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Integrated Model and Index for Circular Economy in the Built Environment in the Indian Context

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Abstract

Sustainable development aims at minimising waste and reducing exploitation of natural resources and energy, so that needs of the future generations are taken care of. Circular Economy (CE) is a new drift towards sustainability that aims at minimising waste and promoting material reuse, thereby creating a regenerative system. The construction industry is responsible for the extraction of raw materials and generation of waste in large quantities, thereby making it an opportune sector for transition to a circular economy. On account of the complex nature of the built environment comprising various phases and associated actors, a proper framework or indexing for the circular economy is missing at present. This study aims to develop an integrated model of CE in the built environment which considers various construction stages and applicable strategies. An index for measuring the circularity potential in construction materials is also proposed, based on attributes developed from literature review and analysis of questionnaire survey. Simple Additive Weighting Method (SAWM), an elementary multi-criteria decision-making method is used for developing the index. It is anticipated that Circular Economy Potential Index (CEPI) would support decision-making in the initial stage of construction projects and help to compare the circularity of materials.

Keywords

Circular Economy; Recycling; Integrated Model; Index; Built Environment

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Introduction

Human activities continuously extract resources from nature and dump waste and harmful effluences back to landfills, thereby deteriorating the quality of the environment around us. This awareness induced the need of promoting sustainable development, considering future generations while achieving current growth targets (Elia, Gnoni and Tornese, 2017; Govindan and Hasanagic, 2018). There is endless exploitation of nature in a linear pattern for which the consequences are resource depletion, pollution of land, water and air, leading to endpoint environmental impacts such as carbon emissions, global warming and climate change (Ghisellini, Ripa and Ulgiati, 2018; Foster, 2020). In India, the annual material waste generation is sixty-two million tons, of which, forty-three million tons are collected, thirty-one million tons are deposited in landfill areas and only twelve million tons are treated (Kamble, Raju and Vishnu, 2020).

Due to the large volume of construction activities required to support urbanisation, the construction industry is among the topmost in contributing to negative environmental impacts. The built environment is the largest consumer of materials and the highest producer of waste globally, and it is expected to increase steadily in the future (Stephan and Athanassiadis, 2018). Similarly, it is responsible for forty to fifty percent of raw material consumption, thirty to forty percent of energy use, and about thirty-eight percent of greenhouse gas emissions worldwide (Seyis, 2020). Globally, more than three billion tons of construction and demolition waste is generated every year, which forms about fifty percent of the total solid waste (Akhtar and Sarmah, 2018). Waste is generated during different phases of building construction but is maximum at the end of life when it is demolished and disposed of (Benachio, Freitas and Tavares, 2020). Therefore, there is a great potential for converting this waste into new construction materials, which would prevent it from going to landfills, thereby helping to reduce raw material consumption. Literature suggests that by promoting recycling, buildings could be considered as a "material bank" that can supply a major part of the construction materials needed for future buildings (Minunno, et al., 2018; Leising, Quist and Bocken, 2018).

The present linear economy model follows a 'take - make - dispose' pattern that encourages single use of materials followed by disposal after use, without any concern about the environmental impacts (Kamble, Raju and Vishnu, 2020). Circular economy (CE) is a school of thought that promotes cyclic use of materials and inspires to extend the useful life of a product. The core idea is to close the loop and to create interlinked systems where the waste output from one organisation becomes the input for another (Cheshire, 2019). A change in mindset is inevitable to consider waste as a potential resource and not as a burden to be dumped (Ghisellini, Ripa and Ulgiati, 2018). To enable a systematic shift, knowledge and awareness of CE principles should be imparted to the society, along with guidelines for supporting and monitoring (Kirchherr, Reike and Hekkert, 2017; Minunno, et al., 2108). CE is pertinent to all domains of life, whereas it is only widely observed in the case of metals, paper, glass, plastics and water (Haas, et al., 2015). The construction industry demands a shift from linear to circular economy whereby materials can be circulated in the system thereby reducing raw material extraction and waste generation. Techniques for measuring the extent of circularity are essential to acknowledge the efficiency of circular systems. Various studies have proposed indicators or index of circularity, a few of which are 'end of life recycling efficiency rate', 'recycling input rate' and 'circularity rates using mass balance' (Rombach, 2013; Di Maio and Rem, 2015; Mayer, et al., 2019). Overall, defining an index for construction materials, based on CE parameters, would be helpful for material selection and design of structures in line with CE principles.

Research Background

Several studies have attempted to advance the shift towards a circular economy and explored various theories and strategies in support of CE. The following section provides a quick overview of the various dimensions of CE by categorising it into eight major aspects, followed by other dimensions of CE in the built environment and the research motivation.

1. Material flows: There are two types of material flows, the *biological cycle* (*socioeconomic loop*) consisting of degradable and non-toxic materials that naturally return to the environment, and the *technical cycle* (*ecological loop*) comprising of industrial materials that may contain toxic elements and retained within the system by recycling. (Haas, et al., 2015; Haupt and Zschokke, 2017; Nuñez-Cacho, et al., 2018; Cheshire, 2019).
2. Social, Economic and Environmental dimensions: Most studies on CE consider the environmental impacts and economic gain of implementing CE (Ghisellini, Ripa and Ulgiati, 2018), and it generally targets social welfare through minimising resource use and pollution (Pomponi and Moncaster, 2016). Hence CE has social, economic and environmental implications and the three pillars of sustainability hold good for CE as represented in Figure 1, below.

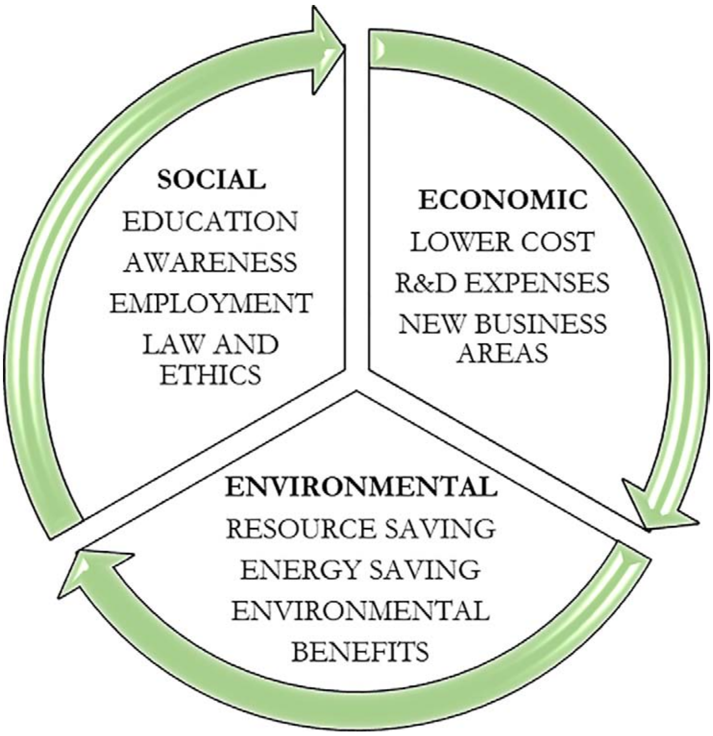

Figure 1. Three pillars of circular economy

3. Principles of circular economy: Ellen MacArthur Foundation (2013) proposed principles of CE as 'designing out waste', 'improving resilience by adopting diverse systems', 'making use of renewable energy sources', 'thinking in systems' and 'considering waste as food'. The basic principles of CE shall be listed as (i) *Design out waste* focusing on minimising waste and pollution, (ii) *Keep materials in use* suggesting an extension of the life of products by creating loops and (iii) *Regenerate natural systems* implying restoring materials consumed and using renewable energy (Ellen MacArthur, 2015).
4. The 'R's of circularity: The founding principles of CE are identified as '3R's which are "Reduce, Reuse and Recycle" aiming to overcome environmental challenges (Ghisellini, Cialani and Ulgiati, 2016). An extended framework of '9 R's consider Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover (Kirchherr, Reike and Hekkert, 2017; Foster, 2020) with an order of preference based on the level of circularity as shown in Figure 2, given below.

