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An Investigation of Factors Affecting Reduction of Construction Waste Generation in Egypt

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Abstract

In Egypt, construction projects produce a large amount of waste that reaches 40-50 million tons per year. Most construction wastes are landfilled or illegally dumped, causing land and water contamination. Construction waste can greatly affect construction project performance, as it affects the construction costs, time, productivity, and sustainability. In this research, the key influencing factors for waste management were investigated using a survey of construction practitioners in Egypt, so the waste can be controlled and reduced effectively. The study concluded that selecting contractors with the best experience in construction works and the usage of proper materials for storage facilities can significantly reduce waste generation. In addition, the proper planning layout of construction projects, using materials before expiry dates, and early communication of design changes among all contracting parties are the key factors for waste minimization. A decision support system model, built on the relative importance from the analysis, is designed to support construction teams to improve construction and demolition waste reduction performance in construction sites.

Keywords

Construction and Demolition Waste; Waste Management Practices; Waste Causes, Decision Support System; Backward Chaining

1. Introduction

The construction industry continues to grow as its activities can sustain the means for growth, wealth generation and enhancement of life quality

(Ibrahim, Roy, Ahmed & Imtiaz, 2010). With the acceleration of urbanization and the development of the construction industry in the past decade, construction, demolition, and renovation activities have generated large amounts of construction waste materials (Peng, Scorpio, & Kibert, 1997; Yuan& Shen, 2011). The rate of global expansion of urbanization was 54.3% in 2016 (Kourtit, 2014; Ritchie & Roser, 2018). Today, the rate of global urbanization has reached 55% (Buettner, 2015). This rate results in excessive construction and demolition waste (CDW) production (Ye& Yuan, 2014). The next urbanization population is expected toadd 1.5 billion new citizens between 2015 and 2035 (Duan, Miller, Liu, &Tam, 2019), after which urbanization will cover 68% of the world by 2050 (Buettner, 2015). The construction growth rate in Egypt is the highest compared to the rest of the fastest growing countries in the Middle East and North Africa an average of 7.5% in 2018 compared to a global growth rate of 5.7% (Attia, 2022).

Projects with ineffective collaboration and coordination can produce construction mistakes that can lead to unwanted construction waste. Construction waste can have a significant impact on organizational performance and productivity (Alwi, Hampson, & Mohamed, 2002). According to (Mhaske, Darade, & Khare, 2017), waste from the construction industry has a rapid negative impact on the environment every year. In addition, CDW is a burden on customers, because they finally must bear the cost of waste disposal. Therefore, CDW management is important for enhancing the performance of the construction industry (Kulatunga, Amaratunga, Haigh, & Rameezdeen, 2006).

2. Literature Review

2.1. Definition of CDW

Construction and demolition waste (CDW) is a general term that defines the waste generated by economic activities such as construction, renovation, maintenance, and demolition of buildings and civil works. Waste is generated from demolition materials (from previous constructions on site), material damage, design changes, offcuts, temporary work materials, packaging, etc. Excavated materials and soils are also considered waste (Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl, 2018).

2.2. Composition and Quantities of CDW

Measuring the generation of CDW is a key to all efforts to appropriately manage it (Lu, Peng, Chen, Skitmore, &Zhang, 2016). The composition of CDW varies greatly by site type. Road construction produces a large amount of excavation, if it cannot be used anymore, it becomes waste, and the demolition of a building produces a large amount of concrete waste. Construction of new buildings, when using concrete structures, produces 18~33 kg of concrete waste per m^2 of building area, wooden structures produce one-tenth of the waste. Construction waste from Egyptian housing construction projects usually consists of bricks and blocks, concrete, metal, wood products, roofing materials, plastics, clay tiles, drywall and gypsum, and glass (Menegaki & Damigos, 2018).

It is estimated that the European Union produced700 million tons of CDW (excluding soil) in 2017. In addition, Germany was 85 million tons, France was 65 million tons, and the United Kingdom was77.4 million tons in 2010, making them the three largest CDW generators in the European Union. China produced 1.13 billion tons of CDW in 2014 and is considered the world's top producer of CDW. Meanwhile, the United States generated569 million tons of CDW in 2017, including construction activities, and road and bridge constructions. Australia produced over 20 million tons of CDW from 2016 to 2017.According to the Egyptian Ministry of Environment, Egypt's total solid waste volume in 2020 was123 million tons, of which approximately40 million tons are CDW (Menegaki & Damigos, 2018; Pickin, Randell, Trinh, &Grant; Attia, 2020; Attia, 2022).

The normal process from CDW generation to disposal in Egypt is as follows: CDWs are generated and collected at construction sites. Few contractors apply on-site sorting (usually called site sorting); where recyclable building materials such as metal and wood are sold to waste recycling plants for further treatment. The waste transporters move the waste to designated locations as advised by city authorities or illegally dump CDW in unauthorized areas to avoid long transport distances and costs.

