Minimizing Construction Waste: Management Practice Strategies across All Project Stages

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ABSTRACT

Construction waste resulting from building projects is one of the most damaging activities for the environment because the former can be produced at any stage of a project. This study emphasizes the importance of waste management and outlines the significant environmental and economic consequences of construction waste, by examining the construction materials that generate the highest percentage of them in construction projects. Additionally, the causes of waste generation in construction projects at each stage was determined, in order to contribute to the development of effective remedial strategies for reducing this type of waste. A quantitative descriptive approach was deployed, distributing a questionnaire to 270 participants from the Iraqi construction industry. Finally, statistical analysis was used to analyze the questionnaire data with SPSS software V.26. The results showed that concrete and aggregate constituted 45%, timber 25%, plaster 15.7%, and soil 9.3%. It was also demonstrated that the main reasons for waste generation in construction projects at different stages are the design and detail complexity, inappropriate material supply, and insufficient material quantities. The most efficient strategies for reducing waste are clarifying drawings, and incorporating renewable resources into designs, ensuring efficient procurement and material handling.

Keywords-waste construction; waste management practice; construction stages; quantitative method

I. INTRODUCTION

Over 40% of the global solid waste is produced from constructions, including concrete, wood, metal, glass, and plastic, making it difficult to be disposed or managed [1]. This large amount of solid waste results in soil and water contamination, produces significant quantities of methane from the decomposition of the organic matter, worsening the greenhouse effect and the deterioration of the environment [2]. Failing to properly manage construction waste can result in higher disposal costs, penalties for non compliance with regulations, and missed opportunities for material recovery and reuse [3]. Efficient waste management strategies can reduce these expenses; therefore, the building sector needs to adopt more sustainable procedures to minimize its environmental impact and enhance its economic efficiency [4]. Global demand for buildings and infrastructure is high since housing, sanitation, and healthcare are essential for supporting the growing population. Construction materials are used to meet this demand; however, manufacturing them results in the overexploitation of natural gravel and sand. Technologies continue to encounter obstacles related to implementation and environmental efficiency. Limited knowledge and practical constraints have hindered the adoption of technologies that could prevent construction waste. Nevertheless, the proper utilization of the latter can ensure the supply chain security, reduce the consumption of natural resources, and facilitate the transition to a circular economy. Standardizing the existing methods for treating waste materials and byproducts produced during processing is a first step toward formulating policies that facilitate their extensive use. This research examines the obstacles and opportunities, as well as the necessary tactics for advancing the minimization of construction waste to develop sustainable infrastructure in the future. The construction industry in Iraq uses a major part of the National Gross Domestic Product (NGDP) [5]. During 2023, the total cost of complete and incomplete constructions was around 2.55 trillion dinars, having increased by 25.5% since 2022. The value of the materials used in buildings during 2023, was 72% of the total cost, having increased by 30.4% since 2022 [6]. These findings do not comply with the nations' efforts for sustainable development, arising issues of safety, productivity challenges, quality concerns, and cost overruns. The methodology for overseeing building projects in Iraq requires a modification, which could be achieved through waste management. This study aims to identify the construction materials that generate waste in the construction projects and the causes of waste generation during the design, implementation, and procurement phases. It also aims to identify the best strategies to reduce waste using the most efficient management practices in construction projects.

II. CONSTRUCTION MATERIAL WASTE

Construction material waste, such as bricks, concrete, and wood, is produced by various activities and accounts for 35% of the total waste generated compared to other industries [7]. Despite the challenges of accurately assessing the average amount of waste generated on construction sites, the latter adversely affects projects, communities, and ecosystems, as shown in [8]. Waste materials in landfills are among the most harmful for the environment and their processing can result in great cost overruns and time delays [8, 9]. Authors in [10] revealed that construction material waste consists of sand (12.51%), brick (14.49%), timber (10.95%), and cement (10%). Authors in [11] determined that the major components of construction waste were reinforced cement concrete (5.16%), brick (6.82%), ceramic (5.51%), tiles (6.68%), steel rebars (4.67%), paint (6%), and wood (6.14%). Authors in [12] found that the most common waste were concrete (16.5%), wood (14.5%), reinforced cement (12.1%), asbestos (10.5%), glass (9.4%), asphalt (7.3%), and tile ceramics (6.1%).

