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CIRCULAR ECONOMY (CE) BASED MATERIAL SELECTION: DEVELOPMENT OF A CE-BASED '10R' EVALUATION FRAMEWORK FOR BUILDING CONSTRUCTION PROJECTS IN SRI LANKA

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ABSTRACT

The building construction industry is globally identified as one of the major consumers of materials. Thus, the material wastage in building construction projects is very excessive. In the Sri Lankan construction industry, it was identified that the main reason for generating material wastage is the absence of proper material selection criteria. The concept of Circular Economy (CE) has been obtained the world attention in reducing material wastage in the construction industry as it targets zero waste and pollution throughout the lifecycle of materials. Applying CE principles in the material selection not only reduces the wastage of materials but also reduces the use of virgin materials. Hence, this research aimed for developing a CE-based 10R evaluation framework for materials selection in order to reduce the wastage of materials in building construction projects in Sri Lanka. A comprehensive literature review was first conducted to review the concept of CE, CE principles and its importance for reducing material wastage in the construction industry. Deductive approach was chosen as the suitable research approach in this study. Survey method was applied as the suitable research strategy under quantitative phenomenon. A questionnaire survey was conducted with a conveniently selected sample of 58 industry professionals to collect the data. The collected data were analysed by using Weighted Mean Average (WMA) technique. As key findings derived through analysis, the level of importance of each CE principle for selection of materials was determined. Accordingly, the CE-based 10R evaluation framework for material selection was developed as the main implication of this research. Various strategies, such as reusing demolition materials, adopting prefabricated building components, developing plans to on-site recycle and using alternative materials were also proposed to implement the all identified CE principles assuring a successful application of the developed framework.

Keywords: *Building Construction; Circular Economy Principles; Evaluation Framework; Material Selection; Sri Lanka.*

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1. INTRODUCTION

Construction waste has been identified as a major dilemma in the construction industry as one of the largest worldwide waste streams (Spišáková, et al., 2021). It has emerged as a tremendous environmental issue in both economically developed and developing countries (Mohammed, et al., 2022). As stated by Ekanayake and Ofori (2004), construction waste includes any material that is used on the construction site itself for filling, recycling, reusing, incinerating, or composting land rather than the project's intended specific purpose except earth material.

Improper material selection is one of the main factors contributing to construction material wastage (Ayegba, 2013). Further to the author, the selection of suitable material is critical in completing projects on time, on budget, and at the intended quality and to minimise construction wastage. Also, an efficient and effective waste minimisation strategy for a construction project is a vital component of sustainable building design. Therefore, it is essential to select the appropriate and sustainable construction materials by adopting innovative approaches (Song and Zhang, 2018). Many approaches and concepts have been introduced by experts for minimising waste generation during construction. Among all these concepts "Circular Economy" (CE) has been received an increasing attention as it promotes the most efficient reuse and recycling of resources, goods, and components to minimise waste formation. CE can be applied as a sustainable approach for material selection as it generates various benefits, such as minimising cost overruns, improving the overall life cycle cost-benefit of the project and improving the sustainability of the project. Thus, considering the concept of CE in selection of construction materials is vital to consider.

Accordingly, this research aimed to develop a CE-based 10R evaluation framework for material selection in order to reduce the wastage of materials in building construction projects in Sri Lanka. This paper is mainly focused on answering two (02) research questions as follows;

1. What is the level of importance of CE principles on material selection of building construction projects in Sri Lanka?
2. What are the strategies to implement the identified CE principles for reducing the material wastage of building construction projects in Sri Lanka?

2. LITERATURE REVIEW

2.1 SOURCES OF CONSTRUCTION MATERIAL WASTAGE

For a better material waste management strategy, it is important to identify the reasons behind the generation of waste. According to previous research, construction material waste can appear from the establishment of the project to the end of its life cycle (Nagapan, et al., 2012). Table 1 summarises the sources of construction material wastage identified by reviewing 05 key research papers.

