Understanding Circular Economy and its Potential Impact on the Construction Industry

by
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A thesis submitted to the Department of Construction Management,
College of Technology
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

IN CONSTRUCTION MANAGMENT

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University of Houston
July 2022

DEDICATION

I would like to dedicate this thesis, especially to my parents, and my wife, Manam Khan, without whose support this thesis would not have been possible.

ACKNOWLEDGEMENTS

I want to sincerely thank my thesis advisor, Dr. Lingguang Song, for his tremendous support during my master's thesis. He gave me the right direction and always encouraged me equally during time of failure and success. I also want to express my sincerest gratitude to Dr. Lu Gao for his gracious support and feedback. His motivation for perfection will always inspire me in my future career. I appreciate the external committee member, Ms. Najla Baeshen for helping me throughout my thesis and sharing professional experiences. I would like to acknowledge my professors, the department, and my fellow colleagues for their constant support throughout my research.

ABSTRACT

The construction industry is responsible for over 35% of the extraction of natural resources and 30% of the world's solid waste. This happens because the construction sector mostly applies a linear economic model of "take, make, dispose of", using materials to construct buildings, dispose of them at the end of their life, as they are assembled for single-use, and have no potential for reuse. In the last few decades, a paradigm shift has taken place across the industry, with the adoption of a circular economy model that aims to keep materials in a closed loop to maintain their maximum value, and thus greater potential for reducing waste generation, environmental impacts, and resource extraction for the construction industry throughout the design, procurement, construction, and operations. This research aims to identify the latest developments in how a circular economy can benefit the construction industry through long-term life-cycle value creation, and what changes need to be made to embrace a circular economy. To achieve this goal, a systematic literature review, case study analysis, and an interview study were carried out. The analysis of the case study has confirmed that by adopting the principles of the circular economy in the construction of the people's pavilion, the Company has achieved economic, environmental, and social benefits as well. After conducting the whole analysis we can conclude that moving away from a 'take, make, and dispose of' consumption model, circular economy strategies can help on our journey towards a net zero economy along with financial gains. This research has identified why and how construction companies should make efforts to execute CE in their projects to attain financial and social benefits along with environmental benefits. This study will be helpful for countries like America as it provides them with the route to initiate CE in the construction sector to control the scarcity of resources.

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CHAPTER 1: INTRODUCTION

1.1 Background

Circular Economy (CE) can be explained as a concept used to ensure that there is a closed-loop flow of materials to reduce the consumption or continuous use of the available natural resources (Wright, et al., 2019). CE as an economic development framework addresses fundamental causes of global challenges such as loss of biodiversity, climate change, waste, and pollution while also revealing new opportunities for economic development (Ellen MacArthur Foundation, 2019). CE is believed to hold the potential to transform the way we design, manufacture, consume and dispose of materials. It is based on three fundamental principles: waste and pollution elimination, the preservation of reusable products and materials, and ecological regeneration systems (Ellen MacArthur Foundation, 2019).

Population growth and rapid urban expansion impose severe pressure on the finite resources of the planet. The availability of resources is widely debated on whether the issue is a scarcity of resources or the difficulty to upscale production capacity quick enough to meet demand, which may be more related to social, economic and geopolitical aspects. It is widely recognized that the construction industry consumes large quantities of resources while producing a large number of wastes and emissions. For a long time, the construction industry has operated on a "linear" model, which means that it has generally involved the use of raw materials to make building materials, and the majority of waste generated during the construction and demolition process is discarded afterwards while some wastes are recycled. To preserve natural resources and the prosperity and safety of our people and communities now and in the future, we must rethink the current linear model and investigate how a circular economy model could help.

According to Ghisellini and colleagues (2018), CE aims at promoting new designs, maximum reuse of goods, components, and other materials to conserve the natural ecological systems, refurbishing or repairing existing structures, and recycling construction materials while decreasing material waste generation. In the context of engineering and construction projects, CE involves changing the current design and construction methodology to one that maximizes the best potential value of construction materials and products and further improves construction materials utilization patterns to extend their product life. The lifecycle of a built facility starts from planning, design, and construction, to operation, maintenance, and demolition. Planning and design are primarily guided by specific owners' needs and market demand. CE-inspired innovative design concepts, such as design out waste, design for resource efficiency, design for deconstruction and disassembly to ensure adaptability and flexibility, have been highly valued by early adopters for their benefits in environmental conservation, cost reduction, improvement of aesthetics, comfort, and/or convenience as exemplified in a well-designed facility (Ellen MacArthur Foundation, 2019).

The public has also increasingly put reducing wastes in construction, operation, and demolition under scrutiny. This reflects the fact that the construction industry produces very high volumes of waste from construction, remodeling, and demolition due to high resource consumption associated with construction material manufacturing yet a low product recovery rate (i.e. reuse of construction materials) (Alberto, 2020). Alberto Lopez (2020) argued that CE provides a conceptual framework that spans different industries to tackle the above issue. It can potentially help the construction industry to make a breakthrough in practices, such as highly efficient usage of available natural

resources, refurbishing structures, and recycling of construction materials, which can lead to construction waste minimization and reduction of negative environmental impacts.

Past studies on circular economy for the construction industry shows that they were concentrated on recycling Construction and Demolition Waste (C&DW) only, thus lack of attention on other aspects of design and construction as advocated by CE (Adams, Mohamed, Tony, & Jane, 2019). Generally, companies are involved in the sustainability, and green building rather than implementing CE. Companies are adopting practices to attain the UN sustainable development goal and belief that these practices are similar to CE (United Nations Development Programme, 2015). However, CE is different and useful to attain the big picture of the sustainability in the terms of financial and social returns along with environmental benefits. CE is different and new than other existing sustainability practices in the market including LEEDS, Lean or green buildings but usually companies have a misconception that CE is similar to green buildings and sustainability. According to Giliam et al. (2021), a holistic and integral approach towards CE is needed to ensure that the underlying CE goals of contributing to sustainable development and establishing a systemic shift should be implemented. However, to make business-sense of CE adoption, the industry must also have a complete understanding of various benefits associated with such adoption.

After reviewing all the definitions and elaborations, it can be observed that CE revolves around the idea of minimum consumption of resources resulting in minimum waste and lesser greenhouse emissions to maintain sustainable development. Figure 1.1 is showing the Circular Economy by Resolve Framework.

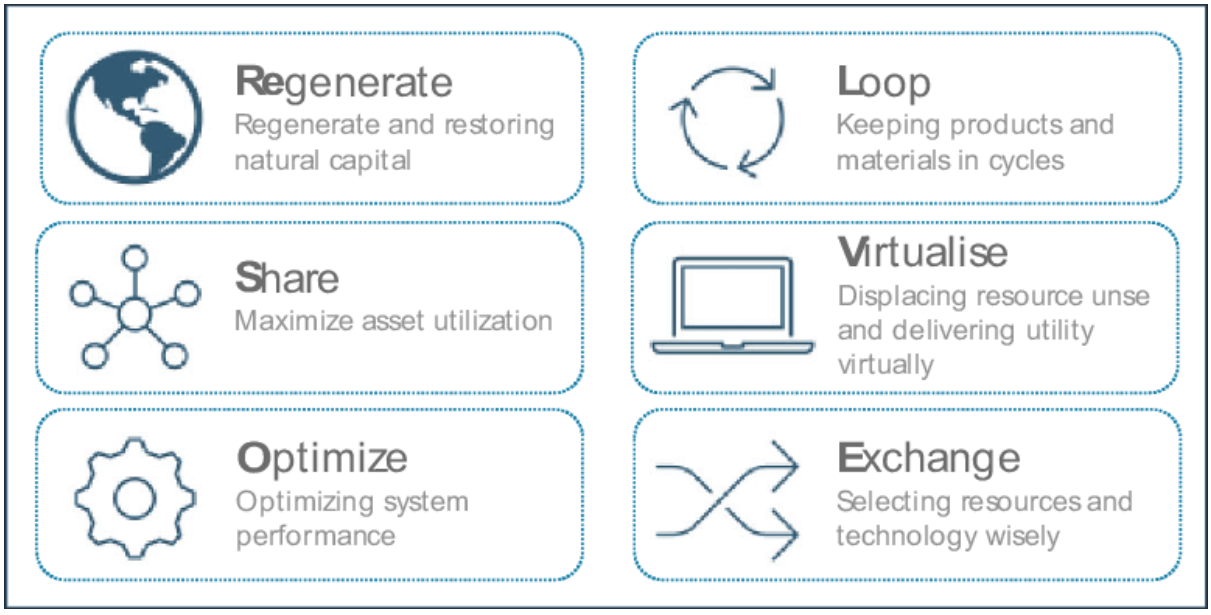


Figure 1.1 Circular Economy in accordance with RESOLVE Framework

(Gower & Schroder, 2016)

1.2 Problem Statement

The CE theory and practice are still largely in their infancy, such as in North America. However, it has the potential to disrupt many industries, including the engineering and construction sector. It is beneficial to first gain a better understanding of the CE concept and its impact on current engineering and construction practice before its possible adoption in real-world projects. Specifically, the following research questions will be investigated:

1. CE is a new concept if not unheard of by many in the construction industry in North America. Given the increasing attention on sustainability and climate change, along with the potential benefits of CE, the industry needs a better understanding and awareness of CE.

The current linear model of design and construction is a straightforward linear process. They are based on finite raw materials being used to build structures that have a limited life

expectancy, and toward the end of their lifecycle, those structures are demolished if necessary, and the waste is deposited in a landfill (Gower & Schroder, 2016).

According to Bergstorm (2020), every year in the United States, the construction industry waste constitutes a large proportion of the total amount of generated waste. For example, in 2017, about 569 million tons of construction and demolition waste was generated. This linear model does not allow for asset end-of-life consideration for proper refurbishing, repairing, recycling, and reuse of materials, completely against the CE principles. Thus, the circular model promoted by CE requires a rethinking and redesign of the traditional designs and construction strategies to reduce raw materials consumption and increase recycled materials usage. According to (Pomponi & Moncaster, 2017), CE is an attractive approach to address current challenges in sustainability and to shift away from the current linear model which takes the form of "take-use-dispose." The limited awareness of CE and lack of interest and knowledge were identified as significant challenges associated with CE adoption. (Adams, Osmani, Thorpe, & Hobbs, 2017). Additionally, various other reasons including financial concerns were raised by stakeholders, such as increased costs or the perception of low return-on-investment or direct benefits to a business. Therefore, there is a need to improve the awareness and understanding of CE as a new and disruptive concept in the construction industry context.

2. Improving efficiency, sustainability, and reducing environmental impacts are not new to the construction industry. New theories and practices were constantly brought into design and construction work, such as lean project delivery, Leadership in Energy and Environmental Design (LEED) and green construction, standardization, modularization, and design-for-demolition, which have played an active role in reducing project cost and

duration, improving energy efficiency, and minimizing carbon footprint among other benefits. However, how do CE concepts relate to or are different from these existing strategies?

For example, some of the newer capital projects have been constructed and earned LEED certifications, which aim at promoting sustainable construction in terms of planning, design, energy, water, and material efficiency, along with environmental quality. While sharing some similar goals, CE is also different from LEED, such as CE's unique focus and practice of designing and reuse of materials with recyclability components. While the two concepts can be complementary to each other, they may cause conflicts in decision-making, such as material selection balancing cost, functionality, sustainability, and recycling objectives.

3. What are existing CE practices and what are the costs (design, procurement, construction costs etc.) and benefits (environmental, cost, quality, safety, etc.) of these CE practices?

Numerous past studies indicate that the construction industry in general is hesitant in adopting new concepts and technologies, and CE has no exception, largely due to the risk and uncertainty in costs and benefits of adopting them. However, there have been some steps in implementing strategies that are related to CE as more entities are placing a focus on reporting ESG efforts against the United Nations 2030 Sustainable Development Goals (UNSDGs) (United Nations Development Programme, 2015). Hence, we need a conceptual cost-benefit analysis framework to help stakeholders understand various costs and benefits associated with the implementation of CE.

4. Finally, what are the perceived challenges in adopting the CE concept and what is the future research needed to tackle these challenges.

Since its introduction in the construction industry in European countries, the adoption of CE has faced different challenges. After all, CE is the latest attempt to conceptualize a viable integration of economic activities with environmental and resource concerns. It is therefore important to identify these challenges; both perceived or anticipated, associated with CE adoption, and outline possible course of research actions to overcome the challenges.

1.3 Objectives

The objective of this research is to gain a better understanding of the CE concept about existing industry practices, clarify the benefits of CE, and identify challenges in CE adoption and future research needs.

The specific objectives of this research include the following:

1. To improve awareness, and understanding of the CE concept and its implementation strategies.
2. To clarify the relationship, synergy, and potential conflicts between CE and various existing design and construction strategies.
3. To assess the economic, social and environmental benefits associated with the implementation of CE.
4. To explore the challenges of using Circular Economy in construction as a business model and identify future research needs.

1.4 Expected Contribution to the Industry

This current research contributes to the construction industry literature by improving a better understanding of CE and its implementation strategies. A better understanding of CE and the benefits in the terms of social, economic, and environmental perspectives will be valuable to construction industry professionals and improve collaboration among different project

stakeholders such as clients, contractors, suppliers, financial institutions, and government/regulation entities to achieve overall sustainability goals of UN. A better understanding of CE and adoption issues will be valuable to construction industry professionals and improve collaboration among different project stakeholders such as clients, contractors, suppliers, financial institutions, and government/regulation entities to achieve overall sustainability goals. A better understanding of CE, its costs and benefits, and adoption issues will be valuable to construction industry professionals and improve collaboration among different project stakeholders such as clients, contractors, suppliers, financial institutions, and government/regulation entities to achieve overall sustainability goals.