III. CONSTRUCTION WASTE CAUSES

There are two categories of physical waste: structural and finishing. The usage of materials, such as concrete, steel, and brick in structural activities during the construction stage results in structural waste. Finishing waste comprises materials, such as mosaics, cement, tiles, and paint utilized in the implementation of projects [13]. They are the result of various conditions and activities, including unsuitable treatment, lack of transportation coordination, procurement issues, changes in design, unsuitable storage, and unskilled workers and subcontractors [14]. These findings underscore the significance of labor in controlling waste, which is produced from negligence and a lack of competency. A significant amount of waste can be circumvented during the construction phase by ensuring that all employees are committed to operating without the oversight of management or incentives [15]. Furthermore, material deterioration during delivery and a paucity of packaging and supplies have been identified as significant sources of waste material treatment [16]. Substandard transportation and inadequate ordering can also result in the production of waste [17]. A multitude of factors may contribute to this issue, including the usage of materials that do not align with the established specifications and the implementation of an ineffective strategy for competent procurement [16]. According to the original plan, the alternation and subsequent return of supplies by the contractor after a prior purchase can result in waste. Furthermore, the inadequate and inefficient storage of materials, such as cement in wet environments is a significant contributor to waste generation [16]. Table I displays the classification of these causes into four categories.

IV. CONSTRUCTION PROJECT WASTE MINIMIZATION

Construction sites generate a considerable amount of waste on an annual basis, which increases contractors' cost considerations, including transportation, disposal, and procurement expenses [18]. A reduction in waste volume at construction sites is expected to result in decreased expenditures for raw material procurement and landfill disposal fees. An effective waste management is critical for a sustainable building economy. This necessitates the regulation and minimization of waste generation through the involvement of skilled builders and contractors. A recent estimate suggests that over 80% of the on-site refuse is recyclable and reusable [19]. The building and demolition waste industry has relied on variables, such as population growth, urban expansion, and landfill expenses in specific regions.

TABLE I. CONSTRUCTION MATERIAL WASTE CAUSES OVERVIEW

	No.	Cause
Design and documentation stage	DC1	Lack of attention in coordinating product dimensions
	DC2	Modification of the design during the construction phase
	DC3	Lack of awareness by designers of alternative products
	DC4	Complexity in design and details
	DC5	Drawing information needs to be clarified
	DC6	Incorrect specifications
	DC7	Poor site layout
	DC8	Poor knowledge of construction techniques by designers
	DC19	Lack of participation by contractors in the design stage
	DC10	Commencing work before completing documentation
	DC11	Lack of quantity estimation
	DC12	Inadequate finance for the project
Procurement	PC1	Ordering either more of less material than what is required
	PC2	Purchasing products that do not meet the required specifications
	PC3	Supplying inappropriate materials to the site
	PC4	Replacing required materials with more expensive materials
	PC5	Replacing materials with unnecessary higher quality materials
	PC6	Material price inflation
	PC7	Unsuitable strategies for competent procurement
Material storage and handling	MC1	Overloading means of transport
	MC2	Lack of proper transportation planning
	MC3	Poor planning for material storage
	MC4	Theft
	MC5	Material damage on site
	MC6	Unnecessary inventories on site
	MC7	Inconvenient material storage
	MC8	Incorrect handling
Construction stage	CC1	Mistakes in choosing the correct materials
	CC2	Insufficient quantities due to poor planning
	CC3	Equipment failure
	CC4	Inclement weather
	CC5	Improper storage of materials
	CC6	Incorrect construction techniques
	CC7	Insufficient construction techniques
	CC8	Poor communication between project parties
	CC9	Conflicts between labor or with the project team
	CC10	Lack of tools and equipment
	CC11	Producing extra amounts
	CC12	Manufacturing faults
	CC13	Onsite material control shortages
	CC14	Inadequate guidelines for handling
	CC15	Lack of skilled subcontractors
	CC16	Unpackaged supplies
	CC17	Lack of packaging and supplies
	CC18	Lack of decision-making
	CC19	Inadequate quality site documentation
	CC20	Lack of contractor experience
	CC21	Delayed arrival of materials
	CC22	Poor cooperation between the contractor and workers
	CC23	Manufacturing defects that lead to reworks
	CC24	Additional orders or modifications of orders by the client
	CC25	Inadequate training of workers
	CC26	Poor site management