2.3. Construction Waste Management

Construction Waste management is the process of identifying, analyzing, and managing waste from construction projects. In June 2022, Egypt has developed a strategy and a 5 years action plan to properly manage the increasing amounts of CDW. The Action Plan aims to increase CDW reuse and recycling percentages up to 50% by the end of 2030 through the establishment and operation of recycling stations. The presidency of Egypt has assigned 500 million EGP to build 38 CDW recycling stations across Egypt. The Action Plan also calls for the development of "Technical guidelines" for CDW procedures and recycling stations (codes, specifications, guidelines, forms, contract models), developing incentives and penalties to encourage proper CDW Management practices. It also aims to development of a central national CDW database (generation, accumulated quantities, operation, relocation, and Develop ECO labeling code for green recycled materials/product (Attia, 2022). In China, the Ministry of Housing Urban and Rural Development announced an action plan in 2015 to promote the manufacture and application of eco-friendly building materials, with building materials and waste treatment and reuse being the main task of construction waste reduction from its source (Lu & Yuan, 2011).By implementing waste reduction management at the design and construction stages, waste generation can be reduced by 40.63%, which has high economic and environmental advantages, and offers a definite standard value for implementing reduction management for companies and governments (Liu, Yi, & Wang, 2020).

Increasing attention is being paid to minimizing CDW and integrating the concept of sustainable development in order to coordinate the relationship between economic development and sustainable construction (Wang, 2014). For example, (Park&Tucker, 2017) considered waste reduction strategies to be the most efficient waste minimization strategies. The benefits of CDW management are numerous, including environmental protection against pollution and destruction, economic benefits, reduced energy consumption, and reduced emissions (Guerrero, Maas, & Hogland, 2013; Park & Tucker, 2017; Huang, Wang, Kua, Geng, Bleischwitz, & Ren, 2018). Construction waste minimization can be implemented to support environmental policy efforts, encourage waste avoidance measures, discourage the most unwanted disposal behaviors, and avoid the unfavorable effects of unfriendly treatment and disposal behaviors (Begum, Siwar, Pereira, & Jaafar, 2006).

2.4. Causes of Construction Waste

One of the biggest problems facing Egypt's construction industry is the lack of advanced CDW management plans. The top five causes of construction waste are continuous design changes, inappropriate storage of construction materials, inappropriate handling of materials, effects of weather, and suppliers ordering errors (Kaliannan, Nagapan, Sohu, &Jhatial, 2018).

Factors include used material that is not properly selected and can easily break or crush during handling or implementation by a percentage of 12.51%. Meanwhile, 11.39% is caused by poor material control at the site and4.67% is from applying inadequate waste management practices (Wibowo & Koestalam, 2015).Stakeholders behaviors, lack of financial support, and lack of compensation and penalties programs can disrupt CDW management operations (Chen, Li, & Wong, 2022).

The lack of comprehensive skills and special training for construction crews causes waste. To see improvements in CDW management requires effective professional practice by all practitioners in the construction industry. If the workers involved are inexperienced, activities such as formwork construction, plastering, and handling produce a large amount of construction waste (Wang, Kang, &Tam, 2008).

Other important factors to consider are the high cost of recycling, lack of standard recycled materials, and lack of communication and stakeholders awareness.

In traditional logistics, most materials are stored as they arrive at the construction site. This means that the material is moved twice from the point of storage to the point of installation. This doubles handling of materials and leads to waste of time and energy. In addition to increasing the risk of materials damage and the percentage of waste, and subsequent costs. Improper storage as materials directly outdoor storage is unsuitable that can cause damage or deterioration of building materials.

Building materials packaging waste is an additional source of CDW. Approximately 5% of packaging cement waste is reported to be due to broken bags along with the cement remaining in the packaging (Lu & Yuan, 2010).

2.5. Best Practices to Manage Construction Waste

It is especially important to have a plan to minimize construction waste at the source. Waste that is difficult to avoid at its source can be effectively handled through incentive measures that have a clear impact over time. Waste management strategies can be categorized according to the 3Rs to reflect their importance, which is related to reduction, reusing, and recycling needs (Wang, Li, & Tam, 2015). In addition, CDW materials that are difficult to be recycled could be used as a back filling in earth work activities, which is a strategy for recovery. Reduction is the most effective of the three strategies (Esin&Cosgun, 2007). Not only does it minimize waste generation, and the problems associated with waste disposal, and their environmental impact, but it is also the most cost-effective method (Lu & Yuan, 2011).There is a general agreement that the principles of reduce, reuse, recycling can lead to a sustainable future (Huang, Wang, Kua, Geng, Bleischwitz, & Ren, 2018).

The Best Practices of CDW management contribute to the principles of the circular economy. Most defined best practices are based on maximizing the reuse of materials, recycling materials, and applying of quality assurance system of materials obtained from waste.

3. Research Objectives

This research has the following objectives:

a. Identify the main factors that impact the generation and management of construction waste on-site.
b. Determine the relative importance of the identified management factors for construction projects in Egypt.
c. Develop a framework to link construction waste generation causes with best practices to reduce waste generation.

4. Research Methodology

This study uses quantitative analysis to investigate and evaluate common CDW management practices based on the views of construction engineers and practitioners in the Egyptian construction industry. To achieve the objectives of this study, an extensive literature review was conducted to identify best practices for managing construction waste. A total of 57 factors of CDW management were identified and divided into seven groups related to Construction Method, Design, Human Resources, Waste Management Administrative, Procurement, Material Flow, and Regulations. A questionnaire survey was conducted to gather opinions on these factors. The questionnaire consisted of two parts. The first section is designed to collect information about respondents such as company roles and experience years of respondents. In the second section, respondents were asked to evaluate each of the 57 individual factors in terms of their importance to CDW management. A five-point scale was used to categorize the answers, which are 1-Not Priority, 2-Low Priority, 3-Neutral, 4-Moderate Priority, and 5-High Priority. All respondents are construction engineers and industry experts to reflect the views of the various stakeholders involved in CDW management.A decision support system model was built on the relative importance from the analysis of the questionnaire to assist site managers find the most relative factors affecting generation of CDW at sites, hence they would be able to avoid those factors and reduce amounts of CDW. This model links CDW generation causes with best practices to manage CDW generation.

