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Quantifying materials waste in the Egyptian construction industry: A critical analysis of rates and factors

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ABSTRACT

Construction and demolition waste (CDW) is a critical challenge facing the construction industry. It leads to deterioration of the triple bottom line of sustainability. Unfortunately, the CDW management research in Egypt lacks studies investigating (1) the variations in CDW generation (CDWG) among different types of construction projects, and (2) the factors affecting CDW reduction (CDWR). Based on a benchmarking approach, this research (1) quantifies CDW in terms of generation rates and costs among different construction project types in Egypt, and (2) investigates the relationship between CDWG and different adopted CDWR factors. Using structured interviews, a comparative case study was conducted to investigate industrial, residential, commercial, and infrastructure projects. Analysis of results demonstrated that CDWG rates and costs differ from one project type to another due to the project's nature, size, and complexity on the one hand, and the applied CDWR factors such as waste-efficient practices, awareness, culture & behaviour, and legislation on the other hand. On average among the four project types, it was found that "timber", "sand", and "bricks/blocks" are the most wasteful materials. It was also found that "practices" and "legislation" are the least applied CDWR factors on average among the four project types, which need to be better applied for better CDWR results.

1. Introduction

Construction and demolition waste (CDW) is a global challenge facing developed and developing countries. According to studies carried out by Yılmaz and Bakış [1] and Redling [2], CDW contributes up to 50% of the total annual generated solid waste (SW) globally. CDW has a severe negative impact on the triple bottom line (TBL) (i.e. financial, social, and environmental aspects) of sustainability [3,4]. It results in many health and environmental problems due to its biodegradation in landfills [5,6]. Additionally, it affects the overall economy of countries in which it reduces the efficiency, effectiveness, value, and profitability of construction firms [7]. This can be proved by the fact that approximately 10% of total construction materials cost is wasted as CDW [8], while construction materials and equipment contribute up to 50–60% of total project cost and affect 80% of its schedule [9]. In Egypt, the situation is very critical in which up to 40% of total construction materials cost is wasted, which is equivalent to 16% of total building cost (i.e. labour and materials cost) [10]. It is worth mentioning that the waste in total materials cost must not exceed 4% under any circumstances [10,11].

The few studies of CWM research in Egypt carried out by Hany and Dulaimi [12], Garas et al. [13], and El-Desouky et al. [14] lack comparative studies to quantify CDW in terms of generation rates and costs among various construction projects (i.e. industrial, residential, commercial, and infrastructure). This is important to (1) identify the variability in CDWG rates among different construction projects according to their type, size, complexity, and adopted CDWR factors; and (2) clarify the financial loss caused by CDWG in terms of costs of total materials waste. Moreover, there is a lack of investigation on the relationship between the different CDWR factors and CDWG. According to a recent investigation of different studies carried out by Daoud et al. [15] about the CDW problem in the Egyptian construction industry, it was concluded that four main factors are influencing CDWG as follows: (1) deficiencies in

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waste-efficient practices; (2) lack of awareness on different levels towards the CDW problem and its solution; (3) absence of appropriate culture & behaviour towards CDW reduction (CDWR); and (4) lack of strict legislation enforcing CDWR. Unfortunately, the primary dominant practice of dealing with CDW in Egypt is dumping at illegal dumpsites, on residential streets, and on agricultural lands, which led to an escalation of the hazards caused by CDWG [5,16].

Accordingly, the main research questions which need to be investigated according to the aforementioned limitations in the Egyptian CWM research are as follows:

(1) How much is CDW generated among different construction projects in the Egyptian construction sector?

(2) How do the CDWG rates change based on the different adopted waste-efficient materials procurement practices, legislation, measures of culture & behaviour, and awareness measures in the Egyptian construction sector?

2. Research aims and contributions

This study's aims are as follows:

(1) To quantify CDW among different project types in terms of generation rates and costs in the Egyptian construction sector; and
(2) To investigate the relationship between CDWG and different adopted CDWR factors in the Egyptian construction sector.

This study's aims are achieved through a comparative case study, including four different construction projects types by adopting mixed methods research, in which qualitative and quantitative viewpoints, data collection, analysis, and inference techniques are adopted as investigated later in the research methodology section.

The main contributions of this study are as follows:

(1) Demonstrating the variations of CDWG in terms of rates and costs among different project types in the Egyptian construction sector to determine which projects tend to produce a high amount of CDW and how this can be translated to financial losses; and
(2) Demonstrating how CDWR factors can help in reducing CDWG. Also, identifying which factors need enhancement and improvement based on their applicability level among the investigated projects to achieve better results of CDWR.