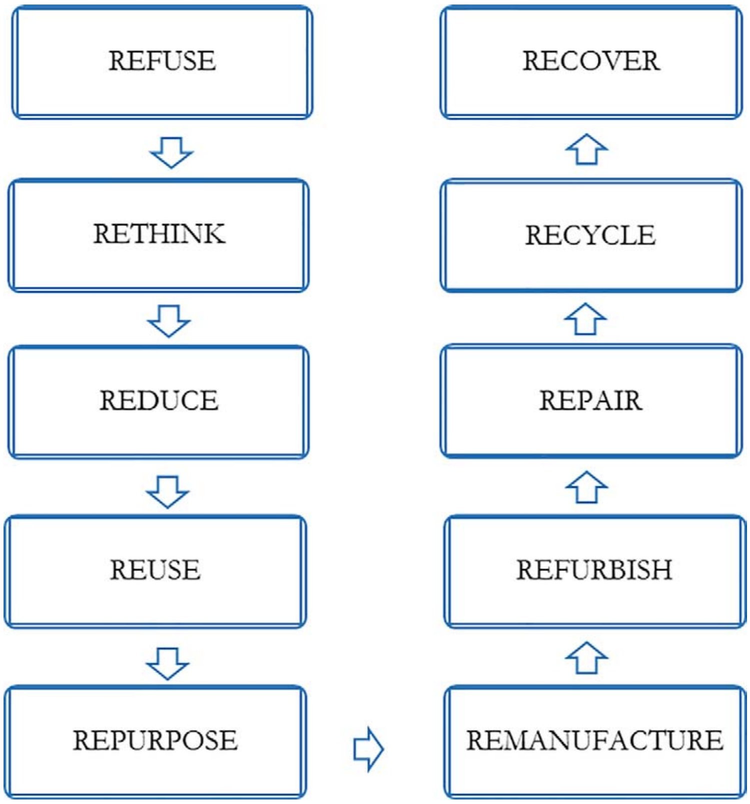

Figure 2. R's of circularity

5. Circular economy strategies: Many strategies were proposed for the implementation of CE in the built environment. '*Design for Disassembly*' (DfD) denotes designing building components that can be disassembled at end of life and used without processing (Geldermans, 2016) whereas '*Design for Adaptability*' (DfA) indicates designing structures that can serve different purposes with slight modification (Cheshire, 2019). '*Design for Deconstruction*' (DfD) enables recovery of building materials for reuse, recycle or remanufacture (Akinade, et al., 2020) while '*Design for Reuse*' (DfR) stands for a design that incorporates the use of recovered materials in new structures (Ginga, et al. 2020). '*Design for Manufacture and Assembly*' (DfMA) suggests making standardised components and then assembling them at the site (Gao, Jin and Lu, 2020).
6. Levels of circular economy: CE can be defined in three different levels, *micro, meso and macro* where micro considers one product or organisation, meso considers a group of industries and macro considers the city or nation, (Elia, Gnoni and Tornese, 2017; Kirchherr, Reike and Hekkert, 2017; Marin and De Meulder, 2018) as depicted in Figure 3, shown below.
7. Shearing Layers of Building: The four-layer system of the building was introduced by Frank Duffy in 1990, based on the expected lifetime of components as 'Shell – the structure with 50 years, Services – electrical and plumbing system having 15 years, Scenery – partitions and ceiling considering 7 years and Set – furniture with a few weeks' of life expectancy. The concept of 'six shearing layers' was proposed by Stewart Brand in 1994, constituting (i) Site – eternal and having no change, (ii) Structure – foundation and load-bearing elements - 50 to 300 years, (iii) Skin – exterior faces of the building - 20 to 50 years, (iv) Services – 10 to 20 years (v) Space – walls, ceiling and floor - 3 to 10 years and (vi) Stuff – furniture which may change weekly or monthly (Pushkar and Shaviv, 2016; Geldermans, 2016; Cheshire, 2019).

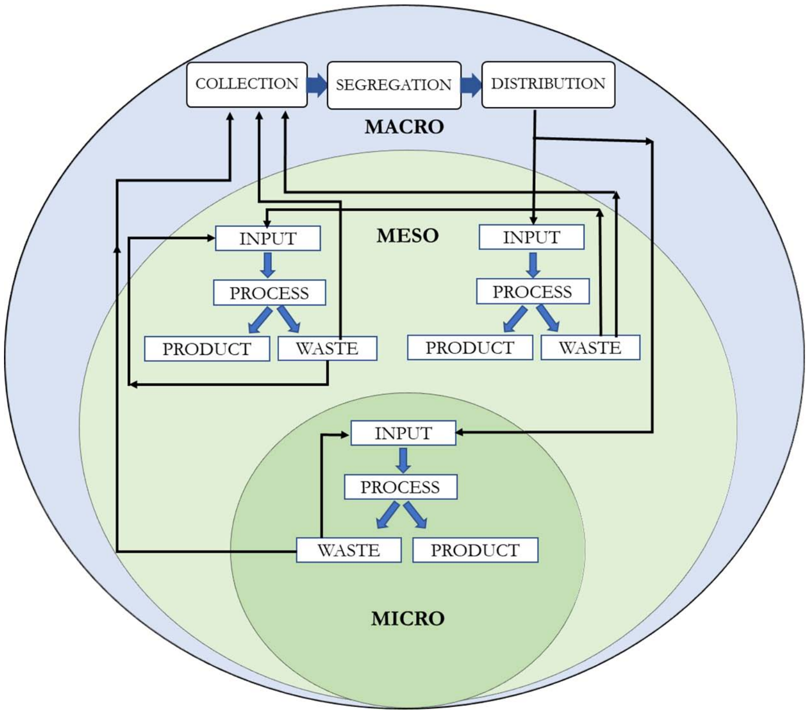

Figure 3. Levels of circular economy

8. Life cycle stages for circular economy in the built environment: CE should be considered in different phases of building, starting from raw materials till demolition and circularity should be observed in *manufacturing of building materials, construction activities, operation, end of life and project design phase* (Akanbi, et al. 2019; Hossain, et al., 2020; Benachio, Freitas and Tavares, 2020).

As described above, even though there is good awareness of CE principles, research on the applicability of CE in the built environment is in its initial stage. However, in the last few years, the literature review shows a steady increase in the number of studies and rising popularity of concepts among practitioners, politicians and academicians (Ghisellini, Cialani and Ulgiati, 2016; Levoso, et al., 2020). The origin of CE can be traced back to theories of environmental economy, ecological economy and industrial ecology, while recent refinement of the concept owes to concepts such as cradle to cradle, regenerative design, biomimicry, performance economy and blue economy (Ghisellini, Cialani and Ulgiati, 2016; Leising, Quist and Bocken, 2018; Benachio, Freitas and Tavares, 2020; Hossain, et al., 2020). The circular model sustains resources in the economy for a longer time by repeatedly using materials in the same form or different forms, thus increasing its value by extending its utility (Cheshire, 2019). The main aspects of CE such as Reduce, Reuse, Repair, Recycle and Renewable resources are not new ideas, but the CE model provides a framework to tackle the major problems of resource scarcity and waste management (Haupt and Zschokke, 2017).