5. Data analysis and discussion

5.1. Data Collection

The questionnaire covered different types of participants such as consultants, civil engineers, field managers, quality engineers, design engineers, project managers, supervisors, technical office engineers, technical office managers, etc. Most of the respondents were from Cairo and Giza governorates. Sample size for the questionnaire was calculated by using equation (1).

$$S.S. = \frac{Z^2 * P * (1-P)}{C^2} \qquad (1)$$

Where S.S. stands for sample size; Z stands for values for confidence levels (1.96 for 95% confidence level); P stands for percentage of choice, expressed as a decimal (0.5 is used to determine the sample size needed); and C stands for confidence interval, expressed as a decimal.

$$Sample\ size = \frac{(1.96)^2 * 0.5 * (1-0.5)}{(0.08)^2} = 150$$

The questionnaire was distributed to 150 representative participants, and 122 responses were received from questionnaires with 81.3% response rate which is acceptable in research that depends on the questionnaire as a tool for data collection, and does not affect the results significantly (Fowler, 2002). The respondents have been classified into three categories depending on their company role as shown in **Figure1**.One-half of the respondents were consultants (53.3%), while owners were (21.3%) of the respondents and contractors were (25.4%).

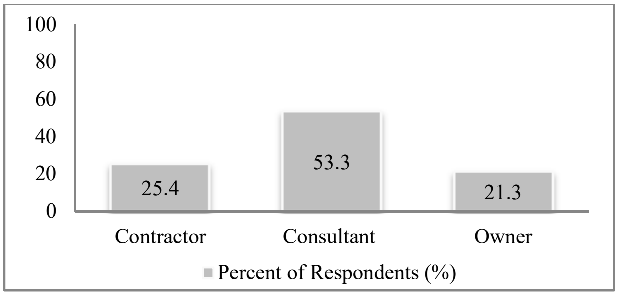

Figure 1. Distribution of respondents by company role.

Almost one-third of the participants (30.3%) had years of experience within (5-10) years, while (18%) of participants had years of experience within (10-15) years. In addition, (29.5%) of participants had years of experience less than 5, and (22.1%) of participants had more than 15 years of experience as shown in **Figure2.**

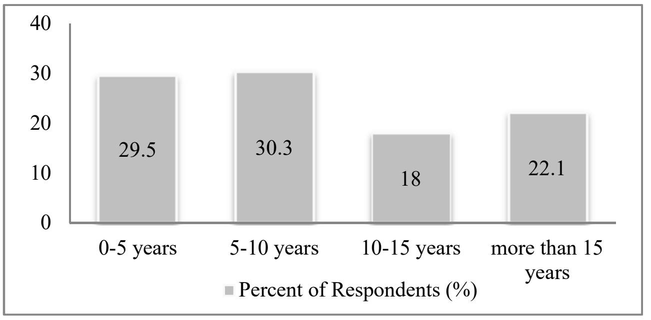

Figure 2. Distribution of respondents by Years of Experience.

An index value of the 57 factors was calculated using equation (2), to evaluate the relative importance of each factor::

$$V_i = \frac{\sum_{j=1}^{5} M_{ij} S_j}{\sum_{j=1}^{5} M_{ij}} (i = 1, 2, ..., 57; j = 1, 2,..., 5). \qquad (2)$$

Where $\mathbf{V_i}$ = importance level of a factor that affect CDW management; $\mathbf{S_j}$ = the effectiveness rating of each factor to successful CDW management that is related to values of likert scale according to the chosen rating by respondents (S1 = 1, ..., S5 = 5); and $\mathbf{M_{ij}}$ = the number of respondents who choose the $\mathbf{j^{th}}$ effectiveness rating ($\mathbf{S_j}$) for the $\mathbf{i^{th}}$CDW management factor. When large number of respondents ($\mathbf{M_{ij}}$) select higher rates at the rating scale ($\mathbf{S_j}$), this will translate into higher values of importance ($\mathbf{V_i}$). This equation is widely used to identify the relative importance of a variables by calculating the importance index value of the variables (Shen & Liu, 2003; Tam, 2008). By entering the findings into SPSS 15.0, the mean and standard deviation of each element were calculated. Next, we ranked the success factors according to the average score. If the means of two or more factors are the same, the one with the smaller standard deviation is assigned the higher rank.

5.2. Analysis of Construction Waste Reduction Factors

In line with the circular economy's classic 3R, the CDW reduction strategy comes first. This is because waste reduction strategies and measures can significantly avoid CDW (Ghisellini, Ripa, & Ulgiati, 2018; Huang, Wang, Kua, Geng, Bleischwitz, & Ren, 2018). Efficient waste management strategies include a combination of complementary means, such as regulations, economics, and educational tools. Numerous factors influence plans to reduce waste from construction sources. The mechanisms required to achieve this direction include providing technical guidance to contractors on waste reduction & separation, the mandate to quantify CDW generated at construction projects and equipping the city authority to monitor the transportation of CDW from all construction sites using GPS devices on all trucks (Attia, 2020).The following seven waste reduction categories were proposed for this study to identify the comprehensive key factors.