As shown in Table 1, human errors (lack of supervision, poor workmanship, etc.) and wrong selection of materials can be identified as the major sources of material wastage in the construction industry. Hence, the material selection was considered in this research for adopting the CE principles for reducing the wastage of materials in building construction projects in Sri Lanka.

Table 1: Sources of construction material wastage

Sources of material wastage	Source of Reference					%
	R1	R2	R3	R4	R5	
Human errors (lack of supervision and poor workmanship etc.)	X	X	X	X	X	100%
Poor delivery of materials	X	X	X	-	X	80%
Poor storage methods	X	X	-	-	X	60%
Carrying out material manually or by wheelbarrows	-	X	-	-		20%
Not following a proper material reconciliation system / unavailability of the right quantities ordered and on-site	X	X	-	-		40%
Design modifications during the construction stage	X	-	X	X		60%
Site errors	X	-	-	-		20%
Wrong or improper selection of materials	X	X	X	X	X	100%
Lack of attention in dimensional coordination	-	-	-	X		20%
Cutting materials in different sizes and uneconomical shapes	X	-	-	-	X	40%
The residue (Paint, mortar, plastic)	-	-	-	-	X	20%
Dropped, spoiled, or discarded materials during the transportation (Ceramic tiles, roofing tiles, Bricks, Blocks)	X	-	-	-	X	40%

Reference: [R1] Sweis, et al., 2021; [R2] Manewa, et al., 2007; [R3] Liyanage, et al., 2019; [R4] Kulatunga, et al., 2005; [R5] Rameezdeen, et al., 2004

2.2 IMPORTANCE OF CIRCULAR ECONOMY FOR CONSTRUCTION MATERIAL SELECTION

As stated by Gardetti (2019), implementing the CE concept is a need rather than an alternative nowadays. According to Adi and Wibowo (2020), implementing a CE strategy will reduce waste by 30% of the total trash produced by 2025. Further to the authors, CE is a better choice for reducing the quantity of waste produced in the building industry (Adi and Wibowo, 2020). Some of the key benefits for materials exposed by CE are higher material recycling, increased product re-use, and repair, increased material production, more robust long-lasting goods, maximise material recovery, avoiding unnecessary waste, promotes using sustainable materials, avoiding landfills, reducing the end life of materials, minimizes depletion of scarce materials, reduces environmental damage by minimising waste, reduces valuable material losses, increases raw material efficiency, reduces the extraction of virgin raw materials, limit material costs and project cost overruns (McCarthy, et al., 2018; Ekins, et al., 2019; Liyanage, et al., 2019).

CE principles are mainly based on the 3R methodology (Reduce, Reuse, Recycle) which is derived from waste management principles (Han, et al., 2017). Furthermore, this has been developed as a 6R methodology for products over multiple life cycles, such as construction materials. 6R methodology includes Reduce, Remanufacture, Reuse, Recover, Recycle and Redesign (Jawahir and Bradley, 2016). A recent research study carried out by Munaro et al. (2020), introduced that CE principles are mainly based on the concept of Design, Reduce, Reuse, Recycle, Reclassification, and Renew according to findings of past research studies on CE principles.

However, Potting, et al., (2017) proposed a conceptual CE framework that consists of 10 principles. Although there are 10 principles, the framework is titled as "9R framework." It is the only framework that has been established with a large number of "R" principles in the existing literature, namely Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover.

By reviewing key literature on various CE methodologies and frameworks developed by the research scholars, 10 CE principles namely Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover were identified, which were considered in developing the CE based 10R evaluation framework in this research (refer to Section 4).