3. Literature review

CDW quantification is critically important because it leads to the proper establishment of efficient waste management systems at both project and regional levels [17]. At the project level, it can help the project managers to modify the material purchase schedule, to organise the stockpiling on-site and to decide the potential waste recycling benefit and disposal cost. It helps estimate the total CDWG of all projects in a specified region at the regional level. The information of regional CDWG can help decision-makers set more realistic policies, specifying the establishment of new waste facilities, and organising labour and truck resources. A recent study was carried out by Hany and Dulaimi [12] to determine the composition of CDW for main construction materials in Greater Cairo (GC) based on 37 semi-structured interviews. The case study was based on a vast residential compound built on 33,600,000 m^2. It was found that timber is the highest wasted construction material, as listed in Table 1. This timber waste is because it is used in framework and shuttering for concrete. Moreover, labours do not have the high skills needed for using new tools to minimise timber waste, and there is a lack of using prefabricated elements which can reduce timber waste significantly [12].

However, different studies carried out by Garas et al. [13] and El-Desouky et al. [14] reported different statistics regarding the CDW composition for main construction materials. First, Garas et al. [13] successfully collected 30 completed survey questionnaire from a representative sample of first-grade contractors, who are the most capable in Egypt, to determine CDW percentages for different construction materials. Second, El-Desouky et al. [14] also successfully collected 28 completed survey questionnaire from a representative sample of first-grade contractors in Egypt to investigate the CDWG rates of different construction materials. Also, El-Desouky et al. [14] reported another different statistics of CDW generation (CDWG) rates for a study carried out by Ragab et al. (2001). The results of these studies are summarised in Table 1.

All of the aforementioned studies reported each material's CDWG rate as a percentage of the total purchased amount. Comparing the results of the studies mentioned above as listed in Table 1, the inconsistency among these studies' statistics can be easily detected as they mainly depended on experts' knowledge and they do not depend on statistical records which is the case in this study. In Egypt, almost no recorded data are available, based on regular feedback on previous projects, to predict the precise amounts and types of CDW generated during CD operations. Contractors tend to know approximately the amount of CDW generated during a given project according to previous experience [14]. Both studies of Hany and Dulaimi [12] and Garas et al. [13] agreed that "timber" is the most wasteful material in Egypt. On the other hand, Ragab et al. (2001), as reported by El-Desouky et al. [14], claimed that "sand" is the most wasteful material in Egypt. In contrast, El-Desouky et al. [14] reported "bricks" as the most wasteful material in Egypt.

Most of the construction waste management (CWM) research in the last decades focused on waste-efficient practices of minimising CDW during design and construction stages. Still, limited research explored CDWR during the materials procurement stage, a critical interface between design and construction phases, despite its high impact on reducing CDWG and total project cost [18]. According to

Table 1
Results of different CDW quantification studies in Egypt.

Study	Ragab et al., 2001 (cited in El-Desouky et al. [14])	Garas et al., 2001 [13]	Hany and Dulaimi, 2014 [12]	El-Desouky et al., 2018 [14]
	Average Percentage of Waste			
Timber	–	13	40	20
Sand	7.2	9	17.5	8
Steel	3.9	5	3.5	6
Cement	3.8	5	4.5	10
Concrete	3.2	4	3.5	5
Bricks	5.9	6	5	35
Tiles	5.1	5	5	10

a study carried out in the UK by Fadiya et al. [19], it is claimed that inefficient materials procurement contributes about 11.2% towards total CDWG. Moreover, Eze et al. [20] identified 20 main reasons for CDWG in construction sites, in which poor procurement management (i.e. wrong purchasing order – quality, number, time of order) had the sixth rank among other reasons. Also, Ajayi et al. [18] claimed that materials procurement is responsible for purchasing the wasted materials, and it was also claimed that materials procurement contributes up to 50% of the total project cost. The literature review revealed different effective ways of waste-efficient materials procurement practices such as materials procurement measures, materials procurement models, and green materials procurement approach [15,21–23]. These three different ways are discussed in detail in the following paragraphs.

