ISSN: 2524-1354 (Online), ISSN: 2519-7851 (Print)
Africa Habitat Review Journal
Volume 19 Issue 3 (December, 2024)
http://uonjournals.uonbi.ac.ke/ojs/index.php/ahr

Construction Timber Waste Management as a Circular Economy Resource:
A Case of Affordable Housing in Kenya

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Received on 26th August, 2024; Received in revised form 15th October, 2024; Accepted on 5th November, 2024.

Abstract

Construction projects are key economic stimulus with creation of jobs and attraction of investors. These projects suffer inefficiencies and under-utilization of resources. Timber is one of the key inputs for construction projects that if not properly managed results in project failure. This study adopted a cross-sectional survey design and targeted a sample of 73 project managers in six affordable housing projects located in Nairobi and its environs. Stratified sampling technique was applied by grouping the respondents as per project. A drop-and-pick later technique was used to collect data; thereafter appropriated statistical techniques such as regression and correlation were conducted to validate the hypothesis. The study established that technical, organizational, social, legal and environmental factors had positive influence on construction timber waste management in affordable housing projects in Nairobi. The study further established that proper community engagement especially employing the gender card in construction timber waste management contributed towards success and sustainable construction projects. The study recommended adoption of modular construction methods for mass production of affordable housing units, use of design visualization tools e.g. BIM, industry regulators such as NEMA and NCA to conduct capacity building programs on need and methodologies for sustainable construction, promote gender equity on construction sites, enhance management controls for timber products procurement and finally legislation & enforcement of policies on accessibility and proximity to government recycling facilities.

Keywords: Circular economy, timber waste, waste management, affordable housing, sustainable construction

INTRODUCTION

Construction industry is important in economies worldwide due to its contribution to nation building through industrialization, job creation FDI attraction, enhanced livelihood for citizens and provision of essential facilities. Globally, the construction output has been on the rise in the recent decades and is expected to reach US$ 15.2 trillion by 2030. Africa case is no different with economies such as Nigeria, Ghana, Ethiopia, Tanzania, Mozambique and Kenya having seen a similar trend with increments of between 1.5% - 4.1% in its GDP from construction. Durdyev and Ismail (2022) indicated the sector is significant in economic growth because of it highly visible output which stimulates economic growth through intersectoral linkages with other sectors.

In Kenya, KNBS (2023) reported that the sector has seen boon of activities post COVID-19 period. The growth being attributed to the 58% increase in new buildings and 7.7% increase in government investment in roads. Kenya's strategic plan anchored in the vision 2030 focuses on provision of decent and affordable housing (GOK, 2023). In the last three midterm implementation plans (MTP 1, MTP II and MTP III) the sector has experienced a drib and drab growth. Despite various interventions the housing sector features low home ownership ratings (Giti, Kakumu & Oyaro, 2022). The recent approval of the Housing Levy paved the way for establishment of a housing fund that will bring cashflow needed by government to finance the program (Muiruri, 2023). In the 2023-24 budget

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paper, the government has committed KES 35.2 billion towards the AHP, with target of achieving 200,000 units annually. The government has so far commissioned 7No. AHP projects across the country that are set to produce 31,990 units. The affordable Housing Program is designed to promote the growth and development of hustler investments, Jua kali industry and MSMEs as this is key plank for BETA the current blueprint for national development. This unique component of involving MSME in AHP projects brings a new perspective given the views of (Wei, Zhang & Sang, 2023) regard their enthusiasm to construction waste management.

THEORY

Construction Waste

The issue of construction waste has attracted global attention due to its catastrophic impact to the environment. In China which deemed as global leader in construction, an estimated 2.4billion tons of construction waste is generated annually accounting for 30% - 40% of municipal waste (Hao, Chen, Bao & Xing, 2018). It is also estimated that buildings generate up to 33% of the greenhouse gases (GHG) emissions of which timber and packaging contributed 33% and 31% respectively of the total. Lau, Whyte and Law (2008) concur with CDM (1998) that major sources of construction waste are similar in commercial and residential projects. Timber waste is the largest portion with an estimated 40% of the total construction waste. Poon, Yu and Jallion (2004) concur that timber occupies the largest percentage of construction waste especially in the cast in-situ projects.

