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s.journal@nbu.edu.sa

Key causes contributing to material waste in construction projects in the Kingdom of Saudi Arabia

Mohammed Algahtany

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Abstract: Material waste generated from construction projects is increasing significantly with rapid urbanization and construction development and has been recognized as a major environmental issue. To manage this waste and minimize its impact, a comprehensive understanding of the causes of material waste is required. The purpose of this study was to investigate the causes of such waste generation in the Northern Border Province of Saudi Arabia. Causes were identified from the literature and interviews, and then grouped into six clusters: workers, design and documentation, management, procurement, handling, and external sources. To determine the significance of material waste causes, a questionnaire survey was distributed to professionals working in construction projects. The data were analyzed using the average index method, and causes were ranked according to their importance levels. In addition, the data were analyzed according to their categories and based on the perspectives of contractors and consultants. The results showed that the top ranked five causes of material waste increase are damage to materials due to projects failure and extensions, unskilled labor and technicians, improper usage, design changes during construction, and poor implementation or failure to follow engineering and industrial principles. Analysis of cause clusters showed that worker-related causes are the major contributors to material waste generation, followed by design- and documentation-related causes. These findings will provide professionals in the construction industry with a better understanding of waste causes to apply suitable minimization solutions and develop effective waste management plans.
Keywords: Construction projects, material waste, waste causes, waste management, Saudi Arabia

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* **Corresponding Author:**
Assistant Professor, Civil Engineering Dept., Faculty of Engineering, Northern Border University.Arar, Kingdom of Saudi Arabia.

e-mail: Mohammed.algahtany@nbu.edu.sa

المملكة العربية السعودية
جامعة الحدود الشمالية (NBU)
مجلة الشمال للعلوم الأساسية والتطبيقية (JNBAS)
طباعة ردمد: 1658-7014/ إلكتروني – ردمد: 1658-7022
www.nbu.edu.sa
s.journal@nbu.edu.sa

العوامل الرئيسية المسببة للهدر في المواد في المشاريع الإنشائية في المملكة العربية السعودية

محمد القحطاني

(قدم للنشر في 1444/2/16؛ وقبل للنشر في 1444/7/4هـ)

مستخلص البحث: مع التطور العمراني والحضري السريع يزيد التركيز على الهدر في المواد في المشاريع الإنشائية وتعتبر الدراسة الشاملة للأسباب المؤدية إلى الهدر في المواد الإنشائية خطوة رئيسية لإدارة الهدر وتخفيض معدل مخلفات البناء لتقليل تأثيرها السلبي. يهدف هذا البحث إلى دراسة العوامل المسببة للهدر في المواد في المشاريع الإنشائية في منطقة الحدود الشمالية في المملكة العربية السعودية. تم جمع العوامل المسببة لهدر المواد من الأدبيات المرجعية ومن دراسة استطلاعية ومن ثم تم تصنيف العوامل إلى ست مجموعات وهي مجموعة العاملين، التصميم والتوثيق، الإدارة، المشتريات، التعامل مع المواد وعوامل خارجية. ولتحديد أهمية عوامل الهدر في المواد، تم توزيع استبيان على المهنيين العاملين في مشاريع الإنشاءات لتقييم أسباب الهدر. تم تحليل بيانات الدراسة باستخدام طريقة مؤشر المتوسطات وتم تصنيف عوامل الهدر بناء على مستوى الأهمية. بالإضافة إلى ذلك، تم تحليل بيانات الدراسة وفقاً لفئات عوامل الهدر وبناء على وجهات نظر المختصين العاملين مع المقاولين والاستشاريين. أظهرت نتائج الدراسة بأن الأسباب الأعلى تقييماً هي: تلف المواد نتيجة تعثر المشاريع وتمديدها لفترات طويلة، قلة خبرة ومهارة العمالة والفنيين، سوء استخدام المواد، تغيير التصميم خلال الإنشاء، سوء التنفيذ في الموقع وعدم اتباع أصول الصناعة والأصول الهندسية. بالإضافة إلى ذلك أظهر تحليل نتائج مجموعات العوامل أن مجموعة الأسباب المتعلقة بالعاملين هي المساهم الرئيسي في زيادة الهدر في المواد الإنشائية متبوعة بمجموعة الأسباب المتعلقة بالتصميم والتوثيق. نتائج الدراسة سوف تقدم للمتخصصين في أطراف المشاريع الإنشائية فهماً أفضل لمسببات الهدر لتطبيق حلول متوائمة لتقليل الهدر وتطوير خطط فعالة لإدارة هدر المواد الإنشائية.