First, there are four clusters of materials procurement measures for CDWR as follows: (1) suppliers' low waste commitment; (2) low waste purchase management; (3) effective materials delivery management; and (4) waste efficient bill of quantity [15,23]. Each cluster consists of several measures which should be adopted to reduce CDWG, in which the total number of measures is 16. For example, suppliers' low waste commitment includes four main measures: suppliers' flexibility in supplying small quantities or modification to products in conformity, commitment to take back scheme (packaging, unused, reusable, and recyclable materials), supply of quality and durable products, and usage of minimal packaging (without affecting materials safety). Also, low waste purchase management includes five main measures: procurement of waste efficient materials/technology (pre-assembled/cast/cut), purchase of secondary materials (recycled and reclaimed), purchase of quality and suitable materials, avoidance of variation orders, and correct materials purchase. Effective materials delivery management includes four main measures: effective protection of materials (during transportation, loading & unloading), effective on-site access (for ease of delivery), efficient delivery schedule, and usage of Just in Time (JIT) delivery system. Finally, waste efficient bill of quantity includes three main measures: accurate materials take-off, prevention of over/under ordering, and reduced waste allowance. These different measures can be considered while preparing for materials purchase and during materials purchase and delivery to the site.

Second, there are three materials procurement models in the construction industry as follows: specialty contractor procurement model (SCPM), general contractor procurement model (GCPM), and owner procurement model (OPM) [23]. In SCPM, a specialty contractor is responsible for procuring materials for the project owner. In GCPM, the general contractor is responsible for procuring materials for the project owner. While in OPM, the project owner directly procures the required materials from the vendors. The GCPM was introduced to the supply chain to help in CDWR. However, it has been proven to be inefficient more than SCPM. Both models suffer from inadequate materials management process, which leads to CDWG. The OPM is better than both models regarding CDWR. Comparing the three models regarding procured materials' cost, both models GCPM and SCPM are similar in materials cost. The OPM provides slightly less expensive costs of procured materials than GCPM and SCPM. Accordingly, OPM and SCPM are more preferred than GCPM regarding CDWR. **Third**, the Egyptian green pyramid rating system (GPRS) defined five criteria for green materials procurement approach [15,22]. These criteria are as follows: (1) using renewable materials and materials manufactured using renewable energy; (2) using regionally procured materials and products; (3) reducing of overall material use; (4) using alternative building prefabricated elements; and (5) using environment – friendly, sound and thermal insulation materials.

In the next sections, this paper discusses the adopted research methodology in this research to investigate the CDW problem in the selected construction projects. After that, it presents the qualitative and quantitative data analysis and results of the investigated projects. Additionally, it presents a discussion based on comparing the data analysis results of these four projects. Finally, the paper presents a conclusion and recommendations for improving the current situation regarding CDWR and enhancing sustainability in the Egyptian construction industry.

4. Research methodology

The research methodology, designed to achieve the abovementioned aims, adopts a mixed-methods approach in which qualitative and quantitative data are used to investigate the four construction projects. The research methodology consists of different steps, as discussed in detail in the next subsections and summarised in Fig. 1. As investigated in the previous section, the literature review helped extract the CDWR factors and identify the previous studies carried out in Egypt related to CWM research.

4.1. Design of structured interview questionnaire

The interview questionnaire was divided into four main sections, as seen in Appendix A. Section 1 investigates demographic information of the respondents and their firms. Section 2 aims to determine the CDWG rates in main building materials (i.e., timber, sand, concrete, cement, reinforcement steel, tiles, and bricks/blocks) and each materials' item cost type in the selected construction projects. Also, it investigates brief information about these projects. Section 3 aims to explore the current adopted materials procurement practices in the selected construction projects. Finally, section 4 aims to evaluate the current status of awareness, practices, culture & behaviour, and legislation at the respondents' firms from their perspective. It is worth mentioning that the word "practices" used in this context refers to waste-efficient materials procurement practices.

The interview questionnaire's face and content validation was done by reviewing by ten experts to ensure that the questions are straightforward, focused, and match the addressed objectives. The number of selected experts satisfies the recommended maximum number for face and content validation, as stated by Wai Lam et al. [24] and Saiful and Yusoff [25]. The ten experts were chosen as follows: (1) five industry professionals who hold managerial positions in the construction industry; and (2) five academics who are professors of construction engineering and management. All experts have more than 15 years' experience of industrial work or teaching and research, respectively. From the respondents' feedback, the average time taken to complete the questionnaire was approximately 45–60 min. Also, there was a consensus among the selected experts that the interview questionnaire should be conducted using the Arabic language or a mix between Arabic and English languages. This is due to the complexity of some used terminologies and concepts and the fact that the English language is not the first language in Egypt, but some terminologies and technical phrases had to be said in English. Accordingly, a mix between Arabic and English languages was adopted in this study.