The situation is not any better in Kenya with an estimated 25% of municipal waste in Dandora dumpsite attributed to construction waste (Tanui, 2019). The government through NEMA, NCA and county government has instituted several regulations to mitigate solid waste pollution. Globally renowned strategies such as reducing, reusing, replacing and recycling are now being adopted in local projects especially in the affordable housing projects where prefabricated technologies are being encouraged (GoK, 2019, & Cytonns, 2022).

The NCA recommendations from its recent study to develop a construction and demolitions waste strategy that promotes the circular economy model (NCA 2021). The model works by attaching financial value to waste. A financial value can be attached to waste generated as a means of mitigating GHG emissions through emission trading (ETS) or contractors can repurpose waste creating a financial value along the lifecycle of the construction material (Hughes, 2019). In their paper, Daian and Ozarska (2009) found that MSMEs ignore timber waste management strategies because of lack of knowledge, awareness and understanding on cost-benefit and value of recycling waste. This study therefore contextualizes the factors that influence construction timber waste management in affordable housing projects in Nairobi Kenya.

Construction Timber Waste Management in a Circular Economy

Construction timber waste generated during construction, demolition, restoration or remodeling can be categorized into three types; untreated timber, engineered timber and painted timber waste. (FEON, 2023). Furthermore, Israt, Guomin, Muhammed, Bhuiyan and Satheeskumar (2022) in their study on circular economy of timber waste noted the following physical forms of timber waste in buildings projects; offcuts, shavings, sawdust, framings, anchors, chippings, slab mouldings and timber props. These were found in varied sizes and particle texture.

Timber has found preference in construction of buildings in the recent past because of various reasons including; low carbon footprint compared to alternative construction materials, long shelf life if well treated, extensive carbon sink among other reasons (Meso, 2022). Timber products are perfectly placed to contribute to circularity. Timber is recycled and used in production processes as a composite material. Recycling and reusing timber increase economic as well as environmental gains to the sector. The circular economy then emerges as a prominent concept applicable to construction projects decoupling economic profit from resource depletion or environmental degradation (Mohsen et al., 2023). It also helps in maintaining the environment and enables regeneration of resources for the production process (Maier, 2022). The **Figure 1** adopted from Maier (2022) shows circularity concept for timber as a construction material.

FIGURE 1
Timber and construction material in a circular economy
Source: Maier, 2022

In this context, construction timber waste management focuses on eliminating waste or reducing the amount of waste generated or reusing waste materials or even recycling waste. The broad intent is minimizing timber waste materials finding their way into landfills or municipal waste stations. Responsible management of construction timber waste is vital for feasible resource management to achieve sustainable buildings (Ajayia et al., 2015). Many researchers have shown concern on waste management leading to various environmentally friendly strategies. Waste and resource action programme a UK no-profit organization in their 2015 action plan noted that waste management is a responsibility that is shared among all stakeholders starting from the client, suppliers, contractor and even the project management team. It further identifies the client as the core to proper waste management practice in the project. A study carried out in Malaysia by Nagapan et al., (2012) identifies causes of construction waste to fall in the following categories; design, workers, management, procurement, site conditions, handling and other external factors. In building construction projects several factors will influence the generation of timber waste linked to different causes. Agyekum, Ayakarwa and Adjei-Kumi (2013) collated some cause of construction waste from the four key sources in a building construction project as shown in **Table 1.**

Overview of Factors that Influence Construction Timber Waste Management

Literature review identified 19 factors that influence construction timber waste management in construction sites. Exploratory factor analysis was then used to reduce data to a smaller set of summary variables whilst exploring the underlying theoretical structure of the phenomena. The four exploratory factors established; technical, legal & environmental, organizational and socio-economic are detailed in **Table 2**.

RESEARCH METHODS

The study assesses factors that influence construction timber management in affordable housing construction projects. A cross-sectional survey design involving data collection and analysis of data from a population at one specific time was employed. Data collection was carried out within the period of December, 2023 and

TABLE 1
Causes of construction waste

Design	Operational	Material Storage and Handling	Procurement
Lack of attention to dimensional coordination of products	Errors by tradesmen	Damages during transportation	Ordering errors
Changes made to design while construction in progress	Accidents due to negligence	Damages due to inappropriate storage	Lack of possibilities to order small quantities
Designer inexperience in method and sequence of construction	Damage to work done caused by subsequent trades	Materials supplied in loose form	Purchased product/ materials not meeting specification
Lack of attention on standard sizes available in the market	Repetitive work due to use of incorrect materials	Use of whatever material close to working place	
Designer unfamiliarity with alternative products	Unclear required quantities due to improper planning	Unfriendly attitudes of project team and operatives	
	Equipment malfunctioning		

