Research Article ISSN 2832-9384

Journal of Materials and Polymer Science

The Uncertainty of Reusable Building Components/Materials A Subsidiary of Circular Economy in the Africa Construction Sector: The Issue of Affordable Housing in Kenya

Christian Jonathan

Politecnico di Milano Italy.

***Corresponding author**

Christian Jonathan,
Politecnico di Milano Italy.

Submitted : 17 Apr 2024 ; Published : 3 May 2024

Citation: Jonathan, C. (2024). The Uncertainty of Reusable Building Components/Materials, J mate poly sci, 4(2) :1-8.
DOI : https://doi.org/10.47485/2832-9384.1053

Abstract

There is growing interest in the adaptation of circular economy approaches in the construction sector, for developing African countries like Kenya with an increase in construction activities leading to more generation of construction wastes. The approach of circularity presents an alternative to reuse these construction or demolition wastes thereby lowering environmental risks and providing for a lower price for building components/materials required for affordable building projects. However, there is little, or no information on these reusable building components/materials, which lowers the confidence by construction stakeholders in using them. No information on its possible new life longevity (durability), its possible maintenance budget, and no means of enabling a design team to plan for its acquisition (accessibility) in a design project. This paper adopted a review of previous literature on these topics to search for possible solutions to the research questions, of which some literature provided only a list of requirements needed to give a level of information to reusable building elements. The paper went further to provide proposals for an information catalogue that would enable the insertion of reusable building elements' Indicators of service (availability, reliability, and maintainability) obtainable from experience with the elements. Also, a format for a maintenance budget plan would be required during the new service life of the reused element. And a means of simulation using the Monte Carlo simulation tool to obtain reliable viability of access to reusable building elements in a transitional building in its design stage. These proposals would have to be put into practice to ascertain their effectiveness, meanwhile, other areas of further studies are provided in the paper.

Keywords: Affordable housing, Building components, Circular Economy, Indicators of service, Reuse, Uncertainty.

Introduction

The construction sector contributes to the trends of future cities, whereas global cities contribute to 50% of global greenhouse gas emissions, consuming nearly 70% of the global energy sources (Ninni, 2023). The global impact of the construction sector on raw material consumption is quite alarming with over 3 billion tons of raw material used in steel production, the unprecedented growth in population especially in developing countries would immerse more pressure on the demand for raw materials especially in the urban cities (Iyer-Raniga, 2019). Alternatives could be the initiatives of Circularity which involves extending the life cycle of components, thereby reusing building materials, reducing construction wastes, saving cost through reusable components, and reducing carbon emissions by avoiding the dependence on raw materials extraction and production processes. This initiative is an approach that should be considered starting from the design stage as outlined by the Ellen MacArthur Foundation on the adaptation of the Resolve Framework including Regenerate, Share, Optimize, Loop, Virtualize, and Exchange. Furthermore, the study by (Chen et al., 2022) suggested that Circularity in the Construction Sector could be divided into the three categories of Design, Construction, and Demolition of which the design stage involves designing for deconstruction/disassembly and designing with reusable building components and materials. However, what level of information is provided for a construction/waste that is to be reused?

An overview of circular economy in the African construction sector: the issue of affordable housing in Kenya.

The initiative of Circular Economy in Africa is gaining momentum over the years, this is driven by the race for economic growth (The Veolia Institute review, 2021). However, it's still regarded as a survival economy because it mostly involves local recycling. Other practices involve repairing, repurposing, and direct reusing, etc. It therefore becomes important to attach a level of value and confidentiality to these practices.

In Kenya, the population growth has left a record 2 million housing deficit due to the inability to afford housing, within the low-income population (Kieti, Rukwaro, & Olima, 2020). In parallel the population growth has also led to an increase in construction activities with a backdrop of an increase in construction wastes leaving behind further environmental risks (Tanui, 2019). Fortunately, there is also a growing interest in circularity in Kenya with the 2020 Revision of the Kenyan Building Code to prioritize the reuse and recycling of salvaged materials during demolition (Netherlands Enterprise Agency, 2021). The adoption of a circular economy in Kenya's Construction Sector involving the use of reusable building components/materials could enable the mitigation of construction waste, and environmental benefits, create more possible job opportunities for stakeholders involved in the supply chain, and could enable achieving an affordable home by the low-income population if the reusable building components/materials are obtainable at lower price compared to the new products. But what level of guarantee to using these reusable components/materials?

