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Structural Equation Modelling PLS-SEM to Investigate Waste Generation in Roadway Construction Projects in Libya

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ABSTRACT

The construction industry has grown rapidly worldwide in the past decade, resulting in a significant increase in construction waste. In Libya, the construction sector has been a significant contributor to environmental degradation. To control this impact, there is an urgent need to understand how this waste is generated and how to manage it. This study aims to develop a PLS-SEM model to investigate the factors influencing construction waste generation in roadway projects. A comprehensive literature review identified 26 factors contributing to waste generation, which were then grouped into six categories: Work execution, Materials management, Design and planning, Manpower, Site management, and External factors. Additionally, the review identified 13 effects of construction waste generation, categorized under three sustainability aspects: Environmental, Economic, and Social effects. To gather data on these factors and effects, a questionnaire survey was conducted among professionals (including civil engineers, quantity surveyors, designers, and site engineers) from contractor and consultant firms involved in Libyan roadway projects, specifically those with expertise in roadway construction in the north and central regions of Libya. Respondents were asked to rank the causes and effects of construction waste generation. To determine the significance of various factor groups contributing to waste generation in road construction projects and to evaluate their sustainability-related impacts, a hierarchical model was developed and analysed using the PLS-SEM method (Smart PLS software 4.0). The model's results indicate that manpower-related factors have the most substantial influence on construction waste generation. Materials management factors were the second most significant contributors to waste in roadway construction projects. Furthermore, the study found that construction waste generation significantly impacts both economic and environmental aspects. This model could assist construction stakeholders in preventing construction waste and mitigating its adverse effects on sustainable performance.

Keywords: Construction waste, Cause-Effect, PLS Model, Roadway projects in Libya

النمذجة بالمعادلات البنائية PLS-SEM لدراسة توليد النفايات في مشاريع إنشاءالطرق بليبيا

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ملخـــــــص البحـــــث

شهد قطاع البناء نموًا سريعًا على مستوى العالم في العقد الماضي، مما أدى إلى زيادة كبيرة في نفايات البناء. في ليبيا، كان قطاع البناء مساهمًا كبيرًا في التدهور البيئي. للسيطرة على هذه الآثار، توجد حاجة ملحة لفهم كيفية توليد هذه النفايات وكيفية إدارتها. تهدف هذه الدراسة إلى تطوير نموذج بنمذجة المعادلات البنائية باستخدام طريقة المربعات الصغرى الجزئية **(PLS-SEM)** لدراسة العوامل المؤثرة في توليد نفايات البناء في مشاريع الطرق. حددت المراجعة الشاملة للأدبيات 26 عاملاً تساهم في توليد النفايات، والتي تم تجميعها بعد ذلك في ست فئات: تنفيذ الأعمال، وإدارة المواد، والتصميم والتخطيط، والقوى العاملة، وإدارة الموقع، والعوامل الخارجية. بالإضافة إلى ذلك، حددت المراجعة 13 تأثيرًا لتوليد نفايات البناء، مصنفة ضمن ثلاثة جوانب للاستدامة: الآثار البيئية والاقتصادية والاجتماعية. لجمع بيانات حول هذه العوامل والآثار، تم إجراء مسح استبياني بين المهنيين (بما في ذلك المهندسين المدنيين، ومساحي الكميات، والمصممين، ومهندسي المواقع) من شركات المقاولات والاستشارات العاملة في مشاريع الطرق الليبية، وتحديداً أولئك الذين لديهم خبرة في إنشاء الطرق في المنطقتين الشمالية والوسطى من ليبيا. طُلب من المشاركين ترتيب أسباب وآثار توليد نفايات البناء. لتحديد أهمية مجموعات العوامل المختلفة المساهمة في توليد النفايات في مشاريع إنشاء الطرق وتقييم آثارها المتعلقة بالاستدامة، تم تطوير نموذج هرمي وتحليله باستخدام طريقة المربعات الصغرى الجزئية **(PLS-SEM)** (برنامج **Smart PLS 4.0**). أشارت نتائج النموذج إلى أن العوامل المتعلقة بالقوى العاملة كان لها التأثير الأكبر على توليد نفايات البناء. وكانت عوامل إدارة المواد ثاني أهم المساهمين في النفايات في مشاريع إنشاء الطرق. علاوة على ذلك، وجدت الدراسة أن توليد نفايات البناء يؤثر بشكل كبير على الجوانب الاقتصادية والبيئية على حد سواء. يمكن أن يساعد هذا النموذج أصحاب المصلحة في قطاع البناء في منع نفايات البناء وتخفيف آثارها السلبية على الأداء المستدام.