كلمات مفتاحية: مشاريع الإنشاء، هدر المواد، عوامل الهدر، إدارة الهدر، المملكة العربية السعودية

للمراسلة:
أستاذ مساعد، قسم الهندسة المدنية، كلية الهندسة، جامعة الحدود الشمالية، عرعر، المملكة العربية السعودية.

e-mail: Mohammed.algahtany@nbu.edu.sa

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1. INTRODUCTION

The construction industry contributes to environmental degradation and is considered one of the major producers of material waste. Worldwide, the construction industry uses 36% of produced energy, is responsible for 37% of released carbon dioxide due to construction activates into the Earth's atmosphere (UN Environment, 2021). Furthermore, natural resources decreases with construction activates, as the construction industry is the largest consumer of raw materials (UN Environment, 2021). Construction activities also negatively impact the environment by producing large amounts of waste material. Luangcharoenrat, Intrachooto, Peansupap & Sutthinarakorn (2019) compared several studies and identified that construction waste in 13 developed countries was responsible for 13% to 60% of waste in landfills.

In the Gulf region, the Gulf Cooperation Countries (GCC) are classified usually in the top 10% of countries with the highest waste production per capita in the world, (Kabir *et al*., 2013). It is estimated that approximately 120 million tons of construction and demolition (C&D) waste is produced annually by GCC (Ouda, Peterson, Rehan, Sadef, Alghazo, & Nizami, 2018). In the Kingdom of Saudi Arabia, one of the main sources of solid waste is the C&D activity. The increase in the country's population growth rate and urbanization levels has led to the rapid development of construction projects that significantly add to waste (Ouda *et al*., 2018). For example, 4.5–6.35 million tons of C&D waste are produced annually in Jeddah city, which has 14% of the country's total population (Alzaydi, 2014). In the Eastern Province of Saudi Arabia, 81 construction companies were studied by Ouda *et al*. (2018), who found that 86.4% of construction and demolition waste was landfilled annually and only 13.6% reused or recycled.

Identifying the causes and relative impact of waste is essential for developing effective waste management strategies. Adopting and applying these strategies in construction projects leads to waste reduction and brings many benefits, including the reduction of construction and disposal costs by minimizing the amount of wasted construction material, and the conservation of natural resources (Ling & Lim, 2002). The relationship between the causes of cost overruns and those of material waste were compared by Saidu & Winston, (2016), and the results showed that all incidents of material waste cause cost overruns in construction projects. The study concluded that effective application of waste management would result in a reduction in project costs. The reduction of carbon dioxide emissions (CO_2) is another benefit of reducing waste, while maintaining the health of laborers and nearby communities and increasing the longevity of landfill sites (Lingard, Graham, & Smithers, (2000). In addition, waste minimization provides a competitive advantage for all involved companies by improving overall performance and quality (Luangcharoenrat *et al*., 2019). Furthermore, the application of waste minimization processes promotes workforce productivity and skills, and enhances social, environmental, and economic sustainability (Al-Rifai & Amoudi, 2016).

2. LITERATURE REVIEW

The identification and classification of waste composition in the construction industry are essential for identifying causative factors and for effectively managing these wastes. Generally, the waste generated by C&D activities can be classified into two main groups: physical and nonphysical waste (Saidu & Winston, 2016). Physical waste is directly referred to as the solid waste resulting from activities such as building, roadwork, and demolition. Examples of solid waste include brick, steel, sand, tiles, glass, paper, blocks, wood, plastics, and concrete (Nagapan, Abdul-Rahman, Asmi & Hameed, 2012). In the EU, construction waste is divided into different categories: concrete, brick, tile, ceramic, asphalt, coal, wood, plastic, glass, metals, materials containing asbestos, insulation materials, rocks, soils, soils obtained from dredging, waste containing gypsum, and 'other' (Waste Thesaurus, 2015). This type of waste results in a complete loss of material and is regularly removed from construction sites to enter landfills (Nagapan *et al*., 2012). Nonphysical waste is related to cost

and time overruns in projects resulting from undesired activities that can cause physical waste, such as unnecessary movement of workers or materials, overproduction, rework, and waiting time (Nagapan *et al*., 2012; Memon, Abdul-Rahman & Memon, 2014). Furthermore, inefficiency in the construction process can lead to nonphysical waste owing to the overuse of materials, equipment, money, and workers (Ma, 2011).

