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COST IMPACTS OF CIRCULAR APPLICATIONS TO CONSTRUCTION ACTIVITIES: A CASE OF SRI LANKA

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ABSTRACT

The need to transition towards a circular economy (CE) paradigm has increased due to the growing environmental burden associated with rising resource consumption and waste generation in the construction industry. Although the construction phase constitutes a relatively small proportion of the overall building life cycle, it exerts a disproportionately high environmental impact due to the extensive use of virgin materials. Nevertheless, the implementation of CE during this phase is constrained by the lack of awareness of its economic incentives. Therefore, this study seeks to assess the cost impacts of integrating CE into construction activities within the Sri Lankan context. Using a multiple case study approach, the research evaluates the cost implications of CE practices in construction of two multi-storied buildings. Data were gathered through semi-structured interviews and review of documents, including Bills of Quantities and as-built records. The findings demonstrate that CE applications are currently concentrated within eight (out of forty-one) major activities, including excavation, concrete and masonry, primarily operationalised through basic 3R (Reduce, Recycle, Reuse) principles. This limited applications of CE yielded total cost savings of approximately 2% to 4% of the contract value. Notably, of the two buildings, the green building exhibited higher savings (4.39%) compared to the non-green building (1.89%). By providing empirical evidence of economic cost savings resulting from CE applications, the study contributes to enhancing the adoption of CE in the construction sector. These findings highlight that the greater integration of CE practices during construction stage would enhance the sustainability of the construction projects.

Keywords: *Circular Economy; Construction Activities; Cost Implications; R – Principles; Sri Lanka.*

1. INTRODUCTION

According to the United Nations, it is projected that the world population will reach up to 8.5 billion in 2030 (United Nations, 2021). Population growth and urbanization are identified as coupled factors which increase resource consumption in the built environment (Pullen et al., 2012). This intensive use of resources ultimately leads to a significant amount of construction waste. According to Tafesse et al. (2022), the building sector consumes 40% of raw materials and produces approximately 35% of total waste to

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the environment, which represents one third of global waste. Moreover, the higher resource consumption increases the embodied carbon emission (Palomar-Torres et al., 2025). Addressing this environmental burden has urged shifting from the linear take-make-dispose based economy to circular economy (CE) (Çimen, 2021).

The CE is widely defined as a system in which materials are continuously cycled, minimizing waste while supporting and regenerating natural systems through reduced resource extraction and closed loop flows (Akhimien et al., 2021). In practice, CE is often operationalized through hierarchical R-principles that aim to transform construction processes into regenerative closed loop systems (Ghisellini & Ulgiati, 2020). The R Frameworks demonstrate conceptual maturity and adaptability of CE in its implementation across building lifecycle. Based on a proactive cradle-to-cradle framework Akhimien et al. (2021) emphasized that circularity must be integrated throughout the entire building lifecycle from design and planning, construction, operation, maintenance to deconstruction phases (Pomponi & Moncaster, 2016). On a slightly different note, Charef et al. (2021) have concluded that the limited attention on cost impacts as one of the significant barriers in adopting CE to the design and end-of-life management stages of a construction project.

Although the construction phase represents a relatively small portion of the building life cycle, Fagone et al. (2023) highlighted that it has a significant influence on environmental impacts. Furthermore, the review of CE applications during the construction phase indicates that existing studies are largely limited to the qualitative identification of techniques for utilizing recovered components obtained through building deconstruction and incorporating recycled materials into construction projects (Rahla et al., 2021). In another recent study, Fagone et al. (2023) have formulated a circular construction site methodology to monitor the circularity process, using green certification protocols and KPIs. However, the study fails a quantitative assessment of cost effects of CE implementation. With regards to CE implementation in overall lifecycle, Charef et al. (2021) state that it is impeded by multiple barriers spanning across organisational, economical, technical, environmental, political, and societal dimensions. Furthermore, Adams et al. (2017) have stressed the importance of studying cost benefit of CE implementation due to the associated higher upfront costs in construction.

Green concept aims to promote efficient resource use in the production process and consumption, by reducing waste generation which aligns with definition of circular economy (UN environment programme, 2018). Further, the World Green Building Council states that 'resources and circularity' is one of areas which they are focusing on in the process of transforming the construction sector to a more sustainable and healthier built environment (World Green Building Council, n.d.). In another recent study, Li et al. (2025) have identified that the circular economy implementation is contributing to maturation of green building research by aligning construction workflows with global carbon reduction targets and science driven sustainability efforts. Building on these insights, Moustafa et al., (2025) stated that integrating CE strategies into green buildings would enable a sustainable and efficient built environment.