الكلمات الدالة: نفايات البناء، نموذج PLS SEM,السبب والتأثير، مشاريع الطرق في ليبيا

1. Introduction

In Libya, the government of national unity has decided to revive construction projects that have been suspended since 2011. Like many other developing countries, the construction industry in Libya is facing numerous challenges, including cost overruns, time overruns, low quality, low productivity, variations, and construction waste generation. While construction and demolition waste holds significant potential for reuse and recycling, these practices remain underdeveloped in Libya **[1]**. Demolition and construction waste constitutes more than 30% of the total solid waste disposed of in landfills **[2]**. There is an urgent need to develop policies and solutions to address this phenomenon. This involves responsible waste management, encompassing waste treatment, reuse, recycling, and disposal. Moreover, reducing waste at its source is the most effective approach. To understand the root causes and impacts of this waste, a hierarchical causal model can be valuable. From this perspective, the researcher employed the Structural Equation Modelling (SEM) technique to develop such a model.

2. Literature Review

2.1 Concept of construction waste

Researchers today define construction waste as any inefficiency that leads to the excessive use of equipment, materials, labour, or capital in the construction project [3]. This concept encompasses both material losses and the execution of unnecessary work, which leads to additional costs without adding value to the project [4]. Construction waste is substantial compared to other waste types and poses environmental and social challenges [5]. Its composition varies widely due to many factors like construction methods, project types, and location. For decades, many experts in the construction sector have held the belief that the amount of construction waste generated is directly correlated with the volume of debris disposed of from a project site. According to [5] the proportion of construction debris that is landfilled in many countries ranges from 19% to 50% of the total amount of waste, Table 1.

Table 1. Ratio of construction waste to the total amount of construction waste produced [5]

Canada	Japan	Denmark	Hong Kong	Chili	England	Australia	Germany	Brazil	USA
27%	20%	27%	28%	34%	32%	20-30%	19%	50%	29%

Reducing waste by controlling its sources of generation is the most effective approach to mitigating this issue. This requires a deep understanding of the factors that generate waste, their influences, and the interrelationships between them. This study aims to achieve precisely this understanding.

2.2 Causes of construction waste according to previous studies

To better understand the Libyan context, this review concentrates on studies conducted in Asia, Africa, and the Middle East, regions exhibiting construction waste generation trends more closely aligned with Libya.

Khalil et Al-Zubaidy conducted a study in Iraq [3] to investigate the main causes of waste generation in building projects, the study reveals 15 factors influencing construction waste generation and categorizes them into 3 groups: (site management and practices), (materials handling, transportation and storage), and (materials management on site). The findings of the study indicated that damage to materials on site, double handling of materials and incompetent contractors' technical staff were the most significant factors of each category, with Relative Importance indices [3]. Ndukwe Ibe [6] identified 75 factors likely to cause waste generation in construction projects from a review of the literature []. The study confirms that deviations from the approved blueprints, design modifications, and the utilization of inefficient methods are the primary causes of construction material waste at Abuja building sites. The study also demonstrates that these factors impact waste generation at various stages of Nigerian construction projects. Poor supervision is identified as the most significant contributor to material waste generation.

A study was conducted to investigate the phenomenon of waste generation in construction projects in Egypt. This research investigated previous literature focusing on: the design process and its impact on construction waste, and global and national waste management strategies. Subsequently, three case studies were introduced and analysed to examine the role of design for waste reduction strategies in minimizing construction waste during the design stage. The study recommended the following to mitigate construction waste: minimizing design errors, improving communication and collaboration among stakeholders, and reducing unexpected design changes during the execution phase [7].

In the same context, the top causes of construction waste in Indonesia were waste-inducing site and human resource management approaches, inadequate collaboration and support among stakeholders, equipment management approach, material logistics management, poor working environment, and poor communication on the construction site [4].

To understand the key factors contributing to construction waste in Jordan, a study was conducted by Al-Rifai and Amoudi [8] identified two primary categories: management-related and workforce-related. The study found that the most significant factors included:

- Lack of skilled workers and subcontractors.
- Absence of a robust quality management system.