2.3 MATERIAL WASTAGE IN THE SRI LANKAN CONSTRUCTION INDUSTRY

Jayawardane (1992) stated that material wastage in the Sri Lankan construction industry has exceeded its limit. According to the research study carried out by Rameezdeen, et al. (2004), material wastage in the Sri Lankan construction industry is around 25% of sand, 20%of lime, 14% of cement, 14% of bricks, 10% of ceramic tiles, 10% of timber (formwork), 7% of rubble, 7% of reinforcement (steel), 6% of cement block, 5% of paint, and 3% of asbestos sheets. They found out that in Sri Lanka approximately 38% of construction firms do not have any policies on waste and there are very few recycling contractors. According to Liyanage, et al. (2019), with the standards, such as International Standard Organisation - ISO 9001, and ISO 14001 material wastage is being controlled in Sri Lankan construction sites. Further, Liyanage, et al. (2019) stated that generated waste in Sri Lankan construction projects is either distributed to recyclers or most of the time waste is dumped into landfills. Many past researchers have come up with strategies that influence the Sri Lankan construction industry towards the concept of CE in the selection of materials, such as promoting sustainable, eco-labelled, green materials, procuring materials from green-certified suppliers, pre-planning the places to use materials, double-checking quantities before ordering materials and using renewable materials rather than using non-renewable materials, to name a few (Athapaththu and Karunasena, 2016; Liyanage, et al., 2019; Wijewansha, et al., 2021). However, there is no proper method introduced for selecting suitable construction materials based on the concept of CE for building construction projects in Sri Lanka. Accordingly, the importance of 10R principles for material selection of building construction projects was evaluated to develop a CE-based 10R evaluation framework.

3. RESEARCH METHODOLOGY

In this study, no new theories were built up using the data that were collected and identified CE principles through the comprehensive literature review were tested. Therefore, deductive approach was chosen as the suitable research approach in this study. To rank the level of importance of each CE principle for the selection of building materials, statistical numeric data were gathered. Furthermore, the data were gathered through predetermined questions and the findings were shown in numbers and graphs. Therefore, the quantitative approach was followed to scale the research to provide larger sets of data for reliability and validity.

A questionnaire survey was carried out to evaluate the level of importance of CE principles for developing a CE-based evaluation framework for material selection of building construction projects in Sri Lanka. Based on the 10R principles introduced by Potting, et al. (2017), the questionnaire was prepared. The questionnaire contained 4 sections. The first section was a brief introduction to this research study and the confidentiality of the data provided by the participants. Second section collected the respondent's demographical data such as their profession and their years of experience in the construction industry. Respondent's contextual data were gathered from the third and fourth questions. The third section gathered respondents' awareness of CE and measured the level of importance of each 9R CE principle for material selection in building construction projects in Sri Lanka to reduce material wastage. This question was prepared using the Likert scale where the respondents were asked to rate the importance of CE principles for minimising material wastage in building construction projects in Sri Lanka within the scale ranging from 1 to 5. (1=Very Low, 2=Low, 3=Moderate, 4=High, 5=Very High). The fourth section gathered the strategies proposed by survey respondents to implement CE principles in the material selection of building construction projects in Sri Lanka.

The construction professionals who are having knowledge and experience 05 years of experience in the fields of material selection, CE and waste management were identified as the targeted population for distributing the questionnaire. Creswell (2014) stated that an appropriate research sample is important to reflect the entire population. The non-probability, convenient sampling technique was adopted in this research. Rather than picking randomly from the entire population throughout the given period, this by considering the recruitment of a set of individuals who were easily available, 58 construction professionals were selected by using non-probability convenience sampling technique. An online survey was conducted by using Google forms. The questionnaire was distributed to 58 industry professionals and 37 responses were received in return. Table 2 shows the response rate which reflects the percentage of the number of responses received against the number of questionnaires distributed.

Table 2: Response rate of the questionnaire survey

Category	Distributed Questionnaires	Number of respondents returned	Response rate
Project manager	3	2	67%
Engineer	21	16	76%
Quantity surveyor	19	13	68%
Architect	9	3	33%
Contractor	4	1	25%
Material supplier	1	1	100%
Total	**58**	**37**	**64%**

As stated by Richardson (2005 as cited Nulty, 2008) response rate of 50% is regarded as an acceptable response rate in social research surveys. As stated in table 2, the response rate of the questionnaire survey was 64%.