The creation of an effective framework for developing sustainable waste management is important for any construction industry that wants to achieve a commendable sustainable development profile [20]. The management of construction and demolition waste involves the following principles: the elimination of waste whenever feasible, the reduction of waste wherever practical, and the reutilization of materials that would otherwise be discarded. For instance, discarded materials, such as concrete, bricks, and stones can be repurposed into valuable resources, like cement, and recovered flooring straw [21]. In the city of Baghdad, significant amounts of waste are generated during the construction projects due to the rapid population expansion, projected from 6 to 8% per year. Material waste at construction sites in Iraq is caused by inadequate site supervision, design flaws, substandard materials, untrained labor, poor material quality, design alterations, inaccurate specifications, inadequate storage facilities, improper handling procedures, inefficient material scheduling, erroneous supplier recommendations, and surplus resulting from bulk purchasing. These factors increase waste production at construction sites. Various waste-reduction strategies promote sustainable construction and effectiveness [22]. On-site waste management regularly helps prevent and minimize waste. According to [23], the major indicators for dealing with waste management are separating and recycling, reusing, employing waste prediction methods, planning for on-site waste management, designing for flexibility and demolition, effectively procuring waste, and applying regulation and tax measures. Effective site management includes material logistics control, waste segregation, material reuse, and reducing material landfill. Authors in [24] determined that the top-ranked strategies in waste construction management were conducting supervisor training courses on waste reduction strategies, using a standard design procedure, providing incentives to encourage workers to reduce waste on site, buying adequate raw materials, and conducting training courses for handling labor, storage, and transportation. The major methods of reducing material waste in the construction industry include appointing waste management officers, using prefabricated or off-site production of components and integrating a material waste reduction plan [25]. Other methods include using standardized design dimensions, experienced design teams, sufficient building ingredient sizes, uniform forms and spacing, avoiding design modifications, designing off-site construction, gaining precise contract documents, providing precise specifications and accurate material estimations, providing drawings with simplified and suitable details, taking material availability into account during the design stage, and adopting renewable resources in the design. Authors in [14] ranked the critical success factors for adopting efficient waste management strategies, as well as the most important waste minimization strategies, as follows: securing a subcontractor for waste disposal, reducing design changes, providing safe storage facilities for materials, adopting reusable materials, preventing waste incorporation into soil, securing waste collection containers, allocating spaces for waste segregation, constructing with standard materials, and providing on-site material compactors, as shown in Table II.

A. *Materials and Methods*

This study uses a quantitative technique and a questionnaire survey to gather primary data, whereas secondary data were obtained through a literature review, focusing on four target groups to understand their perspectives: engineers, site supervisors, contractors, and project managers.

TABLE II. RECENT CONSTRUCTION WASTE MANAGEMENT PRACTICE STRATEGIES

	No.	**Strategy**
Design and documentation stage	DS1	Reducing changes in design
	DS2	Integrating regulations of a material waste reduction plan
	DS3	Adopting renewable resources in design
	DS4	Considering material availability and design execution
	DS5	Provide drawings' suitable details
	DS6	Provide precise specifications
	DS7	Design insufficient information
	DS8	Select experienced design teams
	DS9	Design standardized dimensions
Procurement	PS1	Waste-efficient procurement
	PS2	Regulation and tax measures
	PS3	Precise contract documentation
	PS4	Supply materials with correct quantities
	PS5	Provide materials with accurate specifications
	PS6	Purchase materials from reliable suppliers
Material storage and handling	MS1	Provide safe facilities for sorting materials
	MS2	Activity execution adopting reusable materials
	MS3	Suitable construction material handling
	MS4	Directing labor in material handling
Construction Stage	CS1	Construction with standard materials
	CS2	Provide material compactors on site
	CS3	Allocate space for waste segregation
	CS4	Prevent waste incorporation
	CS5	Secure a subcontractor for waste disposal
	CS6	Good organization between suppliers and construction staff to avoid over-demand
	CS7	Secure containers for waste collection
	CS8	Conduct training courses for laborers
	CS9	Schedule construction activities weekly
	CS10	Mixing, transmitting, and casting of concrete at suitable time, provide skilled workers
	CS11	Efficient strategies to provide suitable site management methods
	CS12	On-site waste material recycling
	CS13	Check supplied materials for correct quality and size
	CS14	Appoint waste management officers
	CS15	Conduct training courses for supervisors on waste reduction strategies
	CS16	Incentives to encourage workers to reduce waste on site
	CS17	Identify administrators to manage waste

Three hundred surveys were distributed at construction sites to individuals involved in various activities at different levels in multiple cities in Iraq. Of those, 270 were returned, resulting in a response rate of 77%. After the organization agreed to collaborate with the researcher, 28 construction sites were visited in Iraq to discuss the study's objectives and goals. The materials measured at the beginning of the study were concrete and gravel, timber, bricks, plaster, steel, and soil. The study primarily assessed activities involving the typical materials used in the local construction sector, monitoring the procedural work of each activity, including the supply, transportation, handling, stock of materials and errors made by workers. By monitoring the building sites, staff can identify actions performed and report on how activities are completed. The survey questions were designed to gather data for the investigation and address the research inquiries. The survey consisted of four sections. Section A included questions about the types and percentages of waste generated from construction materials. Section B included demographic information, such as job position and work experience, as illustrated in Table III, while section C included 53 questions about the causes of increasing construction waste across four subsections. Finally, section D consisted of 36 questions across four subsections related to strategies for minimizing construction waste, as portrayed in Table III.