Previous research, including studies by [3-15] identified 26 cause factors; these factors were subsequently classified into six categories based on the primary cause responsible for construction waste. Figure 1 shows the categories of factors of waste generation.

- Work execution, caused by: incorrect construction method, lack of construction equipment, incorrect selection of equipment, unsuitable equipment, and poor site layout.
- Materials management caused by: low quality materials, delivery of materials that are not according to schedule, material handling on site, and inappropriate use of materials.
- Design and planning, caused by: site documentation system that is not integrated well, unclear specifications, low-quality drawings, delay in revision and redistribution of construction drawings, design changes, and low-quality design.
- Manpower, caused by: unskilled labourers, lack of supervision, sub-standard subcontractors, personnel, and inexperienced field supervisors.
- Site management, caused by: poor planning, poor information distribution, and lack of coordination among construction stakeholders.
- External factors, caused by, among others: site condition, weather, and damage caused by a third party.

2.3 Effects of construction waste

Construction waste is often perceived as a detrimental and unproductive byproduct of development, with significant negative impacts on the surrounding environment [16]. The situation with construction waste in Libya is indeed a serious concern. Illegal dumping practices are exacerbating the problem, leading to significant environmental and public health issues [17, 18].

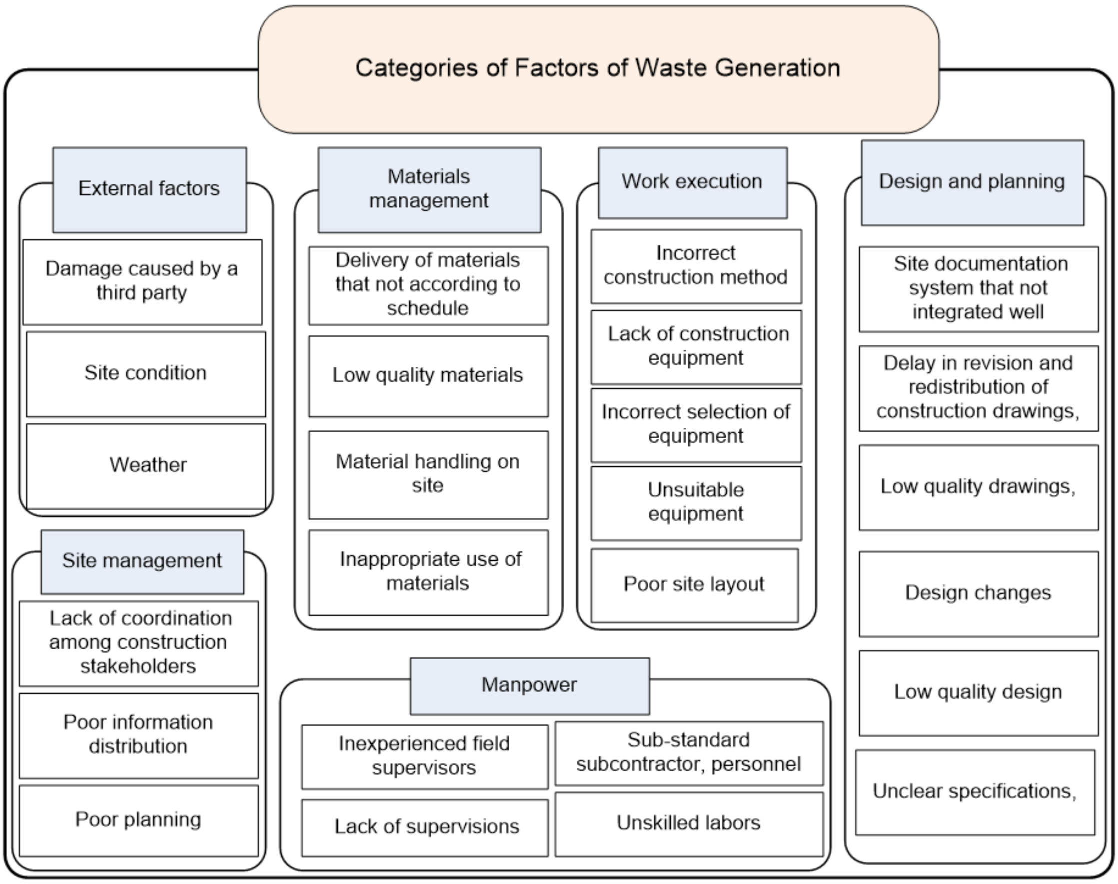

Figure 1. Categories of factors of waste generation

Based on extensive research and literature reviews, the primary effect factors driving the generation of construction waste can be broadly categorized into three main groups. Figure 2 illustrates the main categories of construction waste effects.