4.2. Selection of cases and participants

This study was conducted as a multiple case study (i.e., comparative case study) of four different construction projects (i.e., industrial, residential, commercial, and infrastructure project) located in Egypt. The number of cases included in this study satisfies the recommended number of cases in a comparative case study, as stated by Eisenhardt [26] and Creswell [27]. Moreover, the number of

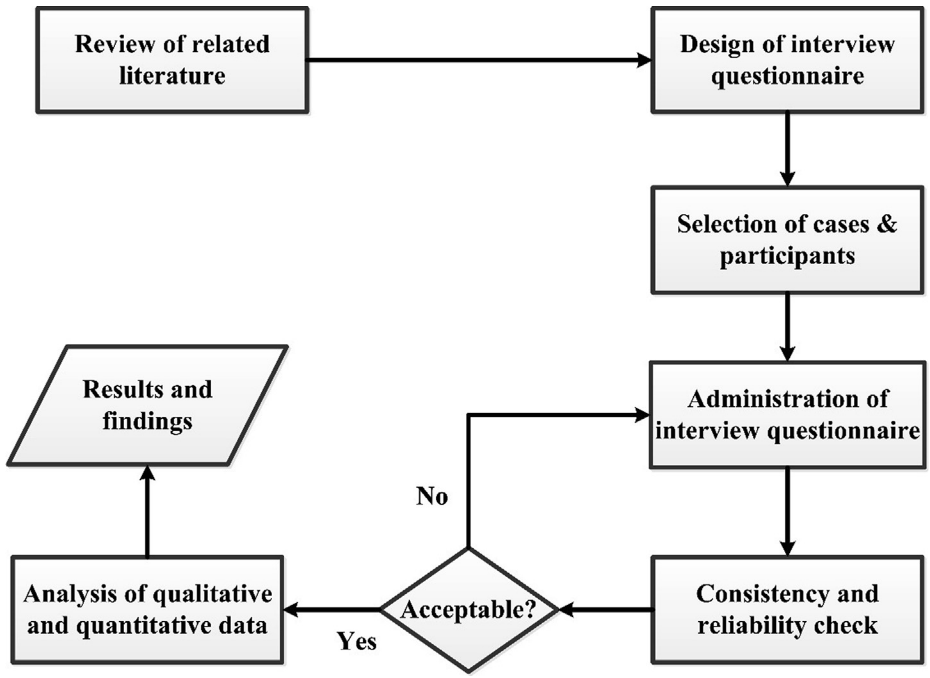

Fig. 1. Summary of research methodology.

these cases is convenient due to the local construction industry's nature and resources constraints in data collection from the targeted participants. The cases were selected via direct contact with the researchers in this study. The direct contact facilitated the data collection from the targeted four construction projects based on his referrals to procurement managers and project managers of these projects, which can be referred to as "snowball sampling".

4.3. Administration of interview questionnaire

A project manager and a procurement manager of each project were invited to participate in this study given the nature of their roles in controlling and dealing with project resources (i.e., materials, labours, and equipment). Every single case consists of two participants and the comparative case study in total consists of eight participants participating in eight interviews, in which the participants have more than ten years' experience. The number of interviews included in the comparative case study is sufficient given the study's nature as a phenomenological study and the homogeneity among the participants' roles and experiences [28,29,30,31,32]. It was made sure that the participants got brief information about the study aim at the beginning of the interview. It was also made sure that the participants carefully read and signed the consent form before starting the interview. A mix of Arabic and English languages was used during the whole interviews.

4.4. Checking consistency and reliability – Cronbach's alpha

A measure of consistency, called Cronbach's alpha coefficient, is statistically derived to verify that the responses of the participants towards the evaluation of the different CDWR factors (i.e., awareness, practices, culture & behaviour, and legislation) are consistent and the used measurement tools (i.e., Likert scales) are reliable. The value of Cronbach's alpha coefficient ranges between 0 and 1. The closer the Cronbach's alpha coefficient is to 1, the greater the internal consistency of the data collected from the participants towards evaluating the different abovementioned factors [33]. Interpretations of Cronbach's alpha coefficient values towards consistency measurement are summarised, as seen in Table 2.

