Breaking Barriers: Enhancing Construction and Demolition Waste Management in Egyptian Residential Projects

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Abstract

Integrating sustainability principles in all stages of construction decision-making is crucial for achieving optimal benefits while maintaining the functionality of residential projects. However, limited research has focused on identifying and analyzing primary barriers to effective construction and demolition waste management (C&DWM) in Egypt's residential construction projects and their impact on sustainable waste management practices. This study aimed to address the question: "What barriers impede the implementation of C&DWM in Egyptian residential projects?" Previous research highlighted general barriers to C&DWM, which were contextualized using a questionnaire survey in the Egyptian building sector. The survey targeted industry practitioners in Egypt, specifically those working in various construction companies with expertise in construction management or civil engineering. The survey received responses from 90 out of 120 participants, resulting in a high response rate of 75%. The exploratory factor analysis (EFA) reveals that barriers to C&DWM can be classified into four distinct constructs: culture, resources, efficiency, and procurement. These constructs were integrated into a model using partial least squares structural equation modelling (PLS-SEM). The findings underscore that cultural barriers emerge as the primary hindrance to effective C&DWM implementation, whereas procurement barriers were found to have the least impact. This study makes a substantial academic contribution by providing empirical evidence on the classification and impact of various barriers to C&DWM in a developing country context, specifically Egypt. It introduces a novel application of PLS-SEM to model the relationships between cultural, resource, efficiency, and procurement barriers and their effect on C&DWM implementation. Furthermore, the study offers practical insights and actionable recommendations for policymakers and industry practitioners in developing nations, emphasizing the need for targeted strategies to address these identified barriers. The methodological approach and findings of this study fill a significant gap in the existing literature and can serve as a reference for future research in similar contexts, contributing to the broader discourse on sustainable construction management.

Keywords: sustainability, construction and demolition waste management, barriers, Egypt, developing nations.

1 Introduction

As the global population continues to expand, there is an increasingly urgent demand for the development of civil infrastructure and buildings to satisfy housing needs. The construction sector, currently accounting for approximately 13% of the world's GDP, is projected to increase to 14.7% by 2030. However, alongside its economic advantages, this growth places substantial environmental strains due to issues such as resource depletion, CO2 emissions, and the generation of landfill waste (Ali et al., 2022).

Construction and Demolition Waste (C&DW) encompasses waste generated from the construction, renovation, and demolition of buildings and other structures (Doan and Chinda, 2016). It constitutes a significant proportion of the waste that ends up in landfills (Wu et al., 2016), leaving lasting impacts on the local ecosystem (Yuan and Shen, 2011). Yahya and Boussabaine (2006) argued that between 20% to 30% of construction materials' total weight is lost during the construction phase. Subsequently, a substantial volume of these materials is disposed of in landfills after the buildings or facilities have outlived their usefulness (Wu et al., 2016; Lu et al., 2011a).

The economic consequences of such resource wastage are substantial (Dajadian, 2014), given that construction materials represent 40% of the global economy's material flow (Reza et al., 2011). Effective management of C&DW is crucial to mitigate these impacts both environmentally and economically (Ding et al., 2016a). The literature underscores multiple benefits of C&DW management (Doan and Chinda, 2016), including significant cost savings on construction projects where material costs typically account for 50-60% of total expenditures (Khanh and Kim, 2015). Moreover, managing C&DW reduces disposal fees and conserves vital landfill capacity (Hao et al., 2008), while also potentially lowering energy consumption, CO2 emissions, and environmental risks associated with waste management (Reza et al., 2011).

Despite its potential benefits, effective waste management remains a significant challenge in the construction sector of developing nations like Egypt (Manowong, 2012). Egypt's building industry confronts substantial issues related to construction material waste (Garas et al., 2001). C&DW often ends up on roadways and in facilities lacking proper management infrastructure. Many landfills in Egypt are hazardous and lack protocols to prevent waste self-ignition, leading to heightened environmental contamination (Abdelhamid, 2014; Azmy and El Gohary, 2018). The biodegradation of C&DW in these landfills further exacerbates severe environmental and health concerns (Azmy and El Gohary, 2018), negatively impacting the efficiency, value, effectiveness, and profitability of construction enterprises. Additionally, C&DW imposes detrimental effects on national economies (Memon et al., 2015).

Residential construction in Egypt has experienced a significant surge in recent years, propelled by urban development initiatives aligned with Egypt's Vision 2030. However, the saturation of available areas for accommodating population growth has contributed to the deterioration of urban environmental quality, resulting in challenges such as pollution, congestion, and the depletion of green spaces. In response, the government has embarked on decentralization efforts by establishing new communities and cities across Egypt. Notable projects include the National Project for the Development of Sinai, the New Administrative Capital, and others aimed at mitigating these urbanization-related issues (Daoud et al., 2018a) (Daoud et al., 2018b).

This study addresses a significant gap in the literature by investigating the specific barriers to C&DW management within Egyptian residential construction. Existing global research has identified common barriers, but there is a dearth of literature focusing on the unique context of Egypt. A comprehensive understanding of these barriers is essential for devising customized strategies aimed at improving waste management practices, advancing sustainability goals, and fostering the development of Egypt's construction sector.

To bridge this research gap, the study aims to identify the most significant barriers hindering the implementation of effective C&DW management practices in Egyptian residential projects and provide mitigation strategies. This aim can be achieved through the following steps: (1) Employing a comprehensive literature review to identify various barriers; (2) Conducting a questionnaire survey with industry professionals to rank these barriers; (3) Applying EFA to categorize the different variables; and (4) Using PLS-SEM to examine the impact of various barriers on effective waste management practices. This unique approach contributes a novel aspect to the research, specifically tailored to the context of Egypt.

This study offers an innovative contribution to construction management in Egypt by identifying and understanding barriers to C&DW management in building projects. Employing PLS-SEM to construct a mathematical model is novel in Egypt and promises valuable insights into mitigating these barriers and improving C&DW management practices. The findings will benefit managers, engineers, researchers, and senior management by highlighting critical barriers that need addressing for successful implementation.

2 Literature review

2.1 Barriers Related to Culture

Cultural barriers in construction and demolition waste management (C&DWM) are significant and multifaceted, often deeply embedded in the attitudes and practices of industry stakeholders. One of the primary cultural barriers is the lack of awareness and education regarding sustainable waste management practices. Many construction workers and managers in developing countries, including Egypt, are not adequately trained in effective C&DWM strategies. This knowledge gap leads to poor implementation and adherence to sustainable practices, as workers are not fully aware of the environmental and economic benefits of waste reduction (Ajayi et al., 2016). Without comprehensive training programs and educational initiatives, the construction industry will continue to struggle with waste management inefficiencies.

Moreover, the attitudes of construction workers towards waste reduction significantly impact the success of C&DWM initiatives. In many cases, there is a general apathy towards waste management, with workers prioritizing project completion over sustainable practices. This is particularly evident in developing countries where rapid urbanization and economic pressures demand quick project turnarounds, often at the expense of environmental considerations (Begum et al., 2009). Changing these attitudes requires a cultural shift within the industry, emphasizing the importance of sustainability and its long-term benefits.

Project timelines often exacerbate cultural barriers, as tight scheduling prioritizes rapid project completion over effective waste management. Contractors and project managers are frequently under pressure to meet deadlines, leading to the neglect of C&DWM practices. This emphasis on speed over sustainability results in significant waste generation and inefficient use of resources (Ding et al., 2016). Addressing this issue requires a reevaluation of project planning processes to incorporate waste management as a critical component rather than an afterthought.

Finally, the lack of regulatory and supervisory support further perpetuates cultural barriers to effective C&DWM. Regulatory bodies and supervisors play a crucial role in enforcing waste management practices, but their insufficient involvement often leads to poor adherence to protocols. In many developing countries, including Egypt, regulations regarding C&DWM are either lacking or not adequately enforced, resulting in widespread non-compliance (Teo & Loosemore, 2001). Strengthening regulatory frameworks and ensuring active supervision can significantly improve waste management practices by holding stakeholders accountable and promoting a culture of compliance.