In this context, the current study aims to assess the cost impacts of integrating CE principles into construction activities by considering both a green building and a non-green building.

2. CE PRINCIPLES AND APPLICATIONS OF CIRCULAR ECONOMY PRINCIPLES TO CONSTRUCTION ACTIVITIES

"R-principles" (or R-imperatives) are used to operationalise the circularity. While 3R (Reduce, Recycle, Reuse) model is widely recognised as the foundational framework, there are notable evolution of the principles to include multiple iterations including 4R, 5R, 9R, and 10R (Reike et al., 2022). Charef (2024) specifically identifies transition to a 4R model through inclusion of Recovery, highlighting the need of prevent the energy or value being lost to the system, while Mrad and Ribeiro (2022) have assessed a comprehensive 10R framework comprising Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, Reuse, Reduce, Rethink and Refuse, to evaluate the impacts throughout the whole building lifecycle as part of circularity. Expanding this hierarchy further, Kochanski et al. (2024) analysed material use and costs based on 11R principles as effective CE implementation. In another recent study, Uvarova et al. (2023) has introduced 60R principles in broad general context classified into major four groups of Reduce, Reuse, Recycle and Reverse logistics. However, Zhu and Feng (2026) have analysed multiple R-principles and stated that 3R principles remain central to all the variations. Collectively, these variations of R-principles demonstrate the evolving and increasingly comprehensive approach to operationalise circularity across different contexts, still maintaining the basic emphasis on resource efficiency and waste minimisation. Pearlmutter et al. (2019) found that green buildings are one of the nature-based solutions contributing to circularity, especially through transforming the urban built environment into circular cities. CE implementation in green building construction enables effective resource utilisation and cost savings in construction phase (Giorgi et al., 2022).

Although construction phase is relatively shorter in entire building lifecycle, it is the point of highest material flow and waste generation (Fagone et al., 2023). Gamage et al. (2024) studied the relationship between the CE practices and lifecycle stages of construction projects and concluded that the practices in construction stage including use of offsite construction, reducing waste generation, optimising the resource usage, and prioritising reuse and recycled materials into the process. Phear and Fraser (2024) have focused on developing a new standard for sustainable earthworks especially through the practices of reducing use of natural resources, adopting regenerative solutions and reuse of existing waste materials in earthworks. Yet, there are several further applications of CE practices, especially during the construction phase, as summarised in Table 1.

Table 1: Construction activities and CE applications

Construction Activities		CE Applications	CE Principle	Sources
Preliminary work	Site selection	Soft re-use of brownfield sites	Reuse Retrofit	(Bardos et al., 2016)
	Provide temporary utilities	Use of harvested rainwater for potable water requirements	Rethink	(Diehl de Souza & Ghisi, 2020)

Construction Activities		CE Applications	CE Principle	Sources
Excavation and filling	Filling obtained from excavated material	Collaborate on techniques to reduce labour and fuel requirements in the cut-and-fill procedure	Reuse Recycle Reduce	(Phear & Fraser, 2024)
		Reuse of excavated soil		
Concrete work	In-situ concrete work	Use of fly ash mixed concrete by reducing cement content	Reduce	(Abushanab & Alnahhal, 2023)
		Reuse of excavated soil as fine aggregate in cement mortar	Recycle	(Priyadharshini et al., 2018)
		Recycling plastic and using it as aggregates	Recycle Reduce Repurpose	(Alqahtani et al., 2021)
		Use of recycled concrete waste as aggregates	Recycle Reduce	(Akbulut et al., 2025)
	Formwork	Reusable formwork	Reuse	(Balasbaneh et al., 2024)
	Precast work	Use of precast concrete columns, and beams	Reduce	(De Silva & Vithana, 2008)
Masonry work	Brick and block work	Reuse of demountable walls	Reuse	(Buyle et al., 2019)
	Brick work	Mix of organic waste in clay brick production	Reduce	(Lozano-Miralles et al., 2018)
	Block work	Block production by utilizing fly ash	Reduce Replace	(Shi et al., 2019)
Carpentry	Woodwork	Use of wood residue applications, such as MDF	Recycle	(Vamza et al., 2021)
Off-site manufactured components	Prefabricated structures	Reuse of concrete elements	Reuse Refurbish	(Kromoser et al., 2025)
		Reversible use of dismantled steel for prefabricated elements	Reverse	(Rahla et al., 2021)
		Waste reduction with the use of prefabricated elements	Reduce	(Tam et al., 2005)
		Reuse of prefabricated timber frames	Reuse	(Lisco & Aulin, 2024)
	Prefabricated buildings	Disassembly and reusing	Reuse	(Minunno et al., 2018)
Partitioning		Recycling of gypsum plasterboard	Recycle Repurpose	(Jiménez Rivero et al., 2016)