1.5 Thesis Organization

This report is organized into five chapters, including this introductory chapter. Chapter 2 explores previous research in the form of a literature review. Chapter 3 outlines the methodology adopted in this study, including case study, interview study, and data analysis. Results from the case study data analysis and thematic analysis are presented in Chapter 4. The conclusion and future research will be discussed in Chapter 5.

CHAPTER 2: LITERATURE REVIEW

This section discusses the past and current studies concerning the application of circular economy in major capital projects. This section also discusses the current level of awareness about the circular economy among the various stakeholders, and how it can be improved in the coming future for robust implementation of the circular economy on capital projects.

2.1 Awareness of Circular Economy

The first objective of this study is to improve the awareness, understating, and implementation of CE strategies in capital projects in the construction sector. The most crucial step is to improve the awareness of the Circular Economy in the construction sector. This purpose can also be accomplished by raising the importance of CE and the reasons why we need to shift towards a Circular Economy from the traditional strategies as well as elaborating on the opportunities, environmental, social, and economic benefits due to the implementation of the circular economy. First, it is essential to explore current awareness of CE in the market through different surveys and even responses by the attendees of various sectors.

According to Green construction bond, an online survey was conducted to analyze the level of awareness, and examination of challenges and enablers. The respondents of the questionnaire consisted of consultants (26%), contractors (25%), clients (14%), product manufacturers (10%), and designers (7%). some other respondents were also included such as government representatives (4%), and trade associations covering reuse flooring, building products and concrete (4%). More than half of the respondents were from large organizations. A meeting event was also conducted for this purpose. (58%) attendees were from large companies having more than 10 years of experience in the construction sector (Adams, Mohamed, Tony, & Jane, 2019).

2.1.1 Current Circular Economy Awareness in the Market

The responses of respondents in the GCB survey can be summarized in Figure 2, showing that the designers (2.09 on a scale of 4?), clients (1.96), and sub-contractors (1.63) had a very low level of awareness about CE, leading to a negative impact on the uptake of the circular economy. However, most of the manufacturer attendees were aware of CE due to the existing work of various material sector trades and their attention to sustainability. The awareness of CE in respondents' organizations as a whole was perceived to be lower than their own. Figure 2.1 is showing the level of awareness of the circular economy in the construction sector by GCB, 2016

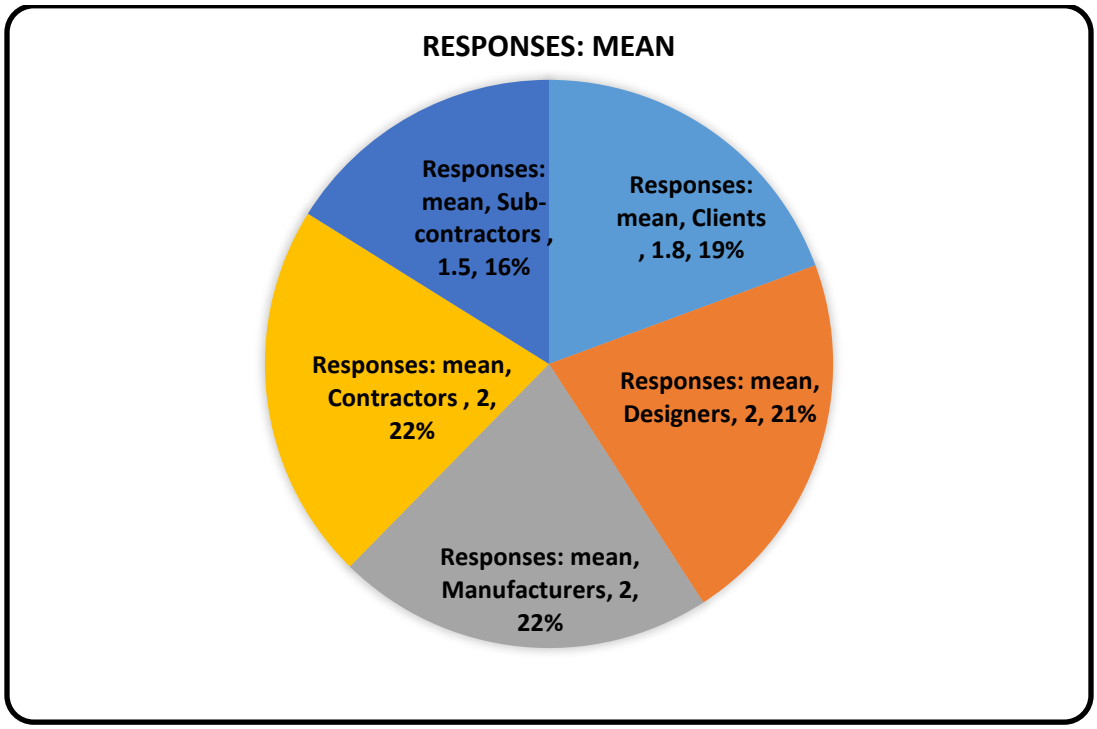


Figure 2.1 Level of awareness for circular economy in the construction sector by GCB,2016 (1)

It is clear from the results that most of the respondents were fully aware of the facts of CE so to further improve the CE awareness approach, it is necessary to articulate the benefits of CE transparently and measurably. This approach was supported in the breakout session, especially in the business case. It had been proven through the survey and event responses that the lack of knowledge, interest and limited awareness were the main challenges in the implementation of CE.

2.1.2 Understanding the Strategies of CE adoption in capital projects

The concept of circular economy has gone through several stages of evolution ever since its inception in the 1970s. Several studies on circular economy explained that the founding principle of CE lies in the efficient management of supplies and waste by reducing the unwanted or discarded material, minimizing the energy requirement and material in a closed loop (Geissdoerfer, 2017).

According to World economic forum (2016), the approaches involved in the circular economy include durable design, repair, remanufacturing, refurbishing, reuse; maintenance and recycling which can be executed in capital projects and the techniques to achieve them are designed for adaptability, durability, deconstruction, adaptability, closed-loop material, and the dematerialization among others.

To facilitate the implementation of CE strategies, the construction industry is so far leaning towards design and system views to achieve a better life cycle result. To attain such a sustainable consequence, the principles of closed-loop design are considered. Sassi (2008) framed a standard by which materials can be assessed as a part of a closed loop cycle.

Moreover, it is insufficient just to address the material itself without paying attention to the construction or the installation practices. To be classified as a closed loop cycle, the material has to satisfy two overall conditions:

1. Able to be extracted from the building when deconstructed.
2. Components of the material can be reused and/or recycled upwards within the closed loop material cycle.

To satisfy the first criteria, the building has to be constructed in a way that it can be deconstructed later. The second phase involves the disposal of material and its constituents through closed-loop cycles. This can be done by utilizing building elements and materials from old buildings through

reuse or recycling infinitely through organic and industrial processes to upgrade the material's quality.

Several studies analyzed the value of reutilization of materials using various recovery techniques. According to Ness et al (2015) steel should be tracked digitally to facilitate its use in new buildings. However, the potential for reutilization of steel depends upon its quality condition.

2.1.3 Implementation of CE strategies in capital projects

Different project stakeholders, such as clients, designers, contractors and manufacturers, can view CE implementation.

- Role of client

Project clients play a major role in providing an environment for CE adaptation at a project level. Nevertheless, it has been observed that there is a lack of experience and a long-term vision in choosing their implementation strategy. It is also the key challenge faced by other businesses in the construction supply chain for CE implementation. For clients to play the central role, support is required from other players of the supply chain by providing new business models, technological innovations, and proofs of advantages of CE applications and providing information and assurances about performance (Adams, Osmani, Thorpe, & Hobbs, 2017).

- Role of designers

The role of the designer's circular economy has become even more relevant than that of the traditional value chain. A designer acts as a facilitator among various stakeholders in order to integrate proficiencies and mutual advantages. Designers have a chance to apply circularity throughout the project lifecycle by the development of innovative CE strategies. In order to ensure longevity, reuse, flexibility, reuse and deconstruction design, CE strategies must be incorporated in the initial stage of a project.

CE begins with circular product design, and in the case of construction, the products have a very long life e.g., the Pantheon and Colosseum are still viable building even being 2,000 years old. This longevity is achieved by not only good design but also through good maintenance and management. The building designer however cannot do this alone. They needs up-to-date knowledge about the latest materials on market from manufacturers.

- Role of manufacturers/suppliers

Manufacturers and suppliers play a pivotal role in creating and sustaining a circular economy. Their products are designed considering biological and technical nutrient cycles and ensuring the restoration by intension and design. Hence, the value of the product stays preserved throughout the project life cycle. For technical nutrients, the products must be designed for long life, upgrade, recycle, repair, reuse, or remanufacture at the end of their life. For biological nutrients, the products must be designed for composting and recycling of nutrients.

Material suppliers and manufacturers can work at both ends of the recycle/reuse cycle through the application of take back scheme (Tserng, Cheng-Mo, & Yun-Tsui, 2021). In this scheme, a supplier or manufacturer can take used materials back at the end of their life, thus more value can be extracted from the used materials and lesser virgin material will be needed for the production of new material as the claimed material can re-manufactured and recycled.

- Role of contractors

Contractors have the opportunity of choosing circular materials, and minimizing material, water and energy wastes on the project site. Novel technologies like product passports and embedding data into computer-generated construction model are required to give assurances to the contractors regarding the quality and legality of the recycled materials (Blomsma & Brennan, 2017).

According to Carra and Magdani (2017), contractors have already been applying prefabrication and computer generator models to upgrade the efficiency and to reduce the cost and time spent on

site. More improvement in digital instruments would be required for close coordination of the rest of the value chain with contractors. They may also support contractors to achieve goals for zero waste of construction, closed loop, recycling of water and energy as well as significantly decreasing the risks related to health and safety on the construction sites by utilizing human assistance or automatic machines.

- Implementation Approach

To implement the strategic circular elements, as shown in Figure 2.2, a phased approach is developed for the short-term gain and viability for long-term value creation. (Ellen MacArthur Foundation, 2019)

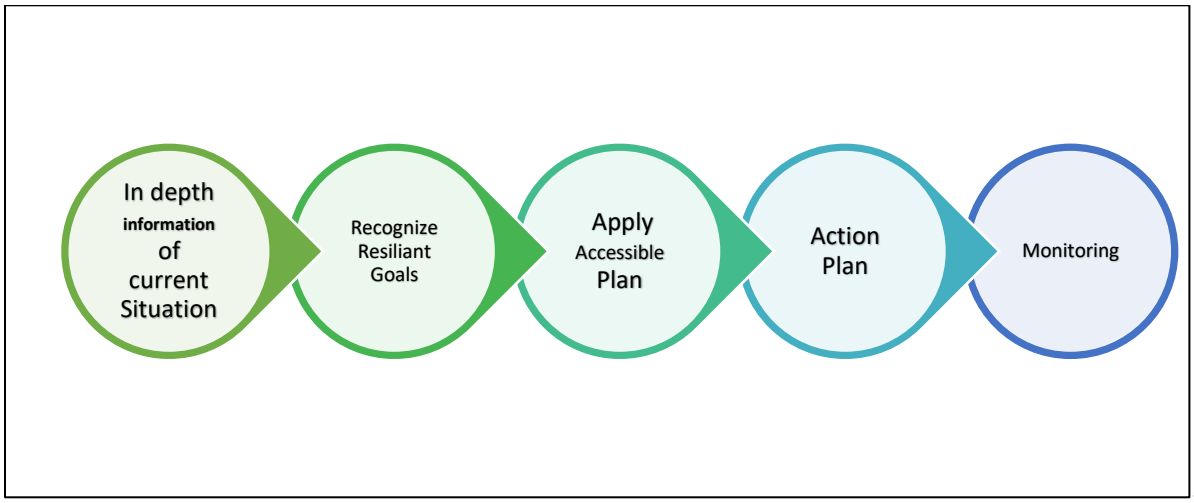


Figure 2.2 Implementation Approach for CE in Capital Projects by Ellen MacArthur Foundation

2.2 CE and various existing design and construction strategies

The second objective of this study is to clarify the relationship, synergy, and potential conflicts between CE and various existing design and construction strategies. Many other strategies for sustainable construction have come into development for quite a while, such as lean project delivery, LEED and green building codes, standardization, modularization, design-for-

deconstruction and Living Building Challenge etc. Table 2.3 below provides a comparison of CE with these existing industry practices.