5.2.1. Analysis of Construction Method Related Factors

Much research has been done to reduce CDW at various stages of construction projects, including increasing designer sensitivity, adopting prefabricated building components at the design stage (Tam, Tam, Zeng, & Ng, 2007; Baldwin, Poon, Shen, Austin, &Wong, 2009), and implementing on-site sorting (Wu, Ann, & Shen, 2017). There is evidence that prefabs can reduce construction waste by up to 84.7%. Prefabricated columns and foundations have avoided 75% of the total waste expected with traditional construction methods. Introducing the prefabricated technology can reduce waste generation by up to 100% (Tam, Tam, Zeng, &Ng, 2007).

Other recommended low-waste construction techniques include the use of steel structures, the use of drywall instead of traditional load-bearing walls, the reuse of concrete for sidewalks, and the use of bulk cement.

Although most of the mentioned measures are originated in western society, we still believe it could be gradually introduced to the Egyptian market. Especially, with the current awareness of importance of applying sustainable practices throughout the construction industry and in our cities at large.

On-site reuse of soil remains a significant proportion of the waste could be diverted from landfills (Begum, Siwar, Pereira, & Jaafar, 2009). Not only does it reduce pressure on landfills, but it also eliminates the need to transport materials or reprocess them by recycling, which requires the use of some energy (Ajayi, Oyedele, Akinade, Bilal, Owolabi, & Alaka, 2014). In addition, the reuse of materials such as reclaimed and off-cuts materials for construction activities can be achieved by identifying construction activities that may enable secondary materials, rather than using raw materials that require large amounts of energy.

Collection and segregation of construction waste contribute to managing it. Waste collecting bins are identified for each type of waste. Containers' size and number are estimated properly. Temporary collection bins are usually placed next to the working zone to increase the efficiency of waste Collection and segregation (Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl, 2018). Factors related to this category are listed below in **Table 1.**

Table 1. Rank of Construction Method Related Factors

Factor	Mean	Std. Deviation	Group Rank	Over-all Rank
Usage of proper materials storage facilities	4.39	0.838	1	2
Promote usage of metal formwork	4.11	1.038	2	11
Minimize rework during a construction phase	4.06	0.939	3	14
Adoption of low-waste modern building technologies	3.84	0.982	4	21

Factor	Mean	Std. Deviation	Group Rank	Over-all Rank
Increasing off-site prefabrication	3.64	0.971	5	35
Reuse of off-cuts materials (such as wood)	3.57	0.978	6	38
Excavated soil should be used for back-filling on the same site	3.44	1.084	7	44
Re-use of waste materials	3.34	1.002	8	49
Plan number and size of construction waste containers needed for each type of waste	3.38	1.167	9	46
Setting up temporary containers at each building zone to collect construction waste	3.32	1.023	10	50
Provide waste collection bins for each sub-contractor	3.32	1.047	11	51
Usage of demolition and excavation materials for landscaping	3.02	1.052	12	56

As shown in **Table1**, the top three site management factors to promote waste reduction and control are: Usage of proper materials storage facilities, Promotion of usage of metal formwork, and Minimize rework during the construction phase. While the least ranking factor is the Usage of demolition and excavation materials for landscaping. The total weighted mean for construction method-related factors is 3.6189.

5.2.2. Analysis of Design Related Factors

Monitoring design compliance and ensuring that construction workers are working according to design documents is an important role for the site management team. For this reason, the role of modern construction managers requires sufficient knowledge of design interpretation, just as designers need knowledge of construction progress and a sequence for waste design (Ajayi, Oyedele, Kadiri, Akinade, Bilal, Owolabi et al., 2016).

The Design change is a great cause of rework and following waste generation in construction projects. This is increasing if such changes are not properly communicated to the project team. This finding supports previous studies suggesting the need for a design freeze to reduce the waste resulting from construction activities (Osmani, 2013; Oyedele, Regan, Von Meding, Ahmed, Ebohon, & Elnokaly, 2013). Rework due to design errors or lack of compliance with project drawings can add more than 5% to the project cost. Therefore, to reduce the waste produced by construction activities, the construction management team needs to fully understand the design documents and make sure that the construction activities are following the design documents (Hwang, Thomas, Haas, &Caldas, 2009).

As shown in **Table2**, the top two site management factors to promote waste reduction and control are Standardization of design to increase modularity and early communication of design changes among all contract parties. While the least ranked factor is avoiding easily fragile materials from being used. The total weighted mean for design-related factors is 4.0269.

Table 2. Rank of Design Related Factors

Factor	Mean	Std. Deviation	Group Rank	Over-all Rank
Early communication of design changes among all contract parties	4.20	0.760	1	6
Choosing durable materials	4.16	0.903	2	7
Standardization of design to increase modularity	4.15	0.800	3	8
Ensure fewer design changes during construction	3.85	0.933	4	20
Avoid overly complex designs	3.80	0.962	5	22
Avoiding easily fragile materials from being used	3.69	1.099	6	25

5.2.3. Analysis of Human Resources Related Factors

Before starting a construction project, contractors and workers should begin training to raise awareness of CDW management and learn how to handle on-site situations. The training program focuses primarily on construction project management, construction materials, construction technology, construction site supervision, technical assessment, and construction safety (Attia, 2020). All workers, whether related to contractors or subcontractors, must be familiar with on-site waste management procedures. (Loosemore, Lingard, & Teo, 2002) Confirmed the importance of human factors to minimize waste and noticed that changing attitudes could prevent waste.