TABLE III. DEMOGRAPHIC INFORMATION OF RESPONDENTS

	Frequency	Percentage
Job position		
Project manager	55	20.5
Site supervision	56	20.7
Contractor	22	8.1
Engineer	137	50.7
Total	270	100
Experience in years		
5-9	31	11.3
10-15	42	15.4
16-20	97	36.1
>20	100	37.2
Total	270	

In order to assess the content validity of this questionnaire, a panel of five construction waste management experts performed an evaluation [26]. The first edition of the questionnaire was sent to five experts, whose responses prompted modifications and enhancements to many topics. Since all items in the current questionnaire represent independent formative constructs, this study used a test-retest approach to estimate the reliability of all items rather than the Cronbach's alpha. Spearman correlation coefficients were calculated between the test and retest, revealing that all values exceeded 0.8, indicating acceptable reliability for the questionnaire. After validation and pilot testing, the questionnaires were distributed. The four construction stages were correlated with causes of construction waste, such as design (12 items), procurement (7 items), material waste and handling (8 items), and construction (26 items). A total of 53 items were used to collect the data in section C. Section D of the questionnaire comprised four subsections with 36 items: design (9 items), procurement (6 items), material storage and handling (4 items), and construction (17 items). A total of 350 questionnaires were distributed to project directors, site supervisors, contractors, and engineers with construction industry experience, who volunteered to participate in the study. The data were subsequently analyzed using SPSS V 23 and statistical techniques, such as frequency, percentage, mean, standard deviation, and the Relative Importance Index (RII). Two prevalent response distortions linked to the sequence of response options are primacy and recency biases. Primacy bias refers to respondents' inclination to choose one of the first alternatives provided. This may occur when a respondent quickly scans the survey and selects the first answer with which they agree. Recency bias refers to the tendency to select an answer that appears toward the end of a list. When presented with a long list of possibilities, respondents are more likely to recall the choices they encountered last when picking an answer. A reliability study using Cronbach's alpha was performed to assess the survey's internal consistency. Cronbach's alpha was 0.917 for the 54 items in section C and 0.957 for the 37 items in section D, indicating a high level of dependability. To identify the primary sources of construction waste and provide waste reduction indicators, a ranking and analysis were performed based on the RII of the Likert scale. To determine the relative ranking of the studies, the scores were transformed into significant indices using:

$$RII = \Sigma WA \times N \qquad (1)$$

where W is the weighting given to each factor by the respondent, ranging from 1 to 5, 1 having low significance and 5 very high significance, A is the highest weight (A = 5), N = 270 and $0 \leq \text{RII} \leq 1$.

V. RESULTS AND DISCUSSION

A. *Construction Waste Percentage*

Figure 1 shows which construction materials resulted in the highest quantities of waste, according to the responses as a percentage. Concrete and aggregates were at 45%, followed by timber at 25%. Plaster and soil created less waste, at 15.7% and 9.3%, respectively, but their influence on waste formation should not be neglected. The questionnaire results indicate high waste rates for most building materials except steel and bricks for which the waste rates were acceptable. Authors in [10] revealed that construction material waste consisted of sand (12.51%), brick (14.49%), timber (10.95%), and cement (10%). Authors in [11] determined that the major components of construction waste were reinforced cement concrete (5.16%), brick (6.82%), ceramic (5.51%), tiles (6.68%), steel rebars (4.67%), paint (6%), and wood (6.14%). Authors in [12] found that the waste consisted of concrete (16.5%), wood (14.5%), reinforcement (12.1%), asbestos (10.5%), glass (9.4%), asphalt (7.3%), and tile ceramics (6.1%). These percentages are considered high compared to the research results in the countries in which the studies were conducted. This requires reducing the percentage of construction materials used in construction projects.

B. *Construction Waste Causes*

Table IV shows that the arithmetic mean values of the responses are all greater than 3, confirming that the proposed causes in the design stage result in waste in building projects. Additionally, it was noted that all RII values were high (0.7). According to [27], in construction designs, the complexity of design and details are the most significant factors resulting in waste, making it difficult to accurately estimate materials and quantities [24, 28]. The results revealed that several factors, particularly the absence of customer interest in waste minimization and negative attitudes toward it, act as deterrents to the proactive and sustainable execution of waste reduction techniques throughout the design process. These issues stem from mistakes made during the construction and renovation efforts, as well as from improving the material value.

