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MINIMISING CONSTRUCTION AND DEMOLITION WASTE USING CIRCULAR ECONOMY CONCEPT TO ACHIEVE SUSTAINABLE URBAN DEVELOPMENT

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ABSTRACT

Urban development significantly increased construction activities, which led to the generation of Construction and Demolition Waste (CDW) and inefficient resource exploitation. Most of these CDWs end up in landfills, and most countries give little attention to sustainable practices in this area. "Circular Economy" (CE) is one of the best ways to reduce CDW and the use of resources. Even though CE is not a new idea, it is not fully used to reduce CDW because the construction industry is still based on a linear economy and building materials are designed to be used linearly. Hence, this paper aims to investigate how CE can contribute to minimising the CDW to achieve sustainable urban development. This study adopts a qualitative approach to examine the strategies used to minimise the CDW in Sri Lanka. Multiple holistic case studies with three large-scale construction projects in the Colombo district were selected, and semi-structured interviews were used to get first-hand information. Manual content analysis was used for data analysis. Findings noted that disposal is unavoidable for all 14 CDW types, and e-waste was counted as the 15th type. The 3Rs (reduce, reuse, and recycle) of CE are quite popular among the projects, and the other 8Rs of Cimen (2021) of the CE concept are challenging to put into practice. To increase the knowledge and application of CE principles among built environment experts, this research provides recommendations based on a desk study by gathering case studies from secondary sources where CE principles are extensively applied for CDW minimisation.

Keywords: *Circular Economy (CE); Construction and Demolition Waste (CDW); Sri Lanka; Sustainability; Urban Development.*

1. INTRODUCTION

Every day, thousands of migrants arrive in urban areas all over the world to gain opportunities for a better life (Zhang, 2015). Fifty-five percent (55%) of the world's population lives in cities right now and globally, more than two-thirds of the population will probably reside in cities by 2050 (United Nations, 2014). It has to do with changes in lifestyle, more use of natural resources, higher demand for energy, and the commercialisation of urban life (Iossifova, 2012). Urban population and urban

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development (construction industry) both are interlinked with one another (Chen, et al., 2013). Globally, the construction industry is one of the most important sectors in urban development because it consumes a high volume of natural resources and energy, produces a large amount of waste, and contributes significant amounts of toxic air emissions, thus potentially playing a key role in sustainability (Wang (2014). Moreover, massive urbanisation has boosted infinite construction, and construction and demolition waste (CDW). Which has resulted in nasty and fatal impacts on urban sustainability and survival in terms of economic values and environmental safety (Aslam, et al., 2020). Further, Aslam et al. (2020) state that urbanisation is one of the prime factors, which influenced CDW generation and Nitivattananon and Borongan (2007) mentioned that parallel to rapid urbanisation, environmental impacts from CDW increasingly become a major issue in urban waste management. Similarly, the CDW is inevitable and needs to be managed during the urban development (Dong, et al., 2019; Wu, et al., 2017). Further, CDW had several negative effects on the environment, such as land degradation, carbon and greenhouse gas emissions, landfill and resource depletion, water pollution, and high energy consumption (Akanbi, et al., 2018). In other words, the minimisation of CDW can have multiple long-term benefits including waste minimisation, cost-saving, spreading out existing landfills, safety, and support of a sustainable environment and economy (Shen, et al., 2004).

The Circular Economy (CE) concept is one of the considerable solutions to minimise CDW, as it would reduce environmental impacts while contributing to economic growth (Lieder & Rashid, 2016; United Nations, 2021). It constitutes a novel regenerative system to optimise the use of materials and their value throughout their lifecycle phases and to minimise waste (Bocken, et al., 2016). It has been developed and has gained recognition globally in Germany, Japan, China, and Europe in the field of construction (Merli, et al., 2018), but it is still not widely used. In addition, Osobajo et al. (2022) say that the construction industry is one of the key sectors with the most potential for CE adoption, and the European Commission (2015) says that CDW is a priority in CE policies. For the CE Concept to be more widely used in the industry, more knowledge and tools need to be developed (Lacy & Rutqvist, 2015). This industry takes longer to implement new ideas because buildings are unique projects with a long supply chain that makes things even more complicated (Pomponi & Moncaster, 2017). Since buildings are often torn down when they reach the end of their useful lives, it seems impossible to reuse materials in the construction industry. As a result, Smol et al. (2015) state that the construction industry should do a better job of using its resources. Due to the unique design expected in each facility, standardisation is not encouraged. When the products used for construction are circularly designed, the waste at the end of the life of the building can be minimised. Therefore, CDW is inevitable until the CE is fully incorporated within the built environment, which is not going to happen soon.