Construction Activities		CE Applications	CE Principle	Sources
Composite flooring	Composite concrete work	Use of GLT- concrete slab as a sustainable and reusable solution	Reduce Rethink Reuse	(Balasbaneh et al., 2022)
		Reuse at the end of a lifecycle by using demountable steel-concrete floor	Reuse	(Brambilla et al., 2019)

As seen from Table 1, the CE applications are limited to eight major construction activities. In terms of CE principles, Reduce, Recycle and Reuse are mostly implemented, with the minimal application of Retrofit, Repurpose, Refurbish, Reverse, and Rethink.

3. RESEARCH METHODS

A multiple-case study approach was used to explore the CE implementation in construction activities and to quantify the related cost implications. Two educational building projects of different profile were selected as presented in Table 2. Although the case selection was not intended to target a specific building function or green-certified project, the projects were chosen based on their accessibility and the availability of cost data. Nevertheless, the inclusion of a green-certified case enabled an examination of the influence of green certification on construction circularity, while the functional similarity of the projects enhanced the comparability of the study findings. Data were gathered through semi-structured interviews with project managers, with over 10 years of work experience engaged in the construction-phase of the selected buildings and from BOQs, as-built drawings, and cost records maintained at the site. The project managers of each project were selected as the sole participants representing their respective projects due to their comprehensive knowledge and understanding of the subject, as well as their familiarity with the selected projects. The New Rules of Measurement 2 (NRM2) work sequence was considered to identify the CE applicable activities systematically and to be consistent across the selected cases. Cost implications due to CE integration were calculated using BOQ rates, and cost records maintained at the site. The cost impact of each activity was calculated as cost per Gross Internal Floor Area (GIFA) basis. The methods used to derive the cost impacts of CE applications along with respective cost impacts are presented in Table 3.

Table 2: Summary profile of the selected educational buildings

Information	Green Building - GB	Non-Green Building - NGB
Contract value (LKR)	3.03 Bn	0.72 Bn
GIFA	27,781 m²	3,258 m²
Current status	In operation	In operation
Green certification	Platinum – GREENSL, UDA Blue Green	Not certified
Number of buildings	Five buildings with varying number of storeys – single to 10	Single building with six storeys
Structure	Concrete; Brick and block work; slab roof	Concrete; Brick and block work; Prefabricated steel roof

As seen from Table 2, though the selected buildings differ in contract value and GIFA, the cost impact due to CE applications for each activity were normalised by calculating 'cost per GIFA' and then presenting the value as a percentage of the total contract value, thereby reducing the effect of variation. , However, it is expected that the number of buildings available within the project and the green certification could influence the CE applications and the cost effects while, building function could have less/no effects on the results.

4. RESULTS AND DISCUSSION

This section presents the analysis of CE principles applicable to construction activities and the respective cost impacts.

4.1 CIRCULAR ECONOMY POTENTIAL IN CONSTRUCTION ACTIVITIES

The participants' views were sought on the CE applicable construction activities, by referring to NRM2 work sequence and CE principles derived from the literature. The results of the collated views are presented in Table 3. Of the forty NRM 2 based work sections, CE applications are found only in eight work sections. Aligning with literary findings, CE applications have been practiced in preliminary work, excavation and filling, concrete, masonry, and partitioning works in the selected buildings. However, the specific CE measures varied within some of these sections. For example, the preliminary works section exhibited only two CE applications in the literature review, but four applications emerged from case-study analysis. Regardless of these differences in implementation, similar observation is noted in terms of applicable CE principles as well, mostly revolving around the basic 3Rs. Worth still, that green building context has promoted the application of Recycling while non-green building has used the Reduce concept in most of the activities. This distinction suggests that green building projects tend to incorporate material recovery and recycling-oriented approaches, such as the use of recycled aggregates or industrial by-products, whereas conventional construction practices primarily focus on resource efficiency and waste minimization measures, such as reducing material use or improving operational efficiency on site.