Source: Agyekum et al., 2013

TABLE 2
Factors influencing construction timber waste management

Item	Variable	Factors influencing Construction Timber Waste Management
	Technical factors focus on the usage, processes and operations that are involved with technical aspects of timber waste management.	1. Choice of technology to construct the AHP project influences the waste management system. Hao et al. (2018) noted an average of 70% waste reduction with application of prefabrication & modular construction. 2. Accurate grading of construction timber giving detailed data of fibre orientation and location of knots was found to reduce waste wood cut-off prior to finger jointing for long members (Olsson, Briggert, & Oscarsson, 2019). 3. Waste timber grading is vital for efficient recycling and ensuring wood is repurposed in the most appropriate manner (ETM, 2023) Contaminants such as paints, varnishes, preservatives, nails, staples among others hinder the recycling process and require additional treatment which is costly 4. In the AHP project risk of replication of design error is costly as units are done en-masse. Agyekum, et al. (2013) notes designer experience in the method and sequence of construction is key in waste management. 5. Cousins, (2023) opines that comprehensive information modeling and visualization of designs helps in decision making on materials requirements, constraints and site challenges in a manner to reduce waste. 6. Ikau et al. (2016) considered the most important factor in procurement of material as the purchase of materials. The compliance to specification was found to impact heavily on waste reduction.
	Socio-economic factors are the multidimensional construct comprising multiple factors regarding the societal standing both social and economic.	7. According to Nagapan et al (2012), in Malaysia, many projects are reported as abandoned due to cost and time overruns and is linked to poor management of finances and wrong specifications. Thus, failure of projects indirectly stems from waste from materials, non-physical materials and resource wastages. 8. Menegaki and Damigos (2018) identified a bad perception of ineffectiveness of waste management practices leading to the workers not willing to recycle or reuse waste that has no economic value. The situation worsens when considering demolition wastes.

Item	Variable	Factors influencing Construction Timber Waste Management
		9. Ektewan (2012) found that with financial incentives, stakeholders are encouraged to better manage wastes by recycling and reusing construction wastes. 10. Esposito (2021) notes that there is limited marketplace for reclaimed timber due to the inherent high-level of contamination. The contamination levels compounded with other factors such as availability of power, access roads and proximity to recycling plants impacts the recovery costs. (Agyekum, et al., 2013) 11. Abarca-Guerrero et al. (2017) indicated that social, cultural and lack of awareness of eco-friendly and sustainable construction impede efforts for better timber waste management in construction sites. 12. According to Menegaki and Damigos (2018) found that gender equity has direct influence and women in construction are generally more aware and conscious about waste and abiding in waste management practices.
	The organizational factors refer to the organizational characteristics (such as safety culture), the management activities (such as safety leadership and safety training) and the human interaction such as safety communication and team management (Liu et al., 2023).	13. Nagapan et al (2012) identified poor planning and control by project management team as a key contributor to construction waste generation. 14. According to Manowong (2017), variance in availability and application of laws and regulations for construction waste management had an influence on the specific strategies initiated in sites. 15. Saadi, et al. (2016) noted that attitudes and other behavioral factors of people in construction site informed waste management practice in Malaysia. Further, they noted that the attitude of the contractor in regard to managing construction wastes, dictated the individual behavior of construction workers.
	Legal & Environmental factors are the aspects anchored on the legal framework that influence waste management practices (Agamuthu, 2008)	16. Manowong (2017) found that inadequacies in the existing legal framework caused legal barriers that hamper waste management. 17. Dania et al. (2008) noted that government failure to implement policies regulating management of wastes had influence on the knowledge and skills of construction workers on managing waste on site. Further, it led to contractors focusing on project delivery with little concern on environmental issues. 18. Haregu et al. (2017) revealed the presence of weak institutional capacities, structures and enforcement measures in existing waste management policies resulting in poor and ineffective waste management. 19. Gichamba and Kithinji (2019) found that there is significant importance for instituting appropriate laws and regulations regarding construction waste due to the benefits they offer to the projects

Source: Author, 2024

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January, 2024. A comprehensive literature review identified 28 factors that influence construction timber waste management practices in AHP projects with Nairobi City County. The following research questions guided this research:

1. How do technical factors influence construction timber waste management in AHP within Nairobi City County?
2. How do socio-economic factors influence construction timber waste management in AHP within Nairobi City County?
3. How do organizational factors influence construction timber waste management in AHP within Nairobi City County?
4. How do legal & environmental factors influence construction timber waste management in AHP within Nairobi City County?