The data collected from the respondents through the questionnaire survey were evaluated using the Weighted Mean Average to rank the importance of CE principles for minimizing material wastage in building construction projects in Sri Lanka. Weighted Mean Average (WMA) was calculated as per the formula shown in Eq. 01:

$$W = \frac{\sum_{i=1}^{n} wiXi}{\sum_{i=1}^{n} wi} \qquad (Eq. 01)$$

Where, Σ = summation, w = the weights (Number of respondents), x = the value (1 to 5).

Data analysis and key research findings are presented below.

4. DATA ANALYSIS AND FINDINGS

This section presents the key findings on the importance of CE principles in material selection, which were derived through data analysis. The proposed CE-based 10R evaluation framework is also presented. Finally, various strategies were proposed to implement CE principles in the material selection of building construction projects in Sri Lanka.

4.1 ASSESSMENT OF THE LEVEL OF IMPORTANCE OF CE PRINCIPLES

Table 3 shows the results of the data analysis, which represents the CE 10R principles, ranked as per the level of importance of each CE principle in terms of material selection in building construction projects in Sri Lanka.

Table 3: Importance of CE principles for material selection

CE principle	WMA	Rank
Reuse	3.78	1
Reduce	3.76	2
Recycle	3.65	3
Recover	3.57	4
Refuse	3.38	5
Repair	3.35	6
Refurbish	3.30	7
Rethink	3.24	8
Remanufacture	3.22	9
Repurpose	3.14	10

Accordingly, the most important CE principle in terms of minimising material wastage in building construction projects in Sri Lanka can be identified as "Reuse" (WMA=3.78). The 2nd and 3rd most important CE principle is "Reduce" (WMA=3.76) and "Recycle" (WMA=3.65) respectively. The main 3R CE principles have been identified as the most important principles in the results. Furthermore, according to the results derived through analysis, Reuse (WMA=3.78), Reduce (WMA=3.76), Recycle (WMA=3.65) and Recover (WMA=3.57) principles have obtained WMA around 4. Other CE principles such as Refuse (WMA=3.38), Repair (WMA=3.35), Refurbish (WMA=3.30), Rethink (WMA=3.24) & Remanufacture (WMA=3.22) have obtained mean weighing around 3. Repurpose (WMA=3.14) can be identified as the least important CE principle according to the results.

The importance of CE principles through the questionnaire survey was compared with the data found in the literature review to improve the reliability and validity of the findings as shown in Figure 1. According to Figure 1, it is obvious that the priority order for material selection in building construction projects in Sri Lanka has deviated from the priority order introduced by Potting, et al. (2017), in the product chain.