Cronbach's alpha coefficient was calculated via **SPSS V26**© software for the different CDWR factors in section 4. It was noticed that all the values exceeded 0.7, as listed in Table 3. This means that the consistency among the responses exceeded the minimum limit of being acceptable, and the used measurement scales for data collection are reliable per the recommendation of George and Mallery [33]. This confirms that there is no need to redesign the questionnaire and recollect the data or exclude any responses. Finally, the overall Cronbach's alpha coefficient was calculated for the whole section of the factors resulting in a value of 0.95. This indicates an excellent overall level of internal consistency and reliability of scales.

4.5. The approach of qualitative and quantitative data analysis

Qualitative data analysis was carried out using **NVivo 12**© software in which it helped organise the collected textual data and

Table 2
Determining consistency through Cronbach's alpha coefficient value Source: George and Mallery [33].

Cronbach's Alpha Coefficient Value (α)	Interpretation of Consistency
$1.0 \geq \alpha \geq 0.9$	Excellent consistency
$0.9 > \alpha \geq 0.8$	Good consistency
$0.8 > \alpha \geq 0.7$	Acceptable consistency
$0.7 > \alpha \geq 0.6$	Questionable consistency
$0.6 > \alpha \geq 0.5$	Poor consistency
$\alpha < 0.5$	Unacceptable consistency

Table 3
Calculation of Cronbach's alpha for different factors

Evaluated Factors	Number of Items	Number of the Questions in the Interview Questionnaire	Cronbach's Alpha Coefficient Value (α)
Awareness	4	Q11 – Q14	0.79
Practices	3	Q15 – Q17	0.85
Culture & behaviour	5	Q18 – Q22	0.91
Legislation	2	Q23 – Q24	0.83
Total	14	Q11 – Q24	0.95

interpret it. First, the qualitative responses of each respondent were entered separately in **NVivo 12**© software. Then, thematic analysis was conducted via **NVivo 12**© software by "coding" the related textual data and assigning them to "child node" (i.e., subtheme). Finally, the "child nodes" are assigned later to their relevant "parent nodes" (i.e., theme) which represent the "themes" investigated in the questionnaire. The qualitative data analysis results of the four projects are demonstrated in Tables 4, 7, 10, and 13.

Quantitative data collected via the interview questionnaire are classified into: (1) ranges of CDWG rates; and (2) scores given on Likert scales to evaluate the different CDWR factors. Likert scales are suitable for collecting attitudinal information about the subjective matter [34]. For CDWG rates, the weighted arithmetic mean is calculated using **Microsoft Excel 2016**© software to consider an average CDWG rate, as shown later in Tables 5, 8, 11, and 14, taking into consideration the weight of each expert's opinion based on the number of years spent in the industry as indicated in Equation 1.

$$CDWGrate = \frac{CDWG1 \times yearsofexperience + CDWG2 \times yearsofexperience}{sumofyearsofexperienceofbothrespondents} \quad (1)$$

The quantities of materials used in the project and cost per materials unit were retrieved from projects' documents as introduced by the interviewed managers. Accordingly, the total costs of used materials were calculated using Equation 2.

$$Totalcostofprocuredmaterial = totalquantityofprocuredmaterial \times costpermaterialunit \quad (2)$$

After that, the cost of wasted materials is estimated based on the calculated CDWG rate for each material, as indicated in Equation 3.

$$Costofwastedmaterial = \frac{CDWGrate \times totalcostofprocuredmaterial}{100} \quad (3)$$

Finally, the percentage of total wasted materials cost in relation to total procured materials cost in a project is calculated using Equation 4.

$$Percentageoftotalwastedmaterials'cost = \frac{totalcostofwastedmaterials}{totalcostofprocuredmaterials} \times 100 \quad (4)$$