Various studies have identified and assessed the causes of construction waste generation in a global context. A study determined the root causes of construction waste generation through an extensive literature review, questionnaire survey, and practitioner validation (Kaliannan, Nagapan, Sohu, & Jhatial, 2018). The results identified five main root causes of material waste in construction projects: design changes, poor handling of materials, incorrect storage of materials, errors while ordering from suppliers, and the impact of weather. Researchers recommend that practitioners mitigate these five causes of waste management plans. Another study reviewed the global literature and classified causes into seven groups: design, worker, handling, site condition, management, procurement, and external effects (Nagapan, Rahman, & Asmi, 2011). These findings indicate that frequent design changes are the most common cause of construction waste generation. Semi-structured interviews were conducted to study waste management in Australia (Newaz, Davis, Sher & Simon, 2022). and found that the key causes included experience and training of site operators, knowledge, potential for onsite sorting, and identification of the economic value of diverted material. These factors are considered important for waste management plans.

In the Middle East, several studies have identified and assessed the causes of construction waste generation in different countries. One study on the Saudi construction industry (Gopang & Latif, 2021) focused on the causes of waste in a public transport project (Riyadh Metro), which consisted of six train lines and 85 stations with a total length of 176 km. The causes were grouped into six clusters: design, construction management, construction site conditions, construction material procurement, construction material handling, and external causes. The study surveyed 118 construction professionals working on metro projects and analyzed the data using the average index and factor analysis. The study identified that the top five causes of construction waste were rework, lack of experience, lack of a management plan, poor workmanship, and incorrect material storage. Additionally, causes analysis was applied using the Exploratory Factor Analysis (EFA) method to the top 15 causes. Five causes responsible for the construction waste were identified: workers' issues, management, improper handling, material-related issues, and design.

Al-Hajj & Hamani (2011) interviewed and surveyed professionals from medium and large construction companies in the United Arab Emirates (UAE) to identify and assess the causes of material waste in construction projects. The study analyzed data through the calculation of weighted average values and standard deviation. They identified that the top direct causes of material waste in UAE construction sites were poor design, resulting in excessive off-cuts, workers' lack of awareness, and rework and variations. In contrast, the top indirect cause of material waste was the lack of legal and contractual incentive. The researchers identified the most frequent measures which decreased the amount of construction waste as adequate storage, staff training, and delivery of materials just prior to their need on site.

In Oman, a study was implemented to identify different causes leading to material waste in construction projects at Muscat and Nizwa cities (Latif, 2020). A structured questionnaire was used to evaluate the perceptions of professionals working with consultants, clients, and contractors. Construction waste causes were grouped into six major categories in the questionnaire: handling, design, workers, procurement, management, and site conditions. The average index method used for analysis concluded that the most significant causes in each category were incorrect material storage, frequent design changes, worker's mistakes during construction, errors in quantity surveys, poor supervision, and poor site conditions.

In the Iraqi construction industry, construction waste-related issues, such as increases in project costs and illegal landfill disposal, negatively affect the industry, with less priority given to waste management and minimization systems, which leads to increased annual construction waste (Khaleel & Al-Zubaidy, 2018). The study investigated the effects of 15 causes and categorized them into four groups: material handling, transportation and storage, on-site material management, and site management and practices. Construction engineers assessed these causes through a questionnaire survey and analyzed the data using the Relative Importance Indices (RII). The research findings concluded that the double handling of materials, damage of materials on site, and unskilled contractor technical workers were the most important causes in each category. Al-Rifai and Amoudi (2016) selected from the literature thirty-nine causes of material waste in the Jordanian construction industry and surveyed construction professionals through semi-structured interviews. Material waste was identified and grouped into two main categories: workforce-related and management-related factors. The most significant causes were lack of skilled workers and subcontractors, rework required because of workers' errors, lack of a quality management system, design changes, and changed orders during the construction stage.
In summary, studies have identified and assessed the causes contributing to construction waste generation in different countries in the Middle East. Only one study focused on transportation projects (Metro), while other studies investigated the causes of waste in general construction practices. Four studies utilized questionnaire surveys in the data collection process and analyzed the data using similar calculations, and only one study collected data using semi-structured interviews. Various causes of construction waste were identified in all studies; however, rework, lack of experience, and design changes were frequently identified as the top causes of construction material waste.