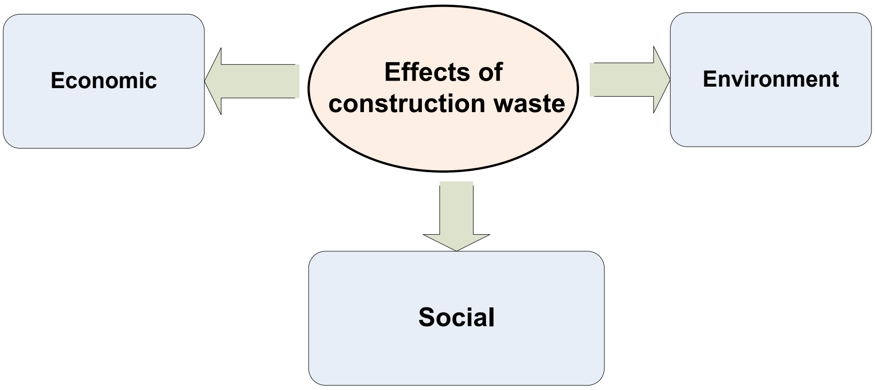

Figure 2. Categories of construction waste effects

- ❖ Environmental Factors: These encompass the ecological impacts of construction waste, such as: soil and water contamination: leachate from improperly disposed waste can contaminate soil and groundwater.
- ❖ Economic Factors: These relate to the financial implications of construction waste, including: increased project Costs: Improper waste management can lead to unexpected expenses, such as fines for illegal dumping and the cost of transporting waste to landfills. Also, lost revenue due to wasted materials represents a direct loss of investment for construction companies. In addition, inefficient waste management practices can disrupt construction schedules and reduce productivity.
- ❖ Social Factors: These encompass the social and community-level impacts of construction waste, such as: Public health risks: Improperly disposed waste can attract pests and disease vectors, posing health risks to nearby communities. Likewise, illegal dumping and unsightly piles of construction waste can degrade the aesthetic appeal of neighbourhoods. Also, construction activities and associated waste can disrupt daily life for residents in affected areas. Table 2 provides sustainability impacts with factors.

Table 2. Sustainability impacts with factors

Effet on	Factor	References
Environnent	Environnemental pollution	[9]
	Shortage of land	[13]
	Increasing of illegal dumping	[13]
	Ecological damage	[13],[14]
Economic	Transportation of waste	[11]
	Increase project cost	[19]
	Increase landfill fees	[11]
	Increase price of materials	[11]
	Delay in schedule	[19]
Social	Mental health effect	[12], [13]
	Physical health effect	[14], [20]
	Injury to public	[21],[22]
	No aesthetic	[16]

3. Development of the Initial Conceptual Model and Hypotheses

From the literature review, 26 factors contributing to construction waste generation were identified and categorized into six main groups based on their underlying causes. Separately, 13 impact factors resulting from construction waste were identified and classified into three categories. To effectively analyze the cause-and-effect of construction waste generation via the SEM technique, a hypothetical model illustrating the relationships between these factors and variables is crucial. This model serves as a foundation for empirically testing the hypothesized relationships among the variables[9]. Figure 3 presents the proposed initial conceptual model for the cause-effect relationships of construction waste generation.

The following hypotheses were derived from the model:

H1: Work execution has a significant relationship on the construction waste generation.

H2: Material management has a significant relationship on the construction waste generation.

H3: Design and planning have a significant relationship on the construction waste generation.

H4: Manpower has a significant relationship on the construction waste generation.

H5: Site management has a significant relationship on the construction waste generation.

H6: External factors have a significant relationship on the construction waste generation

H7: Construction waste has a significant impact on environment.

H8: Construction waste has a significant impact on economic.

H9: Construction waste has a significant impact on social.