Monitoring tools are required to ensure that CE strategies are environmentally friendly and not just resulting in problem shifting (Mayer, et al., 2019). Life Cycle Analysis (LCA) and Material Flow Analysis (MFA) are methodologies used to measure environmental performances of CE solutions (Pomponi and Moncaster, 2016; Zanni, et al., 2018; Jalaei, Zoghi and Khoshand, 2019; Akanbi, et al., 2018). Overall, the CE monitoring framework shall be classified into two as 'direct CE indicators' that focus on material resources and waste circulating rates and 'indirect CE indicators' that measure subsidiary aspects that help to track CE (Moraga, et al., 2019). Some of the common circularity indicators used in the literature are the Building Circularity Index, CE Indicator, Circularity Performance Indicator, Eco-efficient Value

Ratio, End of Life Recycling Rates, Reuse Potential Indicator and Recycling Index (Finch, et al., 2021). Comprehensively, a CE model should be able to monitor inputs, outputs, resources, production, distribution, consumption, waste management, design and education (Suárez-Eiroa, et al., 2019).

'Economy' of a nation is defined as a system that facilitates the production and distribution of goods and services, controlling the supply chain and consumption pattern in society, consisting of non-government organisations and the government (Schiller, 2011; Fiksel, Sanjay and Raman, 2020). While 'economy' deals with 'what to produce, how to produce and for whom to produce', CE focuses on how to produce without affecting the environment and by maintaining social harmony. CE enables economic growth, reduces ecological footprint, increases community resilience and decreases dependence on raw resources (Fiksel, Sanjay and Raman, 2020). It leads to a regenerative system by imparting self-renewing capabilities as in the case of using renewable energy sources or returning nutrients to the soil (MacArthur, 2013). A regenerative design invokes harmony pattern between the local ecosystem and the built environment, supporting local culture, production and consumption (Mang and Reed, 2012). In CE, materials are reintroduced into the system to replenish itself, incorporating collaboration among actors and making the system regenerative (Cole, 2012). The idea of 'smart cities' supports urban regeneration, which is an indicator of sustainable development that in turn drives social and economic development (Akotia et al., 2020; de Kock and Carta, 2020).

CE in the Construction Industry

CE is a concept that can be worked out in any industry or society, and it works best when different systems join together as a group to form the loop. The construction industry is huge and diverse, having great potential to accommodate circular principles owing to the availability of large quantities of waste and enormous material requirements associated with it (Akanbi, et al., 2019). Waste generated during the construction activities and demolition of structures constitute a major portion of municipal waste and they are separately termed as Construction Demolition Waste (CDW).

Buildings are generally not designed for recycling or material recovery and at present, the most economic method is to demolish buildings and dump the waste in landfills. The building materials remain in the use phase for a long time, and it cannot be assured that they can be recovered at end of life (Finch, et al., 2021). Current manufacturing methods and practices in the construction sector render recycling and reusing non-profitable and this leads to unsustainable landfilling (Fini and Forsythe, 2020). Foreseeing the multi-fold rise in the built area in India, the government introduced CDW management measures in 2016, to tackle the challenge of meeting the material demand and handling the waste in the construction sector (Faruqi and Siddiqui, 2020). The composition of CDW in India is recorded as 25% concrete, 30% masonry bricks, 35% sand and soil, 5% metals, 2% wood and 3% other materials (Kumar, Shrivastava and Gupta, 2020). Concrete is one of the major contributors to carbon footprint, being the structural element in most of the construction projects (Akhtar and Sarmah, 2018). A major part of the negative environmental impacts of the construction sector is attributed to CDW and hence many studies are based on the recycling of CDW and recycled additives in concrete (Jalaei, Zoghi and Khoshand, 2019; Jain, Singhal and Pandey, 2020).

Various aspects of CE are discussed and established through different studies, but there have been limited efforts in understanding the adaptation levels of CE in the built environment domain. Similarly, there are only very few studies that discuss the measurement of CE in the construction sector, especially in the Indian context. The report of Ellen MacArthur Foundation (2016) has identified '*cities and construction*' among the three areas having the highest opportunity for CE in India, along with the agriculture and automobile sectors. Therefore, a transition from a linear to circular economy is a need of the hour, which can be accomplished with the active involvement of different stakeholders. Once there is more public demand the recycling business encompassing the construction industry will flourish. The built environment has a complex structure and consists of different phases involving large quantities of materials and actors. CE strategies applicable to various phases are different, which have been examined separately in the literature. A consolidated picture of CE strategies for different stages of the building is not available.

This study, therefore, attempts to frame an integrated model of CE that is applicable in the built environment, illustrating the strategies complying with the different phases of its life cycle. Similarly, studies reveal that lack of awareness about the CE approach is one of the barriers in shifting towards a circular system (Ghisellini, Ripa and Ulgiati, 2018; Hamid, et al., 2020). Hence it is required to survey the general understanding of CE concepts in the construction industry. The popular quote on management, "what gets measured can be managed" implies that to be able to manage and promote circularity, it should be measured first. A proper indexing system for measuring circularity is lacking in the current situation and a scale is advantageous to decide the CE potential. The basic units of buildings are construction materials and therefore, a new indexing method is developed in this study to monitor circularity in construction materials by compiling multiple attributes of CE.

Methodology

The study identifies various aspects of CE discussed in the literature and aims to have a comprehensive picture of CE strategies relevant to the built environment. A survey on awareness about the CE concept in the construction industry is carried out, which contributes to spreading the knowledge. To facilitate measuring and comparison of construction materials, an index is framed based on certain attributes. Thus, the study is structured into three parts-

i. Framing an integrated model of CE in the built environment:
ii. Development and analysis of Questionnaire survey
iii. Framing Circular Economy Potential Index for Construction materials

AN INTEGRATED MODEL OF CE IN THE BUILT ENVIRONMENT

The construction industry functions in various phases, starting from planning, design, extraction of raw materials, manufacture of components, construction activity, building maintenance and operation, end of life and demolition. Strategies that shall be adopted for the implementation of CE in different phases of construction are represented in a single model. An integrated CE model for the built environment is proposed as shown in Figure 4, given below.

The design phase is most suitable to introduce the shift to circularity in construction because if CE strategies are incorporated in this initial stage, circularity follows in other phases. CE strategies such as Design for Adaptability, Design for Disassembly, Design for Deconstruction, Design for Reuse and Design for Manufacture and Assembly should be incorporated in the design phase (Akinade, et al., 2020; Gao, Jin and Lu, 2020). In the manufacturing phase of construction materials, waste from construction or other industry shall be used as inputs and recycled content and recyclability potential of each material shall be recorded. Strategies such as 'cleaner production', 'pollution prevention', 'avoiding toxic contents' and 'use of renewable energy' shall be adopted in this phase (Ghisellini, Ripa and Ulgiati, 2018). In the construction phase, principles of Refuse, Rethink and Reduce should be considered in the entire construction activities, exploring possibilities for zero-waste and zero-energy construction, optimisation and lean construction techniques (Foster, 2020). Building in Layers allows keeping the layers separate considering their life expectancy (Pushkar and Shaviv, 2016), while proper maintenance aid in extending the life of the building in the operation phase. Here appropriate strategies are Reuse, Repair, Refurbish, Remanufacture and use of renewable energy for lighting and heating (Minunno, et al., 2108). At the end of the useful life of the