The Uncertainty of Reusable Building Components/Materials

It is obvious the benefits of reusable building components/materials, but the adoption of these approaches globally not only in Africa or Kenya, but stakeholders' perception is also affected by the potential risk factors associated with the approach (Rakhshan et al., 2020). There are lower environmental impacts when reusing building components/materials compared to recycling because there is lower processing required, these actions would also improve solid waste management enabling healthier cities (Citraningrum et al., 2023). Furthermore, research by (Rakhshan et al., 2020) reveals that economic drivers are one of the motives for reusing building components, as the possible lower prices of recovered materials could enable the lowering of project construction costs. However, stakeholders' perception of using reusable components remains uncertain due to a lack of information on reusable components/materials. As revealed by a poll of respondents by (Citraningrum et al., 2023) in Indonesia there is skepticism about using recovered materials from demolition or construction wastes, particularly the durability of these recovered products but if these waste products are given a level of information it can be passed on for future use, knowing when the products have reached its end of life cycle then it could be recycled or reused in a new phase, this information can also help in maintaining the product throughout its next phase of lifetime. Another issue is the accessibility of these reusable building components/materials as they often require more time to acquire, these are issues that a design team would need to answer, (Rakhshan et al., 2020) if there is an intention to build with reusable building components/materials.

Research Questions

1. Is it possible to obtain expected Indicators of Service (Availability, Reliability, and Maintainability) for a reusable building Component/Material?
2. What could be the Maintainability Budget of Reusable Building Component/Materials in its New Life Cycle?
3. What Variable Parameters should be considered when designing with Reusable Building Components/Materials.

Definition of Terms

Building Components/Materials: The term building components in this paper is used to refer to basic building elements i.e., doors, windows, furniture, sanitary fittings, electrical fittings, etc. While Building materials are used to refer to basic building construction materials i,e bricks, floor tiles, timber, steel, plumbing pipes, roof tiles, etc.

Indicators of Service: The quantification of the total impacts related to the performance of an item is given by service indicators of reliability, availability, and maintainability (Martini, 2023).

Availability: The proportion of time an item adequate level of service (Martini, 2023).

Reliability: The ability of an item to provide an adequate level of service (Martini, 2023).

Maintainability: The ease with which an item can be maintained (Martini, 2023).

Uncertainty: Those events that are impossible or difficult to predict (Martani et al., 2013).

Types of Reuses: (Gorgolewski & Morettin, (n.d.)).

On-Site Reused Component: Whole or individual components on a site example old brick.

Salvaged from other sites: Elements such as bricks, timber, and steel taken from other sites and used in another site (Usually local) require little reprocessing.

Reconditioned or Repurposed Components: Elements taken from demolition or construction sites to a new location require some improvements to be sold again, for example, doors, and windows.

Recycled Building Products: These are readily available building elements that include a significant amount of feedstock taken from demolition or construction, for example, gypsum boards, and steel components.

Background

Indicators of Service (IOS) (Reliability, Availability, Maintainability) of Reusable Building Components/Materials.

Buildings are meant to be for a long lifetime, the performance and the longevity of their elements are better known from the early stage, in terms of the indicators of service it would provide, and the durability of their elements which translates to their availability and reliability more also the maintenance attributes over its life span (Martani et al., 2013). The reliability, however, is also dependent on the Material's Conditional Probability of Failure, a condition state of the material after use for repurposed/recycled Materials (Mansour & Olsson, 2018). These criteria of durability and maintainability are very important when purchasing a new building material, but the argument remains the same for a recovered, or recycled building element (reusable building components or materials) (Rahla et al., 2021) is this information also obtainable? Waste is often perceived as items without information, and the same is the perception of construction or demolition waste from which these reusable materials are retrieved, of which many stakeholders (Architects, Builders, Engineers, Contractors, etc) in the context of Indonesia still doubt the durability and maintainability of reusable building elements (Citraningrum et al., 2023). The lack of trust or confidence in salvaged building elements can also be attributed to a lack of quality or performance certifications (Rakhshan et al., 2020). The underdeveloped reusable building components supply market especially in developing countries also contributes to this lack of confidence in reused building elements (Rakhshan et al., 2020). But how would there be development for possible information towards certifications when there are no procedures or modules for obtaining information on reusable building elements' indicators of service? A suggestion by (Gorgolewski & Morettin, (n.d.)) to include visual inspection, structural testing, and refurbishment of salvaged building components for functional and regulatory standards but still lack attributes on the components' indicators of service. Information like the IOS could become an integral part of reclamation audits, construction, and demolition waste audits (Morgane & Marilyn, 2020).