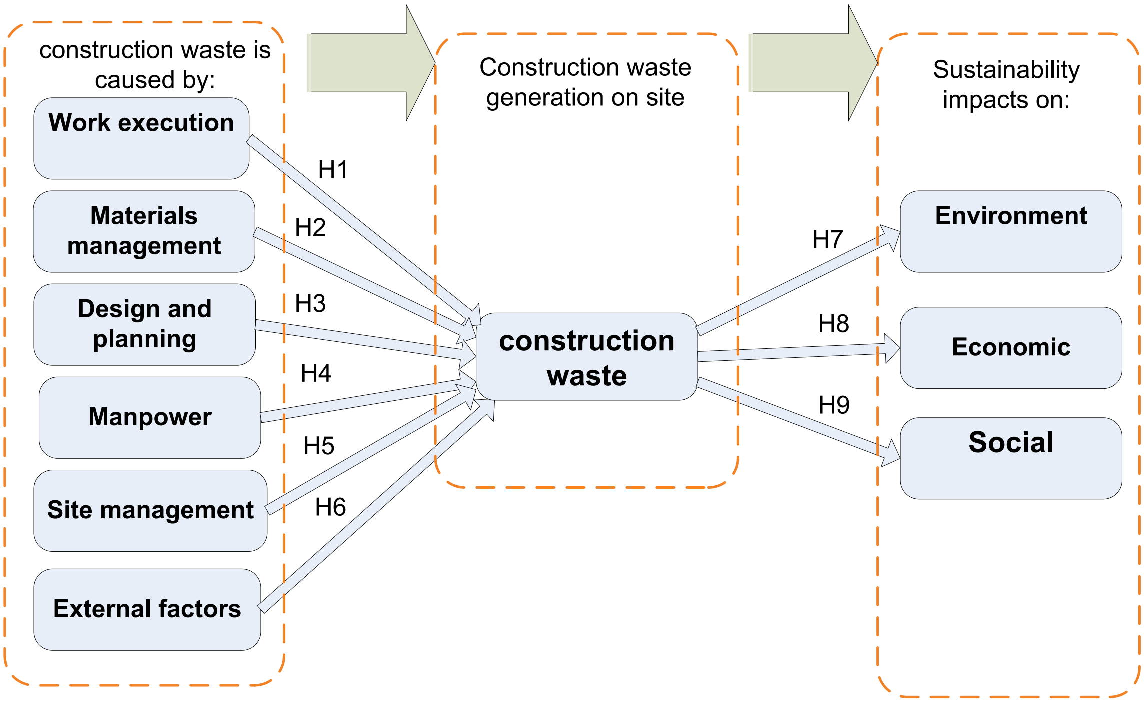

Figure 3. proposed initial conceptual model for the cause-effect relationships of construction waste

4. Data Collection& Sample Size

For data collection, 150 sets of questionnaires were distributed among consultants, clients, and contractors with expertise in roadway construction projects in north and central Libya during 3 months; only 109 questionnaires were returned for a response rate of around 60%. According to [23], it's an acceptable rate. Of these, 96 sets of questionnaires were valid for analysis. Figure 3 presents the proposed initial conceptual model for the cause-effect relationships of construction waste generation; this model has 9 structural paths. Which means, for analysis of the PLS model, the minimum sample size is **10 × 9 = 90**. while the collected sample is **96**. Such a sample size is valid and adequate for PLS SEM analysis to achieve the objective of the study.

5. Data Analysis

5.1 Concept of structural equation modeling SEM

Structural equation modeling (SEM) is a statistical analysis tool widely used by psychologists and sociologists. However, it is underutilized in construction management research despite its distinct advantages[23]. SEM is a multivariate methodology that allows the simultaneous examination of the relationships among independent and dependent constructs within a theoretical model[24]. To assist analysts who use SEM to solve problems, several computer programs have been developed, such as SMART PLS, LISREL, EQS, and AMOS.

5.2 Partial Least Square Structural Equation Modeling

PLS path modeling analysis is a general approach to estimate causal relationships in path models that include latent constructs that are indirectly measured by various indicators [25]. PLS is a technique that uses a combination of principal components analysis, path analysis, and regression to simultaneously evaluate theory and data [23]. The PLS path analysis predominantly focuses on estimating and analyzing the relationships between the latent variables in the inner model. However, latent variables are measured using a block of manifest variables, with each of these indicators associated with a particular latent variable [26]. The main purpose of the model is to determine the significance level of each group of factors on the generation of construction waste, as well as to determine the influence of the construction waste environment. The PLS model contains two parts, i.e. ''measurement model'' and ''structural model. To meet the required criteria, the measurement model must be evaluated before establishing the structural model. By checking the reliability of every factor and the convergent validity of every group, the evaluation of the measurement model was done [27].