Hence, this research aims to investigate how the CE can contribute to minimising CDW to achieve sustainable urban development. The following section presents the research methodology followed by the research findings and discussion. Finally, the conclusions are provided.

2. RESEARCH METHODOLOGY

This research adopted a qualitative approach, using multiple holistic case studies as the key research strategy. Kothari (2004) explained that the qualitative research approach is subjective, exploratory, attitudinal, and involves assessing opinions and behaviours, which facilitates the collection of rich data in an in-depth manner. On the other hand, as CE is a relatively unfamiliar concept among Sri Lankan construction stakeholders, a quantitative approach that usually distances the researcher from the source of data is not preferred. The case studies were conducted in Sri Lanka, where urbanisation has been increasing since 2009 with the end of the civil war in the country (Ranagalage, et al., 2020). The urban development projects mainly consist of residential buildings along with other types such as offices, hotels, and other recreational buildings. Hence, three large-scale construction projects that are a prime part of the urban development in Colombo, Sri Lanka, were selected. Two residential projects, one to cover construction waste and the other to cover demolition waste, have been selected. In addition, a mixed-use development project comprising residential, official, hotel, and recreational facilities has also been selected as the third case study. Table 1 presents the details of the selected cases.

Table 1: Details of cases

Case	Value (LKR)	Start date	Duration	Respondents
Mixed Development Project (M)	104.0 billion	03.08.2014	96 Months	RM1: Top RM2-RM4: Middle RM5: Low
Residential Project (R)	16.2 million	01.03.2019	48 Months	RR1: Top RR2-RM4: Middle RR5: Low
Residential project with demolition (D)	197.5 million	11.04.2020	29 Months	RR1: Top RR2 - RM4: Middle RD5: Low

As Sekaran (2003) stated, when interviews are conducted in a semi-structured manner, it enables the adaptation of the questions necessary, clarifies doubts, and ensures that the respondent is properly understood by repeating the questions. Thus, semi-structured interviews of five (05) respondents from each case with more than 5 years of experience in CDW management were selected. The respondents from each case are from all three management levels as top (01), middle (03), and low (01) with designations including managing director, project manager or head, quantity surveyor, facilities manager, site engineer, material officer, technical officer, and labour.

The case study focused to collect the waste generated from the selected projects and to identify suitable strategies for minimising waste. The quantity of each type of waste generated in the projects was collected qualitatively under three scales low, medium, and high levels. The scaling given by the interviewees based on their qualitative judgement was cross-checked with the available CDW management-related documents at the case study projects. As such the collected data to measure the extent of CDW under each type of waste across three case studies were made comparable. The identified strategies were further studied to see the relationship of such strategies with CE principles. As there is limited application of CE principles in Sri Lankan urban development projects, a desk study was conducted by focusing on secondary-based case studies to identify suitable strategies that are then proposed as the recommended strategies to implement CE principles effectively in the local context. The next section presents the research findings of the research with recommendations.

3. RESEARCH FINDINGS AND DISCUSSION

This section presents the findings on the type and minimisation strategies of CDW, followed by a recommendation for CDW minimisation strategies based on a desk study to address the gaps in adopting CE principles within the local context.