Maintainability Budget of Reusable Building Component/ Materials in its New Life Cycle.

Maintenance is an activity carried out to retain or restore a structure or an item to an acceptable standard. A maintenance budget can be referred to as financial planning to support the execution of maintenance operations (Ogunbayo et al., 2022). This activity is not well practiced in Developing countries, however, research by (Choka, 2012) emphasized on the importance of maintenance in the proclamation of green buildings in Kenya. It's important to note that maintainability is vital in the new life of reusable building components/ materials (Rahla et al., 2021), therefore requires extra attention (Citraningrum et al., 2023) of which knowing the financial budget required could be an extra attention based on the argument that the research project also aims to consider the aspect of affordability. This information would enable users and stakeholders to determine the budgeting even from the initial or design stage. In the case of reused elements, the feedback from their use and maintenance (Martani et al., 2013) during their previous life could be a guide to a possible future maintenance scheme in their new phase of life. Including for maintenance possibilities during the design stage could enable an ease of maintenance reducing unplanned cost and time during the life phase of the elements (Ganisen et al., 2015). The type of maintenance required in this case could be predictive, preventive, or condition-based maintenance (Bartlett & Simpson, 1998).

Considerable Variable Parameters when designing with Reusable Building Components/Materials.

Stakeholders (Architects, Design teams) with the intention of adopting circularity in their designs need to be wary of the time and cost involved. Adopting the use of reusable components/materials despite the possibilities of lower prices for reused materials, the time and effort required to source the materials, striving to obtain information for maintainability and procedures for grading their functionality could be time-consuming and costly (Gorgolewski & Morettin, (n.d.)). The design team or contractors would need to put extra effort into finding these reusable building components/materials, the design also needs to remain flexible, and it would be preferable to acquire the reused elements during the design stage (Rakhshan et al., 2020). With the uncertainties involved in designing with reusable building components/materials more especially the variable of acquisition or accessibility of the elements in a context like Kenya (a Developing African Country), it could be appropriate to adopt the suggestion by (Martani et al., 2013) by introducing a risk simulation tool as a decision guide during the design stage, provided the building design could be flexible or transitional. A tool that could enable the design team to understand the possible number of reused elements accessible (available) for the specific building design stages.

Table 1: Outline of Literature and Identified Research Gaps.

Indicators of Service (IOS) (Reliability, Availability, Maintainability) of Reusable Building Components/Materials.	
(Martani et al., 2013)	The reference did not give procedures for quantifying or managing individual building elements.
(Rahla et al., 2021)	No specific emphasis on how to quantify the longevity of selected building materials and components.
(Citraningrum et al., 2023)	Lack of outline to determine the performance level or reusability of recovered building elements.
(Rakhshan et al., 2020)	Lack of outline to determine the performance level or reusability of recovered building elements.
(Gorgolewski & Morettin, n.d.)	The author did not specify how the procedures of visual perception can enable defining a component level of service.
(Morgane D. & Marilyn M., 2020)	The report only emphasized the importance of supporting information for a reclamation, construction, or demolition audit.
Maintainability Budget of Reusable Building Component/Materials in its New Life Cycle.	
(Ogunbayo et al., 2022).	The reference outlined the importance of a maintainability budget for developing contexts like Nigeria but does not reveal any tool concerning a reusable building element.
(Choka, 2012)	The Author only reveals the importance of maintenance for future buildings in a Kenyan context.
(Rahla et al., 2021) (Citraningrum et al., 2023)	The references only reveal the importance of maintainability in the case of reusable building elements
(Martani et al., 2013)	The reference outlined ways of obtaining future maintainability information, but it's not related to reused material maintainability budgeting.
(Ganisen et al., 2015)	Stressed only the need for and importance of including maintainability in the design stage.
Considerable Variable Parameters when designing with Reusable Building Components/Materials.	
(Gorgolewski & Morettin, n.d.)	The reference presents a list of uncertain variables when designing with reused building elements, without prospect solutions.
(Rakhshan et al., 2020)	No consideration for possible risk factors comparing the building design with the accessibility of reused building elements.
(Martani et al., 2013)	The simulation was not intended for designing with reusable building components/materials.