The construction industry in Saudi Arabia generates large amounts of construction material waste annually, and only one study has investigated this issue in a specific type of construction in the context of the Saudi industry. However, the causes of material waste were not investigated in general practices in the Saudi industry, as that study focused on the causes of construction waste in transportation projects (Metro) in Riyadh. In the northern region of Saudi Arabia, the causes of material waste have not yet been investigated by researchers, and the present study was aimed to identify influential material waste causes in construction projects in that region.

3. RESEARCH METHODOLOGY

The main objective of this research is to investigate the causes leading to material waste generation in construction projects in the Northern Province of Saudi Arabia. This study investigated the causes of material waste in construction practices in governmental projects. The main stages of the research methodology are shown in figure 1.

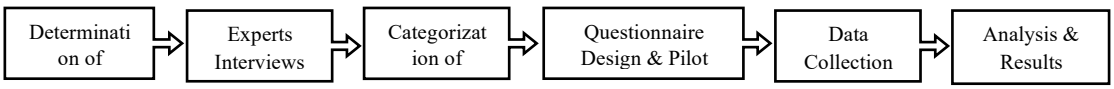

Figure 1. Research methodology stages

The first and second steps of the research methodology were implemented to identify material waste causes that will be assessed in the study through the following steps:

1- A comprehensive list of causes were identified through the review of the studies identified in the literature section. The list of causes were cross referenced and reduced to exclude causes that are only suitable for

specific type of projects and to combine similar causes that have same meaning.

2- Interviews were conducted with five experienced professionals who have more than 20 years of experience in the construction industry and have at least 10 years of experience in the region's projects. The experts reviewed the identified list of causes from the literature to specify the relevancy of the causes to the region projects. The final list of causes included 17 causes as shown in Table 3. The experts added four extra causes that are related to the region and not provided in the literature which are:
    - Damage of materials due to projects failure and extensions for long periods
    - Designer's weakness in writing materials' technical specifications with using words have more than one meaning
    - Poor implementation and failure to follow engineering and industrial principles
    - Failure to adhere to the quality control plan

In the third stage of the research methodology, the identified causes were grouped into six clusters; workers group, design and documentation, management, procurement, handling, and external causes. To specify the categories of the material waste causes, six studies that identified the classification of waste causes based on different categories were utilized as shown in Table 1. These categories were found to be the most frequent categories used in the classification of causes of construction waste. Consequently, the author utilized the studies in Table 1 to classify the causes of construction waste based on the most frequent categories as shown in Table 3.

Table 1. The most used classification categories for causes of construction waste

Classification of Category/ No. of Study	1	2	3	4	5	6	Freq
Procurement	*	*	*		*	*	5
Handling	*	*	*	*	*		5
Management	*	*	*	*			4
Design and Documentation	*	*	*			*	4
Workers	*	*	*		*		4
External	*	*					2
1. (Nagapan *et al.*, 2011) 2. (Gopang & Latif, 2021) 3. (Latif et al 2020) 4. (Khaleel & Al-Zubaidy, 2018) 5. (Al-Hajj & Hamani, 2011) 6. (Luangcharoenrat *et al*., 2019)							