3.1 TYPES AND MINIMISATION STRATEGIES OF CONSTRUCTION DEMOLITION WASTE IN SRI LANKAN URBAN DEVELOPMENT PROJECTS

Although all three cases are measuring their CDW, the method used to measure the CDW is different from case to case. Case M and Case D are more concerned with the weight of CDW waste, whereas Case R is more concerned with the CDW's financial impact. Case M is using both volume and weight to measure the CDW generated in the construction projects, and RM3 stated that "*even though both volume and weight are used to measure, mostly volume (m^3) is used and for few scenarios only weight (kg or ton) is used*". Case D measures only weight in both kilograms (kg) and tonnes. Practically, in both cases, the number of loads (truck or tipper) is used to measure the amount of waste generated in construction projects. However, Case R is using value (cost) to measure the CDW generated in their construction project. Furthermore, RM2 mentioned that the formula used to measure CDW is by deducting the actual usage and the last stock from the received materials [CDW = Received Material – (Actual usage of Material + Remaining stock of Material)]. Accordingly, it is complicated to compare and analyse the different projects because they have different methods of measuring CDW. Hence, the waste generation data across the three cases were measured under the scales of low, medium, and high levels for each level of waste based on the qualitative judgements of respondents to enable the comparison between the types of waste and between the cases. This study is bounded with the common CDW types identified by Gowsiga and Thayaparan (2020), and Table 2 shows the scaling of each of these types of waste across all of the cases so that they can be compared and contrasted. Accordingly, 70% or more of the waste type out of total waste is defined as "high", between 70% and 40% of the waste type out of total waste is outlined as "medium", and less than 40% of the waste type out of total waste is described as "low".

Table 2: The weighted average interpretation of extended CDW types across the cases

No	Waste type	Case M	Case R	Case D	Average
A	Concrete - Portland cement, asphalt, broken parts, and aggregates of concrete	H	M	H	H
B	Asphalt - Asphalt shingles asphalt concrete	L	L	L	L
C	Brick and clay tile	M	M	H	H
D	Ceramic materials (masonry)	M	L	M	M
E	Metals - steel, heavy metals, ferrous	M	M	M	M
F	Timber or wood products - trees, stumps	H	M	H	H
G	Plastics - polyvinylchloride (PVC)	M	L	L	L
H	Packaging waste - cardboard	H	M	H	M
I	Soil and earth, slurry, rocks	L	M	H	M

No	Waste type	Case M	Case R	Case D	Average
J	Gypsum wallboard and plaster/ drywall	H	L	L	M
K	Mineral waste	M	L	L	L
L	Miscellaneous /mixed waste	M	M	L	L
M	Glass	L	L	M	L
N	Paints, solvents, adhesives, caulks, pesticides, wood preservatives, oil, asbestos, polychlorinated biphenyls (PCBs)	H	M	L	M
O	E-waste	N/A	N/A	L	

According to Table 2, concrete is ranked as the major type of CDW in all three cases because it is used to make structural and non-structural panels and represents more than half of construction activity. After that, bricks, clay tiles, wood, and wood products moved up to second place because they are often used in building projects. These three materials have gained a high level of weighted average interpretation. At the medium level, ceramic, soil and earth, slurry, and rocks are listed because they are used a lot in big construction projects but produce less waste than concrete, brick, clay tile, and wood products. Moreover, packaging waste, cardboard, and metals were ranked next based on their usage in construction projects. Following that, gypsum wallboard, plaster, paints, solvents, adhesives, caulks, asbestos, and polychlorinated have been listed based on their weighted average rank. As per the data collection, low-level CDW generation has been listed as mixed waste, plastic, PVC, glass, mineral waste, and asphalts. Then, the CDW minimisation strategies were evaluated against the CE principles, which helped to detect the level of diffusion of knowledge and awareness of the CE concept in the Sri Lankan construction industry, especially in the context of CDW minimisation. Table 3 is a summary of the strategies used in the case study projects for each CDW type stated in Table 2.