On the other hand, the Likert scales used in the interview questionnaire were five-point (i.e., 1–5) scales. All the five-points Likert scales were adopted from studies carried out by Vagias [35] and Brown [36]. Five-point Likert scales were used to increase response rate and response quality and reduce the frustration of respondents [37]. For instance, awareness was evaluated on a Likert scale, in which "1″ means "not aware at all" and "5″ means "extremely aware". Also, different practices were evaluated on a Likert scale to assess the frequency of their application. In this case, "1″ means "never" and "5″ means "always". For the scores given on Likert scales, these scores are firstly normalised for each respondent using the minimum–maximum normalisation approach via **Microsoft Excel 2016**© software. Since different types of scales were sometimes used to measure the metrics (i.e., questions) and to maintain consistency in evaluating the different factors, each appropriate response was "normalised" by assigning it an equivalent normalised value ranging from 0 to 1. This is to enable aggregation on the factor level and to get a representative "composite index" (CI) representing the overall evaluation of the factor [38,39].All aggregation processes were carried out using **Microsoft Excel 2016**© software. Score (1) is represented by normalised score (0), score (2) is represented by normalised score (0.25), score (3) is represented by normalised score (0.5), score (4) is represented by normalised score (0.75), and score (5) is represented by normalised score (1). Then, the normalised responses for the metrics measuring a specific factor were aggregated on the metric level using simple arithmetic mean in which all metrics measuring the same factor are assumed to have equal weights and be independent of each other. Simple arithmetic mean was used in aggregation on the metric level as it is the most common and transparent method used in aggregating different variables [40]. The result of aggregation on the metric level indicates each respondent's evaluation towards the factor which the metrics are measuring as demonstrated in Equation 5.

$$Respondent's(R)evaluationtowardsafactor = \frac{Sumofmetrics'normalisedresponses}{numberofmetrics} \quad (5)$$

After that, the aggregation process took place on the factor level using the respondents' aggregated scores on the metric level. Weighted arithmetic mean was used in aggregation on the factor level to consider the respondents' experience in the weight of the responses, as demonstrated in Equation 6.

$$CI = \frac{R1 \times yearsofexperience + R2 \times yearsofexperience}{sumofyearsofexperienceofbothrespondents} \quad (6)$$

The aggregation on the factor level is represented by CI as investigated in the equation above, a score ranging from 0 to 1, which is then divided over a five-point rating scale to indicate the respondents' overall evaluation of each factor [41]. Values of CI can be interpreted as follows: (0.00 – 0.20) means "poor", (0.21 – 0.40) means "fair", (0.41 – 0.60) means "good", (0.61 – 0.80) means "very good", and (0.81 – 1.00) means "excellent". Finally, the composite indices of all factors are aggregated together using simple arithmetic mean to give an overall evaluation of waste management (WM) at the construction firm executing the investigated project as shown later in Tables 6, 9, 12, and 15. The overall evaluation of WM is named as "WM score". Results and findings are demonstrated in the following sections.

5. Data analysis & results

5.1. Demographic information

The interviews were conducted with four project managers and four procurement managers in total, in which their industrial experiences range between 10 and 36 years. Each interview took place face-to-face for around 45 to 60 min. The participants did not sign for audio or video recording of the interviews on the consent form. Their preferences were respected, and these tools were not used during the interview. Instead, the answers of the participants were written on the interview transcript. It was also made sure that the names of the participants, their firms, and the investigated projects in the case study are kept anonymous in the publications based on the participants' preferences in the consent form. The four selected construction projects were executed by four "first-grade" firms per the classification of the Egyptian Federation of Construction & Building Contractors (EFCBC). It is worth mentioning that first-grade firms are the most capable firms in the Egyptian construction sector [35].

5.2. The four investigated construction projects

As previously discussed in subsection 4.5, this subsection presents the qualitative data analysis of the different projects represented by the managers' responses. Moreover, the quantitative data analysis regarding CDWG rates and costs and the evaluation of the adopted CDWR factors are presented. Each subsubsection presents the qualitative and quantitative data analysis of each project type of the four investigated projects.

5.2.1. Industrial project

See Tables 4-6.

5.2.2. Residential project

See Tables 7-9.

Table 4
Qualitative analysis of the industrial project.