Table 2.1 Comparing Current Strategies with CE

Current Strategy	Definition	Similarities to CE	Divergence from CE
Lean Project Delivery	Lean project delivery focuses on building capital projects to be constructed in an organized manner. It includes pro-environmental and green construction practices by maximizing the use of renewable energy, producing less construction waste and less hazardous building materials. (Ellen MacArthur Foundation, 2019)	The manufacturing sector can benefit from the synergy of Lean and CE. Their combination seems natural as both processes produce effective outcomes with their common element to eliminate waste and value creation. The model of the circular economy presents an idyllic elucidation of the existing global problems of environmental damage resource scarcity and the creation of a closed-loop economic system. On the other hand, Lean has proven successful in waste elimination and creates value by the accomplishment of efficiency and economic benefits.	Lean project delivery is product-focused whereas circular economy has a broader context and is focused on the system production level. Lean project design focuses on maximizing the throughput of a project, which leads to material losses after demolishing. A circular economy looks at the bigger picture and deals with increasing the overall system efficiency by using sustainable practices. A linear economy is a traditional pattern of economy consisting of a take-make-dispose scheme. The linear method maximizes the use of existing raw materials before their transmission into the product disposing of the unusable materials. Whereas, the circular economy is a paradigm shift from the linear economy to one that keeps products and materials in use, and designs out waste and pollution.
LEED	LEED (Leadership in Energy and Environmental Design) is the most widely used green building ranking system globally (Kirchherr, Reike, & Hekkert, 2017). A framework for healthy, highly efficient, and cost-saving green buildings is provided by	The latest version of LEED i.e., LEED v4.1 has brought into the concept of a rating system for the complete building lifecycle and material optimization and reporting. In the latest version of New Construction and Major Renovation, the MR credit requirement complements the CE concepts. For construction and	LEED concepts are relevant to sustainability whereas the concept of circular economy is different. The goal of sustainability is to benefit the economy, environment, and society mainly. Whereas, economic actors are the main beneficiaries of the Circular

	LEED for virtually all types of buildings.	renovation projects, the MR credits require the contractor/client to reduce the volume of Construction and Demolition (C&D) waste to be incinerated or landfilled by reusing, recovering and recycling the materials	Economy (Reike, Vermeulen, & Witjes, 2017) Also, the perspective of responsibilities differs between LEED and circular economy. Within sustainability, the responsibilities are not clearly defined and are shared while it has been indicated by the literature that the responsibilities of a circular economy include private business, policymakers and regulators (European Union, 2020) And all these sectors of the circular economy have different goals, interests, and commitments behind them. In LEED, the major interest alignment is on sustainability between the stakeholders. However, circular economy prioritizes fewer resources consumption and pollution in the environment and financial advantages for companies.
Modularization	Modularization is the process to convert the construction and design of a stick-built plant or monolithic to facilitate modules of the factory fabrication for installation and shipment in the field as a complete assembly. The shift from traditional stick-built towards modularization is the key factor to reduce construction cost and time as described at length in the literature (UKCG, 2021)	Modularization and CE both have major similarities in some aspects. In CE, the design does not only focus on functionality but also emphasizes managing the infrastructure's end life. It also concentrates on how the components can be a part of new production chains or infrastructure. Correspondingly, modularization has already been applied in the building construction sector which contributes to circularity in four ways (EEA Report, 2017) 1) Waste is produced in a smaller quantity in a controlled environment exactly opposite to the traditional construction site. 2) Transportation of material and components is less,	Despite similarities between modularization and circular economy, few differences occur which act as challenges and divergence of modularization and CE. In the modularization process, ~~1)~~ There is a higher level of management effort in the modularization process. ~~2)~~ Before construction, there is a need to design a collision-free crane-lifting plan. ~~3)~~ Additional transportation activities imply higher logistic costs. 4) The management of unnecessary inconsistency geometric risks. 5) Occurrence of uncertainties in off-site logistics.

		thus ultimately reducing emissions. 3) Reduces the demand for raw materials and amount of energy because of the possibility of disassembling, refurbishing and relocating modules to reuse them. 4) Without the destruction of buildings' basic structure, the possibility of repairing or modifying the parts and materials enhances. Modularization can decrease demolishing and construction waste which can improve the deconstruction process hence closed-loop material cycle is achieved.	
Standardization	Standardization is the development of requirements, guidance, supporting tools and frameworks. Standardization includes the Use of modules, assemblies, components, interfaces, methods, or processes that are repeated throughout the project and between projects.	The synergy between Standardization and CE poses great effects on the overall environment. The implementation of CE regulations makes it practicable for organizations, which need to complement national laws and policies. There are few significant Standardization and CE both have a common approach to help preserve material value and functionality for longer and more efficient processes.	Standardization is not a construction process strategy; instead, it is a kind of framework, policy or regulation, which can provide measures to implement the CE strategies in any organization. There are no major divergences between Standardization and CE. However, a little variance occurs when separate standards for sustainability and CE have to be implemented by a company in the construction sector. The sustainability and CE standards can be similar yet different for a single process. Therefore, these variances can be an issue for an organization.

2.3 Economic, social and environmental benefits

The Economic, social and environmental benefits of CE can be examined about the United Nations' 2030 sustainable development goals (UNSDGs) (Salvalai, Sesana, Brutti, & Imperadori, 2020).

There are various environmental benefits, which can be achieved through CE implementation in construction projects. All these environmental benefits are related to UNSDGs. Due to the implementation of CE strategies in construction projects, major environmental concerns such as climate change can be resolved with greater efficiency.

2.3.1 Benefits of the implementation of CE

It is significant to provide the information and knowledge on the social, environmental and economic benefits achieved by the implementation of circular economy strategies, to the stakeholders. Here are some major benefits of CE reported in past literature (Europarl & Ton, 2020)

Decreases the utilization of non-renewable resources

- Reduced pressure on our environment
- Reduces carbon emissions
- Stimulates innovation
- Boost up the economic growth (an additional 0.5% of gross domestic product),
- Promotes zero waste
- Unlocks new business opportunities for companies
- Waste prevention, eco-design and re-use are such measures which can save money

- More durable and innovative products will be provided to the consumers, which proliferate the quality of life ultimately saving money in the long term.

The case study of Better Future Factory (2018) has proved that by applying CE strategies in their business processes, various social and environmental benefits can be achieved. Better Future Factory produced sustainable design products. This company introduced a better way of transforming the plastic waste stream into scalable and valuable products by implementing CE strategies. Currently, 9% of global plastic waste has been recycled every year, but the problem arises when the converted product could not be used for another useful lifecycle. Therefore, the implementation of a closed-loop cycle and reuse of plastic waste introduce sustainable products for future generations. Better, Future Factory used plastic building wastes, thus reducing waste, contributing to zero-waste production and material reuse. It promotes the eco-designs of buildings. Ultimately, it saved the money of various companies during different phases of their business.

Similarly, outside of the construction industry, a study by CLT Company proved that various environmental and social benefits could be achieved by implementing CE (Piacenza, Tumer, Seyedmahmoudi, Haapala, & Hoyle, 2013). In 2012, CLT Company collected over 2 million dead phones from consumers. Usually, there was no such mandatory electronic waste collection policy, law, or regulation to recycle such electronic waste. However, following the principle of a close loop cycle, the company proved that it was possible to utilize the waste for numerous useful products leading to the business success of the company. The closed loop of dead phones also enhanced consumers' awareness of sustainability CLT educated their employees and clients about the benefits of the closed loop. 2 million mobile phones were saved from being disposed and it promoted waste minimization. The step of the burning of electronic waste was eliminated due to which the emission of greenhouse gases especially CO2 was avoided.

These opportunities and benefits associated with CE are in alignment with Sustainable Development Goals SDGs. Economic growth, environmental protection, resource security, utilization of renewable resources, waste management, zero waste production, energy saving, and actions plan for climate change are some of the SGDs which can easily be achieved through the implementation of circular economy strategies in the construction designs of capital projects. Therefore, stakeholders should be educated and trained to implement CE and promote sustainability, which is one of the most significant current matters.

2.4 Challenges and future needs of CE adoption

This section reviews past efforts in understanding the challenges of adopting a Circular Economy in construction as a viable business model and identifying future research needs.

I. Performance and Quality

One barrier to recycling of C&D waste is used material quality condition. To make sure that all the materials are in good condition, they need to be sorted manually and require significant investment in time and labour. Material separation is extremely important for hazardous materials such as timber. In timber separation, contaminated wood is separated from non-contaminated wood, and this step is performed either on-site or at the transfer station. Additional cost for labour work is required for this purpose along with the storage cost.. In short, good separation practices and a corresponding resource investment are required to reuse materials of a large amount.

(ii) Information

Within the construction industry, there is a lack of information on the significance of recycling and the potential environmental benefits of CE. The benefits of using recycled materials are unknown to many practitioners, and these should be discussed with the workforce (Hossain et al 2020).

(iii) Culture and Perception

Various industries do not consider C&D material as a potential source as its value is still not recognized. Most construction practitioners consider the waste as true waste to be simply disposed of, and not as a potential for the renewable source. Internationally, the focus has been shifting towards renewable and recyclable technologies to meet the goals of sustainability. Therefore, a shift of the industry's perception and culture is required from cost efficiency to sustainable solutions.

(iv) Finance

Significant financial investments (e.g. asset investment, payment to promote new business models, and research and development) are necessary to uphold the innovative strategies of CE in the construction sector. Currently, there is a lack of appropriate financial tools for the mass market development of CE.

(v) Missing key economic enablers

Related to the above, CE adoption requires a pricing system covering environmental costs and incentives for recyclers and producers so that they work together to enhance the market for secondary raw materials and performance of specific value chains.

(vi) Limitations of recycling

There are potential limitations in the recycling of certain materials. Due to impurities in recycled materials, indefinite recycling of such materials cannot be performed, such as the reuse of paper, metal and glass (Laubscher & Marinelli, 2014).

(vii) Knowledge, Lack of Technology and Education

There is a lack of technical skills in the workforce to handle CE adoption (Wang H. , Zhang, Gao, & Kuroki, 2018)

In the construction sector, many workers and companies are unaware of the benefits of the circular economy. Education plays a vital role in introducing change from conventional norms.

Construction professionals are responsible to learn the benefits of CE and promote its practice among the workforce. Moreover, regulatory authorities and government also need to conduct seminars and workshops to educate the construction sector. The absence of technology is also one of the barriers to the implementation of CE strategies in the construction sector (Wang H. , Zhang, Gao, & Kuroki, 2020).

2.5 Observations and Summary

From the study of the literature review, it can be observed that there is a major lack of interest combined with a low level of awareness among stakeholders, employees, and business owners regarding CE in capital construction projects. Thus, the progress of CE adoption in the construction sector is slow so far. There is a belief among designers, contractors, manufacturers, and suppliers that the current construction strategies are the analogue of CE strategies so there is no specific reason to introduce CE strategies in the construction sector as this shift will introduce many barriers.

Stakeholders have to face a few barriers to shifting from traditional construction practices toward innovative CE strategies. Some of the barriers are the absence of key economic enablers, high costs, scarcity of workforce skills, and lack of knowledge. It has been observed that financial instability acts as the root cause for many other challenges in the construction sector. In addition,

there is not enough information about environmental benefits and business profit that companies can achieve by incorporating CE into their business practices.

Consequently, an innovative business planning framework is proposed in this study, which is based on the combination of the RESOLVE framework and 5R Imperatives as described later. This framework is expected to lead toward input reduction, waste avoidance, and efficiency gain ultimately improving the environmental performance in the construction sector.

CHAPTER 3: METHODOLOGY

3.1. Proposed framework for the implementation of CE Strategies in capital projects

To implement the circularity within the operation of a capital project, the ReSOLVE framework (citation here) is presented for engineering, procurement, construction, and management (EPCM) projects. EPCM contracts mean that a contractor will provide all Engineering, procurement, construction, and management services to the project client. The EPCM contractor may also hire subcontractors (Skaik, 2009). This framework has significance for the policymakers and practitioners and highlights the growth towards achieving sustainable development goals.

3.1.1 Hybrid Framework of ReSOLVE and 5R Imperative

An innovative business planning framework is proposed here, which is based on the combination of the ReSOLVE framework and 5R Imperatives. ReSOLVE framework consists of six building blocks, i.e., Regenerate, Share Optimize, Loop, Virtualize, and Exchange. Whereas the principles of 5R are Rethink, Reduce, Reuse, Repair, and Recycle, which are more applicable to building projects. The framework of R-imperatives details specific CE-related practices in construction projects. 5R-Imperative is the best fit in combination with ReSolve to ensure some of the circularity practices. The implementation of these building blocks in EPCM contracts can be summarized in the table 3.1.

Table 3.1 Integration of ReSOLVE framework with the construction sector

ReSOLVE Building blocks	Applications in construction s	5R Imperative Framework (Rethink, Reduce, Reuse, Repair, Recycle)
Regenerate	• Zero emissions • Closed loop strategies	**Reuse, Recycle, Repair**
Share	• Maintenance, upgradeability, and designs for durability • Built spaces to be utilized more efficiently	**Rethink**
Optimize	• Long-term planning for the operation stage impacts design • Offsite construction	**Reduce, Rethink**
Loop	• Design for deconstruction • Remanufacture techniques for the procurement of secondary materials	**Reuse, Recycle, Repair**
Virtualize	• Implementation of smart technologies • Introduce BIMS to ensure no unnecessary material is procured	**Reduce, Rethink**
Exchange	• Replace fossil fuels with renewable energy in construction machinery • Introduce technology such as solar panels for building roofs	**Rethink**

3.1.2 Implementation of CE strategies through the project lifecycle

The ReSOLVE framework and its scope during each stage of the project life cycle are described below.

Stage 1: Project initiation/capacity building

At the beginning of a project, various stakeholders of the project should be encouraged to apply the latest construction techniques to implement circularity within their operations. In this phase, *Virtualize* and *Share* part of ReSOLVE will be implemented.