Proposals

Proposal for Indicators of Service (IOS) (Reliability, Availability, Maintainability) of Reusable Building Components/Materials.

The Proposal tends to improvise a catalogue for information on these reusable components/materials to enable an approximation of their expected years of service to be provided after they are refurbished or repaired based on experience from previous materials.

The information catalogue would also take into consideration the remaining amount of time the product can provide adequate service (Reliability) from its manufactured date (End of its first life cycle).

In the case of reused building components i.e., windows, doors, or fittings the maintainability or the period of maintenance periods could be at intervals of i.e., every 5 years for a re-painting which takes not more than 2 days to complete. Perhaps how long it takes to complete the maintenance is less significant, but more significant is the frequency of the maintenance along its service life to enable the determination of the future of cost maintenance along its service life.

The Expected Level of service in its new life (Availability) would enable the determination of the reliable Service in its new life (reliability) after subtracting how long it will take in the frequency of its maintainability.

Another important point of consideration is the Conditional Probability of Failure, which depends on its condition after use (for reusable materials). This can be quantified using a Grading Scale from 1 to 5, indicating from a Very Low Conditional Probability of Failure (1) to a Very High Conditional Probability of Failure (5).

Proposal for a Maintainability Budget of Reusable Building Components/Materials in its New Life Cycle.

Assuming a reusable building component/material is in its New Life Cycle after R-actions of either being directly Recovered, Refurbished, Repaired, Repurposed, or Recycled from other elements, an estimated number of new year's life cycle is approximated followed by an approximated frequency for which the components could need to be maintained (i.e repainted). It would be of good interest for the stakeholders to have a financial budget or plan the cost of the component's future maintenance.

This scenario could be applicable to simple home design with a given number of Reusable building components.

Proposal for Considered Variable Parameter when Designing with Reusable Building Components/Materials.

The proposal for a simulation tool using the Monte Carlo Simulations.

Assuming, a Flexible, transitional design process for an affordable home for the lower income class in Kenya, which is intended to be built in phases incrementally with reusable building components/materials of doors, windows, plumbing fittings, etc. also taking into consideration the cost involved in acquiring these elements. The question of what number of reusable elements could be accessible to complete a given phase then that phase becomes the starting phase that would allow for further transition to other phases. To avoid mistakes from the concept of Flaws of Average that would only consider the most occurring probability from respondents (Martani et al., 2013) but could end up being wrong because it was only an analytical computation, it is possible to estimate this uncertainty with Monte Carlo Simulation which would use the respondent's probability distributions as input conditions for simulations. This is more reliable because it allows the estimating of outcomes of the multi-variable process. Which then allows the retrieval of the most viable outcome after multiple simulations.

Outlook

This chapter presents a critical overview of the proposal response to the identified research gaps. Revealing what has been covered and what could be covered in future studies.

Table 2 : Identifies the Proposal coverage, and Further studies.

Indicators of Service (IOS) (Reliability, Availability, Maintainability) of Reusable Building Components/Materials.	
The proposal in this paper was able to: Provide a catalogue for information on reusable building components materials. Provide a base upon which visual perception and experience could be translated into a figurative rating for the reused element's longevity and the conditional probability of failure. Provided a template for quantifying, qualifying, and managing individual reused elements in a building.	Other important areas for further studies could: A more accurate quantification of reusable element's longevity using material testing. Public opinion on the process of qualification for reusable building elements.
Maintainability Budget of Reusable Building Component/Materials in its New Life Cycle.	
The proposal on the Maintainability Budget was able to: Provide a template to actualize a possible maintenance budgeting when using reusable components/materials including a possible discount rate, and a provision to change the currency for different country contexts. Which could be used in the design stage and during the life of the building.	For further studies, it would be important to compare the maintenance budget of reusable building components and newly manufactured building components in a realistic project to compare the cost of the two cases.
Considerable Variable Parameters when designing with Reusable Building Components/Materials.	
The Simulation proposal was intended for the case of reusable building components/materials. When designing with these reusable elements in a transitional (Flexible) design which should be the starting phase, of which access to the required materials is viable, and which should be the next phase (level) considering the period to acquire the next phase of reusable elements.	Further studies could be for simulations on a non-transitional design, the time to obtain all required reusable elements. And a simulation on the most viable cost of achieving a transitional design for the lower-income class with reusable elements.