As shown in **Table3**, the top two site management factors to promote waste reduction and control are Selecting contractors with the best experience in construction works and Improving the training of the workforce.While the least ranking factor is the Appointment of laborers solely for waste separation and storage. The total weighted mean for Human resources-related factors is 3.9365.

Table 3. Rank of Human Resources Related Factors

Factor	Mean	Std. Deviation	Group Rank	Overall Rank
Select contractors with the best experience in construction works	4.49	0.646	1	1
Improved training of the workforce	4.10	0.827	2	12
Increasing awareness about waste generation in construction	3.93	0.879	3	18
Appointment of labors solely for wastes separation and storage	3.22	1.033	4	52

5.2.4. Analysis of Administrative Related Factors

The on-site waste management plan should initially be as follows: the planning level itself manages the waste generated at the start of the project. By strengthening the supervision and control of site operations, you can not only enhance the building's constructability, but also avoid construction errors. Online meetings can also help workers and others to reach their goals of eliminating waste (Janani & Lalithambigai, 2021).

The success of an integrated management system of the CDW relies on the establishment of an infrastructure for the reduction, collection, separation, transportation, recycling, and disposal of CDW (e.g., containers, GPS monitoring, and tracking systems, central control rooms, databases, procedures manuals, trained personnel) (Attia, 2020).

As shown in **Table4**, the top four site management factors to promote waste reduction and control are Planning the layout of construction projects properly, Using materials before expiry dates, Adopting an effective materials control system, and Performing environmental impact assessments for construction materials during the design phase. While the least ranked factor is Specifying the available location of recycling plant or formal dump site. The total weighted mean for Waste management administrative-related factors is 3.5675.

Table 4. Rank of Administrative Related Factors

Factor	Mean	Std. Deviation	Group Rank	Overall Rank
Plan layout of construction projects properly	4.34	0.788	1	3
Using materials before expiry dates (such as cement, paints, and insulation materials)	4.30	0.924	2	4
Adapt effective materials control system	3.87	0.852	3	19
Perform environmental impact assessments for construction materials during the design phase	3.68	0.964	4	27
Longer project programs and better lead times	3.67	0.966	5	28
Detect the construction activities that can accept reusable materials from construction waste	3.66	1.017	6	31
Adapt and implement Site Waste Management Plan (SWMP)	3.65	1.036	7	32
Register the quantities of generated construction waste	3.57	0.978	8	37
Considering re-use and recycling as targets to be set for every project	3.55	1.029	9	39
Waste audits to monitor and document environmental performance on construction sites	3.49	0.884	10	41

Factor	Mean	Std. Deviation	Group Rank	Overall Rank
Review and monitor the implementation of the waste management plan	3.39	0.940	11	45
Periodically check on the usage of construction waste containers	3.37	0.947	12	47
Dedicate a suitable space for sorting and separation of construction waste	3.12	1.168	13	54
Specify the location of the available recycling plant or formal dump site	3.06	1.187	14	55

5.2.5. Analysis of Procurement Related Factors

The new procurement law (Law No. 182 for Year 2018) has endorsed the "Point System" to evaluate technical offers from contractors, any governmental organization can add points related to CDW management in its conditions to be part of the overall contractor bid evaluation.

Contractors who purchase materials with reusable packaging or bag that are more satisfactory waste management behaviors. It is recommended to use bulk cement, as packaging is the main source of waste in the construction industry (Lu&Yuan, 2010).

There is pressure from rapid civilization and the consequent increase in CDW. Municipalities can be relieved from the burden of CDWs by exporting them to the surrounding area, but this measure can make waste disposal in other cities difficult, and shipping costs will be higher (Ma, Tam, Le, &Li, 2020).Researchers have observed that a just-in-time strategy is a major influencing factor in waste management (Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl, 2018). Factors related to this category are listed below in **Table 5.**

Table 5. Rank of Procurement Related Factors

Factor	Mean	Std. Deviation	Group Rank	Overall Rank
Apply Just-in-time delivery strategy	3.98	0.918	1	16
Owner should add incentive in bidding for a contractor that has a plan to reduce waste and increase recycling	3.66	1.009	2	30
Owners should use contract clauses to penalize contractors for poor waste performance	3.51	1.100	3	40
Develop applications for construction waste re-use at the site	3.48	1.022	4	42
Buying materials that have reusable packing	3.44	0.936	5	43
Avoid unnecessary packaging of materials	3.12	0.992	6	53
Encourage exchanging waste and excavated soil with other nearby sites	2.97	1.067	7	57

As shown in **Table5**, the top three site management factors to promote waste reduction and control are: Applying a Just-in-time delivery strategy, the Owner adding incentive in bidding for a contractor that has a plan to reduce waste and increase recycling, and the Owner using contract clauses to penalize contractors for poor waste performance. While the least ranked factor is Encourage exchanging waste and excavated soil with other nearby sites. The total weighted mean for Procurement related factors is 3.4532.

5.2.6. Analysis of Material Flow Related Factors

Effective material transportation control process is a key aspect in accomplishing waste reduction. Minimizing or ceasing the over-ordering of building materials is vital as damages can also be caused by poor storage regions or because these materials are ordered improperly (Ajayi & Oyedele, 2017).

In the method of unloading construction materials, suitable rigging techniques can make sure that constructing materials are successfully protected from harm at some stage during unloading (De Magalhães, Danilevicz, & Saurin, 2017).