In the current study, to establish the PLS model, the first step involves determining the "factor loading" for each factor. Any factor with a loading value below 0.5 is discarded, and the model is re-run. This iterative process continues until all factors achieve a loading factor of 0.5 or higher (in this research, 13 factors were omitted.) Once this criterion is met, the model is considered reliable. Figure 4 illustrates values of factor loading for each factor in the model. Subsequently, the convergent validity of each factor group within the model is assessed. Using Smart PLS 4.0, the analysis revealed that the Average Variance Extracted (AVE) and the commonality of all factor groups exceeded 0.50. Furthermore, the model's reliability was assessed by ensuring Composite Reliability (CR) values surpassed 0.70.

Consequently, the measurement model met the criteria for convergent validity and reliability, as presented in Table 3. Upon achieving these criteria, the model was deemed suitable for evaluating the significance of each factor group in influencing construction waste generation and assessing their impacts. The assessment was conducted by analyzing the path coefficients for each group of related causes and effects, as detailed in Table 4.

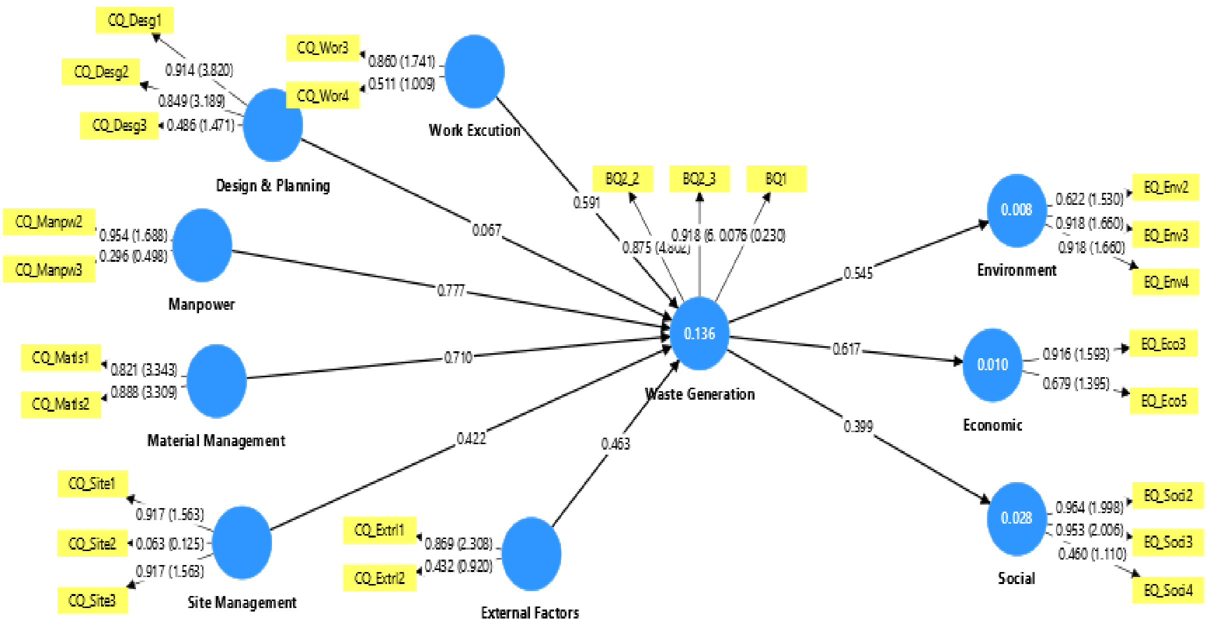

Figure 4. Values of factor loading for each factor in the model

Table 3. Composite reliability and convergent validity parameters for each group

Variable	Composite Reliability (CR)	Average Variance Extracted (AVE)
Work execution	0.753	0.501
Design and planning	0.807	0.597
Manpower	0.709	0.500
Material management	0.845	0.731
Site management	0.732	0.561
External factors	0.716	0.571
Construction waste	0.716	0.538
Environment	0.867	0.690
Economic	0.785	0.651
Social	0.856	0.683