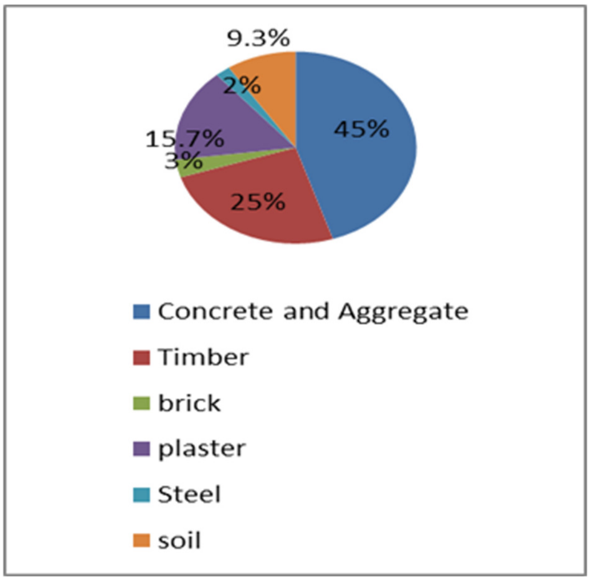

Fig. 1. Responses of participants (as a percentage) rating waste-generating materials.

TABLE IV. CONSTRUCTION WASTE CAUSES AT THE DESIGN AND DOCUMENTATION STAGES

Code	Cause	*M*	*SD*	*RII*	*R*
DC1	Lack in product dimensions	4.07	1.47	.81	5
DC2	Design change	4.26	1.27	.85	3
DC3	inexperienced designers	4.26	1.26	.85	3
DC4	Complexity in design and details	4.38	1.13	.88	1
DC5	Inadequate details of drawings	4.29	1.18	.86	2
DC6	Incorrect specifications	4.29	1.17	.86	2
DC7	Design mistakes	3.97	1.53	.79	6
DC8	Inexperience designer	3.96	1.54	.79	6
DC9	Inadequate contractor experience	4.29	1.25	.86	2
DC10	Beginning work before completing documentation for a project	4.15	1.35	.83	4
DC11	Lack of quantity estimation	4.07	1.47	.81	5
DC12	Inadequate finance for the project	4.26	1.27	.85	3

The superfluous on-site storage of materials and their vulnerability to damage, coupled with the escalating costs from unsuitable materials, utilities, and quality issues lead to delayed deliveries, budget shortfalls, inadequate management, and decreased efficiency and productivity. As presented in Table V, the arithmetic mean values of the responses exceed the mean value of 3. This finding suggests that the respondents agree that the causes proposed in the procurement stage result in waste in the building projects. The most significant factor for this is the material price inflation, which leads to cost overruns [29]. The second most significant factor is the substitution of the required materials with more expensive materials, which results in increased project costs due to waste. The third factor in the rank based on its significance is the purchase of products that do not meet the required specifications and the replacement of the required materials with higher quality materials that are not needed. These elements are identified as the primary contributors to cost inefficiency in construction projects, stemming from deficiencies in decision-making processes. The procurement of materials exerts a substantial influence on the generation of material waste and the aggregate expenses of a project. Material storage and processing procedures are among the most significant factors affecting waste production, as illustrated in Table VI.

TABLE V. CONSTRUCTION WASTE CAUSES IN THE PROCUREMENT STAGE

Code	Cause	*M*	*SD*	*RII*	*R*
PC1	Ordering change	3.84	1.61	0.77	4
PC2	Lack of quality materials	4.00	1.41	0.80	3
PC3	Supplying slow delivery of material	4.41	0.98	0.88	1
PC4	Replacing required materials with more expensive materials	4.26	1.20	0.85	2
PC5	Replacement of required materials with higher quality materials that are not required	4.16	1.35	0.83	3
PC6	Material price inflation	4.41	1.05	0.88	1
PC7	Unsuitable competent procurement strategies	3.80	1.64	0.76	5

TABLE VI. CONSTRUCTION WASTE CAUSES AT THE MATERIAL STORAGE AND HANDLING STAGE

Code	Cause	*M*	*SD*	*RII*	*R*
MC1	Overloading means of transport	3.88	1.56	0.78	6
MC2	Lack of proper transportation planning	4.21	1.30	0.84	4
MC3	Poor material storage	4.54	0.94	0.91	1
MC4	Theft	4.14	1.41	0.83	5
MC5	Material damage	4.43	1.06	0.89	3
MC6	Unnecessary inventories on site	4.48	1.01	0.90	2
MC7	Inconvenient material storage	4.25	1.27	0.85	3
MC8	Incorrect handling	4.56	0.90	0.91	1

The objective of this study was to determine the most significant factors contributing to waste generation. To this end, the arithmetic mean, standard deviation, and relative importance factors were calculated. According to the RII values (0.7), the factors related to waste storage were found to be of great significance. The factors were then arranged according to their relative influence on the waste production during the storage stage. The most significant factors contributing to waste generation are inadequate material storage [30] and improper handling. These findings underscore the efficacy of implementing a comprehensive material storage plan to achieve the waste minimization objectives. During the construction stage, the generation of waste may be attributable to improper on-site practices. As shown in Table VII, the most significant factor contributing to waste during construction projects is the absence of skilled subcontractors, who is responsible for material storage, material specification, construction techniques, and quality control [31]. The evaluation includes factors pertaining to project management and planning, operational relationships, financial aspects, work quality, and project complexities. The second most significant factor contributing to this issue is insufficient quantities of materials, owing to poor planning, incorrect construction techniques, an unsuitable strategy for competent procurement, and delayed arrival of materials at the work site. This has led to delays in the project, as well as the expenditure of financial resources and temporal investment. Additionally, there has been a waste of construction materials due to demolition.