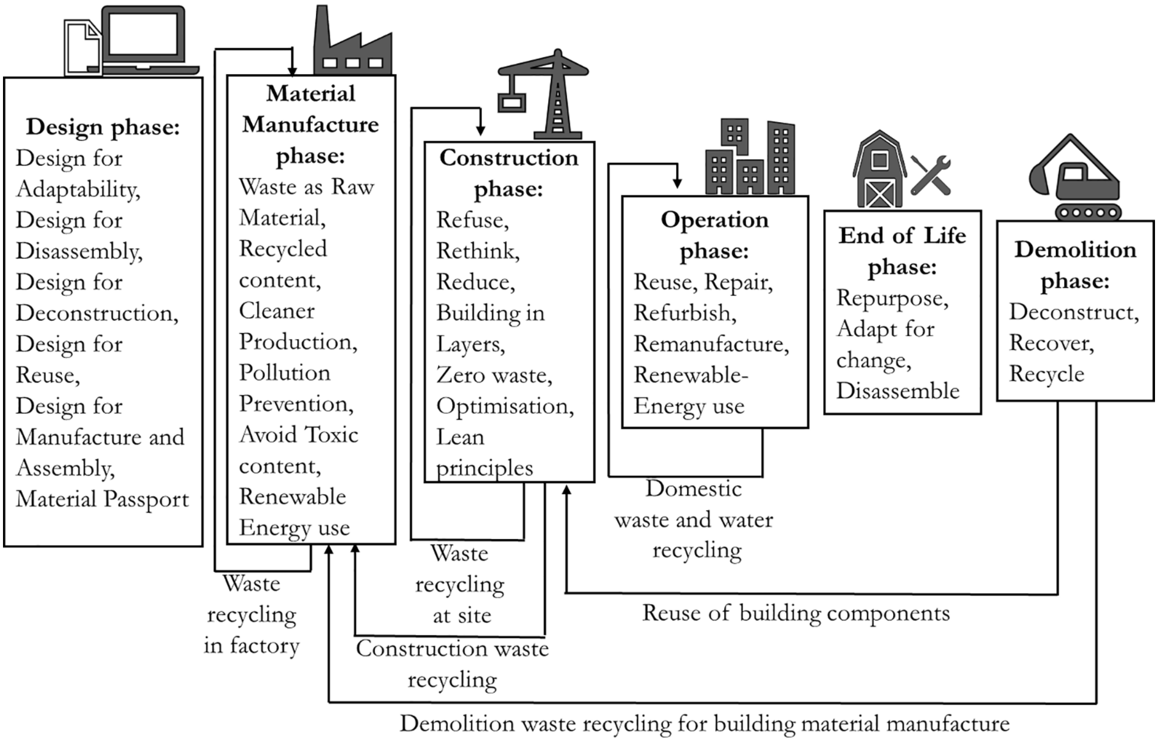

Figure 4. Integrated model for CE in the various life cycle stages of the built environment

building, possibilities for 'repurposing', 'adapting for change' and 'disassembling' should be examined before dismantling (Foster, 2020). In the demolition phase, careful deconstruction and segregation, recovering and recycling of components should be promoted.

QUESTIONNAIRE SURVEY

After developing the integrated framework of CE in the built environment, a questionnaire survey was carried out to capture the awareness of the society about CE concepts and recycling practices in the construction industry. It includes (i) Questionnaire preparation and distribution and (ii) Analysis of the questionnaire responses.

QUESTIONNAIRE PREPARATION AND DISTRIBUTION

The initial step was to develop a questionnaire for collecting data that would provide an insight into general awareness. The questions were framed to provide information on areas where circularity is noticed, materials that are recycled, factors that promote CE and how much each material is recycled. Options were provided for questions with quantitative data and short answers were sought for a few questions. The survey was done through 'Google Forms' and circulated to people working in the construction sector and civil engineering students. An introduction to CE was given at the beginning of the questionnaire for better understanding. Out of the total twenty-five questions, the first five collected personal details including work experience, questions 6 to 15 intended to check the general awareness on CE, questions 16 to 20 gathered quantitative data on recycling of selected materials and questions 21 to 25 were based on principles of CE. The questionnaire is attached as Appendix 1.

ANALYSIS OF THE QUESTIONNAIRE RESPONSES

The response obtained from the survey were analysed for awareness of CE concepts, factors that promote CE, major constraints and promotion of CDW recycling. A total of 102 responses were obtained from people working in the construction field and civil engineering aspirants in India, apart from five responses of Indians working in the UK, UAE and Qatar.

The demography of respondents is shown in Table 1 and the responses obtained are summarised below, in Table 2.

Table 1. Details of respondents

Experience	Percentage of response	No of Respondents
More than 20 years of experience	11%	Managers (21), Estimation Engineers (9), Site Engineers (29), Researchers (15), Civil Engineering students (28)
10-20 years of experience	23%	
2-10 years of experience	22%	
Less than 2 years of experience	44%	

Table 2. Summary of responses

Questions	Responses			
Are you aware of the concept of Circular Economy?	Yes 84%		No 16%	
Do you think the circular economy should be promoted in the construction industry?	Not necessary 0%	If possible 26%	Very much required 65%	If the owner and builder opt for 9%
To what extend is circular economy considered in the construction industry at present?	Not at all 6%	Quite less 64%	Considerably good 18%	No idea 12%
What is the major constraint in practicing circular economy in construction?	Lack of environmental awareness 20%	Lack of technical knowledge 52%	Lack of data about recyclable materials 21%	Increase in cost 7%
Which factor helps in promoting circular economy the most?	Social awareness 28%	Government norms 36%	Certification process 5%	New recycling technology 31%
What factors help to improve the potential of recycling of construction and demolition waste?	Incentives for recycling 38%	New recycling plants 21%	Revision in codes 16%	Change in mindset of society 25%

CIRCULAR ECONOMY POTENTIAL INDEX (CEPI)

Meanwhile, this study proposes a new Circular Economy Potential Index (CEPI) for construction materials using the multi-criteria-decision-making method, SAWM comprising the following steps:

i. Selecting the construction materials for indexing
ii. Fixing the attributes that decide circularity
iii. Assigning points to attributes
iv. Applying Simple Additive Weighting Method for Index

CEPI is developed based on the results of the questionnaire survey which measured the awareness of a selected sample of respondents about the various principles of CE. The below sections talk about the various steps involved in the development of CEPI.

SELECTING THE CONSTRUCTION MATERIALS FOR INDEXING

Among the materials used in the Indian construction industry, the most common and recyclable construction materials were identified as concrete and steel in structure, brick in masonry, wood in doors and windows, aluminium and glass in windows. These selected construction materials are considered as the alternatives for index calculation by SAWM.

FIXING ATTRIBUTES

The dynamic criteria that determine the circularity are referred to as attributes for index calculation. According to the concept of the 'six shearing layers' of a building (Brand, 1994), the recycling potential of materials varies as per the life expectancy of the building layer in which they are used. From the literature, the principles of CE relevant to the construction sector are minimising waste, minimising pollution, extending of the life of products, regenerating natural systems and use of renewable resources. Therefore, the first attribute is the 'building layer' and the second attribute is 'relevance to CE principles'. Two other attributes, based on the questionnaire survey results, are 'recycling percentage' and 'awareness of recyclability'. Thus, four attributes are fixed to develop an index, combining data obtained from literature and questionnaire responses, as shown in Figure 5 below.

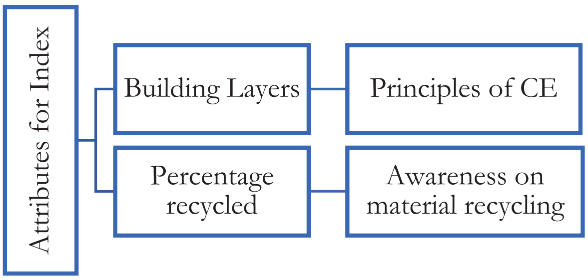

Figure 5. Attributes for CEPI

ASSIGNING POINTS TO ATTRIBUTES

The attributes selected are qualitative and hence for developing the index, points shall be assigned to each of the attributes as mentioned below.