			FROM EXPERIENCE APPROXIMATION FOR REUSABLE BUILDING COMPONENTS/MATERIALS INDICATORS OF SERVICE (IOS)										
								Availability	Maintainabilty			Reliability	
Item I.D	Item Name	Original Manufactured Date	Manufactured Specified Longevity (Years)	Already lived Period End of First Life Cycle (years)	Remaining longevity from the First Life Cycle (years) (D - E)	R-Action performed on the Item	Approximation of New Life Longevity after R-Actions (Years)	Expected New Service Period (Years in days)(F + H *365)	Approximation for Maintenance frequency along its Service Period	Period for each Maintenance Work (Days)	Total Maintainaibility Period (J * K) (Days)	Expected Item Reliability Periods (days) (I - L)	Conditional Probability of Failure
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	
					0			0			0	0	

Figure 1: Excel Spreadsheet catalogue for reusable building elements information and Indicators of Service Approximation. Source: Author, Credits to (Martini, 2023).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Maintenance Operations			Maintenace Costs [€]	Freq. [year] along the item Years of Service	Uniform costs	1	2	3	4	5	6	7	8	9
#	Item Code	Item Name			(UPV)	2020	2021	2022	2023	2024	2025	2026	2027	2028
1	W1	xxx1	€ 36,919.00	23.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
2	W2	xxx2	€ 23,897.00	0.90	€ 26,552.22	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
3	W3	xxx3	€ 20,245.00	8.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ 20,245.00	€ -
4	W4	xxx4	€ 22,420.00	11.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
5	W5	xxx5	€ 24,793.00	10.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
6	W6	xxx6	€ 35,635.00	0.50	€ 71,270.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
7	W7	xxx7	€ 10,197.00	23.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
8	W8	xxx8	€ 10,627.00	15.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
9	W9	xxx9	€ 5,259.00	5.00	€ -	€ -	€ -	€ -	€ -	€ 5,259.00	€ -	€ -	€ -	€ -
10	W10	xxx10	€ 31,560.00	3.00	€ -	€ -	€ -	€ 31,560.00	€ -	€ -	€ 31,560.00	€ -	€ -	€ 31,560.00
11	W11	xxx11	€ 18,389.00	14.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
12	W12	xxx12	€ 19,672.00	28.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
13	W13	xxx13	€ 27,221.00	14.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
14	W14	xxx14	€ 6,049.00	0.12	€ 50,408.33	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
15	W15	xxx15	€ 31,386.00	4.00	€ -	€ -	€ -	€ -	€ 31,386.00	€ -	€ -	€ -	€ 31,386.00	€ -
16	W16	xxx16	€ 35,919.00	30.00	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
17	W17	pittura facciat	€ 24,055.00	5.00	€ -	€ -	€ -	€ -	€ -	€ 24,055.00	€ -	€ -	€ -	€ -
18	W18	rifacimento fa	€ 27,308.00	4.00	€ -	€ -	€ -	€ -	€ 27,308.00	€ -	€ -	€ -	€ 27,308.00	€ -
				Total yearly costs	€ 148,230.56	€ -	€ -	€ 31,560.00	€ 58,694.00	€ 29,314.00	€ 31,560.00	€ -	€ 78,939.00	€ 31,560.00
		Discount rate	6.00%	UPV	16.16									
				5	€ 2,395,617.41									
					SPV	0.94	0.89	0.84	0.79	0.75	0.70	0.67	0.63	0.59
				Actualized total costs (freq. > 1 year)	€ 617,899.65	€ -	€ -	€ 26,498.38	€ 46,491.15	€ 21,905.13	€ 22,248.55	€ -	€ 49,527.31	€ 18,680.32
				Total Maintenance costs (actualized)	€ 3,013,517.06									

Figure 2: Spreadsheet of Maintenance budgeting for possible reusable components to be used in building design or already installed in a building. Source: Retrieved from (Maltese, 2023)