2.2 Barriers Related to Efficiency

Efficiency barriers in C&DWM primarily revolve around operational inefficiencies that hinder the effective management of waste. One significant issue is the improper onsite handling of materials, which leads to substantial waste generation. Inadequate handling practices, such as poor storage, incorrect stacking, and improper handling during transportation, contribute to material damage and loss. This inefficiency not only increases waste but also escalates project costs and delays (Lu et al., 2011). Implementing proper training and management practices is essential to mitigate these issues and enhance the overall efficiency of construction projects.

Frequent changes to work orders and subsequent rework are other significant barriers to efficiency in C&DWM. Changes in project scope, design modifications, and errors in execution often necessitate rework, leading to increased waste generation. Effective planning, clear communication, and robust project management frameworks are crucial to minimize these inefficiencies. By ensuring that all stakeholders are aligned and informed about project requirements and changes, the construction industry can reduce the occurrence of rework and its associated waste (Love et al., 2000).

The lack of supervisor support further exacerbates efficiency barriers in C&DWM. Supervisors play a key role in ensuring that waste management practices are followed on construction sites. Their involvement is crucial for enforcing protocols, providing guidance, and addressing issues as they arise. However, in many cases, supervisors are either not adequately trained in C&DWM or do not prioritize it, leading to poor adherence to waste management practices (Hosseini et al., 2015). Enhancing supervisor training and emphasizing the importance of their role in waste management can significantly improve the efficiency of C&DWM practices.

Worker attitudes towards material conservation and waste reduction also play a critical role in the efficiency of C&DWM. In many cases, workers are not fully aware of the impact of their actions on waste generation and the overall project costs. Educational initiatives and training programs that highlight the environmental and economic benefits of efficient waste management can help change these attitudes. By fostering a culture of sustainability and efficiency, the construction industry can significantly reduce waste and improve project outcomes (Gadenne et al., 2009).

2.3 Barriers Related to Resources

Resource-related barriers in C&DWM often stem from the lack of necessary infrastructure and financial resources to implement effective waste management practices. One of the primary issues is the inadequacy of recycling facilities. In many developing countries, including Egypt, there are insufficient facilities for recycling and reusing construction materials. This lack of infrastructure makes it challenging to manage waste effectively and promotes the disposal of materials in landfills instead of recycling them (Kulatunga et al., 2006). Investing in recycling infrastructure and promoting the establishment of such facilities is essential to overcoming this barrier.

Economic constraints are another significant resource-related barrier. Financial limitations often restrict the ability to invest in the necessary technologies and practices for effective C&DWM. In developing countries, where economic pressures are prevalent, allocating funds for sustainable practices can be challenging. However, the long-term economic benefits of effective waste management, such as reduced material costs and disposal fees, should be highlighted to encourage investment in C&DWM

(Yuan et al., 2011). Policymakers and industry leaders must recognize the importance of these investments for sustainable development.

The lack of client support for sustainable practices further complicates resource-related barriers. Clients often prioritize cost and time savings over environmental considerations, leading to reluctance in adopting C&DWM strategies. Educating clients about the long-term benefits of waste management, including cost savings and environmental impact, can help shift their perspectives and gain their support (Ling & Nguyen, 2013). Encouraging client involvement and commitment to sustainable practices is crucial for the successful implementation of C&DWM.

Inadequate management of off-site activities also poses a significant barrier to resource efficiency in C&DWM. Poor coordination and oversight of activities such as transportation, storage, and handling of materials can lead to significant waste generation. Effective management of these activities is essential to ensure that materials are used efficiently and waste is minimized. Implementing robust logistical and management practices can help address this barrier and improve the overall efficiency of C&DWM (Poon et al., 2004).

2.4 Barriers Related to Procurement

Procurement barriers in C&DWM involve issues in acquiring materials and services that align with waste management goals. One significant issue is the presence of inefficient procurement practices. Poor procurement processes can lead to the over-ordering or under-ordering of materials, contributing to increased waste. Effective procurement strategies that focus on accurate estimation and timely acquisition of materials are essential to minimize waste (Jayamathan & Rameezdeen, 2014). Implementing standardized procurement procedures and training procurement officers can help address this barrier.

Unsuitable inventory management practices also contribute to procurement-related barriers. Poor management of inventory can result in materials being wasted due to damage, expiration, or overstocking. Effective inventory management systems that track and monitor material usage can help reduce waste and improve resource efficiency (Llatas & Osmani, 2016). Adopting technology-driven inventory management solutions can enhance the accuracy and efficiency of material usage.

The quality of materials procured for construction projects also plays a crucial role in waste generation. The use of substandard or low-quality materials can lead to higher wastage rates during construction, as these materials are more prone to damage and failure. Ensuring that only high-quality materials are procured and used in construction projects is essential to reduce waste and improve project outcomes (Ling & Nguyen, 2013). Implementing stringent quality control measures and supplier assessments can help in procuring better-quality materials.

Lastly, the lack of stringent building regulations and policies related to procurement further hinders effective C&DWM. In many developing countries, including Egypt, regulatory frameworks for procurement do not adequately address waste management requirements. Developing and enforcing comprehensive procurement policies that include sustainability criteria can significantly improve waste management practices. Regulatory bodies must collaborate with industry stakeholders to create and implement policies that promote sustainable procurement and support C&DWM goals (Gharfalkar et al., 2015).

Based on a comprehensive examination of the relevant literature related to the categorized four clusters of barriers, Table 1 identifies the most significant obstacles to C&DWM.

Table 1. Barriers to waste management in the construction industry

Code	Barriers	References
D1	Tight scheduling	(Yuan et al., 2020)
D2	Excluding management of waste in the design	(Llatas and Osmani, 2016)
D3	Lack of client support	(Ling and Nguyen, 2013b)
D4	Ineffective practices for procurement	(Jayamathan and Rameezdeen, 2014)
D5	Unsuitable inventory	(Llatas and Osmani, 2016, Yuan et al., 2020)
D6	Improper onsite handling of materials	(Yuan et al., 2020)
D7	Change of work and rework	(Ling and Nguyen, 2013b; Jayamathan and Rameezdeen, 2014; Yuan et al., 2020)
D8	Wasteful usage of materials as a result of the workers' attitudes	(Hosseini et al., 2015a, Ling and Nguyen, 2013b, Llatas and Osmani, 2016, Jayamathan and Rameezdeen, 2014, Yuan et al., 2020)
D9	Lack of supervisors' support	(Ling and Nguyen, 2013b)
D10	The budget for recycling and reuse is insufficient	(Llatas and Osmani, 2016)
D11	Construction workers lack a waste management culture	(Yuan et al., 2020)
D12	The utilization of unsuitable packaging	(Jayamathan and Rameezdeen, 2014)
D13	Inadequate management of off-site activities	(Ling and Nguyen, 2013b; Jayamathan and Rameezdeen, 2014; Llatas and Osmani, 2016)
D14	The deficiency in the skill set of the operatives	
D15	The absence of economically viable recycling and reuse infrastructure	(Yuan et al., 2020)
D16	Individuals lacking expertise in demolition work	(Jayamathan and Rameezdeen, 2014)
D17	Waste management is not included within the scope of national building codes	(Jayamathan and Rameezdeen, 2014, Llatas and Osmani, 2016, Yuan et al., 2020)
D18	The substandard quality of materials	(Llatas and Osmani, 2016)
D19	The lack of obligation stemming from building regulations	(Jayamathan and Rameezdeen, 2014)
D20	Insufficient backing from the general public	(Ling and Nguyen, 2013b)
D21	Insufficient motivation from regulatory bodies	(Ling and Nguyen, 2013b; Jayamathan and Rameezdeen, 2014; Llatas and Osmani, 2016)
D22	The current regulations pertaining to waste management exhibit a dearth of a cohesive policy framework	(Yuan et al., 2020)

3 Research methodology

A survey of studies on barriers to C&DWM was conducted, as illustrated in Figure 1. As part of the pilot study, a compilation of barriers related to C&DWM was disseminated to professionals in the home-building industry with pertinent industry experience. The pilot study was conducted in conjunction with a content analysis investigation of the variables and their respective categories to ensure the comprehensiveness and lucidity of the barriers to C&DWM, as presented in Table 1.