BUILDING LAYERS

Referring to the 'six shearing layers' theory of building, concrete and steel used as structural components are considered under 'structure layer' of building. Brick masonry used in partition walls is considered under 'space layer'. Doors, windows, or façade made of wood, aluminium and glass forms the external 'skin layer' of a building. Materials coming under site, services and stuff layers are not considered in this study. The average life of a building is considered as 100 years and life in years of each layer are structure- 100, space- 30 to 50 and skin- 20 to 30. For material in the space layer having a life of 50 years, there is potential for replacement or recycling twice in the life of the building and similarly for material in the skin layer having a life of 30 years, recycling potential is nearly three times. Points are assigned for materials considering their useful life in comparison with the life of the building as given in Table 3 below.

Table 3. Assigning points based on building layers

Building Material	Layer	Calculation	Points
Concrete – structural members	Structure	100/100	1
Steel – reinforcement	Structure	100/100	1
Bricks - in masonry	Space	100/50	2
Wood – doors and windows	Skin	100/30	3
Aluminium – doors, windows, facade	Skin	100/30	3
Glass - doors, windows, facade	Skin	100/30	3

RELEVANCE TO PRINCIPLES OF CE

Recycling of selected materials is mapped with the relevance to principles of CE, with a score of '1' for mapping and '0' for not mapping. All these materials map completely for minimising waste and pollution when recycled. Extension of the life of products considers whether the material can be reused without any processing at end of life. As concrete and steel reinforcement cannot be reused as such, they score '0' and hence bricks, wooden door frames, shutters, aluminium windows and glass can be segregated carefully and reused, they are assigned a score of '1'. Regenerating natural systems is mapped if the material can return to nature without causing any harm but nourishing the same and hence wood and bricks score '1' while other materials score '0'. Wood is considered renewable in developing nations and hence assigned a score '1'

Table 4. Assigning points based on CE principles

Materials	Minimising waste	Minimising pollution	Extension of life of products by reuse	Regenerating natural systems	Use of renewable resources	Mapping ratio	Point
Concrete	1	1	0	0	0	2/5	0.4
Steel	1	1	0	0	0	2/5	0.4
Bricks	1	1	1	1	0	4/5	0.8
Wood	1	1	1	1	1	5/5	1.0
Aluminium	1	1	1	0	0	3/5	0.6
Glass	1	1	1	0	0	3/5	0.6

while other materials have a score '0'. For each material, the ratio of mapping criteria to the total number of criteria is calculated to derive points as shown in Table 4.

PERCENTAGE RECYCLED

Table 5 below shows the opinion of questionnaire respondents about the recycling percentage of the selected construction materials. For instance, for concrete demolition waste, 34% of the respondents believe that recycling is not possible. Meanwhile, 49% of the respondents believe that about 25% of recycling is possible for concrete demolition waste. The other values in Table 5 follow a similar pattern.

Table 5. Survey Response on the percentage of materials recycled

Construction materials	No recycling	25% recycling	50% recycling	More than 75% of recycling
Concrete demolition waste	34%	49%	13%	4%
Steel reinforcement	36%	38%	19%	7%
Brick/block masonry	27%	48%	22%	3%
Wood in doors and windows	21%	52%	21%	6%
Aluminium and glass in windows and façade	27%	43%	16%	14%

Percentage recycled of these selected materials are used for index calculation after converting it to weighted percentage recycled for each material, as per the equation,

$$\text{Weighted percentage} = \Sigma\, pq \tag{1}$$

where p is the percentage recycled (0, 25, 50 or 75)

and q is the percentage of participants opting for each option as in Table 5.

AWARENESS OF RECYCLABILITY

Survey respondents were asked to mention areas and materials in the construction field where circularity was observed. The ratio of the number of times each of the selected materials was mentioned to the total number of responses is used for index calculation. This ratio shows extend of awareness of the recyclability of the material as given in Table 6.

Table 6. Awareness of recyclability of materials

Material	No. of Responses in favour	No. of response/ total response (102)
Concrete	40	0.39
Steel	39	0.38
Brick	22	0.22
Wood	28	0.27
Aluminium	7	0.07
Glass	16	0.16

SIMPLE ADDITIVE WEIGHTING METHOD FOR INDEXING

A complex system as CE requires a complex decision support system to resolve unstructured issues, thereby enabling integration between various attributes (Nurmalini and Rahim, 2017). Here, the circularity potential of construction materials depends on multiple attributes as mentioned above. Hence selection of material based on circularity potential is considered as a multi-attribute decision-making problem. Mathiyazhagan, Gnanavelbabu and Prabhuraj (2019) proposed an assessment model for selecting sustainable construction materials using hybrid multi-criteria-decision-making (MCDM) tools. There are various MCDM methods, and the Simple Additive Weighting Method (SAWM) is one of the widely used methods (Afshari, Mojahed and Yusuff, 2010). SAWM is based on the weighted summation of each alternative to find a performance rating. A decision matrix (X) is formed with points assigned for the attributes corresponding to each alternative. Subsequently, the decision matrix (X) is normalised to get matrix (R), using the below equation

$$R_{ij} = \frac{Xij}{Max\,(Xij)} \tag{2}$$

Further, the weighted normalised matrix is obtained by multiplying each column by the assigned weight of attributes as $W_j\ r_{ij.}$ Weightage is assigned to the attributes as follows: Shearing layer of the building – 30%, Relevance to principles of CE – 30%, percentage of recycling of material as per survey – 20% and awareness of recyclability of material – 20%.

Finally, Preference Value Matrix (V) is calculated using the equation 3

$$V_i = \Sigma W_j\ r_{ij} \tag{3}$$

Thus, the index value for each selected material is obtained based on the points assigned to attributes for each material. This value forms the Circular Economy Potential Index (CEPI) for that construction material.

Results

Based on the analysis of questionnaire survey results and relevant literature review, an index is developed for evaluating the CE potential of construction materials, using the Simple Additive Weighting Method described above. First, a decision matrix (X) is formed with the selected attributes and the selected materials as the alternatives, as shown in Table 7 below. The points assigned for the attributes are obtained from Table 3, Table 4, weighted percentage calculated by equation 1 and Table 6 respectively.

Table 7. Decision matrix (X)

Attributes	Layers of building	Relevance to Principles	Weighted percentage of % Recycled	No. of response/ total response
Weightage	**0.3**	**0.3**	**0.2**	**0.2**
Concrete	1	0.4	21.53	**0.39**
Steel	1	0.4	24.03	0.38
Brick	2	0.8	25.43	0.22
Wood	**3**	**1**	28.23	0.27
Aluminium	**3**	0.6	**28.9**	0.07
Glass	**3**	0.6	**28.9**	0.16

Further, the decision matrix is normalised to obtain the matrix (R) using equation 2 and is shown in Table 8 below. Normalising the matrix is done by dividing each value in the column by the maximum value in that column.

Table 8. Normalised Matrix (R)

Attributes	Layers of building	Relevance to Principles	Weighted percentage of % Recycled	No. of response/ total response
Weightage	**0.3**	**0.3**	**0.2**	**0.2**
Concrete	0.33	0.40	0.74	1.00
Steel	0.33	0.40	0.83	0.98
Brick	0.67	0.80	0.88	0.55
Wood	1.00	1.00	0.98	0.70
Aluminium	1.00	0.60	1.00	0.18
Glass	1.00	0.60	1.00	0.40

The weighted normalised matrix is further obtained by multiplying each element of the normalised matrix by the assigned weight of the corresponding column as given in Table 9.

Table 9. Weighted Normalised matrix

Attributes	Layers of building	Relevance to Principles	Weighted percentage of % Recycled	No. of response/ total response
Weightage	**0.3**	**0.3**	**0.2**	**0.2**
Concrete	0.10	0.12	0.15	0.20
Steel	0.10	0.12	0.17	0.20
Brick	0.20	0.24	0.18	0.11
Wood	0.30	0.30	0.20	0.14
Aluminium	0.30	0.18	0.20	0.04
Glass	0.30	0.18	0.20	0.08

The Preference Value Matrix (V) is then developed using equation 3 to obtain the index values, which is the sum of elements in a row. This summation of the weighted normalised value of all the attributes is considered as the Circular Economy Potential Index (CEPI) corresponding to each material as shown in Table 10.