Apart from conventional construction activities, green building construction has promoted certain circular applications. For example, the advanced CE principles; Retrofit and Rethink have been applied in green buildings through the selection of brownfield sites and the use of harvested rainwater, respectively. However, the use of recycled materials has been promoted in concrete, masonry and structural metal work of both green and non-green buildings. Besides, building characteristics and quality requirements have induced CE applications. Reuse of existing adjacent access path was enabled as the building contains multiple structures within the given project. Similarly, excavated soil was reused for backfilling as the soil quality was good.

4.2 COST IMPLICATIONS OF CIRCULAR ECONOMY APPLICATIONS

As evidenced above, although the construction activities have greater potential for incorporating various R principles, the practical applications may be hindered by the cost implications of implementing them. The cost impact of CE applications assessed through case study analysis are presented in Table 3.

Of the eight, six work sections contribute to around 1-13% of cost saving in individual construction activities. Excavation & earth filling and doors are activities with exceptionally large percentage of cost savings. A 34% saving is obtained due to reduction of total cost of excavation and backfilling with the use of brownfield site instead of green field. On other hand, repurpose of solid plywood doors contributed negatively to around 80% of cost saving in the total door cost. Amongst the six work sections, concrete has the greater potential for Reduce, Reuse and Recycle and thereby contributes around 11% saving on average to the total cost of concrete. Similarly, use of offsite manufactured, prefabricated steel roof structure result in 7% saving on the total cost of the element via Reduce of on-site labour, material, and time waste. Comparatively, an increased saving is observed in green building over the non-green due to compliance to green requirement. Especially, the activities like use of brown field, rainwater harvesting, recycled and reused materials contributed additional saving in green building context. However, cost savings were calculated solely on the basis of reduced consumption of virgin materials. For instance, in the excavation and backfilling section, savings associated with avoiding transport of excavated soil for disposal and subsequent import of fill material (due to on-site reuse) were not included. Consequently, the present analysis captures only a portion of the total potential cost savings.

Table 3: CE Applications and cost impact

	Construction Activity	CE Application	CE Principle	Cost Impact (Rs. per GIFA) GB	NGB	Derivation of Cost Impact
Preliminary work	Site selection	Selecting a brownfield site instead of a greenfield site	Repurpose Retrofit	No cost record	N/A	N/A
	Provide site access path	Reuse of the access path which was used during the construction of adjacent project	Reuse	253	N/A	Adjust the past cost data using pro-rata method
	Facilitating temporary site offices for the staff	Reuse of materials which are used to erect site offices in previous projects	Reuse	510	547	Percentage of cost of site office as per BOQ
	Provide temporary utility facilities (non-potable water)	Use of harvested rainwater for non-potable water requirements	Rethink Reduce	14	N/A	Quantity of collected rainwater x price per unit of NWS&DB
	Total cost saving on preliminary work			777	547	N/A
	Total cost of preliminary work			12,675	25,477	N/A
	Cost saving as a % of total cost of preliminary work			6.13%	2.15%	N/A
Excavation & filling	Site clearing and excavation	Ensuring efficient fuel usage by comparing the work done and fuel consumption monthly	Reduce	No cost record	No cost record	N/A
	Imported filling	Optimizing excavated soil for backfilling	Reuse	N/A	156	Cost difference of imported and excavated soil
		Use of quarry dust obtained from rock blasting	Recycle	173	N/A	Cost difference of quarry dust filling and sand filling
	Total cost saving on excavation & filling			173	156	N/A
	Total cost of excavation & filling			507	6,890	N/A

