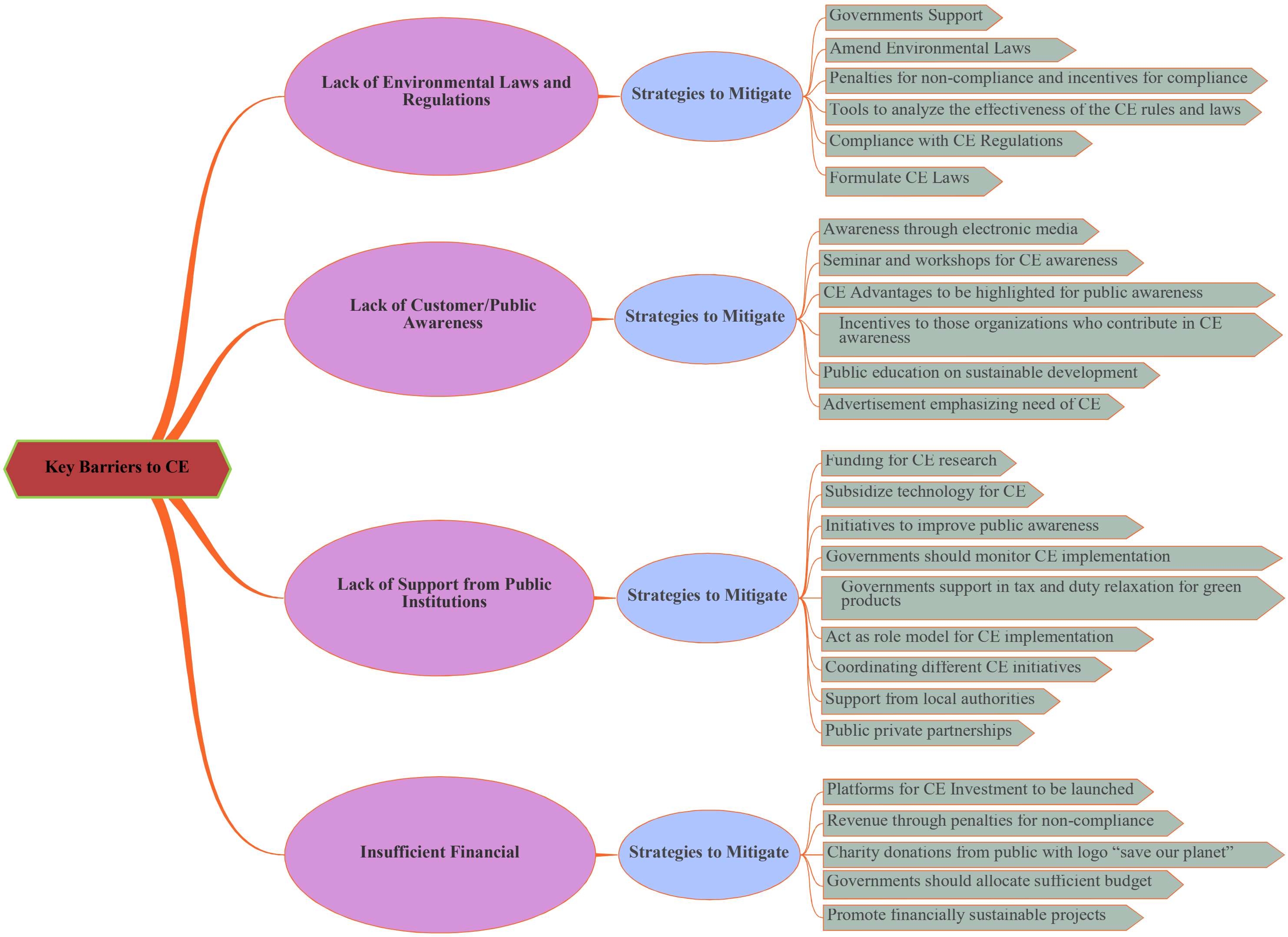


Figure 4- 13: CE barriers mitigation framework

CHAPTER 5

CONCLUSIONS

This research effort has assessed the current state of CE implementation in building sector of developing countries. Based on the 7 variables and 24 CE indicators, a scale for CE assessment for building sector was formulated. Responses from 16 developing countries were gathered to identify current level of implementation of CE in the building sector of developing countries. It has been found that overall level of implementation of CE in building sector is 58 %, which should ideally be closer to 100 %. Out of the 7 CE variables, the best performance was for energy variable, whereas waste variable had worst performance. A special attention by all the stakeholder of building sector in developing countries is required to take serious steps and to consider all the aspects of CE, during all life cycle phases of buildings.

Furthermore, this research has bridged the gap on identification of key barriers to CE, in perspective of building sector of developing countries. Out of 25 barriers, identified from literature, 12 barriers were shortlisted by building sector experts. ISM was used to study the interaction among CE barriers; MICMAC technique, and CE barrier-indicators influence matrix were used to find the key barriers, which impede CE implementation. The major barriers impeding CE implementation, as identified are 'lack of environmental laws and regulations', 'lack of customer/public awareness', 'lack of support from public institutions' and 'lack of financial resources'. These barriers are independent variables, having high driving power and less dependence, if these barriers are mitigated, CE implementation in building sector of developing countries can be improved.

Finally, a CE barrier mitigation framework is proposed, this framework comprises the strategies to overcome key barriers to CE implementation. This framework can help policy makers to mitigate key barriers to CE implementation in building sector of developing countries. This framework has enabled to understand the impediments to CE adoption in building sector; it is envisaged that proper implementation of these mitigation strategies has potential to improve the adoption of CE in building sector.

The limitation of this work is that the scale developed for CE assessment is based on single round of expert opinion, for future work, scale development can be done by using Delphi technique and results of CE assessment may be validated. Moreover, purely quantitative scale can also be used for assessment of CE in future studies. In addition, a repetition of this study in some other part of world may also be conducted to validate the results.

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