The storage area of construction materials should be as close as possible to the construction site, so the transportation distance is shortened, and double handling of materials is prevented, which reduces the risk of damaging these materials (Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl, 2018).

As shown in **Table6**, the top three site management factors to promote waste reduction and control are: Providing appropriate material transportation and storage, Central cutting and storage areas, and Adequate site access for materials delivery and movement, while the least ranked factor is Avoid double handling of materials. The total weighted mean for material flow-related factors is 4.0222.

Table 6. Rank of Material Flow Related Factors

Factor	Mean	Std. Deviation	Group Rank	Overall Rank
Providing appropriate material transportation and storage	4.25	0.659	1	5
Adequate site access for materials delivery and movement	4.11	0.714	2	9
Central cutting and storage areas	4.11	0.752	3	10
Prevention of over ordering	4.06	0.921	4	13
Providing appropriate material rigging and hauling	4.05	0.889	5	15
Returning surplus material	3.94	0.903	6	17
Avoid double handling of materials	3.64	0.963	7	34

5.2.7. Analysis of Regulations Related Factors

Fines can reduce the emissions and disposal of CDW (Ye & Yuan, 2014). Regulations and policies developed by local governments can have an important effect on CDW management practices (Wang, Yuan, Kang, &Lu, 2010). In this regard, the government may charge higher CDW disposal fees. This can reduce the amount of CDW that is landfilled and encourage contractors to separate, reduce, reuse, and recycle waste. For example, a key practice that participate in managing waste is that the subcontractor must be responsible for waste disposal (Attia, 2022).

As shown in **Table7**, the top three site management factors to promote waste reduction and control are: Making sub-contractors responsible for waste disposal, Establishing a reward and punishment system to encourage material savings, and Remove taxes for waste treatment equipment (e.g., crushers),while the least ranked factor is Increasing fees for the dumping of mixed wastes. The total weighted mean for Regulations related factors is 3.6218.

Table 7. Rank of Regulations Related Factors

Factor	Mean	Std. Deviation	Group Rank	Overall Rank
Making sub-contractors responsible for waste disposal	3.72	0.990	1	23
Establishing a reward and punishment system to encourage material savings	3.72	1.006	2	24
Remove taxes for waste treatment equipment (e.g. crushers)	3.69	1.136	3	26
Providing waste management policies	3.66	0.969	4	29
Increase the landfill disposal fee (Gate fee)	3.65	1.052	5	33
Develop rules on dealing with waste by waste-generators	3.57	0.881	6	36
Increasing fees for the dumping of mixed wastes	3.35	1.113	7	48

Among the endless list of waste management practices on construction and demolition sites, key practices for waste management activities are identified and considered as critical success factors. These factors include selecting contractors with the best experience in construction work, Usage of proper materials storage facilities, Plan layout of construction projects properly, using materials before expiry dates and Providing appropriate material transportation and storage. In addition to other factors such as; Early communication of design changes among all contract parties, Choosing durable materials, Standardization of design to increase modularity, Promote usage of metal formwork and Adequate site access for materials delivery, and movement. The least effective practices are listed as follows: Encourage exchanging waste and excavated soil with other nearby sites, Usage of demolition and excavation materials for landscaping, Specify the location of the available recycling plant or formal dump site, Avoiding unnecessary packaging of materials, and Dedicating a suitable space for sorting and separation of construction waste.

6. Decision Support System for CDW Reduction

Currently, construction projects face problems because of the delay in decision-making. This leads to the need for a mechanism that helps managers to make quick decisions. Artificial intelligence technologies, such as decision support systems (DSS), can assist in CDW management. Decision support system is an integrated system of computer tools, it can help planners or decision makers at different processes of construction. The application of DSS today is widely practiced in many applications due to the growing study of DSS and has led to the development of problem-solving method for decision problems. (Bani, Rashid, Hamid, Harbawi, Alias, & Aris, 2009).

6.1. Creating the Decision Support System Modeling

To create a decision support system model, several steps were taken. In the first step, we had to collect data to build a knowledge base by interviewing construction engineers involved in CDW management to identify construction waste common problems in Egypt. Second step, the most critical causes of waste were identified and clustering of related factors was created. Construction waste causes are divided into two main categories which are leftovers and damaged materials. A cause-and-effect diagram was used to link waste causes in linked chains as shown in **Figure3**.