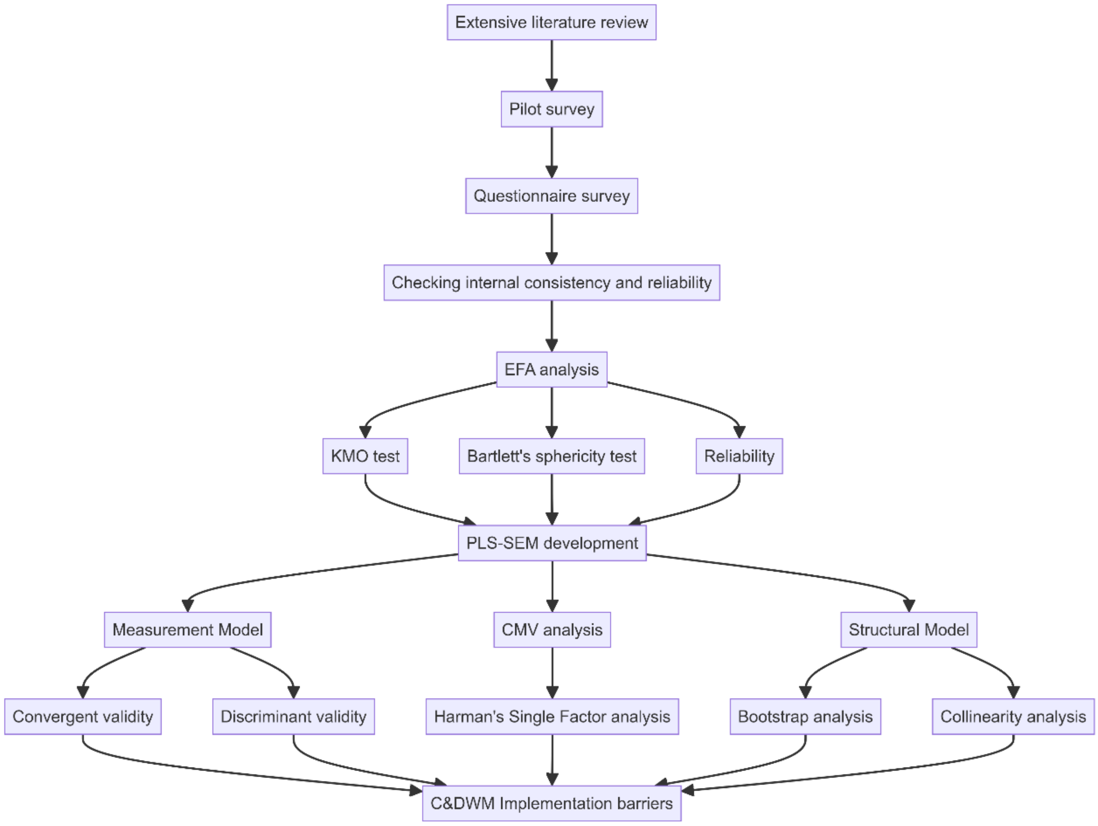

Figure 1. Research Design

3.1 Data collection

To investigate the barriers to C&DWM, a diverse range of engineers specialized in the residential building sector in the cities of Cairo and Giza (i.e., Greater Cairo) were surveyed using a comprehensive questionnaire. Greater Cairo was chosen as the central area of investigation for this study for the following reasons: (1) it includes all similarities and contradictions; (2) diversity in levels of education; (3) a large number of construction projects; (4) it is political, financial, commercial, and administrative governance; and (5) it includes more than 60% of Egypt's CDW (Daoud et al., 2020).

The survey comprised three primary elements: the demographic profile of the respondents, the obstacles to C&DWM, and the open-ended inquiries designed to capture any additional barriers that the participants deemed relevant. On a 5-point Likert scale, respondents rated barriers to C&DWM according to their experience and knowledge, with 5 being the highest, 4 being high, 3 average, 2 being little, and 1 being neither or relatively minor. This scale has been used in earlier studies (Ali et al., 2024; Ali et al., 2023b).

The primary participants targeted in this study were industry practitioners in Egypt specializing in construction management or civil engineering. These participants were chosen based on their direct involvement and experience in C&DWM within residential projects. The criteria for selecting respondents were based on their educational qualifications and professional experience. Participants were required to hold at least a bachelor's degree in civil engineering or construction management and have a minimum of five years of experience in construction management or civil engineering. This criterion ensured that the respondents had sufficient knowledge and practical experience in the field to provide informed insights on the barriers to C&DWM.

The total population of construction professionals in Egypt is estimated to be around 850,000, based on data from the Egyptian Syndicate of Engineers (Bahnasawy, 2022). To determine the appropriate sample size, the SurveyMonkey sample size calculator was used, setting a 90% confidence level and a 10% margin of error.

According to these parameters, the calculator suggested a minimum sample size of 69 participants. However, to ensure robustness and reliability of our findings, we distributed the questionnaire to 120 participants. Out of these, 90 responses were received, resulting in a 75% response rate. This sample size is adequate for statistical analysis and provides a comprehensive understanding of the barriers to C&DWM in Egypt's construction industry. Yin (2009) stated that SEM requires a sample size of at least 100. The utilization of the SEM methodology facilitated the personal contact of 90 out of 120 participants for self-administered surveys, yielding a response rate of 75%. This rate of return was considered suitable for the present investigation (Kothari, 2009; Wahyuni, 2012).

A random probability sampling technique was employed to select the participants. This method ensures that each member of the population has an equal chance of being included in the sample, thereby reducing selection bias and enhancing the representativeness of our sample (Ali et al., 2023c; Noor et al., 2022). To provide a detailed understanding of the respondents' backgrounds, a demographic analysis was conducted. Additionally, 50% of the respondents had less than 10 years of experience, 31.7% had 10-15 years, and 18.3% had more than 20 years of experience in the construction industry. This diverse pool of respondents ensured a well-rounded perspective on the barriers to C&DW management.

Before proceeding with data analysis and the establishment of PLS-SEM as indicated in Figure 1, it was essential to establish the consistency of the responses and the reliability of the chosen measurement method (i.e., the Likert scale) (Elmousalami et al., 2023). To test the reliability and consistency of the collected data, Cronbach's alpha coefficient was employed for the range of variables using SPSS V26© software. The Cronbach's alpha must exceed 0.7 to ensure the reliability and consistency of responses (Alnaser et al., 2024). Consequently, the overall Cronbach's alpha coefficient for the questionnaire was determined to be 0.86, indicating outstanding general internal consistency and reliability of the scales.

3.2 Exploratory factor analysis (EFA)

In accordance with Figure 1, the Exploratory Factor Analysis (EFA) process followed the initial checks for internal consistency and reliability. EFA is a fundamental statistical tool used to uncover the underlying structure or patterns within a dataset containing multiple observed variables. Its objective is to identify latent factors that potentially influence or contribute to the observed correlations among these variables. By conducting EFA, researchers can gain insights into complex relationships, identify key constructs, and simplify the data for further analysis (Kineber et al., 2023b). In other words, the researcher used EFA to identify the main clusters (i.e., constructs) among the associated items (i.e., indicators) to establish measurement criteria. This foundational step is necessary to proceed with model development. Furthermore, EFA is commonly utilized alongside the PLS-SEM approach to discern these constructs (Ali et al., 2023e). The researchers adhered to the procedural guidelines outlined by (Ali et al., 2023e) for conducting EFA.

3.3 PLS-SEM development

According to Kineber et al. (2021a), structural equation modeling (SEM) for multivariate regression was deemed appropriate for this study. In addition, Byrne (2013) underscored the potential of SEM to facilitate confirmatory research inquiries, precisely, the examination of theories pertaining to the associations between latent variables and constructs using observed variables. Furthermore, SEM verifies associations by integrating measurement errors as a component of the model, a characteristic that is absent in comparable statistical methodologies (Byrne, 2013).