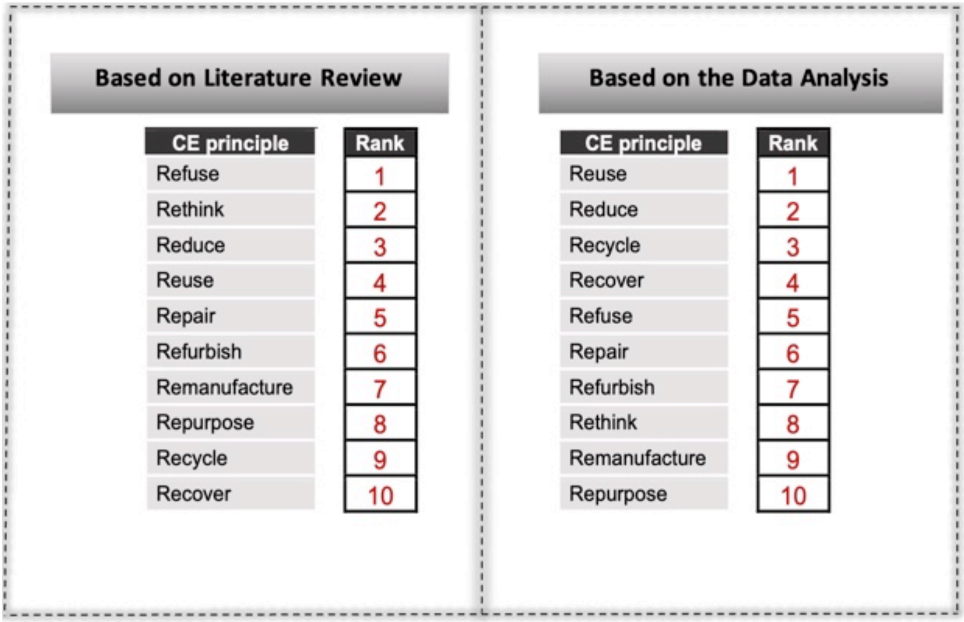

Figure 1: Comparison of CE principles - Literature review vs. data analysis

In the literature review "Refuse" has been identified as the most important CE principle in the product chains followed by "Rethink", "Reduce" and "Reuse". However, the data analysis derived "Reuse" as the most important CE principle for material selection of building construction projects in Sri Lanka. It is further proved by many survey respondents that materials with high reusability provide the maximum benefits of the existing materials rather than going for new material. Further, in the literature review "Recover" was identified as the least important CE principle. However, according to the data analysis "Repurpose" has become the least important CE principle due to a lack of technological advancement relating to the repurpose strategy in the Sri Lankan context.

4.2 THE PROPOSED CE-BASED 10R EVALUATION FRAMEWORK FOR MATERIAL SELECTION OF BUILDING CONSTRUCTION PROJECTS IN SRI LANKA

As derived through analysis, the importance of each CE principle was considered to develop a CE-based 10R evaluation framework for material selection of building construction projects in Sri Lanka. Table 4 provides the importance of each CE principle as a percentage by converting the WMA into percentages.

Table 4: Calculation of the level of importance of CE principles (%)

CE Principle	WMA	Percentage (%)
Reuse	3.78	11.00
Reduce	3.76	10.93
Recycle	3.65	10.61

CE Principle	WMA	Percentage (%)
Recover	3.57	10.38
Refuse	3.38	9.83
Repair	3.35	9.75
Refurbish	3.30	9.59
Rethink	3.24	9.43
Remanufacture	3.22	9.36
Repurpose	3.14	9.12
Total		**100**

Accordingly, various strategies were proposed to implement the CE principles for material selection of building construction projects in Sri Lanka as presented below.

4.3 PROPOSED STRATEGIES TO IMPLEMENT CE PRINCIPLES FOR REDUCING THE MATERIAL WASTAGE

The survey respondents were asked to propose strategies to implement CE principles in the material selection of building construction projects in Sri Lanka, which can be used to assure the practical implementation of the CE principles. The proposed strategies are summarised in Table 5.

Table 5: Proposed strategies to implement CE principles

Rank	CE principle	Proposed strategies
1	Reuse	Getting the maximum outcome from existing materials Reusing demolition & surplus materials
		Reusing materials as secondary masonry
		Choosing materials with high reusability and durability
		Considering reusable steel shuttering materials
2	Reduce	On-site sorting and proper storing of materials
		Adopting prefabricated building components
		Accurately calculating and ordering right quantity
		Using material control & material management
		Proper dimensional coordination
		Using alternative construction methods
3	Recycle	Developing plans to on-site recycle
		Recycling materials for possible reuse (timber etc)
		Using standards such as ISO 9001, and ISO 14001
		Choosing materials with high recyclable content
		Separating waste for an efficient and effective results
4	Recover	Using wood for fossil fuel
		Retrieving energy from non-recyclable materials by incineration
5	Refuse	Avoiding selection of less quality materials
		Refusing hazardous materials such as asbestos
		Using alternative materials
		Avoiding use of virgin material as much as possible