Various capacity-building awareness and training camps should be arranged. This step is very important as without upskilling personnel concerning circularity, a new CE initiative may fail to transform the traditional construction strategies into circular thinking. These training should include all the stakeholders throughout the value chain including designers, contractors, suppliers, manufacturers, project managers, site supervisors and even the field workers. They will be given training on how to use the software such as BIMS, and other apps used for automatic trouble shooting. They should be briefed about techniques for waste minimization and water energy recycling that are planned to implement in the project.

A Circular Skills Programme has been initiated by a sustainable education cooperate known as Lerenvoor Morgen in the Netherlands to reach its ambitious goals to attain full circularity by 2050. This corporate works to fill the gap between professional practice and vocation training in circular economy. This firm has identified that currently gaps exist in digital skills related to Building Information Modeling (BIM,) material-tracking technologies such as Radio frequency identification (RFID) technology spell out, 3D printing techniques, and the application of material passport to aid the construction of modular, adaptive and remount able buildings. (Economy, 2021)

Another best practice during project initiation stage is the elimination of the paper plans and files to save money and time as well reduction of paper waste with the introduction of construction

management software. This software should be available across the value chain where every link in the chain has sufficient knowledge about building design, policies devised for the efficient management of water, construction material, energy and waste to ensure circularity.

3.1.2. Stage 2: Design

The next and most crucial step in every capital project is the design of the project. The designer has the most important responsibility to visualize the operation and end-life of project in the beginning. Therefore, the designs are arranged so it will perform well throughout the project life to accomplish the goals of the circular economy. Here *Regenerate*, *Optimize*, *Loop*, and *Exchange* part of ReSOLVE will be implemented.

There are many ways to phase out waste during the design stage. First is the addition of specified contract clause concerning waste minimization in the contractual agreement. Through this clause, contractor can be penalized for poor waste management performance. Past studies identified that standardization and pre-fabrication of building components may lead to less amount of waste production. The designers can also increase the recyclability and reusability of material through selection of component types and their connections, choice of structural system, and materials to allow flexibility for the installation of prefabricated parts from older projects.

The project should be designed in a way that its material can disassembled and retrofitted in the new projects**.** Several design concepts can be introduced in this stage to facilitate deconstruction such as the use of compressed wheat straw material as a partition panel with paper facing to be used as an alternative to drywall and lightwood, which has the additional benefit of being recyclable and homogenous material. An example is the separation of long-lived components from the short-lived component to allow adaptation and reduction of complexity during deconstruction.

The introduction of rainwater and greywater harvesting techniques can also minimize wastewater. Grey water consists of the water already been used in sinks, dishwashers and baths. This water can be cleaned up and recycled back into the water supply to be used in washing machines, toilets, and outside taps. Using such a system would reduce water consumption by as much as 50%. Rainwater harvesting system is also similar; however, grey water harvesting system does not rely on rain. It is plentiful in supply on regular basis as more clean water being used in dishwashing and showering, more grey water will be produced (Ferguson, 2021).

3.1.3. Stage 3: Procurement

After the design stage, the next logical stage is the procurement of materials for construction. Here *Regenerate* and *Exchange* part of the ReSOLVE will be implemented to ensure circularity of operations.

The most convenient way to reduce the impact of procurement of virgin raw material is to limit the demand of such materials. Alternatively, the demand can be meet through secondary materials procured through reuse, remanufacture, and repair of existing material in the system The material should be procured using renewable and environment-friendly sources. It should be procured locally to the project site as much as possible to limit the carbon footprint from logistics.

Precaution should be taken to ensure that no hazardous or toxic material containing asbestos and lead is procured. These materials can be found in fibrous insulation, synthetic material used as caulking, binders, adhesives, sealants, coating and binders etc. These materials are not only toxic and bad for environment but also been banned by most of the governments around the world. Hence, care should be taken while procuring such materials.

Other ways of ensuring circularity include the introduction of innovative technologies such as 3D printing and LED fittings**.** Promotion of offsite construction involve the procurement of

prefabricated portions of building and reduce onsite use of energy and subsequent emissions. Material take-back schemes should be discussed with the suppliers while passing tenders. The introduction of a product lease instead of owning a new product for every project is also another innovative practice (Hossain, Ng, Antwi-Afari, & Amor, 2020)

3.1.4. Stage 4: Construction

After design and procurement, the next step is to materialize the ideas by using the resources from the procurement stage. Here, *Optimize, exchange, virtualize* and *loop* strategies of ReSOLVE framework will be employed for circularity of construction processes.

Construction process can be optimized using technologies for an efficient broadcasting of information using multimedia tools, combined emails, voice-based tools, and handheld computing such as smartphones and tablets throughout the value chain of capital project. Introduction of BIMS (building information modeling), Ultra-wide band (UWB), RFID (Radio frequency identification), and GIS (geographic imaging systems) is implemented for smart usage of material during the construction phase.

Use of machinery running hybrid technology or battery can be introduced to reduce emissions produced from construction equipment such as dredgers, excavators, concrete mixers etc.

Water must be conserved during construction processes and must not be allowed to mix with nearby water bodies through runoff from the construction site. The building material such as sand and cement should be kept secured to avoid water mixing. An efficient drainage system can be developed that does not let any water to be wasted during construction processes and the same water is kept in the loop throughout this phase.

Use of off-site construction facility as much as possible to save time and energy utilized in onsite construction. Some of the notable offsite construction methods include the use of off-site preassembly, modular building, penalized systems and hybrid system, Prefabricated building unit can be developed in the factories rather on construction site where the carbon footprint of construction can be controlled more effectively (Lu, 2009). Figure 3.1 is citing that material and component in a closed loop during construction project.

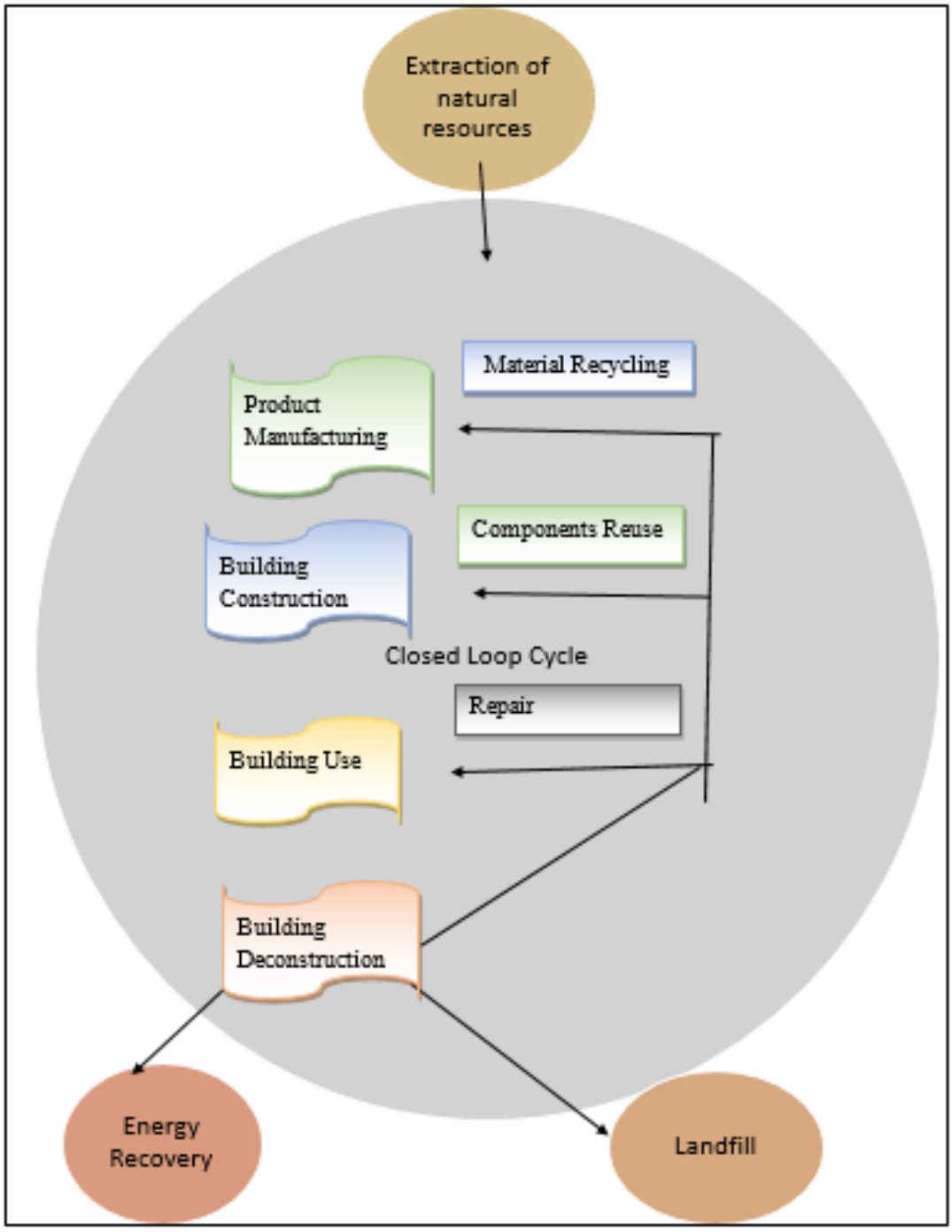


Figure 3.1 Material and component in a closed loop during construction project (Rahla, Mateus, & Bragança, 2021)

3.1.5. Stage 5: Operation and Maintenance

In this stage, Share, Virtualize and optimization strategies of ReSOLVE will be employed. Circular economy strategies can also be employed during the operation and maintenance phase to make the life of the project prolonged through maintenance, repair and upgradation. Most of the water is consumed in the operational phase of the building. Water efficiency can be achieved during operation phase by maximum harvesting of rainwater and grey water and to keep the water in loop as much as possible. Similarly, energy is mostly used in the use phase of the building. The use of such material that are energy intensive upsurges the building has embodied energy. Reduction in energy consumption can be achieved by improving the thermal insulation of buildings. The projects after completion should be utilized as much as possible through asset sharing. The areas in between two building can be utilized as parks/urban agricultural sites.

3.1.6. Stage 6: End of life

At the end of project cycle, efforts should be made to salvage the material as much as possible during the demolition and dismantling process. In this stage, *Regenerate* part of ReSOLVE will be implemented.

Reverse logistics is to be applied on this stage, which involve returning back of the materials from a demolished building to a new project site. By doing so, the life of the materials extracted from the building can be extended. This process requires less raw material and energy, and generates less pollution as compared to recycling. Figure 3.2 is showing the reverse logistics and forward logistics.

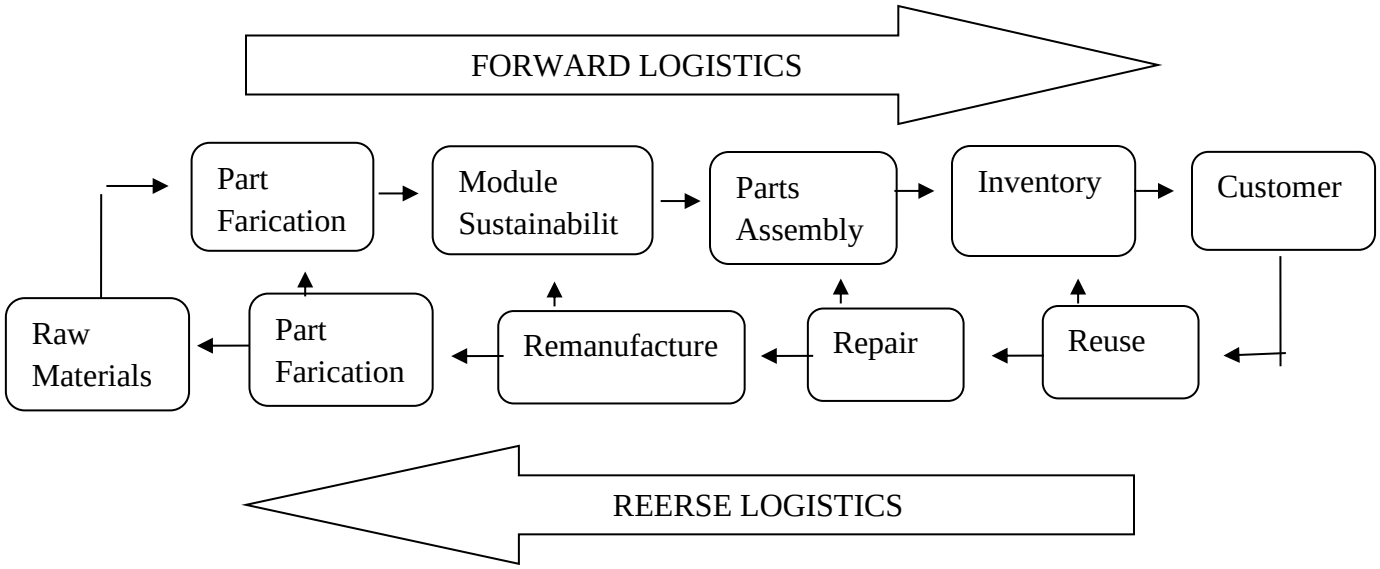


Figure 3.2 Reverse logistics

3.2 Research Methodology

The research method that is used for this thesis is case study research and interview analysis.