Moreover, disputes among project team members or differing points of view can result in erroneous decisions, leading to waste, project delays, and additional costs.

C. Waste Management Strategies

The waste generated in construction projects has a detrimental effect on the environment, causing greenhouse gas emissions.

TABLE VII. CONSTRUCTION WASTE CAUSES IN THE CONSTRUCTION STAGE

Code	Cause	*M*	*SD*	*RII*	*R*
CC1	Mistakes in materials	4.31	1.21	0.86	5
CC2	Insufficient quantities of materials	4.44	1.08	0.89	2
CC3	Equipment failure	4.21	1.28	0.84	7
CC4	Inclement weather	3.87	1.54	0.77	14
CC5	Improper storage of materials	4.00	1.50	0.80	11
CC6	Incorrect construction techniques	4.43	1.11	0.89	2
CC7	Insufficient construction techniques	4.30	1.12	0.86	5
CC8	Poor communication between project parties	4.24	1.15	0.85	6
CC9	Conflicts between labor or the project team	4.39	1.06	0.88	3
CC10	Lack of tools and equipment	4.27	1.16	0.85	6
CC11	Producing extra amounts	4.37	1.04	0.87	4
CC12	Manufacturing faults	3.93	1.51	0.79	12
CC13	Onsite material control shortage	4.12	1.36	0.82	9
CC14	Inadequate handling guidelines	4.29	1.21	0.86	5
CC15	Lack of skilled subcontractors	4.53	0.93	0.91	1
CC16	Unpackaged supplies	4.16	1.30	0.83	8
CC17	Lack of packaging and supplies	3.96	1.50	0.79	12
CC18	Lack of decision-making	4.05	1.45	0.81	10
CC19	Inadequate quality of site documentation	4.10	1.41	0.82	9
CC20	Lack of contractor experience	4.28	1.15	0.86	5
CC21	Delayed arrival of materials to the work site	4.46	0.85	0.89	2
CC22	Poor cooperation between the contractor and workers	3.88	1.53	0.78	13
CC23	Manufacturing defects that lead to reworks	4.39	1.11	0.88	3
CC24	Additional orders or modification of orders by the client	4.20	1.28	0.84	7
CC25	Inadequate training of workers	4.09	1.42	0.82	9
CC26	Poor site management	4.29	1.71	0.86	5

These strategies are classified according to the project stage, strategy design, procurement phase strategies, storage and handling phase strategies, and construction phase strategies. As presented in Table VIII, the most significant approach for minimizing waste during the design stage is to limit the design alterations [30, 32]. A variety of measures may be used to prevent alterations in design, including the specification of features and measurements in drawings, the intricacy of the design, and the involvement of a seasoned designer. The second most critical technique is to ensure adequate quantity, consistency, and spacing of construction materials. This method is critical for achieving waste minimization, as it reduces manufacturing faults and reworks, which can be accomplished through the expertise of a skilled designer. The integration of renewable resources in design and the consideration of material availability during execution were identified as the third most significant factors. The selection of materials for a given project is contingent upon the designer's proficiency in the domain of renewable resources, as well as their ability to ensure the procurement of these materials in a readily available manner. As shown in Table IX, in an analysis of waste management strategies at the procurement stage, the most efficient strategy for minimizing waste is the application of waste-efficient procurement and the provision of materials with accurate specifications.

TABLE VIII. WASTE MANAGEMENT STRATEGIES IN THE DESIGN AND DOCUMENTATION STAGES

Code	Strategy	*M*	*SD*	*RII*	*R*
DS1	Reducing design changes	4.56	0.86	0.91	1
DS2	Integration of a material waste reduction plan	4.16	1.41	0.83	4
DS3	Adopting renewable resources in design	4.23	1.31	0.85	3
DS4	Considering material availability at design execution	4.23	1.25	0.85	3
DS5	Providing simplified and suitably detailed drawings	3.83	1.53	0.77	5
DS6	Precise specifications and accurate material estimation	4.16	1.31	0.83	4
DS7	Sufficient design	4.43	1.02	0.89	2
DS8	Experienced design teams	3.72	1.44	0.74	6
DS9	Incorporate standardized design dimensions	3.48	1.58	0.70	7