A questionnaire survey was constructed for data collection and a pilot study was conducted with the five experts to evaluate the survey content, response time, and appropriateness of the questions. They also checked the translation accuracy of the survey from English to Arabic. The questionnaire survey was conducted in two sections. General information on the respondents was gathered in the first section. The second section included a list of material waste causes identified from the literature and interviews and included the evaluation criteria. The evaluation was conducted using the Likert-type scale. The participants were asked to rate each cause based on their perceptions according to the causes' degree of impact (severity) on the increase in material. A 5-point scale was used for the evaluation of the cause of waste. The severity of the causes was categorized as follows: none, low, moderate, severe, and extremely severe (on a 1-to-5-point scale). The average index formula was used to analyze the data to determine significance, as was adopted by Gopang *et al*. (2021) and Latif *et al*. (2020). The weighted average was calculated as follows:

$$Average\ Index\ (AI) = \frac{W1X1 + W2X2 + W3X3 + W4X4 + W5X5}{N}$$

where N = Total number of participants, W = the constant weighting given to each cause by respondents for severity, which ranged from 1 for none to 5 for extremely severe, and X= the number of response frequencies for each given weight.

The population of the survey was restricted to professionals in three project parties (projects owners, consultants, and contractors) who worked at governmental construction projects located in the Northern Borders region. A total of 90 questionnaire survey forms were distributed online to professionals in the specified population, and only 64 questionnaire forms were successfully received and used in this study resulting into (71%) return rate. This is considered to be a sufficient sample size as scholars normally agree that a sample size of 30 or more is adequate for drawing meaningful results and sufficient for statistical data analysis (Ott & Longnecker, 2015). Responses of participants who work at private projects or do not have experience in the region projects were excluded.

4. RESULTS

4.1. Demographic of the study

General information on the collected data included the demographic information of the study participants. They were asked about the project party for whom they worked, work position, years of experience, and academic qualifications. Demographic data of the participants are presented in Table 2. The majority of the participants were closely related to construction implementation activities. More than half of the participants worked with consultants who usually supervised the implementation of projects, and 36% worked with contractors. It was found that most of the respondents worked as field or supervisor engineers (61%), and 25% worked as project managers. All participants held a bachelor's degree or higher. The participants' years of experience were delineated as follows: 54% with 11-20 years; 34% with more than 20 years.

Table 2. Demographic data of participants

Project Party	**Percentage (%)**	**Work position**	**Percentage (%)**
Owners Consultants Contractors	8 56 36	Project Manager Field or Supervisor Engineer Planning Engineer Other Positions	25 61 6 8
Years of Experience	**Percentage (%)**	**Academic Qualifications**	**Percentage (%)**
Less than 5 5 - 10 11- 15 16 – 20 More than 20	6 6 21 33 34	Diploma or less Bachelor Degree Master Degree PhD	0 87 9 4

4.2. Reliability Analysis

Reliability analysis was performed prior conduction the analysis to assess the consistency and reliability of the survey. Cronbach's alpha is one of the most common techniques used in evaluating the reliability of surveys. The Cronbach's alpha value α ranges from 0 to 1,

where 0 indicating that the survey has no reliability and 1 indicating that the survey is consistent for all variables (Reynold and Santos, 1999). However, the α value must have a score of at least 0.70 to determine that the scale is reliable (Nunnally, 1994). The causes assessed in the study had an overall α value of 0.952, indicating that the measurements of five-point scale had high reliability at the 5% level of significance. Therefore, the survey data are appropriate for further analysis.

4.3. Average Index analysis

Table 3 presents the results of the survey and ranking of causes according to their importance levels using the average index method. Table 3 shows the mean average index, standard deviation, and ranking of the waste causes categories. The top five causes of material waste increase are damage to materials owing to failure and extensions, unskilled labor and technicians, improper material usage, design changes during construction, and poor implementation or failure to follow engineering and industrial principles.

Table 3. Average Index (*AI*) and ranking of construction waste generation causes