Given these attributes, SEM has been acknowledged as a proficient approach for addressing numerous research issues in the field of construction management (Kineber et al., 2021b; Kineber et al., 2021c). According to Ali et al. (2023a), there are two significant approaches to SEM: covariance-based (CB-SEM) and partial least squares (PLS-SEM). PLS-SEM has garnered significant attention in various industries, such as business research and social sciences (Henseler et al., 2016).

The SMART-PLS software, version 3.2.7, was utilized to conduct SEM analysis on the gathered data with the aim of ascertaining the level of significance of the obstacles to the C&DWM. The superior predictive capability of PLS-SEM compared to covariance-based structural equation Modeling (CB-SEM) was initially acknowledged despite the fact that the differences between the two techniques are minimal (Ali et al., 2023c). The PLS-SEM was used for statistical analysis in this study.

3.3.1 Common method variance

Common method variance (CMV) produced common method bias (CMB). The CMB aids in explaining disagreement (or inaccuracy) in the analysis outcome due to the measuring technique instead of the constructions it reflects (Podsakoff et al., 2003). Alternative definitions of CMV include variation overlap related to measuring instrument types and constructs (Podsakoff et al., 2003). MV is particularly troublesome when data are gathered from a single source, such as a self-administered survey (Glick et al., 1986; Strandholm et al., 2004).

Under certain circumstances, self-reported data can distort or mask the scope of the analyzed associations, leading to complications (Williams et al., 1989; Strandholm et al., 2004). The potential significance of the data in this study stems from its exclusive reliance on self-reported, subjective information obtained from a single source. Hence, it is imperative to address these issues to identify common procedural differences.

Kineber et al. (2023a) involved the implementation of a meticulous and systematic one-factor test (Podsakoff and Organ, 1986). Factor analysis identified a single component that accounted for most of the variation (Strandholm et al., 2004).

3.3.2 Measurement model

According to Ali et al. (2023d), the measurement model illustrates the current correlation between entities and their underlying framework. The subsequent segments scrutinized the depth of (a) convergent validity and (b) discriminant validity of the measurement model.

a) Convergent validity

Convergent validity pertains to the extent of concurrence among two or more assessments (referred to as barriers) of a specific variable (known as a construct). It is commonly posited that this is a component of the construct validity. Three tests may be performed to determine the convergent validity of the created constructs in the case of PLS: Cronbach's alpha (α), composite reliability scores (ρ_c) and average variance extracted (AVE) (Abdel-Tawab et al., 2023).

According to Ali et al. (2023c), a threshold of 0.7 for the composite reliability indicates modest reliability. In all forms of research, values that exceeded 0.70 were deemed acceptable, while values above 0.60 were deemed acceptable for exploratory research. The culminating assessment of the course was the AVE examination. The assessment of convergent validity of a model's constructs is commonly measured using a standard metric. A value exceeding 0.50 indicates satisfactory convergent validity.

b) Discriminant validity

Discriminant validity asserts that the constructs being studied possess empirical distinctiveness and that no other measure is capable of identifying them within the context of SEM (Hair and Alamer, 2022).

3.3.3 Structural model analysis

The objective of this investigation was to employ a structural SEM to simulate the importance of C&DWM obstacles. The task at hand requires the computation of the path coefficients linking the observed coefficients. In this case, as shown in Figure 2, a one-way causal connection (path relation) was hypothesized between (C&DWM construct barriers) and (barriers to C&DWM implementation). Here, the structural relationship between the £ and €1 formula in the structural model, which has been recognized as the inner relationship, can be represented by the following linear Equation 1 (Alkilani, 2018): μ=β £+ €1 (1), where (β) is the route coefficient connecting the barriers of the C&DWM components and (€1) is assumed to represent the residual variance at this structural level.

Here, β represents the standardized regression weight, which corresponds to the weight in the multiple regression model. The sign should correspond to the model's predictions and be statistically significant. The issue at hand is determining the relevance of the route coefficient β. Similar to the CFA approach, SmartPLS 3.2.7 software employed a bootstrapping technique to estimate the standard errors of the path coefficients. This was accomplished through 5000 subsamples based on Henseler et al. (2016), who established the t-statistics for hypothesis testing. For the PLS Model, four structural equations for C&DWM barriers constructs were created, illustrating the inner relations between the constructs and Equation 1.

4 Data analysis and results

4.1 Exploratory factor analysis for barriers

The factorability structure of the 22 barriers pertaining to C&DWM was ascertained through EFA. Various common factorability characteristics have been employed to establish connections. The Kaiser-Meyer-Olkin (KMO) factor homogeneity assessment is commonly conducted to ascertain that the partial correlations among variables are minimized (Ali et al., 2023e). A number of at least 0.60 on the KMO index, which ranges from 0 to 1, indicates that factor analysis was successful (Tabachnick et al., 2007).

Additionally, the Bartlett sphericity test implies that when p 0.05 is significant, the association matrix is the identity matrix (Tavakol and Dennick, 2011; Pallant, 2007). Initial KMO sample adequacy is measured at 0.756, higher than the recommended value of 0.6, and the Bartlett sphericity test is significant [2 (563) = 3874.889, p 0.05]. The anti-image correlation matrix indicated that all variables were suitable for factor analysis, as evidenced by the diagonals with values exceeding 0.5. The initial communities indicated the variance of each variable in the presence of all other variables. A low coefficient value of 0.3 suggests that there is poor congruence between the variables and the factor solution. All the initial communities included in this study met the threshold requirements. Each loading factor exhibited a significance level of greater than 0.5. Reliability statistics were compiled for the elements indicated by the EFA. The variables corresponding to each phase of the factor were identified based on the highest loading of each variable in the structural matrix.

Table 2 reveals the extraction of five factors with eigenvalues exceeding 1.0. Additionally, it indicates that two single items, D10 and D22, were cross-loaded into two different components, necessitating their exclusion from the study. Consequently, the number of components decreased from five to four, as both excluded items were associated with component number 5. The first component, labeled "Culture," accounted for 16.119% of the variance. The subsequent component, named "Efficiency," explained 12.963%, while the third component, designated as "Resources," contributed 13.162% to the total variance. The fourth component, titled "Procurement," accounted for 10.476% of the variance. The names assigned to each component reflect the dominant themes or characteristics inferred from the items comprising them. These labels offer a convenient way to interpret and refer to the underlying factors identified through the factor analysis.

Table 2. Factor loadings of barriers of C&DWM

Code	1	2	3	4	5
D1	0.826	-	-	-	-
D11	0.79	-	-	-	-
D14	0.737	-	-	-	-
D20	0.725	-	-	-	-
D21	0.683	-	-	-	-
D6		-	0.654	-	-
D7		-	0.651	-	-
D8		-	0.558	-	-
D9		-	0.554	-	-
D10*		-	0.526	-	0.531
D2	-	0.850	-	-	-
D12	-	0.741	-	-	-
D13	-	0.720	-	-	-
D3	-	0.712	-	-	-
D15	-	0.636	-	-	-
D16	-	0.615	-	-	-
D17	-	0.606	-	-	-
D18	-		-	0.603	-
D19	-		-	0.600	-
D4	-		-	0.526	-
D5	-		-	0.505	-
D22*	-			0.493	0.512
Eigenvalues	7.76	6.768	6.155	4.522	1.511
% of Variance	16.119	12.963	13.162	10.476	6.034

4.2 Common method variance for barriers

The validity of the investigation was compromised by a common method bias, which is a measurement of inaccuracy in the form of variance. This demonstrates the systematic error variance for the calculated and estimated variables (Mackenzie and

Podsakoff, 2012). Harman's single-factor assessment of models, which denotes the number of structural metrics, can be used to quantify this (Podsakoff and Organ, 1986).

This study employed a single factor test to assess the degree of variability inherent in the standard methodology. When the cumulative variance of the constituents was below 50%, the outcomes were not affected by common method bias (Podsakoff and Organ, 1986). As shown in Table 3, the initial group of components accounted for 42.85% of the overall variance. This implies that the variance of the conventional method is unlikely to have a significant impact on the outcomes because it is below the 50% threshold (Podsakoff and Organ, 1986).