The respondents in this study were as stratified sample of 90 management staff (at least 3 staff) from construction firms engaged in the AHP projects within Nairobi City County as documented by the State department of Housing and Urban (SDHUD) as of December 2023 (**Table 3**).

The study employed structured questionnaires containing close-ended questions and multiple-choice questions. The influence was rated on a 1–5-point scale to capture both quantitative and qualitative information, where 1 means not affected, and 5 means very highly affected. The self-administered questionnaires were issued to a sample of 73 respondents that were randomly selected from a pool of 90 project management team members. Random selection was used because it was assumed that all the respondents had an understanding of the construction process and thus had an equal chance of inclusion to participate in the study. The response rate was recorded at 92% after receiving 67 complete questionnaires, which met the threshold of 75% and above, which has been set by many researchers. The preliminary section of the questionnaire collected data on the respondents' background information, while the other parts were designed to consider the aim of the study. Descriptive statistics such as mean, standard deviation, and frequencies were used to interpret the results. Further, inferential statistics was performed to establish relationships among the variables.

RESULTS

Respondent's Profile

The demographics showed that 92.54% of the respondents were male, and 7.46% were female indicating that the male gender highly dominates the AHP projects. distribution of respondents based on their roles revealed a majority were architects (30%) followed by project construction managers (22%) engineers (21%) while quantity surveyors (15%) and finally project developers (12%). A majority constituting 30%, had 6 to 10 years of experience in the construction industry, while the minority, 7%, had 0 to 5 years of experience (**Figure 2**).

Status of Construction timber waste management practice

The respondents were asked to affirm the elements of construction waste management being implemented at the AHP projects within

TABLE 3
Target Population

	Management Staff	Percent
Pangani Affordable Housing Project	12	13.3%
Starehe Affordable Housing Project	18	20.0%
Marigu-ini Informal Settlement	13	14.4%
Kibera Soweto East Zone B	16	17.8%
Park Road Ngara Housing Project	17	18.9%
Shauri Moyo Housing Project	14	15.6%
Total	**90**	**100.0%**

Source: Author, 2024

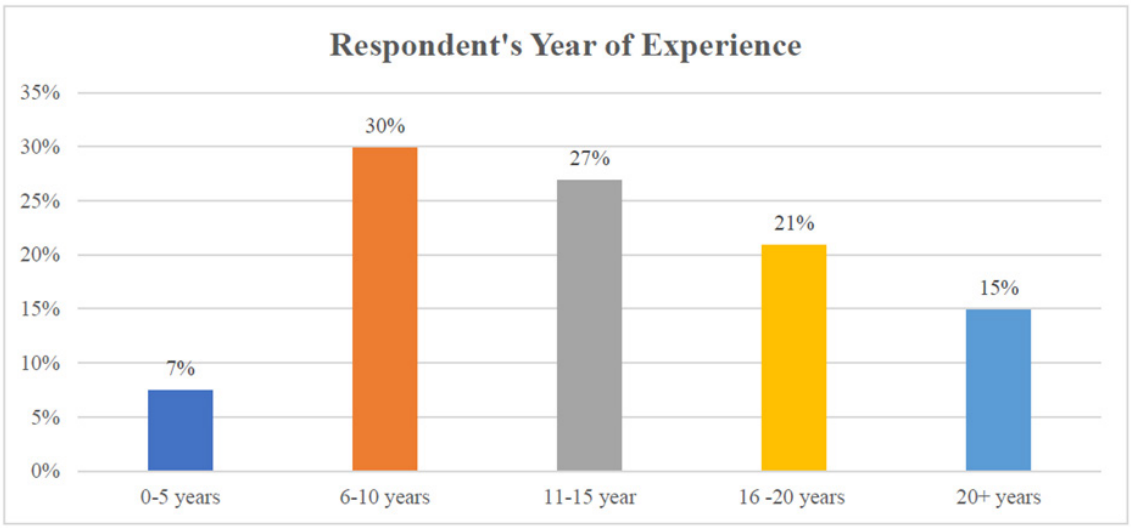

FIGURE 2
Distribution of respondents based on the individual years of experience
Source: Author, 2024

Nairobi City County and environs (**Table 4**). From the findings, the reuse of timber across different construction phases ranked highest, with a M=3.89, SD=0.93). This was followed by increased recycling measures for timber waste (M=3.79, SD=0.87) and a focus on elimination of timber waste at design at (M=3.78, SD 0.83). Timber waste is grading for sale to individuals waste processor such as for firewood was at (M = 3.69, SD = 0.82) while institution of construction processes that provide for reduced creation of timber waste was the lowest at (M=3.5, SD 1.15).