Group	Cause Description	Average Index	SD	Rank
Design and Documentation	Design changes during construction	4.23	0.96	4
	Errors in the design	4.02	1.07	10
	Inconsistency or errors in contractual documentation	3.86	1.09	16
	Designer's weakness in writing materials' technical specifications with using words have more than one meaning	4.08	1.02	6
Management	Failure to adhere to the quality control plan	3.98	0.94	11
	Rejection of materials due to non-compliance to the specifications	3.97	1.13	13
	Damage of materials due to projects failure and extensions for long periods	4.44	0.88	1
	Non integration of material planning with construction schedule	3.75	0.97	18
Procurement	Material ordering errors	4.08	0.99	9
	Incorrect order quantity (over ordering) of material	3.83	1.11	17
	Incompetent material suppliers	3.89	1.03	14
Workers	Improper material usage	4.27	0.87	3
	Poor implementation and failure to follow engineering and industrial principles	4.20	1.03	5
	Unskilled labor and technicians	4.33	0.81	2
	Lack of workers' awareness	4.08	0.85	7
Handling	Inappropriate site storage	4.08	0.96	8
	Inadequate packaging	3.69	0.95	20
	Damages during transportation	3.47	1.09	21
	Improper storing methods	3.98	1.05	11
External	Changes in governmental policies and regulations	3.72	1.04	19
	Theft or vandalism of materials	3.89	1.15	15

Table 4. Mean Average Index (*AI*) and ranking of waste cause categories

Cause Category	*AI* Mean	Rank
Workers group	4.220	1
Design and Documentation group	4.047	2
Management group	4.035	3
Procurement group	3.933	4
Handling and External groups	3.805	5

4.3.1. Workers group

The *AI* and ranks of the four causes categorized in the worker group are listed in Table 3. The participants ranked the 'unskilled labor and technicians' cause as the biggest contributor in this group in this group, with *AI* = 4.33. Unskilled labor and technicians in the contractor and subcontractor teams ranked second. Three out of four causes in the worker group are also ranked in the top five overall causes, which shows the essential impact of workers' causes on material waste generation.

4.3.2. Design and documentation group

The *AI* and ranks of the four causes categorized under the design and documentation groups are listed in Table 3. The participants ranked 'design changes during construction' as the most contributing cause in this group, with *AI* = 4.23. Design changes during construction ranked fourth in its effect, amongst all investigated causes, which shows its important effect on the materials waste generation in construction projects.

4.3.3. Management group

The *AI* and ranks of the four causes which are categorized in the management group are revealed in Table 3. The participants ranked 'damage of materials due to projects failure and extensions for long periods' as the most contributing cause for generating construction waste in this group, with *AI* = 4.44. This factor ranked first in its effect amongst all the causes, which shows its important effect on the materials waste generation in construction projects. However, the other three causes in this group ranked 11th, 13th, and 18th of the overall causes, showing they had less impact.

4.3.4. Procurement group

The procurement group ranked 'material ordering errors' as the biggest cause of waste generation in this group, with *AI* = 4.08 (Table 3). Material ordering errors ranked ninth in its effect among all investigated causes, which demonstrated its lesser effect compared to causes in other groups.

4.3.5. Handling and external groups

The handling and external groups had less of an impact than the other groups. The *AI* and ranks of the four causes categorized in the handling group are listed in Table 3. The participants ranked 'inappropriate site storage' as the biggest cause of waste, with *AI* = 4.08, which ranked eighth. The other three causes in the handling group and the causes in the external group had less effect.

4.4 Consultant and contractor perspectives on factors causing material waste

This section focus on consultants and contractors' perspectives on factors causing material waste to show the differences in in their perceptions. Consultants and contractors were the two main parties participating in this survey and are considered closest to actual implementation activities due to their regular presence on project sites.

The average index scores in Fig. 2 show the top causes of material waste in construction projects based on consultant perspectives. The results

indicate that the two most significant causes are related to workers in the contractor or subcontractor teams, i.e., unskilled labor and technicians, and poor implementation and failure to follow engineering and industrial principle'. The other two causes in the worker group are also the most significant based on consultant perspectives: improper material usage and lack of workers' awareness. The top causes based on consultant viewpoints included causes categorized in other groups, but four causes are also related to contractors and subcontractors: material ordering errors, failure to adhere to the quality control plan, non-compliance to the specifications, and inappropriate site storage.