Table 3: CDW waste minimisation Strategies in Sri Lankan construction projects

No	Strategies	Types of waste													
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
[1]	Proper storage and handling		*	*	*	*		*		*		*	*	*	*
[2]	Use proper estimation	*		*	*	*	*	*		*	*	*			
[3]	Use the proper construction method	*				*	*	*			*	*		*	
[4]	Proper supervision			*	*	*	*				*		*	*	
[5]	Procurement of materials	*			*	*	*			*					*
[6]	Focus more on proper transportation		*	*						*				*	*
[7]	Use skilled manpower	*			*						*				*
[8]	Use substitute materials or components		*				*	*							
[9]	Proper schedule management	*	*												
[10]	Avoid or minimise later changes	*		*											
[11]	Avoid site works (work at a separate location)						*						*		
[12]	Train workers												*		
[13]	Reuse	*		*	*	*	*	*	*	*	*	*		*	*
[14]	Recycle	*			*	*		*	*		*	*		*	
[15]	Disposal	*	*	*	*	*	*	*	*	*	*	*	*	*	*

As per Table 3, a key concern has been given to the "reduce" principle, as strategies from [1] to [12] belong to the reduce principle, and strategy [1] has gained priority as RM2 says, "*it's important to store things carefully in yards without exposing them to the outside to prevent corrosion*", and RD4 said that "*they always make sure that heavy products are not placed, especially on PVC and glass*". In addition, RR2 says that "*after rebar is bound or steel is set up at the site, anticorrosive paint needs to be put on to protect against corrosion until the concrete is poured*". RR1 has pointed out under strategy [3] that, "*having a better formwork system for the structures is the most important thing to do for waste minimisation*", and RD3 has mentioned that "*while cutting metal, proper consideration should be given to the given measurement and actual condition*". Moreover, RD2 has agreed that the available panel size from a demolished building has to be considered while making walls for new buildings. According to RM2 and RD3, measurements, drawings, and the condition of the site must always come first. The actual quantity of materials must also be double-checked before materials and items are ordered. Hereafter, a key concern has to be given to transportation, for instance, wheelbarrows are used when transporting materials to a specific location; always make sure to unload the materials near the respective building, and the trucks should be properly covered while transporting the soil into the site to minimise spillages. RM3 says that "*using skilled and expert workers for installation, formwork, and fabrication will reduce CDW waste more than expected*", and RD4 mentioned that "*if there is not much material requirement, it is always a better idea to use substitutes and alternatives to minimise wastage of material by transporting, storing and handling*". Fewer people say strategy [9], although it is important in construction. This may be because, according to RR5, "*if there is too much concrete for a job, it can be used right away for something else instead of being wasted. For example, it can be used to make slabs and columns at the same time, not along with the schedule*". In contrast, RM4 has stated that "*the planning and the scheduled time should be properly managed to avoid later changes; a further example is that there will be a lot of waste when the concrete doesn't harden quickly enough. Glass and plastic materials are the best examples; it is a better option to cast them in another location and bring them to the site while installing them to minimise wastage*". According to the respondent, workers must be taught how to use materials more efficiently, how to deal with waste, and how to control quality. The major driver towards reducing waste is cost. Time-consuming process for design, drawing, measuring, and making awareness, construction staffs are more focused on achieving progress, sudden changes of plan and variations, weather issues, and time act as the major barriers to implementing the "reduce" strategy to minimise CDW. Further, the cost is the main reason to implement these strategies to "reduce" CDW waste, while the barriers to implementing these strategies are that designing, drawing, measuring, and making people aware of things take a lot of time, so construction workers are more focused on making progress. In addition, the main things that make it hard to use the "reduce" strategy to reduce CDW are sudden plan and variation changes, weather problems, and a lack of time.

"Reuse" has been identified as the next principle to minimise waste after the generation of CDW, and findings reveal that only two of the 14 CDW waste types were excluded, which are asphalt and mixed waste. Some strategies of the "reuse" principle are summed up from the cases as follows: In Case M, they either crush and sell out the collected waste material for landfilling purposes at another site, hand over the material to the approved contractors, or send the material back to the original supplier. In addition, labourers use brick-like materials to lay them under their beds in the labour camps to make even surfaces that are comfortable for sleeping on. In Case R, they always try to use additional cut-off bricks for other temporary works at the site and landfilling purposes within the site. Soil material, except for some excavated earth that can be used for backfilling and soil improvement work under the instruction and approval of the engineer. In Case D, they have a separate location for reuse materials according to their labels and categories. The drivers of implementing the strategies of reuse are cost-saving and environmental friendliness, whereas the challenges are difficulty in educating the laymen at the site level, a quality issue, not being fit for the intended purpose, proper sorting of reusable materials from the generated waste, and mainly the identification of reusable materials.