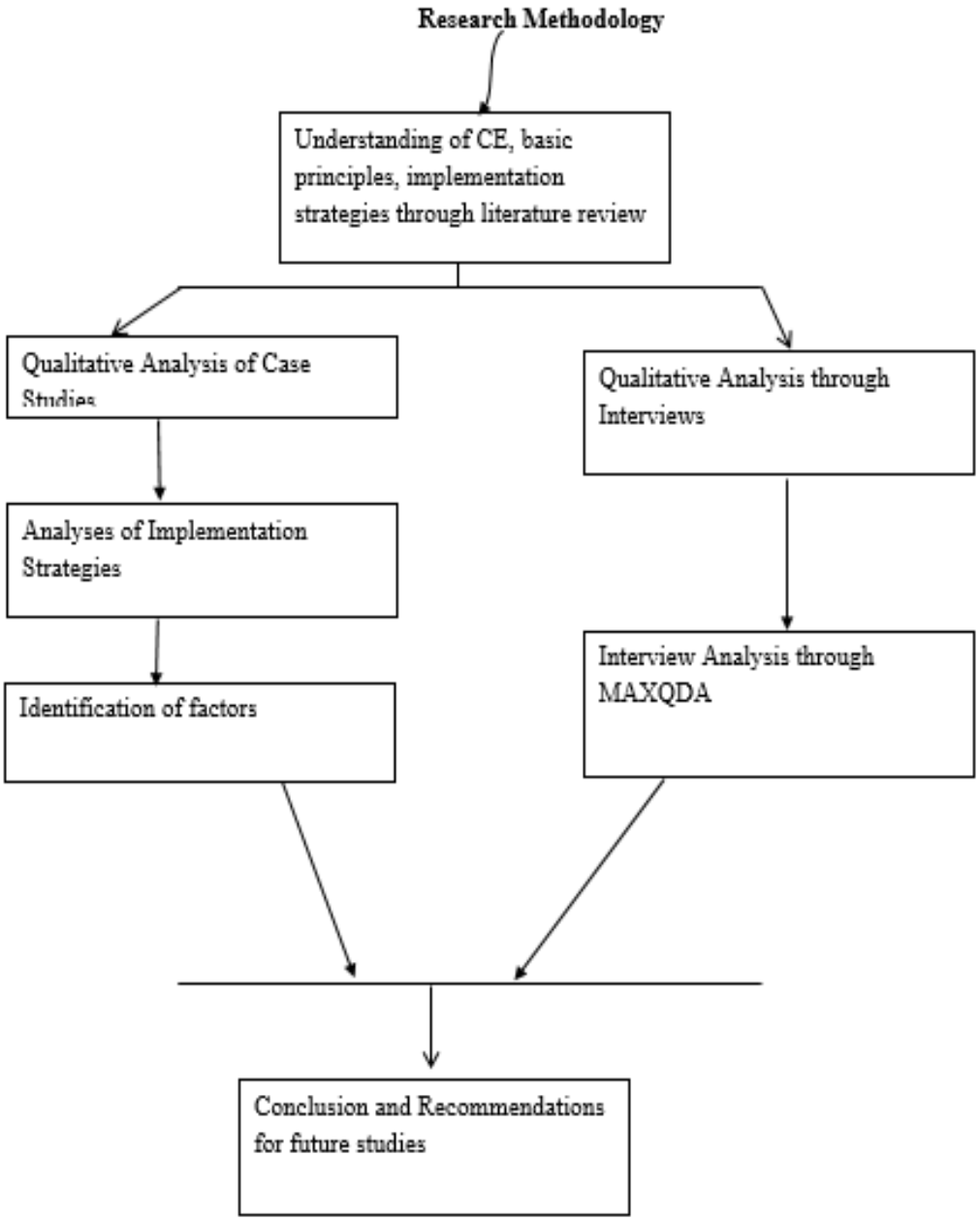


Figure 3.3 Research Methodology

3.2.1 Case Study Analysis

With the help of case studies, the problem and complex issues will be explored. A case study research is the best suitable method to use because of the following two reasons: it does not require control of behavioral events and it focuses on contemporary events. Also explain further that CE adoption is limited; we can learn from information-rich cases (Gorgolewski, 2006).

The adoption of the CE principles in construction projects is limited in the USA and the analysis of the case studies can help to understand the benefits associated with the execution of the CE capital projects. Moreover, companies can learn from rich case studies as well. The purpose of the case study of the people's pavilion is to clarify how a circular economy can force the construction industry to re-imagine a circular-inspired future.

The researcher has selected the case study because people's pavilion is a 100% circular building where no building materials are lost in construction and decommissioning. This case study has some limitations as well, it does not elaborate that how the suppliers or vendors were selected and what was the cost of the borrowed material.

The reason for selecting the case study of the Thames tunnel London is the capital nature of the project and the implementation of the CE principles. This project has also demonstrated how financial, social, and environmental benefits can be achieved simultaneously by applying CE in the capital projects particularly.

3.2.2 Qualitative Interview Analysis

Qualitative interview analysis will also be conducted in this project. This will help to collect the data directly from the respondents. Also, explain that since CE is in its infancy in construction in North America, interview study will help us to better understand the awareness of CE and the plan of market leaders.

The researcher has performed qualitative interview analysis in this project. This will help to collect the data directly from the respondents. CE is in its infancy in construction in North America, interview study will help us to better understand the awareness of CE and the plan of market leaders in North America. Interview Analysis was conducted and qualitative themes were identified using a data analysis software named MAXQDA.

3.2.3 Purpose of Thematic analysis and Software

The researcher has selected thematic analysis because thematic analysis works with an extensive series of qualitative data including media, transcripts, focus groups, and interviews. MAXQDA software (qualitative data analysis software) was used to extract the relevant data from the transcripts provided by the interviewee.

3.2.4 Population and Sampling technique

The population of the study includes the construction companies located and operated in America. The researcher has used the convenience sampling method to conduct interview analysis. The researcher interviewed the representative of two companies and transcripts were recorded to perform an analysis. The researcher has asked the same questions from both companies. The list of the questions is attached in the appendix. Company A was situated and operated in North America, and Company B has headquarters in the UK and operated in UK or Europe mainly. The researcher has selected the convenience sampling method because it allows the collection of data from those respondents who are conveniently available to the researcher.

The main reason behind not conducting survey, selecting few companies for interview analysis, and conducting only two case studies is the limited availability of practitioners due to CE being a new concept with few real world applications in the U.S. construction industry. Therefore, interviews and case studies are the most appropriate research methods given the still-developing

adoption of CE at this stage. The other reasons includes limitation of time and presence of few respondents in real because CE relatively is a new concept in USA especially in construction sector, therefore full understanding and generalizability of fancy CE in market will take some more years to implement at larger scale.

3.3 Ethical Considerations

The following ethical principles are taken into account while conducting the research.

i. The researcher has obtained specific training from CITI to conduct interviews with different companies.
ii. The researcher has avoided any kind of deceptive practices and biasness while conducting the interview.
iii. The personal information including the names of the companies was not revealed in this study or anyone else to ensure the privacy of the respondents.
iv. The researcher has obtained permission from the respondents to use their information in this research.
v. The respondents were completely ensured that the information obtained from them has used only for academic purposes.

CHAPTER 4 DATA ANALYSIS AND DISCUSSION

This chapter describes and reviews the results of the qualitative analysis of the study including two case studies and a thematic analysis of two companies named Company A and B. This chapter focuses on presenting the results according to the research objectives and research questions of the study.

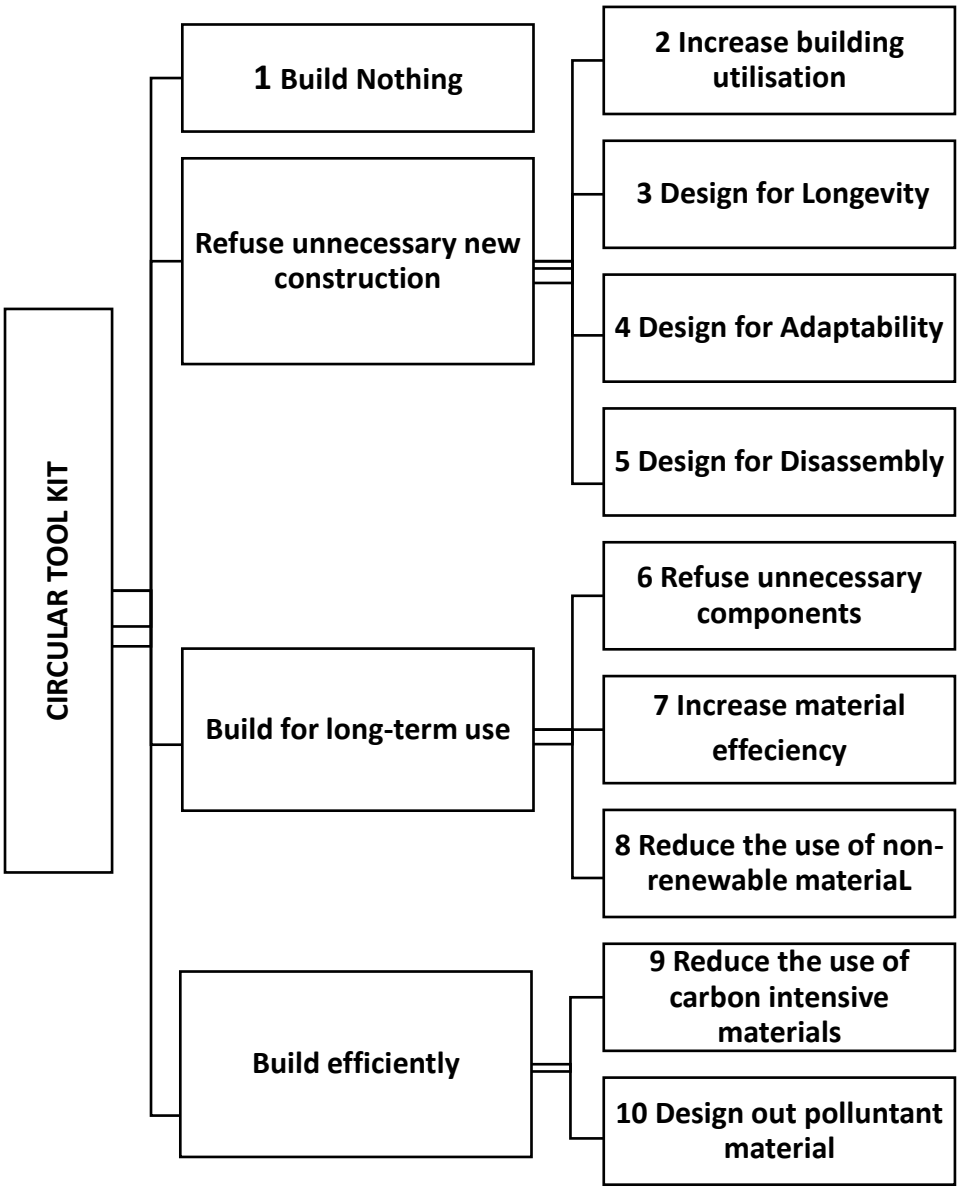
4.1 Case Study of Arup

4.1.1 Overview

In 1946, philosopher and engineer, Mr Ove Arup, founded a company intending to change how the built environment was designed and constructed. In the following 75 years, Arup has become synonymous with some of the world's most ambitious, creative and forward-thinking projects, from the Sydney Opera House to Gaudi's La Sagrada Familia.

In 2020, Arup the World Green Building Council's (WGBC) Net Zero Carbon Building Commitment to achieving net-zero carbon emissions for all assets under its control by 2030. Arup has been a strategic partner of the Ellen MacArthur Foundation, helping develop circular economy thinking and practices worldwide. Table 4.1 below is showing the circular toolkit developed by ARUP and Arthur foundation. The principles of the circular economy have been translated into a prioritized set of strategies and actions relevant to real estate projects through the circular toolkit.

Table 4.1 Circular Toolkit by Arup and Ellan MacArthur



(Arup, Mcarthur, 2022)

4.1.2 Circular Projects of Arup and Toolkit Strategies

Summaries for a few circular projects of Arup are given below. For further studies, (https://ce-toolkit.dhub.Arup.com/case_studies)

3. Design for Disassembly

5. Design for Longevity

8. Reduce the use of virgin and non-renewable materials

Figure 4.1 Recycle House London

Summary:

- The project of the recyclable house encourages construction sector to apply principles of circular economy.
- It is made of recycled and recyclable components and can be put apart like a Lego kit and build into another house somewhere else.
- The project of the recycle house of London has demonstrated that Circular economy can be achieved by using products with longevity, flexibility, potential to reuse and mainly easy for deconstruction.

3. Design for Disassembly

7. Increase material efficiency

Figure 4.2 The People's Pavilion

Summary:

- The people pavilion of Dutch was temporary building.
- The building of pavilion was the first 100% circular building.
- During construction and decommissioning, no material was lost or wasted.
- Building with Zero carbon footprint on this planet
- Perfectly designed for disassembling and enhancing the efficiency of the material.
- Borrowed material was returned to supplier after de-construction
- Help to reduce or mitigate the scarcity of resources

8. Reduce the use of virgin and non-renewable materials

3. Design for Longevity

Figure 4.3 Quay Tower

Summary:

- The Quay Quarter Tower has reduced the usage of the virgin material by retaining 66% of the existing building's columns, slabs and 95% of its interior wall as well.
- 50 % of the material used to reconstruct the Quay tower was used from the existing structure of the building.
- The new implemented design of the tower has helped to save tons of carbon emissions and preserve this planet.