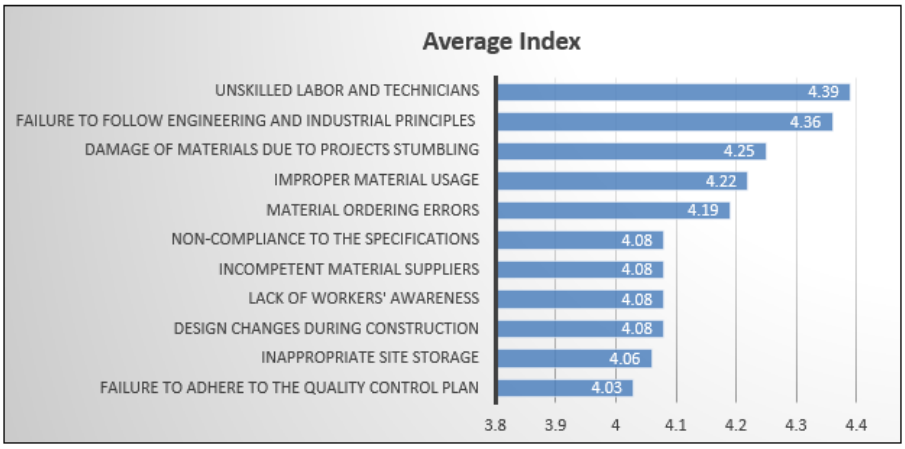

Figure 2. Top factors causing waste, based on consultant perspectives

The average index scores in Fig. 3 indicate the top causes of material waste in construction projects based on the contractor perspectives. The results show that damage to materials due to project failure and extensions for long periods is the most significant factor, which is also ranked first in the top overall causes in Table 3. Three causes from the design group are of significance based on contractor perspective, differing from the results in Fig. 2 as only 'design changes during construction' is significant based on consultants' point of view.

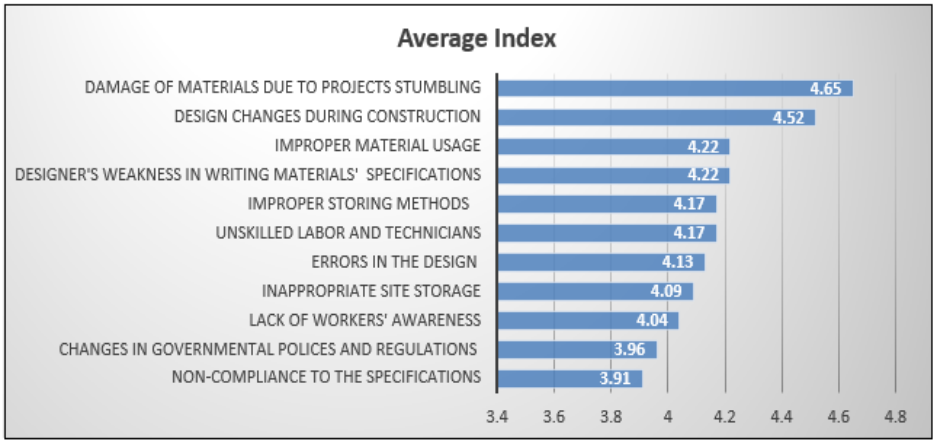

Figure 3. Top factors causing waste, based on contractor perspectives

5. DISCUSSION

Table 3 presents the results of the survey and the ranking of waste causes according to their importance levels using the average index method. The top-ranked cause of material waste increase in construction projects is damage to materials due to project failure and extensions, which are categorized in the management group with *AI* = 4.44. The causes of delays in projects that lead to time extensions should be identified and assessed by professionals to minimize or avoid their impact. The top causes of delays in public construction projects, according to the literature, include awarding projects to the lowest bidder, awarding contractor projects beyond their financial and technical potential, late procurement of materials, late delivery of materials, and delay in progress payments (Alsuliman, 2019; Abdellatif & Alshibani, 2019).

The results in Table 4 show that worker-related causes are major contributors to material waste generation. Unskilled labor and technicians, improper material usage, and poor implementation or failure to follow engineering and industrial principles are the top three causes in this group. These three causes are also ranked in the top five overall causes in Table 3, which shows the essential impact of workers on material waste generation. All worker-related causes are significant based on consultant perspectives, as shown in Fig. 2. Worker-related causes were also categorized as important in two other studies (Gopang & Latif, 2021; Al-Rifai & Amoudi, 2016). Lack of experience, poor workmanship, and inappropriate use of materials are ranked as the top causes of material waste in transportation projects (Gopang & Latif, 2021). Furthermore, the lack of skilled workers and subcontractors, and rework required because of worker error were the top two ranked causes of waste in Jordan (Al-Rifai & Amoudi, 2016). According to Nagapan *et al*. (2011), worker-related causes, such as worker mistakes and a lack of skills and training, are common causes of waste generation. Technical staff and workers in the contractor and subcontractor teams play a crucial role in decreasing waste in the implementation phase of projects. According to Luangcharoenrat *et al*. (2019), technical staff and workers should be willing to change their attitudes and behaviors to achieve successful construction waste management and minimization. Continuous education and training of engineering and industrial principles are essential to minimize worker-related causes of waste generation and to build worker and staff skills.