Table 3. Result of common-method variance

Extracted sums of squared loadings		
Total	**% of variance**	**Cumulative %**
12.13	42.85	42.85

4.3 Measurement model

The evaluation of reflective measurement models, particularly barriers, in PLS-SEM, requires an assessment of internal reliability, convergent validity, and discriminant validity.

4.3.1 Convergent validity

The evaluation of the precision and reliability of the measurement model precedes the examination of the structural model (Hair and Alamer, 2022). The utilization of the measurement model is imperative in assessing convergent validity via four distinct techniques: Outer Loading, Cronbach's Alpha, Composite Reliability, and Average Variance Extracted (AVE) (Alnaser et al., 2024).

Table 4 and Figure 2 display the external loadings of both the initial and revised measurement models for each item, respectively. High outer loads on a structure suggest a close relationship between its primary structural elements: items often need to be removed from the scale if they exhibit exceptionally low outer loadings (below 0.5) (Hair and Alamer, 2022). Therefore, all outer loadings from the original measurement model have been retained, except for three items: "D2", "D15", and "D17", as highlighted in red in Figure 2. A loading factor of less than 0.5, indicating a modest contribution to the pertinent structures, was the reason for their exclusion.

On the other hand, both Cronbach's Alpha and Composite Reliability are considered acceptable and appropriate as they meet the condition of > 0.70. Finally, the AVE test results, depicted in Table 4, indicate that all the structures have passed successfully. The accepted AVE threshold should be over 0.5 (Hair and Alamer, 2022). The AVE values for all components of the study, determined by the PLS algorithm 3.0 and presented in Table 4, exceed 50%. These findings demonstrate that the measurement model is internally consistent and convergent, confirming that the measuring components accurately capture each construct (variable) and do not assess any other constructs in the study model.

Table 4. Convergent validity results

Constructs	Items	Outer Loading		Cronbach's Alpha	Composite Reliability	AVE
		Initial	Modified			
	D1	0.734	0.732			
	D11	0.546	0.549			
Culture	D14	0.609	0.609	0.707	0.811	0.566
	D20	0.676	0.675			
	D21	0.816	0.816			
	D2*	0.343	Deleted			
	D12	0.843	0.869			
	D13	0.864	0.894			
Resources	D3	0.868	0.886	0.903	0.932	0.775
	D15*	0.328	Deleted			
	D16	0.838	0.87			
	D17*	0.357	Deleted			
Efficiency	D6	0.759	0.759	0.737	0.833	0.556

	D7	0.771	0.771			
	D8	0.687	0.687			
	D9	0.762	0.762			
Procurement	D18	0.59	0.59	0.704	0.712	0.582
	D19	0.659	0.659			
	D4	0.597	0.597			
	D5	0.62	0.62			

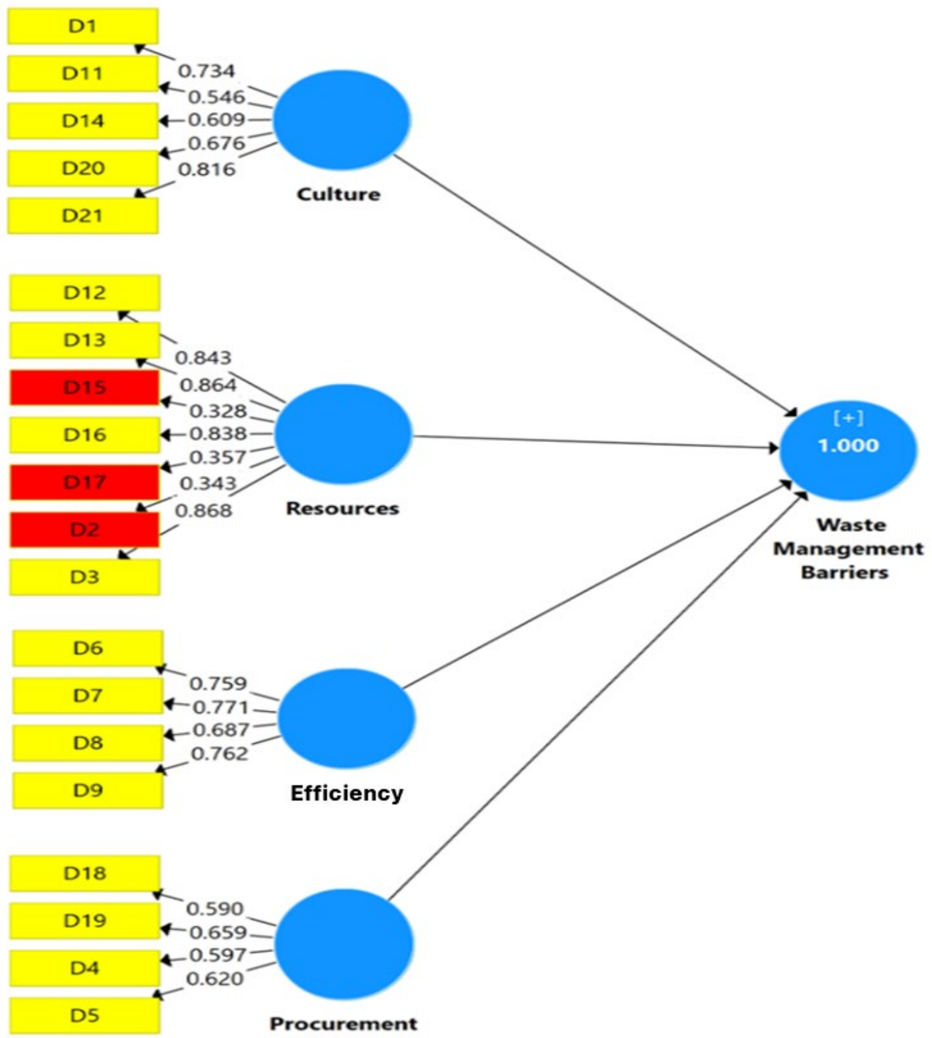

Figure 2. The PLS-SEM initial model

4.3.2 Discriminant validity

Discriminant validity (DV) is well-defined if the experimental criteria distinguish the construct considerably from other constructs. Therefore, the established DV suggests that the construct is typical and correctly identifies singularities that other models' constructs fail (Hair et al., 2013). The DV may be determined using three unique methods to examine DV: the cross-loading criterion, the Fornell-Larcker criterion, and the heterotrait-monotrait ratio of correlations. The square root of the AVE for particular constructs may be correlated with the construct's associations with any available construct. Following the theory of Fornell and Larcker (1981), the square root of AVE should exceed the correlation among the underlying variables. The collected findings validated the DV of the analytical model, as shown in Table 5.

Table 5. Fornell-Larcker discriminant validity results

Constructs	Culture	Efficiency	Procurement	Resources
Culture	**0.683**			
Efficiency	0.582	**0.746**		
Procurement	0.282	0.356	**0.618**	
Resources	0.149	0.01	0.092	**0.88**

Henseler et al. (2015) proposed the heterotrait-monotrait criterion ratio (HTMT) as an alternative approach for assessing dependent variables. Provided that the dual constructs are measured sufficiently, the HTMT represents a distinctive approach to assess structural equation models based on the variance of the dependent variable. This enables the estimation of the accurate association between the constructs, assuming that they are consistently reliable and free from errors. This study employed the HTMT model to assess the dependent variable (DV), as presented in Table 4. (Hair and Alamer, 2022). propose that the HTMT value should be less than 0.90 for theoretically similar constructs and less than 0.85 for theoretically dissimilar ones. Table 6 lists the HTMT values used in this study. Therefore, the constructs showed adequate discriminant validity.

Table 6. HTMT Values

Constructs	Culture	Efficiency	Procurement	Resources
Culture				

Efficiency	0.764		
Procurement	0.412	0.534	
Resources	0.177	0.092	0.174

In this research, the third technique, the cross-loading criteria, was utilized to analyze DV. This approach assesses whether the indicator loading for a specific underlying construct is greater than the loading score for other constructs per row. According to Table 7, the loading score for all indicators of the assigned latent construct is larger than the cross-loading score for the remaining model's construct by row. As evidenced by the outcomes, each construct displayed a high degree of unidimensionality.