1. Refuse unnecessary new construction
2. Increase building utilization

Figure 4.4 Triton Square

Summary:

- The implementation of the circular economy principles in the One Triton Square (ITS) of London has helped to exclude an estimated 40,000 tons of CO2 over next 20 years.
- The team has achieved considerable construction cost savings, faster development route, and marginal gains in terms of finance and environmental preservice by applying the principles of the circular economy.
- By circularity measures almost 43% cost saving was captured as compare to typical new commercial building.

4.2 The People Pavilion

4.2.1 Overview

The temporary People's Pavilion was a bold experiment in sustainability and reuse of materials, forcing the construction industry to rethink a future inspired by the circular economy. The main aim of this temporary building was to provide a solution for the scarcity of resources. The pavilion is a 100% circular building with no material loss during construction and decommissioning with 100% borrowed material from suppliers or manufacturers. 100% borrowed means that all the materials needed to construct the (250 square meters) building have been borrowed from traditional suppliers and manufacturers and the residents of Eindhoven themselves. The Peoples Pavilion by Arup highlights a new future for the circular building, with the bold design featuring new collaborations and intelligent construction methods.

4.2.2 Motivating Factors behind the Adoption of Circular Economy in the People's Pavilion

i. Giving Waste a Value

The introduction of circular economy approaches in a waste-intensive and high-growth sector such as construction represents a tremendous opportunity for Arup to minimize structural waste and thereby derive a greater value from circular construction projects. Materials, products, components and processes are arranged in cycles by Arup to keep them at their highest possible intrinsic value.

ii. Economic Efficiency is crucial

Arup has worked with the Ellen MacArthur Foundation as a knowledge partner since 2016, promoting the application of circular economy principles. This powerful and insightful partnership is focused on bringing about systemic, transformative change both in the built environment and beyond. Both Arup and Ellan MacArthur foundation have identified that introduction of circular economy principles could significantly increase the productivity of the global construction industry and at least generate a saving of $100 billion per year.

4.2.3 Implementation of Circular Economy principles during Construction

Arup has adopted the following strategies behind the Adoption of Circular Economy principles in the construction of the People's Pavilion.

4.2.4 Role of Designers behind the Strategies of Arup

- Design for Disassembly

Arup has adopted a design for disassembly strategy to prevent the use of materials that have negative impacts on planetary boundaries. This strategy also aims to prevent the use of materials in the construction of People's Pavilions that have a negative impact on the health and well-being of building inhabitants.

- Design for Longevity

This strategy of Arup focuses on maximizing the value of the building and its components over time, optimizing value retention and value recovery potential. For example, all the borrowed materials were returned to local suppliers after disassembling the pavilion, therefore that material could be used again for the construction of other buildings.

- Design for Adaptability

The design for the adaptability strategy of Arup aims to activate the adaptation potential during the usage phase in people's potential. It considers two design principles for adaptability: versatility and convertibility, which in turn are related to the required degree of adaptability to system changes. For example, diminish material waste at the construction site or production through off-site prefabrication of the building components.

4.2.5 Role of Suppliers and Manufacturers

- 100 % of the material used in the construction of the People's Pavilion was borrowed from suppliers and manufacturers.
- All borrowed materials used in the construction of the People's Pavilion were returned after it was dismantled.
- Many items have been reused in other construction projects, upholding another important circular economy principle to ensure materials are used at their value throughout the construction supply chain.

Figure 4.5 100 % Borrowed Material of People's Pavilion

4.2.6 Role of Engineers in a truly Circular System

This alternative system of applying CE in construction projects required validation of calculations, accomplished by conducting several experiments in collaboration with the Eindhoven University of Technology. Engineers of Arup have used advanced engineering practices to enhance the material efficiency of structural components of the temporary building.

Engineers of Arup constructed 7-meter tall columns from concrete foundation piles using steel rods reused from a demolished office building. Engineers have effectively and efficiently connected composite timber beams, concrete columns and cross braces with heavy-duty ratchet straps to create a safe and reasonably reliable structure that can withstand strong wind conditions.

4.2.7 Impacts of Circular Economy on People's Pavilion

- Impacts on Processes of Projects

Local suppliers, even the residents, manufacturers, and contractors were involved in the application of the circular economy and the circular economy has provided benefits to all the involved stakeholders.

- All the borrowed materials were returned to local suppliers after disassembling the pavilion.
- The Glass roof was returned to the greenhouse contractor
- All of the materials were returned to local manufacturers, suppliers and contractors after disassembling the pavilion.
- Arup has hired a business process consultant to complete this project.

Economic impacts

The implementation of circular economy principles in the Dutch People's Pavilion offers:

- Profitable service offerings for the client as no virgin material was purchased
- 100 % of the material was borrowed; therefore, the cost of buying new material was eliminated. The borrowing cost of the material was very economical as compared to the cost of the new material.
- Adaptable features with reduced environmental costs for developers.
- The public enjoyed improved services at lower economic and environmental costs.

Environmental Impacts

The pavilion is a practical example of a circular economy, a 100% circular building with no building materials lost and no hazardous effects on the environment. With a near-zero carbon footprint, the structure was made from entirely borrowed materials

4.2.8 Lesson Learned

In addition to environmental and financial benefits, both Arup's circular projects discussed above prove that circular design can be implemented in large capital projects. Dutch People's Pavilion was considered the revolutionary use of the circular economy. Circular projects required creativity and flexibility from everyone including manufacturers, customers, designers and builders. Circular economy principles can help cities meet emission reduction and decarburization targets along with financial benefits by polishing buildings instead of demolishing existing buildings as well.

4.3 Case Study on Circular London

London has been a pioneer in adopting circular construction, from the integration of a circular economy approach in the London Environment Strategy to the policy requiring developers to produce a CE Statement in the draft London Plan. In London, significant organizations are working to adopt the circular economy in the construction and other sectors of London as well (Jackson, 2015). Circular capital projects are considered a new normal in the construction sector of London (Deloitte UK, 2021).

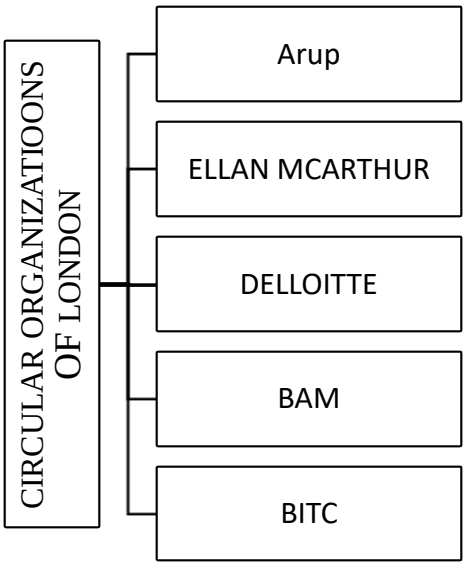


Figure 4.6 Organizations embedding CE in London

Table 4.2 is displaying the circular capital projects in action for London city.

Table 4.2 Circular capital projects of London

Circular Capital Projects of London city
• 1 Triton Square, London
• Thames Tunnel of London
• *Athlete's Village, Stratford, London*
• *Olympic Stadium, Strafford, London*
• *55 Bakers Street in London*
• *The London Circular Building*

4.3.1 Thames Tunnel of the London

4.3.2 Overview

The London Thames Tunnel is a 25km tunnel built under the river Thames and delivered by three joint ventures including BMB for the West contract; FLO for the central contract; CVB for the Eastern contract. London has developed drastically and the population of London continues to grow. The Thames Tideway Tunnel was desperately required to protect the tidal river Thames

from pollution. This case study aims to understand how CE can be applied through innovative design and positive collaboration between the project's contractors, to save significant costs and carbon emissions as well. The Thames Tunnel was built to protect the ecology of the Thames River for at least the next 100 years and to help Britain meet European environmental standards.

4.3.3 Strategies behind the adoption of Circular Principles

According to the management of BITC, adopting the unique way (CE) instead of adopting normal techniques (linear) is not a piece of cake. Such a huge circular economy builds capital projects that are quite rare in the world. Following Circular Principles were addressed in the adoption of circular economy in Tunnel.

- Designing out Carbon Emissions

To achieve the project's goal of reducing the carbon footprint over the life of Tideway, the team is continually looking for innovative solutions to avoid carbon by prioritizing low-carbon materials and redesigning facilities.

- Slow down resource consumption

The notion of circular economy (CE) identifies strategies to slow down resource consumption by eliminating waste and improving resources in the construction of the Thames Tunnel.

4.3.4 Motivating Factors for embedding CE

- A glimpse of the future construction and infrastructure motivates executing CE in the tunnel.
- Positive or no negative impact on the planet due to the adoption of circular principles motivates the transformation of the tunnel.
- Implementing CE approaches could lead to a 40% reduction in emissions by 2050.

4.3.5 Opportunities for applying for CE

- Numerous carbon saving opportunities were identified by CVB within the design of the shaft secondary lining and base slabs In the East section.
- The FLO team has also reviewed the central section's existing design (main tunnel) and identified an opportunity to reduce the liner thickness there as well.

4.3.6 Application of Circular principles in Tunnel

- Reduction in the Thickness of Central Section

The FLO team made a significant decision to reduce the thickness of the central section, which resulted in the central section of the tunnel, a 16% saving on the volume of concrete, a 5% saving on the embodied carbon footprint, and savings of substantial labour cost.

- Redesigning of East Section

The transformation of the eastern section from a flat structure to a dome-shaped structure has consumed 1,500 m3 of concrete compared to 3,500 m3, resulting in a saving of 750 tons of carbon emissions (CO2).

4.3.7 Impacts of Applying Circular Economy in Tunnel

After completion, Thames Tideway Tunnel will help stop tens of millions of tons of sewage from polluting the Thames every year. Through the additional social, environmental and economic benefits this project of Thames will leave a legacy for now and future.

- Social Impact

Created Jobs for 4,000 people including apprenticeships and convicted persons as well. Environmental Impact

The project has saved carbon emissions of 1379 tons by applying circular design principles in two main sites of the Thames tunnel.

- Financial Impact

By applying circular economy principles to the design of the tunnel, 2,000 tons of material were saved, which is almost 31% of the original design. The application of a circular economy results in saving material costs and substantial labor costs of 2.7 million pounds.

4.3.8 Lesson Learnt

This specific and huge Thames project has taught us that designers are the main initiators in executing circular economy strategies in capital projects. The implementation of the circular economy requires the collaboration of customers, engineers and manufacturers, but the role of designers is very important, as they are the initiators in this whole process. This capital project of construction has also demonstrated that by applying CE in construction projects financial, and social benefits can be achieved along with environmental benefits.

4.4 Qualitative Thematic Analysis

The researcher to analyze the interview data for exploring the CE and its impacts on capital project construction conducted a qualitative thematic analysis. The researcher has conducted thematic analysis because thematic analysis works with an extensive series of qualitative data including media, transcripts, focus groups, and interviews. MAXQDA software (qualitative data analysis software) was used to extract the relevant data from the transcripts provided by the interviewee. To conduct the thematic analysis, the researcher must critically analyze the transcripts, identify specific codes and develop themes in a structured way (Ollerenshaw & Creswell, 2002). The researcher has proceeded with the thematic analysis in three phases, as shown in the figure below;

Phase 1: Reading, Interpreting, and Providing Context to Text

At this initial stage of analysis, the understandability, meaningfulness and appropriateness of the data need to be ensured by reading and providing context to the data.

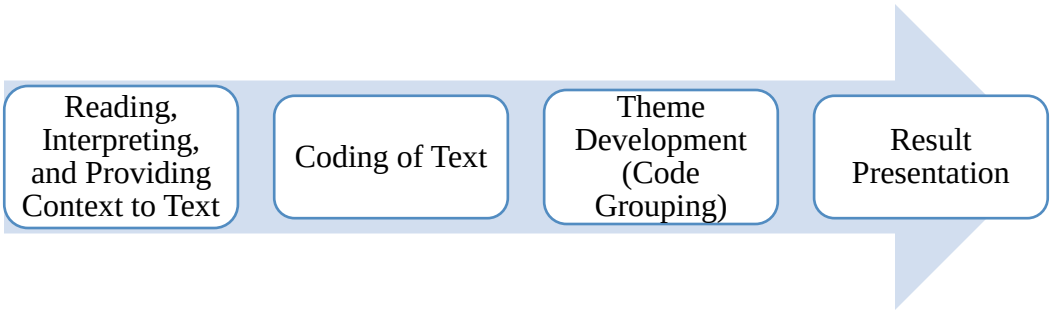


Figure 4.7 Phase 1: Reading, Interpreting, and Providing Context to Text Word Cloud

The researcher developed the word cloud using MAXQDA. To acquire a complete overview of what the data entails word cloud was required. The diagram of the word cloud was a form of short evaluation and developed to portray the most used words in the data. It provides a quick overview of what the data entails before commencing the reading and coding of the data.