Thus, by adopting the SAWM, the Circular Economy Potential Index (CEPI) is estimated for the selected materials – concrete, steel, brick, wood, aluminium and glass.

Discussions

In this study, a novel methodology is proposed to index and rank the materials according to the circular economy potential. As explained in the initial sections, during the disposal stage most of the materials in a building go to landfill. The results from this study can offer better clarity to understand the circular economy

Table 10. Preference Value Matrix

Attributes	Layers of building	Relevance to Principles	Weighted percentage of % Recycled	No. of response/ total response	Circular Economy Potential Index (CEPI)	Rank
Weightage	**0.3**	**0.3**	**0.2**	**0.2**		
Concrete	0.10	0.12	0.15	0.20	**0.57**	6
Steel	0.10	0.12	0.17	0.20	**0.58**	5
Brick	0.20	0.24	0.18	0.11	**0.73**	4
Wood	0.30	0.30	0.20	0.14	**0.94**	1
Aluminium	0.30	0.18	0.20	0.04	**0.72**	3
Glass	0.30	0.18	0.20	0.08	**0.76**	2

potential of various materials from typical buildings and thereby improve the material recycling scenario in the country. The building layers are considered in the study to recognise the fact that different layers have different lifetimes. Certain layers require more frequent refurbishment with new materials indicating that there is more chance of old materials ending up in landfills, hence recyclability of materials used in these layers of building is more important.

For developing the CEPI, attributes considered are qualitative and hence points are assigned to facilitate evaluation, as given in the decision matrix in Table 5. Points are assigned for each material, relative to the life of buildings and the layer in which it is used. For the next attribute, with relevance to CE principles discussed in the literature, materials are assigned points based on their mapping to principles of CE. Attributes concerning awareness of the circularity of construction materials are obtained from analysing the questionnaire survey. Points for percentage recycled of the material are calculated as a weighted percentage given by equation 1. It indicates how likely the material is considered for reuse rather than dumping when a building is demolished. The ratio of respondents favouring each material to the total number of respondents represents acceptance of circularity of that material, based on the survey response to identify areas where circularity is noticed in the construction sector.

Carrying out the SAWM offers relative indexing for the selected materials and attributes thereby enabling comparison. According to the analysis, from Table 8, it can be inferred that circularity potential for the selected materials is in the order – wood, glass, aluminium, brick, steel and concrete. The CEPI value obtained for wood is the maximum, equalling 0.94, which shows its high recyclability and better awareness among people as a recyclable material. Wood is renewable, regenerative and decomposes in soil naturally without causing any harmful environmental effects, hence adheres more to the CE principles. Concrete has the least index value of 0.57, implying that even though there is good potential for recycling, at present concrete is recycled less and forms the major portion to be dumped in landfills. This points to the requirement of enormous processing required for recycling concrete. Concrete and reinforcement steel cannot be reused directly after demolition and hence have a lower score on circularity. Doors and windows made of wood or aluminium and glass are dismantled carefully and could be reused in small projects. Bricks are also separated from demolished masonry for reuse, at many instances. All metals such as steel and aluminium can indeed be recycled by melting the scrap, but it requires a proper system of segregation, collection and processing for efficient recycling. Even if the concrete is considered a sustainable material due to its long life, the possibility of reusing after one life cycle is very limited at present.

The ranking of construction materials based on circularity is not discussed much in earlier literature and the indices proposed are mostly ratios of recycled to virgin product, considering any of the units such as mass, volume, energy, carbon footprint or economic value (Di Maio and Rem, 2015). Single indicators such as resource productivity, waste generation, energy and GHG emissions, pollution reduction and material flow accounting have also been used to analyse CE through previous studies (Elia, Gnoni and Tornese, 2017). Similarly, a collaboration tool for CE in the building sector is developed by Leising, Quist and Bocken (2018) combining literature review and expert interviews based on case studies. These are the efforts that lie close to measuring CE in the built environment but indexing of construction materials using multiple attributes is a novel approach, and the importance of awareness of circularity is established by incorporating it in the index. Thus, developing CEPI based indexing for construction materials helps to quantify the circularity of materials that aid in the material selection.

Conclusions

A transformation to CE is inevitable in all sectors and is most relevant to the construction industry as it solves multiple problems such as resource scarcity and waste management. The construction industry is complex and functions in different phases, where different CE strategies are applicable. The available literature of CE in the built environment is focused on providing more awareness on CE and confined to discussions on how one or a few strategies support CE but does not discuss the relevance to different construction phases. A major output of this study is an integrated model of CE that comprehensively identifies the strategies applicable to the various stages in the construction sector.

A questionnaire survey has been conducted to analyse the awareness of society about the recyclability of construction materials. Based on the results from the survey, the index has been developed for construction materials using the multi-criteria decision-making method, SAWM, by considering the multiple attributes that define the circularity of the material. At present, there are no standard tools to measure the circularity potential of construction materials, barring a few limited efforts. Even though such studies play a critical role in imparting CE-related knowledge to the industry professionals, a proper scale is currently absent to judge the circularity of construction materials, which would serve as an aid for choosing the right material. Therefore, the proposed approach through this study is of much relevance and thereby presents opportunities for further research as well. The study also got few limitations. The study used a survey for analysing the general awareness of CE in the construction sector and the recyclability of building materials and nearly 44% of the respondents had less than two years of experience, including civil engineering students and researchers in this field. One possible impact due to this would be a limited understanding of the percentage of each material recycled in the building demolition stage. However, the survey was primarily intended to capture the general awareness of the society and reflect their view on the possibility of recycling each building material as per their acquired knowledge.

Further, more attributes endorsing CE may be considered for modifying the index, as circularity is an abstract term and a growing research field. In addition, another interesting dimension to explore would be to develop the index for varying stages in a building's life cycle. Overall, CE is a path leading to sustainable development, by increasing the environmental value while improving social welfare by reducing pollution and generating new job opportunities, at the same time contributing to the economy. The promotion of CE is supported by educating about the benefits and possibilities of circularity. The more the awareness of recycling potential for the construction materials, the less is the chance that the material is dumped in landfills after use.

References

Afshari, A., Mojahed, M. and Yusuff, R.M., 2010. Simple additive weighting approach to personnel selection problem. *International Journal of Innovation, Management and Technology*, 1(5), pp.511-15.