Rank	CE principle	Proposed strategies
		Using multiple functional materials
6	Repair	Maintaining detailed specifications of materials
		Initiating a proper maintenance management plan
		Increasing existing material's lifetime
7	Refurbish	Using old building materials as recycled materials
		Renovating and redecorating the existing materials
		Using refurbished materials such as aluminium
		Renovating old building materials to use for new functions
8	Rethink	Using sustainable, eco labelled, green materials
		Considering standardisation & modularisation
		Checking fit for purpose of materials for intended materials
		Substituting recycled materials for raw materials
		Sharing by-products with other industries
		Using renewable materials rather than using non-renewable
9	Remanufacture	Metal & steel recycling in the iron factory
		Producing more robust long-lived products through design
		Manufacturing with recovered material
10	Repurpose	Using construction material waste to produce another product
		Constructing green buildings
		Using demolished material waste for decorating garden
		Selecting materials with multiple purposes
		Using by-products results in the construction process where it's possible

As the key implication of this research, the CE-based 10R evaluation framework for material selection of building construction projects in Sri Lanka was developed as shown in Figure 2.

The level of importance of each CE principle in the material selection is shown in the proposed framework. As shown in Figure 2, the proposed evaluation facilitates a clear indication about the level of adoption of CE principles for material selection in building construction projects in Sri Lanka. Further, this developed indicator and proposed strategies will be beneficial to the industry stakeholders for sustaining their material selection process in building construction projects. By adopting this proposed 10R evaluation indicator and the proposed strategies, the reduction of construction material waste can be optimised. Accordingly, industry stakeholders can identify what are the most important CE principles in the material selection and compare them and call for actions respective parties, such as Design Engineers, Quantity Surveyors, etc. who are involved in material selection process in order to achieve zero material wastage. The proposed framework and strategies can be used as a basis to evaluate the present status of the material selection of building construction projects in order to adopt CE principles for reducing wastage of materials through circularity.