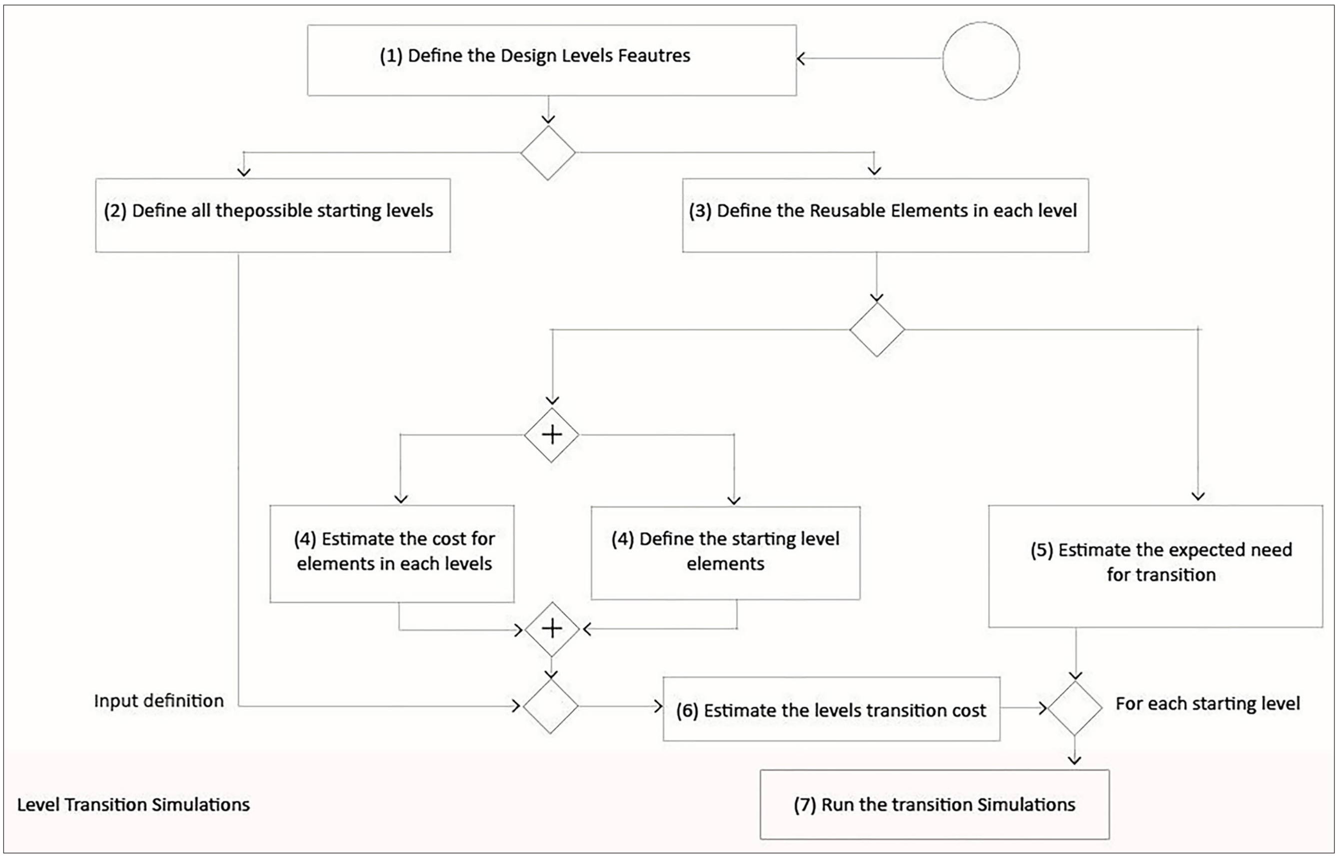

Figure 3: Possible Monte Carlo Simulation WorkFlow. Source: Author, credits: (Martani et al., 2018). (Maltese, 2023)

Conclusion/Recommendation

The uncertainty surrounding reusable building components/ materials is one that the approaches of the circular economy should also be concerned about. Especially in Developing countries where the motives to use reusable elements are based on cost motives. A level of information or level approximation on their expected indicators of service could boost confidence in reusing these elements. This would enable the approximation for a maintenance budgeting for adopted reused elements, the design team should also have to provide a level of certainty on the acquisition of required reused building elements early in the design stage. These could be achieved with the proposal outlined in this paper. However, it's important to have a legislative or regulatory standardization to support the information provided on the elements. Furthermore, it would be necessary to have further studies on a more accurate qualification of an element's longevity using laboratory testing procedures, getting stakeholder's opinions on the provision of information on reusable building elements, comparing the maintenance budget of new building elements and reusable building elements with real project scenarios, and simulation for a non-transitional design with reusable elements based on the time it will take to obtain the required reused elements and the cost viability for a lower class income (affordable Home) transitional design using reusable building elements.