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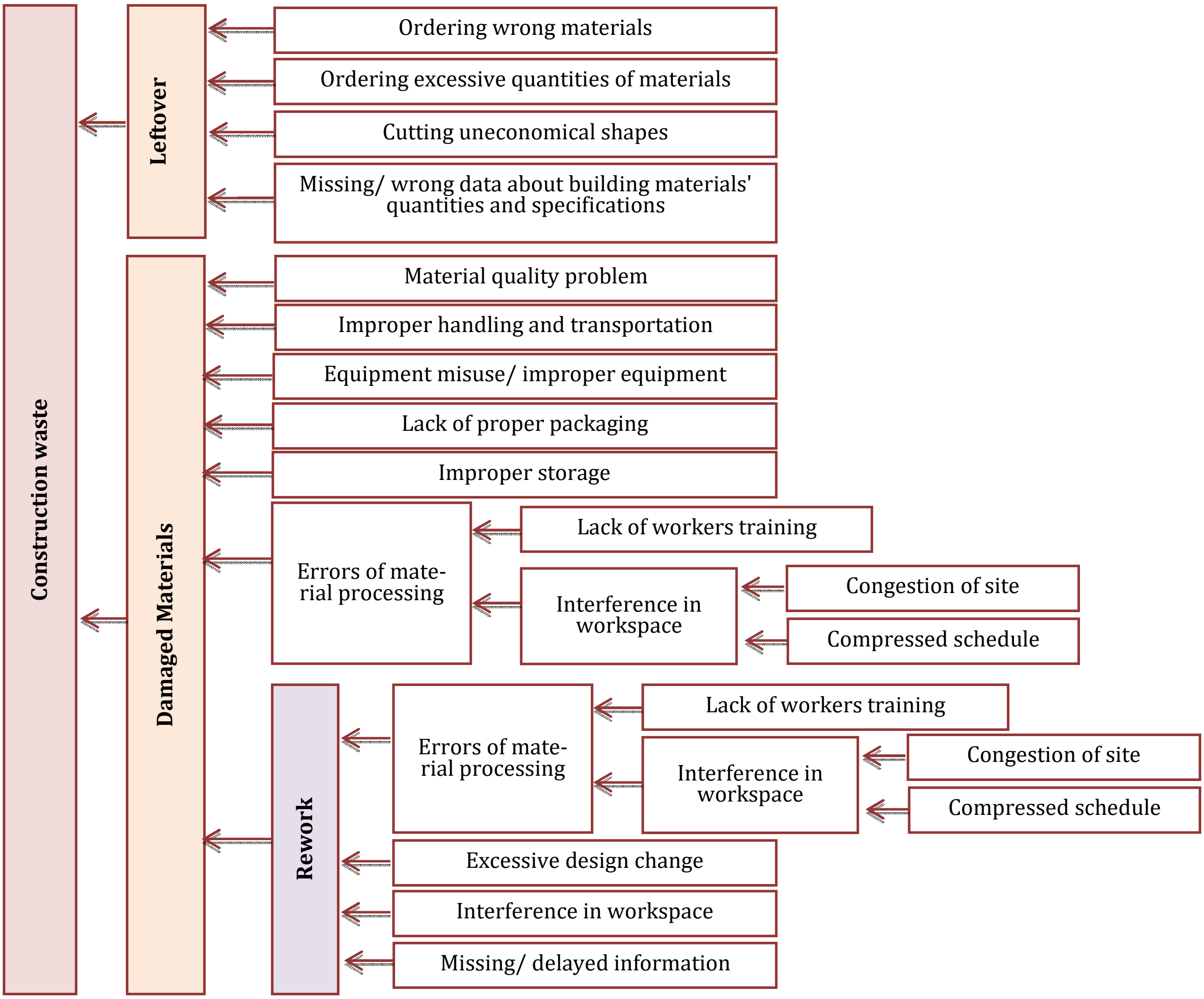

Figure 3. Cause and effect diagram for construction waste common problems in Egypt.

The third step, backward chaining was followed to help the end user in understanding the main causes of construction waste before giving him the best advice. Backward chaining is used by this system to answer the question, why did this happen? This strategy was used to find the cause or reason a particular event occurs in each situation (Sebestyénová, 2007; Khan, Rehman, & Amin, 2011; Al-Ajlan, 2015).

Finally, C sharp coding language was used following if-then-else rules to create this model. The decision support system model has a friendly interface to facilitate data entry and indicate recommendations for reducing waste. The user chooses the certain problem they are facing on site, and the system helps in understanding the main causes of the problem and advice on how to handle it. The questions' sequence is obtained from the backward chain of the cause-and-effect diagram. All advices given by the system are recommended from top ranked factors from the analysis of the questionnaire.

6.2. Implementing the Decision Support system model

The model was created to improve the management of CDW at construction sites; this was achieved by resolving problems that cause construction and demolition waste. The model's goal is to relate waste problems with their solutions based on their qualities. All problems and solutions are coded and related so that the user could solve waste issues, as shown in **Figure4** and **Figure5**. We can see an example of implementing the decision support system model in **Figure6**which shows the problem of ordering the wrong material that is related to the category of leftover. **Figure 7**shows the cause of the problem and the recommended solution to solve it.