This study aimed to investigate the key factors influencing construction waste generation and their effects through path analysis. Based on Figure 5 and Table 4, the findings reveal that factors related to manpower exhibit the strongest influence on construction waste generation, with a path coefficient (β) of 0.777, surpassing other factors. Factors related to material management emerged as the second most significant contributor to construction waste generation, with a path coefficient (β) of 0.710. Factors related to design and planning have the least influence on construction waste generation, with a path coefficient (β) of 0.067. These findings highlight the critical role of effective manpower as well as management of the material in minimizing construction waste, emphasizing the need for robust project planning and implementation strategies.

Construction waste generation exhibited a significant and positive influence on both economic and environmental aspects, with path coefficient values of $\beta = 0.617$ and $\beta = 0.545$, respectively. These findings underscore the multifaceted nature of construction waste, highlighting its potential harm to various aspects of society.

Table 4. Values of path coefficient

Related Factors	Related Effects	(β) Path coefficient
Work execution →	Construction waste	0.591
Design and planning →	Construction waste	0.067
Manpower →	Construction waste	0.777
Material management →	Construction waste	0.710
Site management →	Construction waste	0.422
External factors →	Construction waste	0.463
Construction waste →	Environment	0.545
Construction waste →	Economic	0.617
Construction waste →	Social	0.399

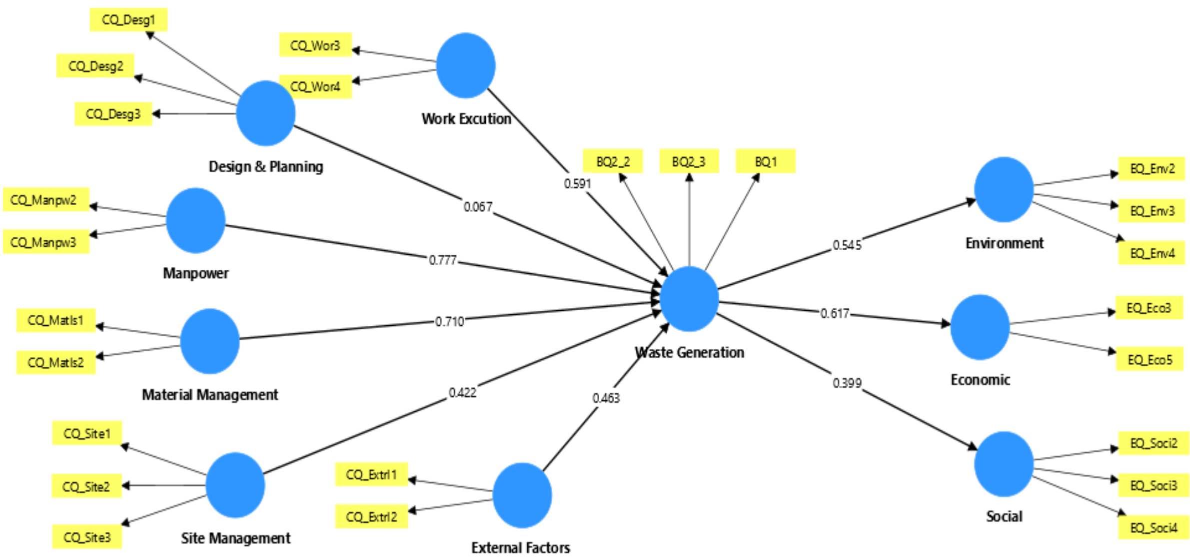

Figure 5 Final PLS SEM model for factors of construction waste generation and their impacts

6. Conclusions

Employing the PLS-SEM technique, supported by Smart PLS 4.0, the model's analysis reveals that manpower-related factors exert the most significant influence on construction waste generation. Materials management factors were identified as the second most substantial contributors to waste in roadway construction projects. Furthermore, the findings indicate that construction waste generation has a significant negative impact on both economic and environmental aspects. The analysis also demonstrates that manpower-related factors indirectly and negatively influence economic and environmental aspects through the generation of construction waste. Moreover, the model's capability to determine the contribution level of each factor to construction waste generation in roadway projects is a key strength. By identifying these factors, understanding their impacts, and recognizing the relationships between them, strategies can be developed to avoid construction waste generation and mitigate its adverse consequences.

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