"Recycle" is the next principle to discuss. It is mostly used to minimise the disposal of waste types such as concrete, rebar, paint, bricks, steel, concrete, glass, packing waste, metal, plastic, and timber. RM3 has highlighted that "*disposing to the approved solid waste contractor will be useful to recycle the materials*", and RD4 has given a true example of their project as they discussed with the supplier about the packaging methods to focus on recycling materials. Retailing to third-party contractors is the only strategy used in all three cases. Recycling has benefits for the economy and the environment, like saving money on resources and reducing pollution. However, Sri Lankan projects do not think much about recycling because there are not many recycling plants in the country. Further, difficulty sorting it out when huge amounts of waste are generated and less technology advancement, as well as less attention to recycling, were identified as the challenges to incorporating recycling strategies for CDW minimisation in Sri Lanka. Finally, the disposal will be the last but used in all three cases for all 14 types of CDW to take away from the construction sites. Dumping and burning are widely used to get rid of trash, while some can be carried out at the same site or else in a different disposal yard. In addition, handing over to the municipal council is also one of the common practices in these cases, irrespective of CDW types.

Furthermore, when questioned, "*Are you aware of any other principles or R-imperatives (the R framework) beyond the 3 R's (reduce, reuse, and recycle)? (e.g.: refuse, repair, refurbish, remanufacture, repurpose, recover, reimagine, and replace)*", all the respondents answered "no" to this question. Most of the respondents did not even know what the term “circular economy" meant. Moreover, it is necessary for the involvement of all persons engaged with construction activities, irrespective of their level (e.g., top management or labour), and it is important to have a single responsible person to manage, ensure, and improve waste management within a construction project. However, unfortunately, in all three cases, there is no single responsible person to look after waste management or minimisation activities, which do share some professions but differ from project to project. In Case M, the Quality Control Department is responsible for the CDW waste management, and the environmental manager, engineer, and site supervisor are directly dealing with waste management. But, in Case R, the project manager is mostly focused on CDW minimisation activities, and the site engineer is in charge of supervising those activities. Case D consists of many professionals in this area as it is mainly engaged in demolition activities, making the possibility of CDW generation also high; these are the technical officer, project manager, site engineer, and site supervisor.

According to the interview findings, it is obvious that reduce, reuse, and recycle strategies are used mainly to reduce the project cost through both reducing the cost of materials that become waste and also getting income from waste materials. Also, Case M respondents said that these strategies stop 30% of the extra costs that would have been added to the project. RM4 detailed that "*cost varies with the type of material, but nearly 30% of the additional cost may be required if not using waste minimisation strategies of reduce, reuse, and recycling*". Likewise, Case R could save around 20% of the additional project cost. In the case of D, around 12% of the project cost is saved through the CDW minimisation strategies. Moreover, RD2 noticed that "*there are different types of CDW materials, among which some waste can be sold in the competitive market, including rebar scraps, H iron, sheet files, light metals, and coppers*". Similarly, sellable items are sold and returned the money to the project, which is credited to the project account.

3.2 RECOMMENDATIONS BASED ON DESK STUDY

Identifying and measuring the waste is essential to minimising whatever the waste is, which should precede the process of elimination, and this can be overcome by implementing a proper waste measurement system. Moreover, complex waste identification and quantification are the prime conditions for effective waste minimisation (Pienkowski, 2014). Accordingly, the types of waste were identified from the literature, and the primary data on the waste generated under the same types were collected using three case studies. The results (Table 2) indicate that all the CDWs identified in the literature apply to all three projects. However, even if e-waste is harmful to the environment, it was identified only in Case D, as it is a demolition project where e-waste is a common waste type. E-waste, or electronic waste, is a generic term embracing various forms of electric and electronic equipment that have ceased to be of any value to their owners (Kiddee, et al., 2013). It generates hazardous and non-hazardous materials that can adversely affect human health and the environment, and thus, it is important to pay attention to managing that properly (Chancerel & Rotter, 2009). Accordingly, e-waste was considered an additional type of waste during the data collection. According to Mallawarachchi and Karunasena (2012), the “3R” is a major concept of e-waste management adopted in developing countries.