Figure 4.8 Word Cloud

Findings

As the word cloud is depicted in the figure above, the most occurring words are in agreement with the research keywords indicating that the transcript data specifically address the focus of the study. The most repeated words in the word clouds are providing suggestions for the development of the themes and identifications of the codes in the data files. Moreover, the word cloud is also reflecting the presence of the research keywords words in the data. Therefore, the diagram of the word cloud has provided a track for the researcher for conducting thematic analysis.

Phase 2: Coding of Text

Each transcript of both interviews was carefully organized at this stage by using the qualitative data analysis software MAXQDA to assign meanings to sentences in the form of code and themes. This entire process was carried out with great care to ensure that important data was not lost during the subject analysis. The coding file can be found in appendix B and C simultaneously.

Phase 3: Theme Development

In the third phase, the established codes were grouped into themes based on the relationships between the codes, and the codes with the same properties were classified as one theme. Thematic analysis was performed using MAXQDA, and the researcher has developed ten themes. The table 4.3 is showing the themes of the study.

Table 4.3 Themes Development

Theme 1: Adoption Status of Circular economy
Theme 2: Overall strategy and steps
Theme 3: Adoption of ready-made tool or developed own toolkit
Theme 4: Internal or external motivating factors
Theme 5: Expected results from implementing this strategy
Theme 6: Preference for any alternative strategies to CE
Theme 7: Response of team members or people in the Organization
Theme 8: Resistance in implementation from team or external
Theme 9: Already adopted business process or practices
Theme 10: Benefits from CE

Theme 1: Adoption Status of Circular economy

Company A: The acceptance level of CE at this company is not high. This is indicated by the fact that it does not use the term CE but sustainability. The company has stated that CE practices have the potential to enhance the sustainability performance of organizations in general. The company's current focus is primarily limited to resource recovery or resource reuse, not a circular economy as companies, suppliers, and clients are not willing to adapt CE due to high pricing. However, the company says it can do much more by discussing CE opportunities with its clients, despite the tough margin issues.

Company B: The adoption status of the CE at this company is quite high. This company connects the industry with its clients by emphasizing case studies and raising awareness regarding the

existing capital projects. In addition, since 2016, Company B has been promoting the execution of the CE principles in the construction sector as a knowledge partner with other foundations.

Theme 2: Overall strategy and steps for follow up

Company A is working with local people to create vendors and find available vendors. The Company is trying to attain marginal gains through team collaboration that could be put together in the terms of financial and environmental performance to attain higher sustainability. They are trying hard to hinder barriers and identify various opportunities.

Company B is identifying various opportunities specifically in UK and Europe by convincing clients and vendors at higher levels. Company B is working to demonstrate the big picture of how the circular economy can help to attain financial return along with environmental gain through successful refurbishment instead of demolishing and building new structures.

Theme 3: Adoption of ready-made tools or developed own toolkit

Company A: Instead of providing ideas for executing CE in a project, the company has developed software to track material data. The company has also developed a sustainability-screening tool, which has about 70 sustainability actions in it for the project team's optional use.

Company B: The Company has developed a circular toolkit that outlines strategies for implementing a circular economy in various construction projects. This toolkit helped Company to practice the circular economy in various construction projects including 1 Triton square of London, the People's Pavilion and many others. The Circular Toolkit allows stakeholders to adopt different strategies and put the circular economy framework into action. For further studies, check the following link. (https://ce-toolkit.dhub.Arup.com/framework)

Theme 4: Internal or external motivating factors

Company A: For this Company, the motivating factor for adopting CE is mainly related to finance and reuse of concrete. For example, the need to reuse concrete is especially significant when the supply of concrete raw materials is limited.

Company B: The Company revealed that the main motivations for adopting CE include financial efficiency and waste reduction by adding value to waste through reuse or recycling. Company B also said that it is necessary to reduce the waste of resources by considering dismantling and reuse of the building instead of demolishing the building.

Theme 5: Expected results from implementing CE

Company A: The Company states that it will adopt new concepts and ideas as it learns over time. The Company also explained that the expected results after the execution of CE could be different from project to project, as it depends upon the requirements of clients and resource availability. The company has also recommended sustainability practices for project consideration, but not mandatory adoption.

Company B: According to this company, the expected results of executing CE in construction projects are dependent on individuals and organizations' learning processes regarding the application of the innovative solutions learned in the real world. Therefore, the company stated that the expected results could be different in the case of different projects and the company primarily focuses on achieving the results according to the strategies of their toolkit. The company prefer to measure circularity in any project by checking the performance of the toolkit application in any specific project.

Theme 6: Preference for any alternative strategies to CE

Company A: The Company has not used CE at all, but they are planning to gradually adopt CE over time. Rather than thinking of CE as a brand new strategy, the company may approach CE as another idea. The company has clearly stated that detailed steps, software, extensive case studies, and surveys are required to embrace and implement CE.

Company B: Company has clearly explained that they do not prefer any other technique to CE for now. However, they have used many frameworks in past including RESOLVE, LEEDS, Green and sustainability frameworks in their different construction projects in the UK and Europe.

Theme 7: Response of team members or people in the organization

Company A: Team involvement is critical because it facilitates possible explanations to keep the process running smoothly, as clients typically inquire about the additions or benefits of executing CE. The Company has elaborated that all of the company's team members considered sustainability a great idea, but according to the team, it is difficult to implement the CE principles in a real project.

Company B: The Company has acquired clarity in their decisions by clearly providing knowledge and displaying benefits associated with a circular economy. All the team members of the Company have shown quite an encouraging attitude by discussing every single point through the detailed sessions.

Theme 8: Resistance in implementation from team or external

Company A: The Company has faced resistance in the implementation of CE from teams or clients due to extra resources and business processes required for the enactment of the CE. The members

in Company A argued regarding the need for adopting CE principles. Internal and external members are also interested in knowing what something different they will achieve by implementing CE in construction projects.

Company B: Due to the initial investment cost required for the implementation of CE principles, the Company often experienced resistance from their clients. The Company has also stated that clients are not completely aware of the benefits associated with the implementation of the CE. The clients are most concerned about the paybacks that can be attained after applying the circular strategies of the toolkits in different projects. Meanwhile, the company seldom face internal resistance because the Company has many experts in the circular economy working for many years.

Theme 9: Already adopted business process or practices

Company A: To promote the application sustainability in their projects the Company has appointed a new CEO in January 2021. The new CEO is playing a significant and dominant role in restructuring the company's conventional practices and bringing changes at a greater pace.

Company B: The Company has appointed a client advisor and business process consultant in 2019 to identify new identify prospects, convince clients, and put into practice CE principles. The client advisors along with the engineers of the Company are working for executing the strategies of the circular tool kit in various capital projects in the UK and other countries. The circular toolkit developed by Company brings together strategies, and case studies to help professionals regarding the execution of the CE in their construction projects.

Theme 10: Benefits from CE

Company A: The Company indicates that sustainability practices have the potential to provide significant economic benefits by reusing materials such as concrete and environmental benefits through low carbon emissions.

Company B: This Company has highlighted the environmental, social and economic benefits of CE, depicted in past projects. The company has further indicated that designing buildings with reconstruction in mind can be a huge driver towards reducing waste in the construction industry company and has rebuilt 1 Triton Square in London using retained materials and saved 19,000 tons of CO2 equivalent. Similarly, in the case of the people pavilion benefits were identified in the term of low economic and environmental costs.

Chapter 5 CONCLUSION AND RECOMMENDATIONS

The construction industry accounts for almost 40% of global CO2 emissions due to the linear economy. Construction alone has a huge carbon footprint: from manufacturing materials like concrete and steel to the transport of those materials, and the on-site electricity used when you build. All of this is called embodied carbon and is responsible for about 11% of global emissions. With so much of our cities already occupied by buildings, maybe the question we should be asking is, "Do we need to build all that space?" This question led us to the “Circular Economy”. After conducting the whole analysis we can conclude that moving away from a 'take, make, and dispose of' consumption model, circular economy strategies can help on our journey towards a net zero economy and financial gains as well. Buildings alone account for 37% of global greenhouse gas emissions, with construction materials losing around 95% of their value during demolition. The circular design framework enables you to futureproof your project. The principles of the circular economy have been translated into a prioritized set of strategies and actions relevant to real estate projects. Understanding the circular economy and its potential impact on the construction industry were studied in this research through a case study and an interview analysis of two companies. Numerous past studies indicate that the construction industry in general is hesitant in adopting new concepts and technologies. Although different companies have adopted bunch of strategies including sustainability. Different entities think that they have adopted CE but in real, they are working on sustainability on large scale. CE has no exception, largely due to the risk and uncertainty in costs and benefits of adopting them. However, there have been some steps in implementing strategies that are related to CE as more entities are placing a focus on reporting ESG efforts against the United Nations 2030 Sustainable Development Goals (UNSDGs) (United Nations Development Programme, 2015).

Major conclusions of the case study analysis can be summarized as follows:

5.1.1 Case Study Analysis

Arup Case Study

- Arup and the Ellen MacArthur Foundation have released a practical toolkit designed to enable a circular economy for buildings. The circular toolkit allows stakeholders to adopt different strategies and implement the framework of circular economy in action.
- People's Pavilion was a bold experiment in sustainability and reuse of materials, forcing the construction industry to rethink a future inspired by the circular economy. The pavilion is a practical example of a circular economy, a 100% circular building with no building materials lost and no hazardous effects on the environment.
- According to a new report from global circular economy experts Circle Economy, the world economy is only 8.6% circular. Case studies, client awareness, proper education, collaboration among designers, manufacturers, suppliers and government policymaking can help all stakeholders understand the key benefits associated with implementing a circular economy in construction. By adopting the principles of the circular economy in the construction of the people’s pavilion, Arup has achieved economic, environmental and social benefits as well.

Circular London Case Study

- According to the report published by the London Waste and recycling board, LWARB London city has a clear opportunity for embedding circular economy principles in the city Policy. The construction sector in London consumes 60% of UK waste to landfills and contributes around 40% of the UK's total carbon footprint; we urgently need to rethink the design and construction of buildings to overcome these impacts (Jackson, 2015).

- With recycled material, innovative design and positive collaboration between the project's contractors, significant cost and carbon savings have been achieved on this massive project Thames tunnel. Thames circular tunnel project demonstrates that applying circular design can add both financial benefits and environmental prosperity to an infrastructure project by applying circular economy principles to design. The Thames Tideway Tunnel is the UK's largest water sector project to date and will protect the Thames for at least the next hundred years.

5.1.2 Interview Analysis

The results of the thematic analysis concluded that CE restricts the consumption of virgin resources, promotes the efficient utilization of resources and fosters cleaner production. Cities are growing, which means we keep on building. We all need space to live, but building buildings is terrible for the planet. Major conclusions of the thematic analysis can be summarized as follows:

- Adoption Status of CE

  The adoption status of the circular economy in company A (situated and operated in the USA) is not high, as they are not using the term circular economy. In the case of Company B, headquarters in the U.K. but operates in the U.S has a higher CE adoption level evidenced by the accelerated development process by challenging standard approaches and maximizing existing materials and components reused to demonstrate the commercial value of a circular economy approach.

- Overall Strategy

Company A is working with local people to create vendors. Working to attain sustainability through team collaboration in the terms of financial and environmental performance. Company B is working

to convince clients and demonstrate the big picture of how the circular economy can help to attain financial return along with environmental gain through successful refurbishment instead of demolishing and building new structures.

- Toolkit or Software

  Company A has developed a sustainability-screening tool and software rather than a toolkit. Company B has released a practical toolkit, designed to enable a circular economy for the construction industry. The circular toolkit developed by Company B allows stakeholders to adopt different strategies and implement the framework of circular economy in action.

- Motivating Factors

Company A has identified the re-use of the concrete and financial factors as the motivating factor behind the adoption of the circular economy. According to Company B, the motivating factors behind the adoption of a Circular economy are economic efficiency and reduction of wastage by giving waste value through re-usage or recycling.

- Expected Results

According to Company A, the expected results could be different from project to project, as it all depends upon the requirement of clients and the availability of resources. Similarly, according to Company B, the expected results could be different in the case of different projects. In the terms of expected results, this Company usually focuses on achieving the results based on the strategies of the circular tool kit developed by them.

- Preference for other strategies

Corporation A has not used CE at all and considering a bunch of strategies or ideas for a long. Company B does not prefer other strategies on CE but they have used many other frameworks in past including RESOLVE, LEEDS, and green and sustainability frameworks in different construction projects.

- Response of team members or people in the organization

Company A has elaborated that all of the company's team members considered sustainability a great idea, but according to the team, it is difficult to implement the CE principles in a real project. The team members of Company B have shown quite an encouraging attitude by discussing every single point through the detailed sessions.

- Resistance in the execution of CE

Company A has faced resistance in putting into practice the principles of CE from teams or clients. Company B does not face internal conflicts but they have to cope with clashes from clients due to pricing issues.

- Already adopted business process

Company A has appointed a new CEO in January 2021, who is restructuring the company and making many changes to enhance the status of sustainability. Company B hired a senior business

process consultant and client advisor in 2019 to identify opportunities and convince clients regarding the execution of circular projects.

- Benefits of CE

Both Companies have considered the benefits of CE in the terms of the economic, social and environmental benefits. Both of them have stated that case studies, client awareness, proper education, collaboration among designers, manufacturers, suppliers and government policymaking can help all stakeholders to understand the key benefits associated with implementing the principles of circular economy in the construction sector.