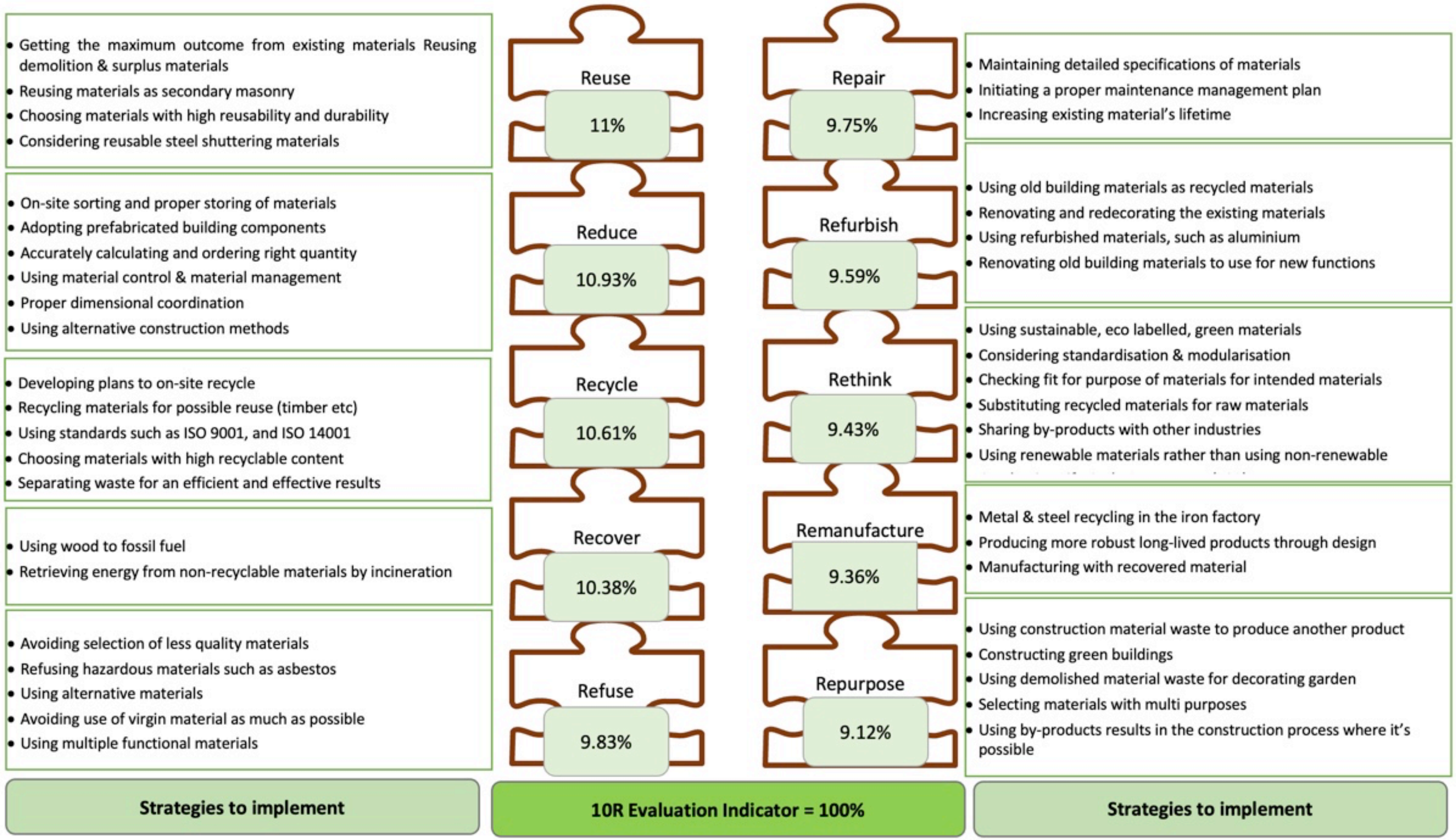

Figure 2: CE-based 10R evaluation framework proposed

5. CONCLUSIONS

In the Sri Lankan construction industry, one of the main reasons behind generating more and more construction material wastage is the absence of proper material selection criteria. To develop a proper material selection criterion, it is necessary to identify the rising concepts and techniques available globally. The zero-waste concept, in other words, the concept of CE has been received increasing attention due to its surprising performances within many industries. The CE principles which can also be identified as the core of the concept of CE, have been applied by past researchers to develop various CE frameworks. According to existing literature, there are only a very few research studies that have been conducted on the application of CE principles in the selection of construction materials, especially in the context of Sri Lanka. Therefore, this paper proposed a CE-based 10R evaluation framework for building construction projects in Sri Lanka. According to the research findings, 'Reuse', 'Reduce' and 'Recycling' are the three most important CE principles while 'Repurpose' is the least important CE principle to be considered in material selection in the Sri Lankan construction industry. Finally, the framework is proposed embedding the 10R evaluation indicator as well as the probable strategies to implement each CE Principle.

This research thus provides new insights and tackles the unexplored areas in material selection in terms of the concept of CE. Also, this research will help construction industry practitioners to realise the significance of reducing construction material wastage by adopting CE principles for material selection of building construction projects. However, this research limited to the adoption of CE principles for material selection of building construction projects in the context of Sri Lanka thus, the developed framework can be generalised to building construction projects with similar industrial settings. Also, the developed framework along with the proposed strategies can be used to make decisions towards zero waste and minimum environmental impacts of material selection in construction projects by focusing on CE. Further, research outcomes can be used by academics and industry professionals as a way forward for future researches in order to further investigate the application of CE principles for material selection by expanding the research to different contexts.

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