The Sri Lankan construction industry does not know much about the CE concept, and even though the respondents know and use the 3 R's, they do not understand the clear connection between them in a circularity concept. In addition, the Sri Lankan construction industry stakeholders does not try to understand or use the other Rs of the CE concept. Further, the study reveals that a lack of knowledge and awareness is the main reason for the limited adoption of the CE concept for minimising CDW. Besides, the lack of collaboration among the supply chain stakeholders, the lack of second-hand materials or product markets, limited research and development, and cultural barriers are some of the reasons why the CE is not adopted (Charef et al., 2021). To address this gap and lack of knowledge and awareness of CE concepts beyond the basic 3R framework within the local context, the authors have further conducted a desk study to collect case studies from secondary sources where CE principles are widely adopted for CDW minimisation. Table 4 summarises the strategies used to manage CDW in a global context, and such strategies are mapped against the 11R framework of Cimen (2021), which is the latest study on CE principles for the building sector.

Table 4: Proposed strategies to minimise CDW based on desk study

CE Principles	Strategies	Sources
Refuse (Removing functions to make products redundant)	• Collaboration and communication among the stakeholders • Make emotional attachments while designing to make owner unwilling to discard it • Rejection of packaging waste and shopping bags	[1] [2] [3] [12] [14]
Rethink (Making use of product more intensive)	• Buildings for multifunctionality • Simultaneous use and sharing of product	[11] [14]
Reduce (Increasing the efficiency of natural resources to make a product)	• Adopt innovative technologies (Building Information Modelling, Internet of Things) • Design Out Waste • Encourage off-site construction (E.g., prefabrication) • Enhance supervision and management during construction • Increase the CDW treatment cost and landfilling cost • Introduction of economic incentive or awarding schemes (E.g., Construction Waste Disposal Charging Scheme or Stepwise Incentive System) • Lessen the usage of purchased products and use them with more care and longer • Making repairs for life extension, for example with consumer-to-consumer support • Material selection (E.g., Eco-labelling Products) • Periodize standardisation in building design (E.g., Modular Coordination) • Sharing economy' through pooling (simultaneous use) and sharing of product • Stricter supervision and punishment must be concurrently enforced for CDW disposal • Use modern methods of construction (E.g., Industrialised Building System)	[1] [2] [3] [4] [14] [16]
Reuse (Reusing a product discarded by another user)	• Adopt better information systems, innovative technologies and market models • Appropriate plants for demolition work / selective demolition methods • Cities could maintain their resources as material banks • Create a strong market for reused materials • Collaborating and communicating among stakeholders • Design for reuse, materials optimisation, flexibility and deconstruction • Enhancement of regulations related to CDW like Pay-As-You-Throw	[1] [2] [3] [5] [6] [7] [8] [9] [10] [13] [16]

CE Principles	Strategies	Sources
	• Enhance supervision and management • Introduction of economic incentive or awarding schemes including Construction Waste Disposal Charging Schemes or Stepwise Incentive System • Imposing standards on reused CDW materials to maintain the quality of reused material and to assure the availability • On-site sorting technique and proper guidance • Procurement Transformation (Revise Standard Form of Contract, Green Procurement) • Usage of modular buildings • Waste collection process (E.g., Appoint Waste Collector)	
Repair (Repairing a product to continue its function)	• Adopt innovative technologies and market models • Preventive maintenance • On-site sorting technique and proper guidance • Select and procure repairable materials • Waste minimal maintenance and easy repair and upgrade adaptability	[1] [2] [3] [10] [14]
Refurbish (Restoring an existing product)	• Adopt innovative technologies and market models • Design for materials optimisation, flexibility and deconstruction	[3] [10] [16]
Remanufacture (Using abandoned parts for a new product with the same function)	• Design for materials optimisation and flexibility and deconstruction	[16]
Re-purpose (Using discarded components for a different purpose)	• Design for repurpose and material optimisation • Design for flexibility and deconstruction	[11] [14] [15]
Recycling (Material is processed to obtain a new material)	• Adopt innovative technologies and market models • Appropriate Plants for demolition work / Selective demolition methods • Continuous development and integration of emerging technologies • Collaborating and communicating among stakeholders • Design for deconstruction technique • Enhance supervision and management	[1] [2] [3] [7] [13] [17]