After conducting the interview analysis and case studies analysis, we can conclude that in Europe the government and other legislative bodies are playing significant role to create awareness regarding the implementation of the CE in the construction sector. The construction sector of the Europe has clearly demonstrated that how the conversion of linear economy into circular economy can help to attain the re-use of natural resources profitably along with environmental benefits. The transformation of circular business models in Europe has clearly revealed interest from researchers, government bodies and practitioners regarding the implementation of the CE in the construction sector of Europe (Deloitte UK, 2021). Different organizations are working in Europe particularly to implement the CE in construction sector (Deloitte UK, 2021) (Arup, Mcarthur, 2022) (EEA Report, 2017). Deloitte has identified seven different types of circular economy business models; similarly, ARUP has identified several case studies. The countries like USA can make the use of the idea of circular economy to foster sustainability and save natural resources of this planet. The government of the USA and United States Environmental Protection Agency (US EPA) should introduce guidelines and procedures for implementing the CE in the construction sector. There is a need to develop new legislative bodies similar to Europe in the USA to implement the principles of the CE in different projects.

5.2 Limitations of the Study

A supreme effort has been made by the researcher to ensure that the best results are presented in this study. The researcher has identified the following limitations in this particular study due to time and other constraints.

i. The first limitation of this study is the small sample size because the sample size of two companies for thematic analysis was not enough to cover the perception of the USA.

ii. The second limitation of this study includes the shortage of time, due to which the researcher was not able to gather data through the proposed questionnaire and interview more companies to capture the big picture regarding the execution of the CE principles in the construction sector of the USA.

iii. The third major limitation is the availability of data regarding the CE, which created the biggest challenge to this research. Despite facing this challenge, the most appropriate procedure is used for data imputation.

5.3 Recommendations for Future Research

Future researchers can work on this project by considering the following points:

- Conduct more interviews with companies who are practically executing the principles of the circular economy in their capital projects to capture the big picture.
- A questionnaire should be developed and distributed among the researchers, industrial experts, clients, contractors and the concerned individuals. A proposed questionnaire is also attached in appendix D; due to the limitation of time, this research was not able to implement the survey. The potential researcher can work on it and conduct quantitative analysis based on the Likert scale to acquire relevant answers to research questions.

- Potential researchers can also consider case studies, particularly from the USA to analyze the implementation and execution of the circular economy in the construction projects of the USA.
- The future researchers will have opportunities to research on understanding the perspective of the clients specifically concerning the adoption of the circular economy in capital projects.

5.4 Implications of the Study

5.4.1 Theoretical Implications

This study significantly contributes to the existing body of knowledge regarding CE. This study will give an understanding to potential researchers regarding how the CE is exerting an impact on construction projects. It will help the academic world in exploring different aspects of CE and different methods for measuring circularity in the construction sector.

5.4.2 Practical Implications

This study will make a significant contribution to the theory development, and policy development regarding the execution of the CE in capital projects. Moreover, this study has also identified why construction companies should make efforts to execute CE and the benefits associated with the implementation of CE. This study has also recognized the possible barriers faced by the organization in implementing the CE. This research provides information that how CE is necessary for construction projects. This study will be helpful for countries like America as it provides them with the route to initiate CE in the construction sector to control the scarcity of resources.

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APPENDICES

APPENDIX A: Interview Questions

1. What is the adoption status of Circular Economy (CE) at your company?
2. What is your organization's overall strategy in adopting CE?
3. What are the internal or external motivating factors for adopting this CE strategy?
4. What results were you looking for from implementing this strategy?
5. Did you consider any alternative strategies to CE to achieve your sustainability goals? What were the important aspects you considered when deciding on a specific strategy to adopt?
6. Please elaborate on your experiences adopting and implementing the strategy(s).
7. How did people in your organization respond to and adapt to the implementing the strategy(s)?
8. What benefits have you realized since implementing the strategy(s)? Please indicate benefits in terms of environmental, social, and economic.
9. Have your organization made any change to the business process/practice to facilitate the implementation of CE?
10. Do you have any lessons learned you would like to share with others that may be considering implementing this strategy(s)?
11. How is your organization measures progress and outcome of CE implementation?
12. Is there anything else you would like to add?

APPENDIX B: Code System of Flour

Code System	Freq
Code System and Themes	41
Therefore, I want to know a little bit about the benefits, which you think.	1
1. environmentally, socially, and economically,	1
2. It's very rare that you would find sustainability not mentioned	1
Any business process or practices, which is already going on in flour?	1
3. We got a new CEO in January of 2021.	1
4. Sustainability is big to him. He refocused the company	1
5. restructured the company so that sustainability is now reporting	1
Did you find resistance in implementation from team and external?	1
6. Yes, Due to extra fund, Cost and Time	1
7. Do really need to do that? Can we do it?	1
8. Can we get the results in different way?	0
how did your team member or people in your organization respond	1
9. more clients are asking for what are innovative solutions t	1
10. However, it is hard to get projects to actually use it.	1
11. Everybody thought it was a great idea.	1
12. What is extra we get from CE?	1
Question, #5 is, did you consider any alternative strategies to CE	1
13. We have not used CE at all.	1
14. It's probably a whole bunch of strategies over time, and rather	1
15. Steps and software’s are required to embrace circular economy	1
16. Implement CE by using Case studies, and survey and interviews	1
What results were you looking from implementing this stragedy?	1
17. Even that's a little too formal to we really didn't take a plan	1
18. companies have been doing recycling	1
19. You know it is you learn over time. You add some things.	1

20. Long way away from sustainability as Circular economy	1
What are the internal or external motivating factors	1
21. Several one would be financial.	1
22. You need to reuse concrete because you can't get a lot of	1
23. there are a lot of motivations to use it and it really has to b	1
Have you adopted readymade tool or developed your own toolkit?	1
24. Yeah, we have. In addition, I would not say toolkit. We have a software	1
25. We also have a screening tool, sustainability screening tool	1
26. CII Tool created in 2010	1
27. help identify sustainability actions and they range from enviro	1
28. each sustainability action addresses environmental social gover	1
29. Re-usage	1
What is your overall strategy? What steps have you prepared to follow?	1
29. The steps have been very much.	1
30. So recycle.	1
31. identifying opportunities, looking at barriers, looking at v	1
32. trying to encourage projects	1
33. Help the communities	1
34. working with a local people to create such a vendor,	1
35. Difficult to get things to market specially in Urban areas	1
36. look for barriers, look for opportunities and look for partners	1
Adoption Status of Circular economy at Flour	1
37. It is not high, but we don't use the term or the phrase circular	1
38. Once our CEO, CII Research is published.	1
39. We have two ones, readiness guide and other ones an implemented	1
40. Following those and then we will start using the term circular	1

APPENDIX C: Code System of Arup

Code System	Freq
Code System and Themes	26
Therefore, I want to know a little bit about the benefits, which you think.	1
1. Environmental, social and economic benefits	1
2. Reduction in CO2	1
3. Low economic and environmental cost.	1
4. huge driver towards reducing waste	1
Any business process or practices, which is already going on in flour?	1
5. hired senior business process consultant in 2019	1
6. implementing the principles of the circular tool kits in various capital projects in UK	1
Did you find resistance in implementation from team and external?	1
7. Arup used to bear resistance from their clients due to high	1
8. never face internal resistance	1
how did your team member or people in your organization respond	1
9. we bring clarity in our decisions	1
10. showed quite encouraging attitude	1
did you consider any alternative strategies to CE	1
11. many frameworks in Past	1
12. No preference on CE for now	1
What results were you looking from implementing this stragedy?	1
13. dependent on how individuals and organizations learn to innovate and apply	1
14. measured circularity by checking the performance of the toolkit	1
15. expected results could be different in case of different projects	1
What are the internal or external motivating factors	1
16. Economic efficiency	1
17. Reduction of waste	1

18. Refurnishing or reusing instead of demolishing.	1
Have you adopted readymade tool or developed your own toolkit?	1
19. developed their own circular toolkits	1
20. circular toolkit allows stakeholders to adopt different strategies	1
What is your overall strategy? What steps have you prepared to follow?	1
21. learn to innovate and apply	1
22. turning ambition into actions	1
23. pioneer in adopting circular construction	1
Adoption Status of Circular economy at Arup	1
24. It is high at Arup	1
25. bringing together the industry and clients by highlighting case studies	1
26. Knowledge partner	1

Creative Coding

APPENDIX D: Proposed Questionnaire for Future Researchers

ACADEMIC SURVEY

IMPACT OF THE CIRCULAR ECONOMY ON THE CAPITAL PROJECTS

1. In which Sector do you classify your Business?

- Residential
- Industrial
- Commercial
- Governmental
- Other ☐

2. Representation of Respondents?

- Clients
- Designer
- Manufacturer
- Contractor
- Other ☐

3. Years of Operations in Construction (Capital Projects)?

- 1-3 years
- 4-7 years
- 8-10 years
- more than 10 years
- others ☐

What is your geographical location?

- USA
- Other ☐

QUESTIONS REGARDING AWARENESS

4. There is a need to encourage clients, designers, contractors, manufacturers, regarding the adoption of circular construction projects.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

5. Awareness regarding the circular economy is limited in the USA as compared to Europe and UK due to:

- Lack of interest

- Lack of Knowledge
- Others

6. To educate clients, designers, contractors, manufacturers it is necessary to conduct:

- Seminars and Workshops by Companies
- Campaign on broad-scale by Government
- Seminar's in University's (HEC)
- Other ☐

7. In my opinion, construction waste is more harmful to:

- Financially
- Environmentally
- Socially
- Other ☐

8. Which entity should play a leading role in promoting the awareness efforts?

- Government
- Higher education Commission
- Companies
- Other ☐

9. In my opinion, a circular economy will help to reduce construction waste:

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

10. There is a need to enhance awareness regarding the difference between Lean, green building, or leads and circular economy.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

QUESTIONS REGARDING IMPLEMENTATION

11. Which is the most Significant enabler in implementing the Circular Economy in the capital project:

- Financial incentives
- Assurance Scheme
- Viable Take back Schemes
- Enabling technologies
- Other ☐

12. All stakeholders lack the proper knowledge regarding the benefits associated with circular economy and seeing big pictures.

- Strongly Agree
- Strongly Disagree

- Agree
- Neutral

13. In my opinion following is the best approach to implement the Circular Economy in the USA particularly:

- Synergy among the client, designer, contractor, and manufacturer
- Training of the Staff/Employees
- Other

14. Identify the most Significant Challenge in implementing the Circular Economy in the capital project:

- Unclear Financial Case
- Lack of Incentives
- Lack of Consideration for end of life issues
- Other

15. In the USA, designers consider minimal maintenance or easy repairs concepts while making designs for capital projects.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

16. In the USA, designers focus on the design for reuse, while making designs for capital projects to implement a Circular economy.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

17. Suppliers prefer secondary materials, less hazardous material and take back schemes in USA to implement Circular economy.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

18. Contractors Prefer to minimize waste by using procure recycled materials and Offsite construction in USA to implement the Circular economy in their projects.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

19. I prefer to apply design in projects that enable decommissioning of assets to support a circular economy.

- Strongly Agree

- Strongly Disagree
- Agree
- Neutral

20. I prefer to apply the following Circular economy approaches to the design process.

- Design for deconstruction,
- Design for reparability
- Design for adaptability
- Others

21. I always advise clients regarding the benefits of applying a Circular economy as compared to lean approaches in Construction.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

22. I prefer to enable operating and maintaining the facility of capital projects in a circular way.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

23. I prefer to make structures that will be move and use in different locations.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

24. I prefer to minimize onsite waste through modular construction

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

25. I prefer to do pre-demolition audit in capital projects.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

26. I genuinely prefer to eliminate waste and maximize reuse during construction on site.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

27. I prefer procurement of materials from suppliers who offer:

- Take back schemes
- No Take back schemes
- Others

Objective 2

28. As a client, designer, manufacturer, and contractor I mostly prefer following strategies in capital projects due to better know how or other reason.

- Leads
- Green buildings
- Lean strategy
- Circular economy
- Others

29. In my opinion, various existing design and construction strategies and circular construction are similar.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

30. Various strategies such as Leads, green buildings, and lean strategies are cost-effective as compared to the circular economy.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

31. To attain long-term benefits, circular construction is better than various strategies such as, Leads, green buildings and lean strategies.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

(ECONOMIC/FINANCIAL)

32. In my opinion, the implementation of a circular economy will help in the reduction of costs in construction project.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

33. Circular economy will help the clients in achieving the long-term financial benefits.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

(Environment)

34. Some key strategies such as Lean, Leads, and Sustainability provide a benefit to cost, quality, yet have a greater negative environmental impact.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

35. The implementation of Circular economy in Capital projects will help in the reduction of CO2 emissions.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

36. The circular economy can help to ensure that circular capital project are suitable for making positive environmental changes.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

(Social)

37. Circular projects can gain a huge amount of goodwill by prioritizing social responsibility.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

(BARRIERS)

38. Despite of the long-term benefits circular economy is facing problems in implementation.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral

39. Identify the most significant barrier to implementing the circular economy in the construction sector.

- Lack of understanding of big picture
- Lack of obligatory legislation
- Competitive Situation
- Difficulty in getting high payment from clients
- Other

40. In my opinion, it is genuinely required to conduct future research for the betterment of circular economy in Construction projects.

- Strongly Agree
- Strongly Disagree
- Agree
- Neutral