References

1. Chen, Q., Feng, H., & De Soto, B. G. (2022). Revamping construction supply chain processes with circular economy strategies: A systematic literature review. *Journal of Cleaner Production, 335*(1), 130240. DOI: http://dx.doi.org/10.1016/j.jclepro.2021.130240
2. Rakhshan, K., Morel, J. C., Alaka, H., & Charef, R. (2020). Components reuse in the building sector – A systematic review. *Waste Management and Research, 38*(4), 347–370. DOI: https://doi.org/10.1177/0734242x20910463
3. Citraningrum, A., Iyati, W., & Wardoyo, J. (2023). Sustainability Through Reuse of Materials and Components in Buildings: An Indonesian Perspective. *Proceedings of the 2022 Brawijaya International Conference* (BIC 2022), 242–251. DOI: https://doi.org/10.2991/978-94-6463-140-1_24
4. Martani, C., Paganin, G., & Talamo, C. (2013). The control, at the design stage, of risks related to buildings management over time. *TECHNE-Journal of Technology for Architecture and Environment*, 6, 109-116. DOI: https://doi.org/10.13128/Techne-13463
5. Gorgolewski, M., & Morettin, L. (n.d.). The Process of Designing with Reused Building Components. 105-109. Retrieved from https://www.irbnet.de/daten/iconda/CIB14291.pdf
6. Mansour, R., & Olsson, M. (2018). Efficient Reliability Assessment with the Conditional Probability Method. *Journal of Mechanical Design, 140*(8). DOI: https://doi.org/10.1115/1.4040170

7. Rahla, K. M., Mateus, R., & Bragança, L. (2021). Selection Criteria for Building Materials and Components in Line with the Circular Economy Principles in the Built Environment—A Review of Current Trends. *In Infrastructures, 6*(4). DOI: https://doi.org/10.3390/infrastructures6040049
8. Morgane D. & Marilyn M. (2020). A guide for identifying the reuse potential of construction products. Retrieved from http://www.nweurope.eu/fcrbe
9. Ogunbayo, B. F., Aigbavboa, C. O., Thwala, W. D., & Akinradewo, O. I. (2022). Assessing maintenance budget elements for building maintenance management in Nigerian built environment: a Delphi study. *Built Environment Project and Asset Management, 12*(4), 649–666. DOI: https://doi.org/10.1108/BEPAM-06-2021-0080
10. Choka, D. G. (2012). University of Nairobi school of the built environment department of real estate & construction management a study on the impact of maintenance management systems on maintenance condition of built facilities (case study of public universities in kenya) a research project submitted in partial fulfillment of the requirements for Master of Arts degree in construction management chapters outline 1. Introduction and problem statement.
11. Ganisen, S., Mohammad, I. S., Nesan, L. J., Mohammed, A. H., & Kanniyapan, G. (2015). The identification of design for maintainability imperatives to achieve cost effective building maintenance: A delphi study. *Jurnal Teknologi, 77*(30), 75–88. DOI: http://dx.doi.org/10.11113/jt.v77.6871
12. Bartlett, E. V, & Simpson, S. (1998). Durability and Reliability, Alternative Approaches to Assessment of Component Performance Over Time. Retrieved from https://www.semanticscholar.org/paper/%E2%80%9C-Durability-and-Reliability-%2C-Alternative-to-of-%E2%80%9D-Bartlett/3120a973b4cffb9f84f49d782ac6edbf3760710c
13. Martani, C., Cattarinussi, L., & Adey, B. T. (2017). A new process for the evaluation of the net benefit of flexible ground-floor ceiling in the face of use transition uncertainty. *Journal of Building Engineering*, 15, 156–170. DOI: http://dx.doi.org/10.1016/j.jobe.2017.11.019.