Factors that Influence Construction Timber Waste Management

A review of the literature identified 28 factors clustered into technical, organizational, socio-economic, legal & environmental that could influence construction timber waste management practices in AHP projects. Respondents (project management team members) were invited through a questionnaire to rate on a scale of 1-5, where 1 represented 'not affected' while five represented 'very highly affected'. The information was analyzed, and mean and standard deviation was presented. As rated by the respondents, the

TABLE 4
Implemented construction waste management practices at the AHP project in Nairobi City County

Elements	N	Minimum	Maximum	Mean	Std. Deviation	Rank
The timber is reused across the different construction phases	62	2	5	3.8871	0.92515	1
There is increased recycling measures for construction timber wastes	62	1	5	3.7903	0.87097	2
AHP construction sites focused on elimination of timber waste at the design stage	63	2	5	3.7778	0.83172	3
Timber waste is graded for resale to other sites or individual waste processors				3.6935	0.82161	4
AHP construction processes has seen a reduction in the creation of timber waste				3.5085	1.15031	5

Source: Author, 2024

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average mean was 3.79 indicating that generally the four adapted and implemented factors significantly influenced construction timber waste management practices. Organizational factors had a mean of (3.932) which was the highest influence factor followed by socio-economic (3.7985), technical (3.5896) and lastly (legal & environmental factors (3.5597) (**Table 5**).

The findings further highlighted the various sub-factors affecting timber waste management in construction projects under the AHP framework **Table 6.** The highest-ranked factor indicates strong agreement that AHP has control measures for proper timber waste management (M = 4.81, SD = 1.68). Workers' reluctance to recycle wood products also scored highly (M = 4.15, SD = 0.81), suggesting a significant barrier to waste management efforts. Prefabrication and enforcement mechanisms were similarly rated (M = 4.13, SD = 1.00 for both), demonstrating their importance in managing timber waste. Despite the presence of experienced designers and government laws, their effectiveness appears to be slightly lower (M = 4.02, SD = 1.05 for both). High recovery costs (M = 3.89, SD = 0.93), the need for better guidelines (M = 3.86, SD = 1.35), and the modelling of construction processes (M = 3.79, SD = 1.05) also influence timber waste management, although to a lesser extent. Cultural factors (M = 3.79, SD = 0.87), legal framework issues (M = 3.79, SD = 1.05), and a lack of awareness among clients and workers (M = 3.78, SD = 0.83) further impede effective waste management.

Discussion of findings

The regression analysis revealed that technical factors had positive significant impact on construction timber waste management practices. These findings imply that deployment of advanced technical aspects in relation to handling timber material can enhance management of timber waste in the construction industry. These findings are in line with Proud (2022) revealing the need of grading as an important process in segmenting timber natural variability into groups of set characteristics. Olsson et al. (2019) argues that accurate grading of construction timber and giving detailed data of fibre orientation and location of knots reduced waste wood cut-off prior to finger jointing for long members.

The organization factors were also found to significantly impact construction timber waste management practices. These findings allude that organization structure in a construction project has an impact on management of construction timber waste practices. These findings align with Manowong and Brockmann (2011) who revealed that contractors management strategies with a play a significant role in reducing timber waste.

Additionally, legal and environment factors significantly affected construction timber waste management practices. The findings allude that proper governing laws and policies on recycling and disposal of waste can improve management of construction timber waste. These findings connect with Manowong and Brockmann (2011) report which uncovers that sufficient legal framework has positive implication on management of construction waste materials.