Figure 4. Friendly interface of the model

Figure 5. The user chooses the category of the main problem occurring on site

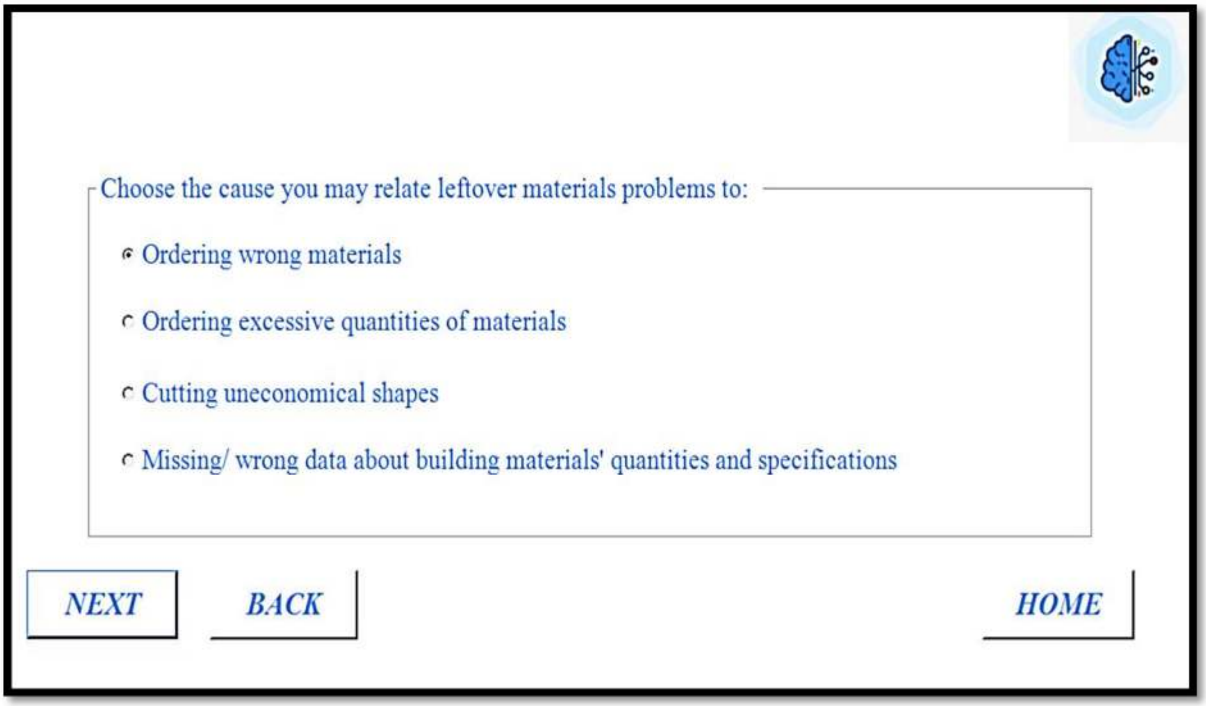

Figure 6. The problem of ordering the wrong material

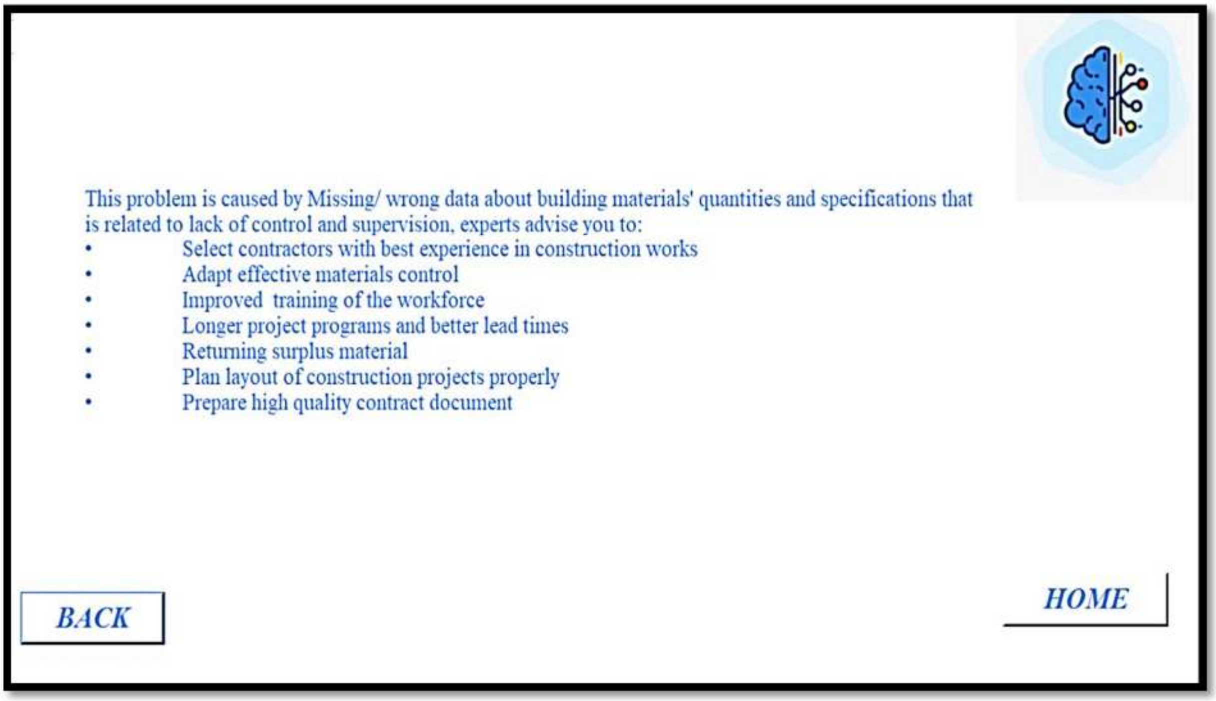

Figure 7. The solution for ordering the wrong material

7. Conclusions

The Egyptian construction industry has an urgent need to apply construction waste management strategies. This is especially necessary as the industry is overusing the landfills with the largest share of waste. After literature reviews and field research, the study used descriptive statistics and analysis to identify the most important site management practices to reduce the industry's waste. This paper explores key management techniques that can impact onsite waste minimization by ranking the most influential factors that cause CDW management in Egypt. This research recommends focusing on some practices to effectively manage construction waste such as Selecting contractors with the best experience in construction works, Usage of proper materials storage facilities, Planning the layout of construction projects properly, Using materials before expiry dates, and Early communication of design changes among all contract parties. This paper introduces a decision support system model, which could be used to identify solutions to a variety of waste problems on site. This model is based on Visual Studio and C sharp programming language. The result showed good acceptable limits of reliability that allowed this model to be used to obtain causes and solutions for waste.

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