Table 7. Cross loadings results

Barriers	Culture	Efficiency	Procurement	Resources
D1	**0.732**	0.415	0.125	0.148
D11	**0.549**	0.492	0.297	0.135
D14	**0.609**	0.285	0.048	0.012
D20	**0.675**	0.273	0.15	0.095
D21	**0.816**	0.471	0.292	0.095
D6	0.523	**0.759**	0.323	0.065
D7	0.395	**0.77**	0.212	0.021
D8	0.259	**0.69**	0.261	0.121
D9	0.502	**0.761**	0.263	0.023
D18	0.127	0.239	**0.584**	0.046
D19	0.121	0.215	**0.662**	0.024
D4	0.304	0.221	**0.596**	0.164
D5	0.027	0.186	**0.628**	0.052
D12	0.081	0.005	0.024	**0.869**
D13	0.116	0.023	0.094	**0.894**
D16	0.111	0.007	0.126	**0.87**
D3	0.201	0.049	0.076	**0.886**

4.4 Structural model (Path model)

Once it is established that the C&DWM barriers are a formative construct, path coefficients (β-value and p-value) and the Variable Inflation Factor (VIF) are utilized to further analyze the collinearity among the formative elements of the construct. The β-value coefficient describes the extent to which the constructs are associated and correlated with each other, with a threshold greater than 0.1 (Hair and Alamer, 2022). On the other hand, the p-value coefficient determines whether the relationships and correlations between constructs are significant and influential, with a threshold of less than 0.05. Finally, the VIF determines the collinearity level between the formative elements of constructs in the model, with a cut-off level of less than or equal to 5 (Ali et al., 2023d).

Figure 3 displays the results of path coefficients, confirming that all values are accepted as they surpass the thresholds. The culture component achieves ($\beta = 0.484$, $p = 0.00$), while resource achieves ($\beta = 0.361$, $p = 0.035$), Efficiency achieves ($\beta = 0.442$, $p = 0.00$), and procurement achieves ($\beta = 0.163$, $p = 0.001$). Additionally, the VIF values for all subdomains were below the threshold of 5, indicating that each subdomain provided a unique contribution to the formation of higher-order structures.

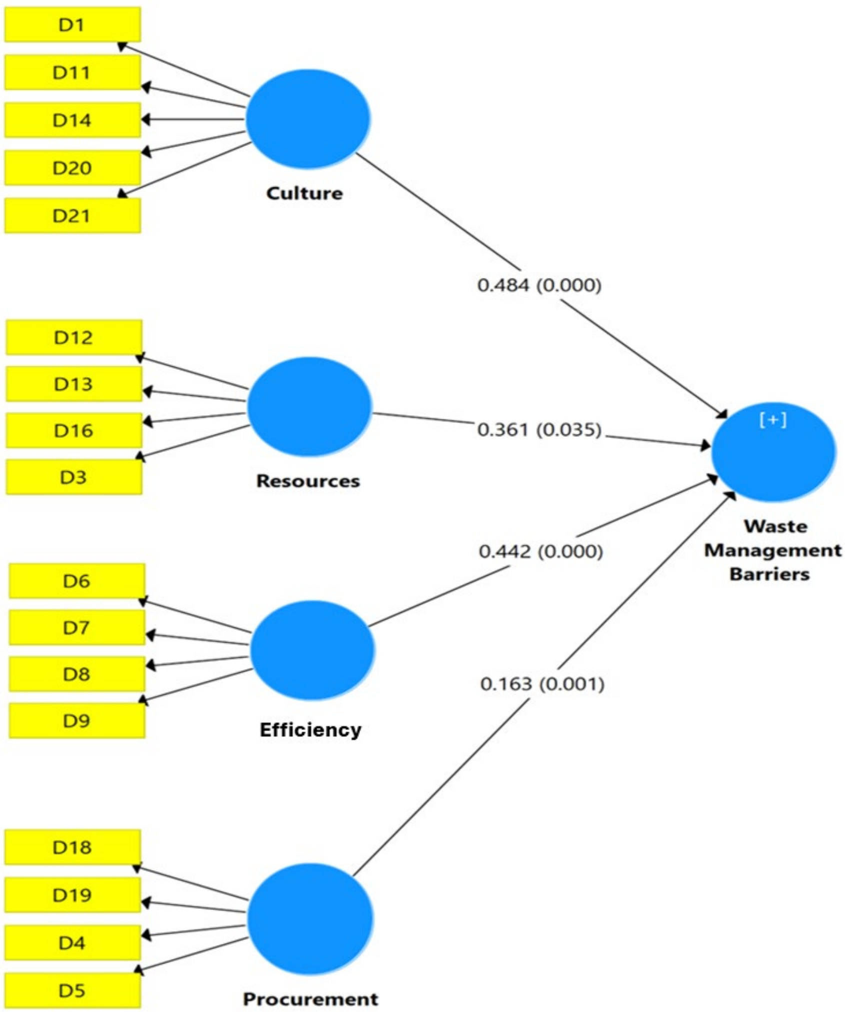

Figure 3. The PLS-SEM structural model

5 Discussion

Although C&DWM is extensively utilized in construction activities in numerous industrialized countries, its adoption in less affluent nations is limited. Like other developing countries, Egypt has encountered challenges and disputes pertaining to construction regulations. This underscores the need to employ working memory principles in order to address these challenges. The decision made by top-level management to incorporate C&DWM as a significant component of their projects will have a substantial impact on the comprehension of C&DWM and its primary construction operations among practitioners. The model proposed demonstrates that the four component barriers significantly influence the adoption of C&DWM. This contributes to improving the feasibility of residential development projects.

Thus, the implementation of C&DWM can enable construction enterprises to achieve cost reduction, time savings, and improved quality while maintaining project functionality. Even if Egyptian building experts generally have a positive impression of C&DWM, they have not yet adopted it (Daoud et al., 2020; Daoud et al., 2022; Daoud et al., 2021a; Daoud et al., 2021b). Therefore, it is necessary to emphasize the most significant barriers to implementing C&DWM to encourage stakeholders to do so. The constituents of the PLS-SEM model can be employed to prioritize the C&DWM obstacles, as delineated in the subsequent sections.

5.1 Culture

The adoption of C&DWM is significantly influenced by cultural factors, which play a crucial role in shaping practices and perceptions within the construction industry(Ali, 2018). The PLS-SEM model, with an external coefficient of 0.484, emphasizes the impact of culture on the implementation barriers of C&DWM. This includes challenges such as tight scheduling, which often prioritizes project completion over sustainable waste management practices. Additionally, a prevalent lack of waste management culture among construction workers further exacerbates the issue, indicating a need for more focused training and awareness programs to enhance the skill sets of operatives in this domain. Moreover, the deficiency in skills among construction workers, combined with insufficient public support and motivation from regulatory bodies, highlights a broader systemic issue within the socio-economic-political context of Egypt's construction market(Ezeah et al., 2013).

These barriers are not merely operational but are deeply entrenched in the attitudes and behaviors that govern construction practices in the region. The lack of public backing indicates a gap in awareness and engagement with sustainable practices, suggesting that efforts to promote C&DWM must also target the general populace to foster a more conducive environment for change (Al-Otaibi et al., 2022). Regulatory bodies play a pivotal role in this ecosystem, where insufficient motivation can stem from a variety of factors, including but not limited to inadequate policy frameworks, lack of enforcement mechanisms, or insufficient incentives for adopting sustainable practices. This points to a need for a comprehensive strategy that not only addresses the technical and operational aspects of C&DWM but also considers the regulatory, cultural, and socio-economic dimensions that influence these practices(Al-Otaibi et al., 2022).