The analysis further revealed that socio-economic factors had a significant impact on construction timber waste management practices. These findings infer that proper community engagement in matters related to waste management can contributes towards suitable waste management practices. For instance, the issue of gender also has a part to play in influencing waste management. According to Menegaki and Damigos (2018)

TABLE 5

Descriptive statistics showing how the different factors were rated

Level of influence (scale of measurement = 1- 5)	Mean	Standard deviation
Organizational factors	3.9328	0.83
Socio-economic factors	3.7985	1.19
Technical factors	3.5896	1.31
Legal & Environmental factors	3.5597	0.88

Source: Author, 2024

TABLE 6
Factor analysis on the Sub-factors impact on timber waste management in AHP construction projects

Factors	N	Mean	Std. Deviation	Rank
Organizational policies for construction timber waste management	59	4.81	1.68	1
Willingness of demolition workers to recycle timber products	62	4.15	0.81	2
Choice of technology to construct AHP project	64	4.13	1.00	3
Institutional capacity for enforcement of CDWM policies and regulations	64	4.13	1.00	4
Designer experience on methods and sequence of construction	64	4.02	1.05	5
Existence of laws guiding the management and handling of construction wastes	64	4.02	1.05	6
High recovery costs of waste from the construction to recycling facility	62	3.89	0.93	7
Existence of organizational guidelines on waste management	59	3.86	1.35	8
Adequacy of building information modelling in the project	66	3.79	1.05	9
Cultural considerations	62	3.79	0.87	10
Insufficient or impractical policies in management of construction wastes	66	3.79	1.05	11
Developer & workers awareness level for eco-friendly and sustainable building construction	63	3.78	0.83	12
Project managers compliance to specification during procurement	64	3.77	1.34	13
Adequacy of project delivery objectives	64	3.77	1.34	14
Lack of specific regulations for construction timber waste management	62	3.69	0.82	15
Use of design replication (type designs) across AHP projects	64	3.69	1.08	16
Financial incentives to encourage timber waste recycling/reusing	62	3.69	0.82	17
Organizational policies on gender equity	64	3.69	1.08	18
Adequate infrastructure for waste separation and grading	57	3.68	1.38	19
Organizational policies for construction timber waste minimization	59	3.66	1.30	20
Adapting the existing legal framework in organizational policies for on reducing/recycling waste	59	3.66	1.37	21
Organizational policies on use/reuse of timber waste	59	3.53	1.49	22
Poor management of project finances	59	3.51	1.15	23
Organizational policies on construction timber handling	59	3.31	1.34	24
Worker training on recycling/reusing waste for economic value gains	61	3.21	1.45	25
Accurate grading of construction timber	60	3.10	1.29	26
Organizational policies on waste timber grading	58	2.76	1.33	27
Project managers attitude towards construction timber waste management	58	2.76	1.33	28

Source: Author, 2024

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gender equity has a direct influence on construction waste management efforts. The researchers found that women who are in the construction industry are generally more aware and conscious about waste and abiding in waste management practices.

CONCLUSION AND RECOMMENDATIONS

This study contributes to the ongoing discourse on the application of construction timber as a circular economy resource by bringing to life the factors that influence timber waste management. The findings reveal that technical, organizational, socio-economic, legal and environmental factors significantly influence construction timber waste management in different ways.

Under the technical factors, the following are the highly influencing factors: choice of technology to construct AHP project, Designer experience on methods and sequence of construction, Adequacy of building information modelling in the project, Project managers compliance to specification during procurement and Use of design replication (type designs) across AHP projects.

The following are highly influencing factors under organizational factors: the organizational policies on construction timber waste management, waste minimization & gender equity, adequacy of infrastructure for timber waste separation and grading, contractors skewed project delivery objectives.

The most influencing factors under the social economic were attitude of demolition workers towards recycling, high recovery costs for waste, developer awareness level of eco-friendly construction and financial incentives for good waste management practice.

The most influential factors under legal and environmental include institutional capacity for government to enforce regulations and policies on timber waste management, adequacy and practicality of existing regulations on construction waste management and lack of a specific regulation for construction timber waste management.

These factors are important to enhance construction timber waste management in affordable housing construction projects with a focus of adopting construction timber as a circular economy resource. The findings of this paper should serve as a practical and significant guide for the construction industry stakeholders and policymakers to realize construction timber is an important resource in circular economy within the construction industry and, more specifically, institution of the necessary safeguards to save the environment. In concurrence with Ayemba, D. (2022, May 24) and Hao et al. (2018) this paper recommends the adoption of modular construction methods for mass production of affordable housing units, use of design visualization tools e.g. BIM, industry regulators such as NEMA and NCA to conduct capacity building programs on need and methodologies for sustainable construction, promote gender equity on construction sites, enhance management controls for timber products procurement and finally legislation & enforcement of policies on accessibility and proximity to government recycling facilities.

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