Akanbi, L.A., Oyedele, L.O., Akinade, O.O., Ajayi, A.O., Delgado, M.D., Bilal, M. and Bello, S.A., 2018. Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator. *Resources, Conservation and Recycling*, [e-journal] 129, pp.175-86. https://doi.org/10.1016/j.resconrec.2017.10.026

Akanbi, L.A., Oyedele, L.O., Omoteso, K., Bilal, M., Akinade, O.O., Ajayi, A.O., Delgado, J.M.D. and Owolabi, H.A., 2019. Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. *Journal of cleaner production*, [e-journal] 223, pp.386-96. https://doi.org/10.1016/j.jclepro.2019.03.172

Akhtar, A. and Sarmah, A.K., 2018. Construction and demolition waste generation and properties of recycled aggregate concrete: A global perspective. *Journal of Cleaner Production*, [e-journal] 186, pp.262-81. https://doi.org/10.1016/j.jclepro.2018.03.085

Akinade, O., Oyedele, L., Oyedele, A., Davila Delgado, J.M., Bilal, M., Akanbi, L., Ajayi, A. and Owolabi, H., 2020. Design for deconstruction using a circular economy approach: Barriers and strategies for improvement. *Production Planning & Control*, [e-journal] 31(10), pp.829-40. https://doi.org/10.1080/09537287.2019.1695006

Akotia, J., Manu, E., Opoku, A. and Sackey, E., 2020. The role of built environment practitioners in driving the socio-economic sustainability aspects of sustainable regeneration. *Construction Economics and Building*, [e-journal] 20(2), pp.89-108. https://doi.org/10.5130/AJCEB.v20i2.7145

Benachio, G.L.F., Freitas, M.D.C.D. and Tavares, S.F., 2020. Circular economy in the construction industry: A systematic literature review. *Journal of Cleaner Production*, [e-journal] 260, p.121046. https://doi.org/10.1016/j.jclepro.2020.121046

Cheshire, D., 2019. *Building revolutions: Applying the circular economy to the built environment*. London: Riba Publishing. https://doi.org/10.4324/9780429346712

Cole, R.J., 2012. Regenerative design and development: current theory and practice. *Building Research & Information*, [e-journal] 40(1), pp.1-6. https://doi.org/10.1080/09613218.2012.617516

de Kock, P.M. and Carta, S., 2020. Trojans of ambiguity vs resilient regeneration: visual meaning in cities. *Construction Economics and Building*, [e-journal] 20(2), pp.6-24. https://doi.org/10.5130/AJCEB.v20i2.6605

Di Maio, F. and Rem, P.C., 2015. A robust indicator for promoting circular economy through recycling. *Journal of Environmental Protection*, [e-journal] 6(10), p.1095-1104. http://creativecommons.org/licenses/by/4.0/. https://doi.org/10.4236/jep.2015.610096

Elia, V., Gnoni, M.G. and Tornese, F., 2017. Measuring circular economy strategies through index methods: A critical analysis. *Journal of Cleaner Production*, [e-journal] 142, pp.2741-51. https://doi.org/10.1016/j.jclepro.2016.10.196

Ellen MacArthur Foundation, 2013. *Towards the circular economy: Economic and business rationale for an accelerated transition*. Cowes, UK: Ellen MacArthur Foundation.

Ellen MacArthur Foundation, 2015. *Towards a circular economy: Business rationale for an accelerated transition*. Cowes, UK: Ellen MacArthur Foundation.

Ellen MacArthur Foundation, 2016. *Circular Economy in India: Rethinking growth for long-term prosperity*. Cowes, UK: Ellen MacArthur Foundation.

Faruqi, M.H.Z. and Siddiqui, F.Z., 2020. A mini review of construction and demolition waste management in India. Waste Management & Research, [e-journal] 38(7), pp.708-16. https://doi.org/10.1177/0734242X20916828

Fiksel, J., Sanjay, P. and Raman, K., 2020. Steps toward a resilient circular economy in India. *Clean Technologies and Environmental Policy*, [e-journal] pp.1-16. https://doi.org/10.1007/s10098-020-01982-0

Finch, G., Marriage, G., Pelosi, A. and Gjerde, M., 2021. Building envelope systems for the circular economy; Evaluation parameters, current performance and key challenges. *Sustainable Cities and Society*, [e-journal] 64, p.102561. https://doi.org/10.1016/j.scs.2020.102561

Fini, A.A.F. and Forsythe, P., 2020. Barriers to reusing and recycling office fit-out: an exploratory analysis of demolition processes and product features. *Construction Economics and Building*, [e-journal] 20(4), pp.42-62. https://doi.org/10.5130/AJCEB.v20i4.7061

Foster, G., 2020. Circular economy strategies for adaptive reuse of cultural heritage buildings to reduce environmental impacts. *Resources, Conservation and Recycling*, [e-journal] 152, p.104507. https://doi.org/10.1016/j.resconrec.2019.104507

Gao, S., Jin, R. and Lu, W., 2020. Design for manufacture and assembly in construction: a review. *Building Research & Information*, [e-journal] 48(5), pp.538-50. https://doi.org/10.1080/09613218.2019.1660608

Geldermans, R.J., 2016. Design for change and circularity–accommodating circular material & product flows in construction. *Energy Procedia*, [e-journal] 96, pp.301-11. https://doi.org/10.1016/j.egypro.2016.09.153

Ghisellini, P., Cialani, C. and Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner production*, [e-journal] 114, pp.11-32. https://doi.org/10.1016/j.jclepro.2015.09.007

Ghisellini, P., Ripa, M. and Ulgiati, S., 2018. Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *Journal of Cleaner Production*, [e-journal] 178, pp.618-43. https://doi.org/10.1016/j.jclepro.2017.11.207

Ginga, C.P., Ongpeng, J.M.C., Daly, M. and Klarissa, M., 2020. Circular economy on construction and demolition waste: A literature review on material recovery and production. *Materials*, [e-journal] 13(13), p.2970. https://doi.org/10.3390/ma13132970

Govindan, K. and Hasanagic, M., 2018. A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *International Journal of Production Research*, [e-journal] 56(1-2), pp.278-311. https://doi.org/10.1080/00207543.2017.1402141

Haas, W., Krausmann, F., Wiedenhofer, D. and Heinz, M., 2015. How circular is the global economy? An assessment of material flows, waste production, and recycling in the European Union and the world in 2005. *Journal of industrial ecology*, [e-journal] 19(5), pp.765-77. https://doi.org/10.1111/jiec.12244

Hamid, S., Mat Isa, C.M., Felix, S.N. and Mustaffa, N.K., 2020. Sustainable management using recycle and reuse of construction waste materials in Malaysia. *ESTEEM Academic Journal*, [e-journal] 16, pp.47-58. http://ir.uitm.edu.my/id/eprint/33244.

Haupt, M. and Zschokke, M., 2017. How can LCA support the circular economy? —63rd discussion forum on life cycle assessment, Zurich, Switzerland, November 30, 2016. *The International Journal of Life Cycle Assessment*, [e-journal] 22(5), pp.832-37. https://doi.org/10.1007/s11367-017-1267-1

Hossain, M.U., Ng, S.T., Antwi-Afari, P. and Amor, B., 2020. Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. *Renewable and Sustainable Energy Reviews*, [e-journal] 130, p.109948. https://doi.org/10.1016/j.rser.2020.109948

Jain, S., Singhal, S. and Pandey, S., 2020. Environmental life cycle assessment of construction and demolition waste recycling: A case of urban India. *Resources, Conservation and Recycling*, [e-journal] 155, p.104642. https://doi.org/10.1016/j.resconrec.2019.104642

Jalaei, F., Zoghi, M. and Khoshand, A., 2019. Life cycle environmental impact assessment to manage and optimize construction waste using Building Information Modeling (BIM). *International Journal of Construction Management*, [e-journal] pp.1-18. https://doi.org/10.1080/15623599.2019.1583850

Kamble, C.B., Raju, R. and Vishnu, R., 2020. An Awareness Study on Circular Economy in India. *Gedrag and Organisatie Review*, 33(2), pp.2559-69. https://doi.org/10.37896/GOR33.02/259

Kirchherr, J., Reike, D. and Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, conservation and recycling*, [e-journal] 127, pp.221-32. https://doi.org/10.1016/j.resconrec.2017.09.005

Kumar, G., Shrivastava, S. and Gupta, R.C., 2020. Paver blocks manufactured from construction & demolition waste. *Materials Today: Proceedings*, [e-journal] 27, pp.311-17. https://doi.org/10.1016/j.matpr.2019.11.039

Leising, E., Quist, J. and Bocken, N., 2018. Circular Economy in the building sector: Three cases and a collaboration tool. *Journal of Cleaner production*, [e-journal] 176, pp.976-89. https://doi.org/10.1016/j.jclepro.2017.12.010