CE Principles	Strategies	Sources
	• Enhancement of regulation related to CDW (E.g., Pay-As-You-Throw) • Eco-industrial park development • Introduction of economic incentive or awarding schemes • Manufacturing of plank products for buildings (E.g., moisture-resistant and recyclable composite material from plastic waste and wood fibers) • Open communication to assure the quality or make trust recycling • On-site sorting technique and proper guidance • Procure recyclable materials and use procurement Transformation • Use as raw material for other industries • Strong developed market for recycling to have a price advantage for recycled materials • Waste collection process (E.g., Appoint Waste Collector)	
Recover (Material is incinerated to recover energy)	• Design for recovery • Production of biomass	[14] [16]
Replace (Replacing with sustainable Material)	• Design for sustainability • Eco-design	[1] [9]

[1]- Adams et al. (2017); **[2]** – Aslam et al. (2020); **[3]**- Chang and Hsieh (2019); **[4]** - Coughlan et al. (2018); **[5]** - Esa et al. (2019); **[6]-** Huang et al. (2018); **[7]**- Leising et al. (2017); **[8]**- Manelius et al. (2019); **[9]** - Marika et al. (2021); **[10]**- Nordby (2019); **[11]**- Reike et al. (2017); **[12]**- Sanchez et al. (2020); **[13]-** Swift et al. (2017); **[14]** - Torgautov et al. (2021); **[15]**- van-Buren et al. (2016); **[16]**- Xu et al. (2021); **[17]-** Zhou et al. (2021)

This will improve the awareness of CE principles among built environment professionals, which in turn will improve the practices of construction professionals in minimising CDW by adopting them. Moreover, waste always means an additional cost to be incurred from both the client's and the contractor's viewpoint, and the frustrations with each other can be driven by the failure of the performance of the contract as well.

Hence, minimising CDW waste leads to saving all three aspects of construction: time, cost, and quality. Further, it ensures mutual understanding and trust among the parties to the contract and the successful completion of the project for the intended purpose within the given time frame. Thus, the CE can lead to dematerialisation by reducing the waste generation and consumption of virgin materials in construction projects, which decouples economic growth from environmental impacts and also creates cost savings for construction projects.

4. CONCLUSIONS

Due to urbanisation, the growing amount of CDW is a pressing problem in many countries. There are many strategies used in different countries to minimise the CDW, such as precast construction, strategies of architects at the design stage, use of BIM, the 3 Rs, material waste minimisation strategies, and a lean approach. Although CE can be considered an appropriate solution to minimise CDW as it would reduce environmental impacts while contributing to economic growth, Thus, this research investigated how the CE can contribute to minimise the CDW to achieve sustainable urban development. Three cases were selected for the data collection and are from a mixed development project, a residential project, and a residential project with demolition. Key findings of the work include that all 14 CDW types identified in the literature appear in Sri Lankan construction projects, and e-waste was identified. Also, CDW minimisation strategies in Sri Lankan construction projects were identified, which belong to the 3 Rs of CE, such as reduce, reuse, and recycle. While the disposal is unavoidable for all 14 CDW types, adopting CE would help to minimise CDW disposal and, in turn, reduce the impact created by landfilling. 3R strategies are used mainly to reduce the project cost, both by reducing the cost of materials that become waste and also by getting income from waste materials. However, the other 8Rs of CE, i.e., refuse, rethink, repair, refurbish, remanufacture, repurpose, recover, and replace, are not understood or applied in Sri Lankan CDW minimisation. The study reveals that a lack of knowledge and awareness is the main reason for the limited adoption of the CE concept for minimising CDW. Therefore, this research recommended the strategies used to manage CDW in a global context, and such strategies are mapped against the 11R framework of Cimen (2021). These recommendations help to improve the awareness of CE principles among built environment professionals, which in turn will improve the practices of construction professionals in minimising CDW by adopting appropriate CE.

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