Design- and documentation-related causes are ranked as the second major contributor, as shown in Table 4. Design changes during construction and designers' weakness in writing effective material technical specifications are the top two causes in this category and are also ranked fourth and sixth among all investigated causes shown in Table 3, highlighting their importance. The top factors from contractor perspectives, as shown in Fig. 3, identified three significant causes in the design group. Design- and documentation-related causes were also categorized as important causes in four other studies (Kaliannan *et al*., 2018; Al-Hajj & Hamani, 2011; Latif *et al*., 2020; Al-Rifai & Amoudi, 2016). According to Nagapan *et al*. (2011), frequent design changes are one of the most dominant reasons for increasing construction material waste. Additionally, it is estimated that 33% of construction waste is generated through design decisions (Osmani, Glass & Price, 2006). One of the main reasons behind design-related causes is designers' lack of knowledge and experience about construction techniques and methods, which causes errors and inconsistencies throughout the design process (Chandrakanthi, Hettiaratchi, Prado & Ruwanpura, 2002). Design and contractual documents, including technical specifications, should be revised in the early stages of projects by designers and contractors to minimize errors, complexity, and inconsistency.

The results presented in this study were limited to construction practices in public projects in the northern region of Saudi Arabia and did not include demolition practices. However, surveying in different regions of Saudi Arabia would give a better understanding of waste causes to further develop a suitable minimization approach. The sample of the study was limited to three project parties (owners, consultants, and contractors). Future studies could include designers and material suppliers.

6. CONCLUSIONS AND RECOMMENDATIONS

This research investigated the causes of material waste generation in construction projects in the Northern Border Province of Saudi Arabia. A literature review and pilot study identified 21 material waste causes in construction projects. The explored causes were classified under six primary categories: (1) worker group, (2) design and documentation, (3) management, (4) procurement, (5) handling, and (6) external. The collected data were analyzed using the average index method, and causes were ranked according to their importance levels. The results identified the top five causes of material waste increase in construction projects as: damage to materials due to project failure and extensions, unskilled labor and technicians, improper material usage, design changes during construction, and poor implementation or failure to follow engineering and industrial principles. Unique causes of material waste generation have been identified through interviewing experts and then evaluated in this research, such as the damage to materials due to projects failure and extensions for long periods and failure to adhere to the quality control plan.

The results of this research show that worker-related causes are major contributors to waste generation. Technical staff and workers in contractor and subcontractor teams play a crucial role in decreasing waste in the implementation phase of projects. It is recommended that human resource management in companies hire well-trained labor and staff with sufficient knowledge and expertise to avoid rework during construction. Continuous education and training in engineering and industrial principles is encouraged to build workers and staff skills. In addition, companies should focus on increasing worker and staff awareness of waste management principles and applications. Design- and documentation-related causes are ranked as the second major contributor. Clients should provide a complete list of requirements before the design stage to avoid changes during construction. Designers must provide comprehensive and applicable designs to avoid errors and inconsistencies in design documents. Design and contractual documents, including technical specifications, should be revised by designers and contractors in the early stages of projects to minimize errors, complexity, and inconsistency.

The research results provide a general overview of the causes of material waste and their relative importance and will provide professionals in different project parties with a better understanding of the waste causes to develop a suitable minimization approach. Professionals in different phases of projects should address the identified and evaluated causes to develop effective waste management plans. Further studies are recommended to investigate the causes of material waste in specific types of construction projects by evaluating the significance of the differences in causes. Further research can be performed to evaluate current practices and develop appropriate waste management approaches to counter the causes of construction waste.

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