TABLE IX. WASTE MANAGEMENT STRATEGIES AT THE PROCUREMENT STAGE

Code	Strategy	*M*	*SD*	*RII*	*R*
PS1	Waste-efficient procurement	4.09	1.39	0.82	1
PS2	Regulation and tax measures	3.87	1.48	0.77	4
PS3	Precise contract documentation	4.06	1.38	0.81	2
PS4	Supply of materials with correct quantities	3.97	1.35	0.79	3
PS5	Provide materials with accurate specifications	4.11	1.34	0.82	1
PS6	Purchase materials from reliable suppliers	3.76	1.50	0.75	5

The significance of these strategies lies in ensuring the provision of materials that meet precise specifications, the selection of materials that result in minimal waste generation, and the incorporation of natural materials derived from renewable resources. The adoption of reliable suppliers, the assurance of the safe receipt of materials, and the procurement of materials that align with specifications are crucial in facilitating efficient purchasing operations [24]. The second most significant factor is to ensure a precise contract documentation, suggesting that contract documents should include regulations for waste management. The third most significant strategy is the provision of materials in precise quantities, a measure intended to prevent cost wastage. As displayed in Table X, a variety of strategies have been employed to minimize waste in construction projects during the material storage and handling stages. The most significant strategy to reduce waste is the proper handling of construction materials, followed by the allocation of labor to the appropriate material handling tasks [30, 33]. Furthermore, it is important that labor receive training in meticulous handling and stacking techniques.

TABLE X. WASTE MANAGEMENT STRATEGIES AT THE MATERIAL STORAGE AND HANDLING STAGES

Code	Strategy	M	SD	RII	R
MS1	Sorting materials	3.53	1.56		4
MS2	Reusable materials	3.99	1.36	0.80	3
MS3	Suitable material handling	4.46	0.84	0.89	1
MS4	Method material handling	4.36	1.04	0.87	2

Table XI presents a comprehensive overview of the waste management strategies categorized according to the construction stage. The findings indicate that on-site waste material recycling and reuse is the most effective strategy for waste minimization [34, 35]. The provision of incentives to encourage workers to reduce waste on site was identified as the second most significant factor [36]. The third most significant strategy is to provide efficient methods and adopt suitable site management techniques. The effective management of construction sites is contingent upon the proper management of waste, which entails its appropriate separation, reuse, and recycling. In addition to the provision of adequate supervision by contractors, subcontractors, and project team members, an effective construction site management ensures the presence of skilled labor, adequate storage, appropriate construction equipment, and means of transportation.

TABLE XI. WASTE MANAGEMENT STRATEGIES AT THE CONSTRUCTION STAGE

Code	Strategy	*M*	*SD*	*RII*	*R*
CS1	Construction with standard materials	4.00	1.42	0.80	10
CS2	On-site waste material recycling and reuse	4.53	0.82	0.91	1
CS3	Allocating space for waste segregation	4.22	1.23	0.84	7
CS4	Preventing waste incorporation	4.10	1.38	0.82	8
CS5	Securing a sub-contractor for waste disposal	4.34	1.05	0.87	5
CS6	Good organization between suppliers and construction staff to avoid over-demand.	4.33	1.11	0.87	5
CS7	Secure containers for waste collection	4.40	1.06	0.88	4
CS8	Conduct training courses for laborers	3.97	1.45	0.79	11
CS9	Schedule weekly construction activities	4.04	1.47	0.81	9
CS10	Mixing, transporting, and casting concrete at suitable times and providing skilled workers	3.82	1.42	0.76	13
CS11	Adopt efficient strategies for suitable site management	4.46	1.04	0.89	3
CS12	Provide on-site material compactors	4.2	1.21	0.86	6
CS13	Ensure correct quality and size of supplied materials	3.8	1.53	0.78	12
CS14	Appoint waste management officers	4.2	1.26	0.84	7
CS15	Conduct supervisor training courses on waste reduction strategies	3.7	1.59	0.75	14
CS16	Incentives to encourage workers to reduce on-site waste	4.5	0.97	0.90	2
CS17	Identify an administrator to manage waste	3.8	1.55	0.78	12

A comprehensive plan, incorporating prefabricated elements and on-site waste separation, is important in order to ensure the efficacy of these measures. The strategy has facilitated substantial waste reduction and enhanced recycling rates in various building projects by offering direction, assistance, and resources. The usage of prefabricated elements and the separation of waste on-site are two crucial tactics that must be employed. The adoption of the Building Information Modeling (BIM) approach in underdeveloped nations, such as Iraq, is hindered by numerous obstacles. BIM is experiencing a surge in adoption within the construction sector, owing to its numerous advantages, including enhanced productivity, superior project outcomes, reduced construction waste, and decreased costs. The challenges associated with this approach include implementation costs, inadequate standards and processes, and a deficiency in BIM understanding. As presented in Table XII, a number of studies on the factors contributing to waste generation and strategies for addressing them have been conducted in Iraq and published in both domestic and international journals.