The socio-economic-political context of Egypt presents unique challenges to the adoption of C&DWM, where rapid urbanization, economic pressures, and political dynamics can influence the priority given to sustainable construction practices. The construction market in Egypt, like in many developing countries, is under immense pressure to deliver housing and infrastructure rapidly, often at the expense of environmental sustainability (El Araby, 2002). This urgency can lead to the sidelining of C&DWM initiatives, which are critical for mitigating the environmental impact of construction activities. Addressing these barriers requires a multifaceted approach that encompasses policy reform, educational initiatives, and public awareness campaigns (Adelman and Taylor, 2002). Regulatory bodies need to be empowered with the tools and resources to enforce C&DWM practices effectively while also providing incentives for compliance (Han et al., 2021).

This could include tax breaks, recognition programs, or direct financial support for projects that prioritize waste management. Furthermore, education and training programs targeted at construction workers and industry professionals can help to build a culture of sustainability within the construction sector (Al Amri et al., 2021). These programs should focus on imparting practical skills for waste management, as well as fostering an understanding of the broader environmental, social, and economic benefits of C&DWM. Public awareness campaigns are also crucial in shifting perceptions and garnering support for sustainable construction practices (Semenza et al., 2008). By highlighting the environmental and social impacts of construction waste, as well as the long-term benefits of C&DWM, these campaigns can play a significant role in changing attitudes and behaviors among the general populace (Ali, 2018).

Overcoming these barriers requires a holistic approach that addresses the underlying cultural attitudes toward waste management, enhances the skill sets of construction operatives, and fosters a regulatory and public environment that supports and motivates the implementation of sustainable practices (Bui et al., 2020). Through concerted efforts across these domains, Egypt can make significant strides toward integrating C&DWM into its construction industry, thereby contributing to a more sustainable and environmentally responsible future. This is consistent with earlier research findings by Arif et al. (2012), Doan and Chinda (2016), and Chang et al. (2017), who recognized government legislation as well as the enforcement of landfill fees as critical variables impacting the management of C&DW, since this can raise awareness about C&DWM. The importance of laws has been the subject of previous research on C&DW (Yeheyis et al., 2013; Yuan et al., 2020).

Duran et al. (2006) referred to the same idea as a productive management technique for C&DW in the Republic of Ireland. As the European Union stated, applying the "polluter pays principle" has led to higher landfill prices. Many experts believe that landfill levies are essential for enforcing sustainable waste management practices in the construction industry (Yuan et al., 2016). Despite the strictness and efficiency of regulations, past research has indicated that their implementation in developing nations is slack (Koushki et al., 2005; Ling and Nguyen, 2013a; Nguyen et al., 2019; Marzouk and Azab, 2014). Consequently, for developing nations such as Egypt, establishing and enforcing regulations are two different matters.

According to Teo and Loosemore (2001) theory of waste management for construction, the implementation of waste management methods within the building sector calls for managers' support. This support will not come until the government, laws, and incentives make the handling of building waste affordable (Teo and Loosemore, 2001). Iran adopted environmental laws and regulations in 1928 when Article 50 of the Constitution declared environmental protection a national obligation (Ghazinoory, 2005). However, as shown by the preceding findings and following Foltz's (2001) views, environmental regulations have remained broad assertions without any legal effect. Therefore, they failed to infiltrate the construction sector to enhance C&DWM. Adopting sustainable construction methods, including waste management, requires community pressure and participation (Valdes-Vasquez, 2011).

5.2 Efficiency

In the construction industry, particularly within Egypt's socio-economic-political context, the "Efficiency" component is pivotal, encompassing several critical barriers that significantly impact project outcomes (Conway, 2005). These include improper onsite handling of materials, the wasteful usage of materials due to workers' attitudes, frequent changes to work orders leading to rework, and a noticeable lack of support from supervisors (Mbote, 2018). These factors not only escalate project costs but also extend timelines, affecting overall productivity and sustainability(Shane et al., 2009). The improper handling of materials and wasteful usage directly relate to a broader cultural and educational gap within the workforce (Mcallister, 2015).

Worker attitudes towards material conservation and waste reduction are shaped by the level of training and awareness about sustainable practices (Gadenne et al., 2009). In Egypt, where rapid urbanization and economic pressures are prevalent, the need for speed often overshadows the importance of efficiency and sustainability in construction processes (Abu-Zekry and El-Kholei, 2005). Changes in work orders and the subsequent rework are indicative of planning and communication deficiencies within the project management framework (Love et al., 2000). These challenges are exacerbated by the lack of supervisors' support, which is crucial for ensuring adherence to best practices and minimizing waste. Supervisors play a key role in enforcing project standards and facilitating effective communication among all stakeholders.

Addressing these barriers requires a multifaceted approach, focusing on enhancing education and training for workers, improving project planning and communication, and fostering a culture of support and accountability at all levels (Adelman and Taylor, 2002). Initiatives to promote a deeper understanding of the socio-economic and environmental impacts of construction activities are essential (Domac et al., 2005). Moreover, integrating technology and innovative practices can significantly improve material handling and reduce wastage (Silva et al., 2017). The socio-economic-political context in Egypt, characterized by a dynamic construction market, presents unique challenges and opportunities (Glavanis and Glavanis, 1990). The government and industry stakeholders must collaborate to develop policies and incentives that promote efficiency and sustainability (Pakdeechoho and Sukhotu, 2018).

This includes regulations that encourage the adoption of green building standards, incentives for using sustainable materials, and penalties for wasteful practices. With an external coefficient of 0.448, the effect of "Efficiency" on the barriers of C&DWM appears to be the same as "Culture." This indicates that stakeholders and experts place a greater emphasis on this element for implementing C&DWM than the median range (high-medium level). The effects of off-site packaging and rough handling of goods were linked as both activities produced upstream waste before goods were transported to their destination.

Lu et al. (2011b) discovered that breakage during transport, processing, and storage might lead to upstream waste. Loose packing with improper unloading, rough terrain that creates considerable shaking during transit, and improper stacking or stockpiling have been identified as the leading causes of upstream material loss (Poon et al., 2004). Brittle materials such as plasterboards, bricks, sanitary fittings, and tiles commonly exhibit upstream waste (Poon et al., 2004). Prior to inclusion in building projects, these losses can be minimized by proper material management (Poon, 2007). This was consistent with the findings of Zakeri et al. (1996, p. 421), who asserted that "improper material supply to sites " is a primary reason for recurrent material shortages on Iranian building sites.

5.3 Resources

The third major component pertains to "Resources." This element consists of the circumstances and environment in which people function to promote successful interaction and professional relationships. This includes barriers such as lack of client support, utilization of unsuitable packaging, inadequate management of off-site activities, and lack of expertise in demolition work. In Egypt's construction sector, "Resources" emerge as a significant factor influencing C&DWM, marked by an external value of 0.361.

This factor encompasses critical barriers such as the absence of waste management consideration during the design phase, the scarcity of economically viable facilities for material reuse and recycling, and national construction regulations that overlook waste management necessities. These issues are deeply intertwined with Egypt's socio-economic and political landscape, reflecting broader challenges in integrating sustainable practices within the construction market. Addressing these barriers requires systemic changes, including policy reform, investment in recycling facilities, and incorporating waste management principles at the design stage to align with global sustainability standards and address the unique challenges of Egypt's construction industry.

5.4 Procurement

In addressing the challenge of "Procurement" for effective C&DWM in Egypt's construction sector, which holds an external coefficient of 0.163%, key issues such as inefficient procurement practices, unsuitable inventory management, subpar material quality, and the absence of stringent building regulations emerge. These barriers, deeply embedded within the socio-economic and political fabric of Egypt's construction market, highlight the need for systemic reforms. Addressing these procurement-related obstacles necessitates a comprehensive approach that involves policy overhaul, enhancing quality control mechanisms, and fostering a regulatory environment that mandates sustainable procurement and waste management practices. This was consistent with the previous studies, which revealed that adopting effective materials procurement practices dramatically contributes to reducing C&DW (Daoud et al., 2018a; Daoud et al., 2018b; Daoud et al., 2022; Daoud et al., 2021a).