Levoso, A.S., Gasol, C.M., Martínez-Blanco, J., Durany, X.G., Lehmann, M. and Gaya, R.F., 2020. Methodological framework for the implementation of circular economy in urban systems. *Journal of Cleaner Production*, [e-journal] 248, p.119227. https://doi.org/10.1016/j.jclepro.2019.119227

Mang, P. and Reed, B., 2012. Designing from place: a regenerative framework and methodology. *Building Research & Information*, [e-journal] 40(1), pp.23-38. https://doi.org/10.1080/09613218.2012.621341

Marin, J. and De Meulder, B., 2018. Interpreting circularity. Circular city representations concealing transition drivers. *Sustainability*, [e-journal] 10(5), p.1310. https://doi.org/10.3390/su10051310

Mathiyazhagan, K., Gnanavelbabu, A. and Prabhuraj, B.L., 2019. A sustainable assessment model for material selection in construction industries perspective using hybrid MCDM approaches. *Journal of Advances in Management Research*. [e-journal] 16(2), pp.234-59. https://doi.org/10.1108/JAMR-09-2018-0085

Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P. and Blengini, G.A., 2019. Measuring progress towards a circular economy: a monitoring framework for economy-wide material loop closing in the EU28. *Journal of industrial ecology*, [e-journal] 23(1), pp.62-76. https://doi.org/10.1111/jiec.12809

Minunno, R., O'Grady, T., Morrison, G.M., Gruner, R.L. and Colling, M., 2018. Strategies for applying the circular economy to prefabricated buildings. *Buildings*, [e-journal] 8(9), p.125. https://doi.org/10.3390/buildings8090125

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G.A., Alaerts, L., Van Acker, K., De Meester, S. and Dewulf, J., 2019. Circular economy indicators: What do they measure? *Resources, Conservation and Recycling*, [e-journal] 146, pp.452-61. https://doi.org/10.1016/j.resconrec.2019.03.045

Nuñez-Cacho, P., Górecki, J., Molina-Moreno, V. and Corpas-Iglesias, F.A., 2018. What gets measured, gets done: Development of a circular economy measurement scale for building industry. *Sustainability*, [e-journal] 10(7), p.2340. https://doi.org/10.3390/su10072340

Nurmalini, N. and Rahim, R., 2017. Study Approach of Simple Additive Weighting for Decision Support System. *International Journal of Scientific Research in Science and Technology*, 3(3), pp.541-44. https://doi.org/10.31227/osf.io/8sjvt

Pomponi, F. and Moncaster, A., 2017. Circular economy for the built environment: A research framework. *Journal of cleaner production*, [e-journal] 143, pp.710-18. https://doi.org/10.1016/j.jclepro.2016.12.055

Pushkar, S. and Shaviv, E., 2016. Using shearing layer concept to evaluate green rating systems. *Architectural Science Review*, [e-journal] 59(2), pp.114-25. https://doi.org/10.1080/00038628.2014.966051

Rombach, G., 2013. Raw material supply by aluminium recycling–Efficiency evaluation and long-term availability. *Acta Materialia*, [e-journal] 61(3), pp.1012-20. https://doi.org/10.1016/j.actamat.2012.08.064

Schiller, B.R., 2011. *The macro economy today*. New York: Tata McGraw-Hill Education.

Seyis, S., 2020. Mixed method review for integrating building information modeling and life-cycle assessments. *Building and Environment*, [e-journal] 173, p.106703. https://doi.org/10.1016/j.buildenv.2020.106703

Stephan, A. and Athanassiadis, A., 2018. Towards a more circular construction sector: Estimating and spatialising current and future non-structural material replacement flows to maintain urban building stocks. *Resources, Conservation and Recycling*, [e-journal] 129, pp.248-62. https://doi.org/10.1016/j.resconrec.2017.09.022

Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G. and Soto-Oñate, D., 2019. Operational principles of circular economy for sustainable development: Linking theory and practice. *Journal of cleaner production*, [e-journal] 214, pp.952-61. https://doi.org/10.1016/j.jclepro.2018.12.271

Zanni, S., Simion, I.M., Gavrilescu, M. and Bonoli, A., 2018. Life cycle assessment applied to circular designed construction materials. *Procedia CIRP*, [e-journal] 69, pp.154-159. https://doi.org/10.1016/j.procir.2017.11.040

Appendix-1

QUESTIONNAIRE ON CIRCULAR ECONOMY (REUSING AND RECYCLING)

A circular economy is an economic model designed to minimize resource input, as well as waste and emission production. Circular economy aims to reach the maximum efficiency in the use of finite resources, the gradual transition to renewable resources, and recovery of the materials and products at the end of their useful life. It is based on three principles: reduce waste and pollution; keep products and materials in use; regenerate natural systems. Main idea is to recover waste for reuse or recycling and creating a system to team up.

Kindly fill up this questionnaire based on your knowledge/experience on circular economy in construction industry.

*Required

1. Email * ______________________
2. Name * ______________________
3. Country ______________________
4. Occupation ______________________
5. Organisation ______________________
6. Work Experience ______________________

   Mark only one oval.

   less than 2 years ◯
   2 – 10 years ◯
   10 - 20 years ◯
   more than 20 years ◯

7. Are you aware of the concept of Circular Economy? *

   Mark only one oval.

   Yes ◯
   No ◯

8. Do you think circular economy should be promoted in construction industry? *

   Mark only one oval.

   not necessary ◯
   if possible ◯

very much required
only if owner and builder opt for it

9. To what extend is circular economy considered in construction industry at present?

Mark only one oval.

not at all
quite less
considerably good
no idea

10. Identify areas where you have noticed circularity in construction field. (Any three) *

___

11. What are the materials having possibility of recycling in buildings? (Any three) *

___

12. What is the major constraint in practicing circular economy in construction? *

Mark only one oval.

Lack of environmental awareness
Lack of technical knowledge of recycling process
Lack of data about recyclable materials
Increase in cost

13. Which factor helps in promoting circular economy the most? *

Mark only one oval.

Social awareness
Government norms
Certification process
New recycling technology

14. Do you think certifications such as GRIHA and LEED gives enough weightage forcircularity for its promotion? *

Mark only one oval.

Yes they provide required weightage
Weightage needs to be increased

15. What factors may help to improve the potential of recycling of construction anddemolition waste?*

Mark only one oval.

Incentives for recycling
New recycling plants
Revision in codes supported by research
Change in mindset of society

16. What is the percentage of concrete demolition waste recycled in your area, toavoid going to landfill *

    Mark only one oval.

    0% ◯
    25% ◯
    50% ◯
    more than 75% ◯

17. What is the percentage of wooden doors and windows recycled in your area, toavoid going to landfill *

    Mark only one oval.

    0% ◯
    25% ◯
    50% ◯
    More than 75% ◯

18. What is the percentage of aluminium and glass in windows and façade recycled inyour area, to avoid going to landfill *

    Mark only one oval.

    0% ◯
    25% ◯
    50% ◯
    more than 75% ◯

19. What is the percentage of recycled content in masonry units used in your area *

    Mark only one oval.

    0% ◯
    25% ◯
    50% ◯
    more than 75% ◯

20. What is the percentage of steel recycled in your area *

    Mark only one oval.

    0% ◯
    25% ◯
    50% ◯
    more than 75% ◯

21. Your suggestions for improving circularity in construction field by reusing *

22. Any one suggestion for minimizing waste in construction industry *

23. Any one suggestion for minimizing pollution in construction industry *

24. Any one suggestion for extension of life of construction materials or products *

25. Any one example of use of renewable resources in construction industry *

26. Any one condition that would help in regeneration of natural systems -i.e., reusingwaste from one system as input for other industry.*

Thank you

Thank you very much for sparing your valuable time and putting efforts for reporting the circular economy practices in your area or project