		Construction Activity	CE Application	CE Principle	Cost Impact (Rs. per GIFA) GB	Cost Impact (Rs. per GIFA) NGB	Derivation of Cost Impact
		Cost saving as a % of total cost of excavation & filling			34.10%	2.26%	N/A
Concrete work	In-situ concrete work	Plain In-situ concrete – Mass concreting	Use of waste concrete as aggregates in screeds	Recycle	1.35	117	Cost of concrete screed
		Reinforced In-situ concrete – Horizontal concreting - slab	Use of fly ash mixed cement in concreting	Recycle	254	114	Price difference of fly ash mixed and ordinary Portland cement
		Formwork	Repetitive use of formwork	Reuse	3,500	3,022	Cost of new formwork
		Reinforcement	Use of recycled reinforcement	Recycle	No cost record	N/A	N/A
	Precast work	Precast concrete goods	Use of precast concrete blocks	Reduce	No Significant Saving	No Significant Saving	N/A
			Use of concrete paving blocks produced by recycled materials	Reduce Recycle	No cost record	N/A	N/A
		Total cost saving on concrete work			3,756	3,252	N/A
		Total cost of concrete work			28,126	38,210	N/A
		Cost saving as a % of total concrete work			13.35%	8.51%	N/A
Masonry work		Block walls	Use of hollow blocks instead of solid blocks	Reduce	268	45	Rate difference of hollow block and solid block
			Use of blocks produced using recycled materials	Recycle	No cost record	N/A	N/A
		Total cost saving on masonry work			268	45	N/A
		Total cost of masonry work			4,530	4,811	N/A
		Cost saving as a % of total cost of masonry work			5.92%	0.93%	N/A

	Construction Activity	CE Application	CE Principle	Cost Impact (Rs. per GIFA)		Derivation of Cost Impact
				GB	NGB	
Structural metal work	Isolated structural members	Use of structural steel produced using recycled materials	Recycle	No cost record	N/A	N/A
	Total cost saving on structural metal work			No cost record	-	N/A
Partitioning	Partitioning system to walls	Use of timber panels produced by mixing rice straw	Repurpose	19	46	Cost difference of timber rice straw mixed partitions
	Total cost saving on partitioning			19	46	N/A
	Total cost of partitioning			1,023	6,254	N/A
	Cost saving as a % of total cost of partitioning			1.84%	0.73%	N/A
Doors	Doors	Use of solid plywood doors instead of timber doors	Repurpose	(203)	(62)	Cost difference of timber and solid plywood doors
	Total cost saving on door fixing			(203)	(62)	N/A
	Total cost of door fixing			254	1,237	N/A
	Cost saving as a % of total cost of door fixing			(80%)	(5%)	N/A
Off-site manufactured components	Use of prefabricated structures	Use of prefabricated steel roof	Reduce	N/A	168	Cost difference of on-site roof and prefabricated roof
	Total cost saving on off-site components			-	168	N/A
	Total cost of off-site components			-	2,556	N/A
	Cost saving as a % of total cost of off-site manufactured components			-	7.46%	N/A
Total cost saving as a % of contract value				4.39%	1.89%	N/A

5. CONCLUSIONS

The main focus of the study was to assess the cost impacts due to CE implementations in the construction activities. The analysis of selected cases reveal that CE applications are seen in limited construction activities. The CE applications are mainly in the form of Reduce and Recycle of waste materials, and Reuse of existing access path, excavated soil, and formwork. The major CE based construction activities include preliminary work, excavation and filling, concrete, masonry, structural metal, partition, doors, and off-site manufactured components. Collectively, CE applications contributed cost savings of approximately 2-4% of the total contract value. However, these savings cannot be readily generalized owing to the inconsistent application of CE principles across the two building contexts. However, there are many other work sections where non-availability of cost data has restricted the assessment of cost impact. Further, the cost impact was based on initial cost, not on the life cycle cost where the impact could be higher due to CE applications during operation and maintenance as well as end of life phases. Moreover, there can be potential CE strategies in the work sections which are not identified through this study due to the limitation of the site conditions. Therefore, the actual cost impact could be greater.

The comparison of the selected two cases in the current study indicates that although there was potential for CE applications in some activities, it has not been incorporated. For example, use of harvested rainwater for non-potable water requirements, use of blocks, and structural steel produced using recycled materials are seen only in green building where it has contributed to additional cost saving. It is worthy to note that the use of strategies like use of brownfield instead of greenfield site has contributed significantly to the cost saving, 34% of cost of excavation & filling. This evidences that green buildings provide more pathways to integration of circularity. The study therefore recommends that professionals responsible should carefully examine the potential CE applications, in compliance with green requirements where possible and thereby assess the cost impact. This would result in significant environmental benefits such as waste, energy and emission reduction, and reduce resource consumption. The limited CE application could be due to lack of knowledge and awareness about the CE applications, and its environmental and economic implications. Therefore, it is recommended that the further study to examine the above in detail. From the practical implementation perspective, the study recommends that there could be design-level interventions, technological integration, or reverse logistics systems that need to be embedded within current construction practices.

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