For minimizing materials waste through materials procurement, efficient materials procurement procedures are categorized into four clusters: (1) suppliers' low waste commitment; (2) low waste purchase management; (3) effective materials delivery management; and (4) waste efficient bill of quantities. Each cluster has several methods that should be implemented to limit the development of materials waste. For instance, suppliers' low-waste commitment includes four primary measures: suppliers' flexibility in supplying small quantities or conforming product modifications, commitment to the take-back scheme (packaging, unused, reusable, and recyclable materials), supply of quality, durable products, and use of minimal packaging (without affecting materials safety).

In addition, low waste purchase management consists of five primary measures: procurement of waste-efficient materials/technology (pre-assembled/cast/cut), purchase of secondary materials (recycled and reclaimed), purchase of quality and appropriate materials, avoidance of variation orders, and purchase of the correct materials. Effective materials delivery management entails four primary measures: effective protection of items (during transportation, loading & unloading), effective onsite access (to facilitate distribution), an efficient delivery schedule, and the utilization of a Just-in-Time (JIT) delivery system.

Incorporating a waste-efficient bill of quantities in Egypt's construction sector, emphasizing exact material take-off, and preventing over- and under-ordering aligns with national efforts towards sustainable development. These practices, set against Egypt's socio-economic and political backdrop, with its focus on urbanization and economic reforms, highlight the importance of sustainable procurement. By integrating these measures into procurement models, Egypt can enhance efficiency, support environmental sustainability, and reduce waste in construction projects, contributing to the country's broader goals of economic resilience and sustainability.

6 Implications

The reorganization of barriers holds the potential to establish a foundation for stakeholders, enabling them to address these hindrances and embrace C&DWM effectively. This initiative is poised to supplant antiquated environmental and sustainable performance standards that have prevailed since the Arab Spring in 2011 (Aboelmaged, 2018). Consequently, Egypt's pursuit of a sustainable economy is imperative, considering the widespread association between sustainable growth and economic prosperity (Laukkanen and Tura, 2020). The mitigation of the barriers mentioned above will significantly bolster Egypt's ambition to foster a stable, sustainable, and competitive economy, propelling it towards its goal of ranking among the top 30 nations (Aghimien et al., 2018).

Furthermore, the model derived from this study has the potential to inspire the adoption of C&DWM practices in numerous other developing countries, particularly those facing similar challenges in their construction projects (Aghimien et al., 2018). This holds particular importance for developing nations grappling with various barriers, including the substantial investment required to address environmental concerns (Pham et al., 2020). As such, integrating C&DWM into construction project design procedures presents these nations with an opportunity to embed sustainability principles. Nevertheless, the specific contributions outlined by this study bear significant ramifications for the construction industry.

The present research study offers a cutting-edge and distinctive contribution to the domain of construction management within the Egyptian context. It delineates a focused inquiry into the identification of barriers pertaining to C&DWM, specifically in building projects. Employing PLS-SEM as a methodological framework for constructing a mathematical model represents a novel and unprecedented approach within the Egyptian context. This method holds the promise of yielding valuable insights into the intricate interconnections underlying the successful mitigation of barriers, consequently enhancing the implementation of C&DWM practices. The findings of this study carry significant implications for both academic discourse and the construction industry within Egypt and beyond.

6.1 Theoretical Implications

This study stands as a significant contribution to the theoretical body of knowledge by offering a valuable resource through various means: (1) Offering a comprehensive enumeration of barriers to C&DWM; (2) Assisting in the formulation and enhancement of more refined theoretical frameworks to comprehend these barriers with greater depth; (3) Prioritizing and emphasizing the significance of each categorized barrier to C&DWM, thereby enhancing comprehension of their intricacies; and (4) Establishing causal connections between different variables, such as barriers to C&DWM and effective implementation, which can enrich the development of theories elucidating these associations.

6.2 Practical Implications

Besides its theoretical and academic implications, this study carries practical implications that hold considerable promise for policymakers and stakeholders in developing countries. These include (1) Furnishing industry professionals with an extensive comprehension of the barriers surrounding the C&DWM method, thereby facilitating its future adoption effectively; (2) Empowering policymakers and governmental authorities to formulate informed policies that advocate for the implementation of C&DWM in developing nations; (3) Providing owners, consultants, and contractors with a valuable resource for assessing and selecting C&DWM implementations to improve the planning, efficiency, and consistency of construction projects; (4) Offering a comprehensive framework for leveraging C&DWM to promote sustainable building initiatives; and (5) Supplying methodological evidence that can aid Egypt and other developing nations in understanding the implications of mitigating current barriers on the practical implementation of C&DWM.

7 Conclusion

The study explored the barriers to effective implementation of Construction and Demolition Waste Management (C&DWM) in residential projects in Egypt. Data analysis revealed critical barriers categorized into four main constructs: culture, resources, efficiency, and procurement. Data collection involved a questionnaire survey targeting industry practitioners in Egypt, with a high response rate of 75%. Exploratory Factor Analysis (EFA) identified the four constructs, and Partial Least Squares Structural Equation Modelling (PLS-SEM) quantified their impacts. Cultural barriers were the most significant ($\beta = 0.484$, $p = 0.00$), followed by efficiency ($\beta = 0.442$, $p = 0.00$), resources ($\beta = 0.361$, $p = 0.035$), and procurement ($\beta = 0.163$, $p = 0.001$).

Cultural barriers included tight scheduling, lack of waste management culture, and insufficient support from supervisors and regulatory bodies. To address these, focused training and awareness programs are necessary to foster a positive disposition towards waste management among construction personnel. Efficiency-related barriers included improper onsite handling of materials, wasteful usage, frequent changes to work orders, and lack of supervisor support. These can be mitigated by enhancing education and training for workers, improving project planning and communication, and integrating technology and innovative practices for better material handling.

Resource-related barriers involved lack of client support, unsuitable packaging, inadequate off-site management, and lack of expertise in demolition work. Addressing these barriers requires policy reform, investment in recycling facilities, and incorporating waste management principles at the design stage. Procurement barriers included inefficient procurement practices, unsuitable inventory management, subpar material quality, and lack of stringent building regulations. Overcoming these obstacles necessitates systemic reforms, quality control enhancements, and regulatory measures to promote sustainable procurement practices.

Despite its comprehensive approach, this study has limitations. The sample size, though statistically adequate, may limit generalizability to the broader Egyptian construction industry. Future studies should include a larger, more diverse sample and expand beyond Greater Cairo to better represent other regions. Reliance on self-reported data introduces potential bias; incorporating objective measures and third-party assessments could validate findings. As the construction industry is dynamic, the barriers identified in this study may evolve over time. Continuous monitoring and updating of the research framework are necessary to capture emerging challenges and trends.

Future research should consider longitudinal studies to track changes in barriers and evaluate intervention effectiveness. Comparative studies between different regions and nations can help develop tailored strategies. The impact of existing policies and regulations should be investigated, potentially involving collaboration with government agencies. The role of technological innovations and stakeholder engagement in enhancing C&DWM practices should also be explored.

This study provides valuable insights for industry practitioners, policymakers, and researchers. Addressing the identified barriers requires a multifaceted approach involving policy reforms, investment in infrastructure, and fostering a culture of sustainability. By implementing these recommendations and addressing the limitations, future studies can further enhance the understanding of C&DWM and support the development of more effective and sustainable construction practices.

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Ethical Approval:

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee**.**

Consent to Participate:

Informed consent was obtained from all individual participants included in the study.

Consent to Publish:

All authors agreed with the content and gave explicit consent to submit and that they obtained consent from the responsible authorities at the institute/organization where the work has been carried out to publish this work.

Authors Contributions:

All authors made substantial contributions to the conception or design of the work; the acquisition, analysis, and interpretation of data. Conception or design of the work was made by Ahmed Farouk Kineber, Ali Hassan Ali, and Ahmed Osama Daoud. Data acquisition was made by Sherif Mostafa and Ali Hassan Ali. Supervision was made by Sherif Mohamed. Data analysis and interpretation of data was made by all authors. All authors read and approved the final manuscript.

Competing Interests:

The authors declare that they have no conflict of interest**.**

Availability of Data and Materials:

The data that support the findings of this study are available from the corresponding author, Ahmed Osama Daoud, upon reasonable request.