VI. CONCLUSIONS

Construction waste, a byproduct of construction projects, has been identified as a primary contributor to environmental degradation, pollution, and carbon emissions. This waste is generated during all phases of a project, underscoring the need for comprehensive management strategies to reduce its impact.

TABLE XII. CAUSES OF WASTE GENERATION AND STRATEGIES IN IRAQ

No	Ref.	Year	Causes of construction waste	Strategies to minimize waste	Material waste percentage
1	[37]	2017	Inadequate equipment used on-site, lack of labor's experience, non-tropical of structural elements during execution	Material accuracy, experienced supervision	Cement 8%, Sand 7.8%, Gravel 8.2%, Ceramic 7.8%
2	[38]	2019	Lack of on-site waste management plan, changes of the design, lack of on-site material control, lack of supervision	Improving contract documents to avoid wastage from design changes, changes in the requirements of the client, avoiding design error	Sand 11%, Aggregate 11%, Cement 9.8%, Concrete 8%, Gypsum 8.6%
3	[39]	2016	Poor management, poor supervision, design mistakes, design revisions	Government control waste, use of computer programs in the planning, high-tech equipment	Cement 13%, Sand 18%, Gravel 15%, Brick 7 %, Ceramic 12%
4	[40]	2021	Poor material storage, lake in design documents, material handling process, bad quality of material, mistakes in design, change in order, insufficient contractor method	Design friendly environment, tinder must be prepared accurately, effective turning for labor, contactor experience	Brick 15%, Sand 12%, Steel 4%, Cement 4%

The objective of this research is to examine critical reduction measures that have been adapted for the developing nations. The findings provide insights into the potential strategies that various stakeholders in developing nations could employ to reduce construction waste at various stages of building projects through the application of targeted measures. The findings suggest that the initiative contributes to the realization of this study's sustainable environmental objectives while generating economic benefits. The result of this initiative is a substantial reduction in carbon emissions, which in turn enhances global responses to climate change and fosters sustainable development. The study showed that the production of concrete and aggregates resulted in a significant amount of waste, with a percentage of 45%. This was followed by timber, which accounted for 25% of the waste generation. Plaster (15.7%) and soil (9.3%) were shown to result in lower amounts of waste than concrete and timber. However, their influence on waste formation should not be overlooked. The study identified design complexity and detailing, unclear drawing information, incorrect specifications, and contractor lack of involvement in the design phase as the most common causes of waste generation. The study revealed that the most effective waste reduction strategies are: clarifying designs with dimensions and details, using building materials of adequate size, ensuring uniformity and spacing, using renewable resources in design, and considering material availability during construction. Cost overruns, the substitution of the required materials for more expensive ones, the purchase of products that do not meet the required specifications and the substitution of materials for higher-quality materials that are not required are among the most significant causes of cost waste in construction projects. Furthermore, critical waste management strategies during the procurement phase include: efficient waste removal, the provision of materials with precise specifications, the usage of natural materials derived from renewable resources, an efficient procurement process, the assurance of accurate contracts, and the provision of materials in the correct quantities. With respect to material storage and handling, the most prevalent causes of waste include inadequate material storage planning, improper handling techniques, the presence of unnecessary on-site stockpiles, and material spoilage on-site. The study further proposes remedial strategies to reduce waste at this stage, including proper construction material handling and the training of workers in proper material handling techniques. In the context of construction projects, the primary factors contributing to waste during the execution phase are: shortage of skilled subcontractors, inadequate material quantities due to insufficient planning, improper construction techniques, delayed material delivery to the site, manufacturing defects resulting in rework, and conflicts among workers or the project team. In order to address the issue of waste reduction at this stage, a number of remedial solutions have been proposed. These include the implementation of on-site recycling and reuse of waste materials, the provision of incentives to encourage workers to reduce waste on-site, and the provision of effective strategies for adopting appropriate site management methods. This research identified several limitations. Firstly, the scope of the data collection is constrained to Iraq. Consequently, the research does not extend to a broader geographic perspective and the survey's scope was limited to individuals involved in 25 distinct projects. As a result, the findings may not be indicative of the broader solid waste management field. In the interest of mitigating potential biases, future studies should consider expanding their sample to include other developing countries. A number of novel advances have emerged that hold great promise for future research, acting as solutions to the construction waste management problem. The employment of digital technology to enhance waste management techniques exemplifies this trend. The planning and completion of construction projects undergoes a radical transformation thanks to the emergence of the Internet of Things (IoT) and Building Information Modeling (BIM). The usage of BIM facilitates the reduction of waste through two mechanisms: first, the accurate estimation of materials, and second, the efficient management of projects. The enhanced coordination of waste collection and disposal is enabled by the real-time data provided by IoT sensors.

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