Theme	Subtheme	Response
Project description	Size	The project consists of four mega military factories. The main works were infrastructure and buildings construction. The total size of the land is around1360 acres.
	Specifications and challenges	Both managers stated that this project's main difficulties were the undulating land surface and its large size. It took a great effort to level the ground surface and execute the infrastructure works in this large area. They added that significant challenges were faced due to rapid changes and variation orders in the project. The variation orders were mainly because of the foreign vendors. There was a lack of coordination between the project owner and the vendors. Moreover, they said that there were many price changes due to the currency devaluation during this decade.
	Duration	This project started in 2009, and it was delivered by June 2019.
	Contractual agreement	The project was delivered on a turnkey basis.
Materials procurement models	Adopted materials procurement model/s	• GCPM
	Reasons behind choosing the adopted model/s	Both managers said that this type of procurement model was stated in the contract. The project consultant only specifies the vendor list. The firm was responsible for materials procurement. Moreover, this model was adopted in order to maximise the firm's profit in the project. The firm calculated the margin profit based on procured materials. The aim was to procure materials with low prices and high quality, which suits the project nature. They added that this model is used to control the delivery schedule of materials based on the project timeline and to control the project budget regarding the procured materials.
	Relationship between the adopted model/s and CDWR	Both managers confirmed that this model was the best option. They said that the firm made a bid among materials vendors and chose the best of them based on those who can provide materials with low costs, high quality, and flexible payment intervals. Both managers claimed that this model gave them full control of materials procurement aspects like budget and schedule. Moreover, they stated that it helped them to track the usage of materials on-site and optimise it. They said that adopting this model allowed them to reduce CDW, delays, and cost overruns.
Materials procurement measures	Adopted materials procurement measures	• Suppliers' flexibility in supplying small quantities or modification to products in conformity. • Supply of quality and durable products. • Procurement of waste-efficient materials/technology (pre-assembled/cast/cut). • Purchase of quality and suitable materials. • Correct materials purchase. • Effective protection of materials (during transportation, loading & unloading). • Effective on-site access (for ease of delivery). • Efficient delivery schedule. • Accurate materials take-off. • Prevention of over/under ordering. • Reduced waste allowance. • Usage of Just in Time (JIT) delivery system. • Avoidance of variation orders. • Other: meeting with product manufacturers to carry out a quality test to ensure that the written materials specifications are accurate.
	Sufficiency of adopted materials procurement measures towards CDWR	Both managers stated that the adopted measures were sufficient towards CDWR. A plan was in place to efficiently store the materials on-site. Furthermore, they commented on the adopted measures. Regarding the measure named "supply of quality and durable products", they said that sometimes the firm is subjected to vendors who supply low-quality materials. Accordingly, these vendors are struck from the vendor list. Regarding the measure named "procurement of waste-efficient materials/technology (pre-assembled/cast/cut)", both managers stated that pre-cast concrete floors and walls were used in this project. Regarding the measure named "correct materials purchase", both managers confirmed that detailed specifications of the materials were sent along with the materials order. Also, they added additional measure not listed in the 16 defined measures. This additional measure is meeting with product manufacturers to carry out a quality test to ensure that the written materials specifications are accurate.
Green building practices	Application of green materials procurement approach	Both managers said that the different criteria were not fully adopted in this project. Only one criterion, which is "usage of alternative building prefabricated elements", was adopted in this project. Prefabricated reinforcement steel of columns, beams, and foundation cages was used. They said that they exceeded the minimum requirement (i.e., 10% of the total quantity) as stated by the GPRS. Both managers stated that they had used 100% of the total quantity as prefabricated reinforcement steel with 0% waste. Moreover, they stated that green building practices are not a familiar concept in the Egyptian construction industry, and it is still in infancy stages.
CDW problem in the Egyptian construction industry	Different reasons for CDWG	Both managers claimed that the main reasons behind such a problem are lack of waste-efficient practices in the industry, poor and careless behaviour, lack of awareness towards the problem, and lack of knowledge among project participants on different levels. Also, there is a lack of coordination among different project parties which plays an essential role in CDWG. Also, there is a lack of adequate practices for dealing with materials, whether during the procurement or on-site. There are no strict laws that can reduce CDW and penalise those who dump CDW at unassigned illegal landfills. Also, there is a lack of awareness towards the Egyptian legislation concerned with CDWM. This indicates that the existing legislation are weak and ineffective.
	Negative impacts of CDW problem	Both managers stated that this is a huge problem in Egypt. They believe that it leads to a high financial loss of firms, especially in megaprojects. It leads to project delays because raw materials are wasted, resulting in waiting for other materials to be brought on-site. Consequently, this leads to a delay in the project schedule. It negatively impacts well-being and the environment. They said that this increasing CDW problem is deteriorating lives, the environment, and the economy.

Table 5
Quantification of CDW in the industrial project.

Material type (unit)	Weighted mean value (%)	Standard deviation (%)	The quantity used in the project (unit)	Cost per unit (EGP/unit)	The total cost of procured material (EGP)	Cost of wasted material (EGP)	Percentage of total wasted materials cost (%)
Timber (m3)	11.77	7.42	1500	2500	3,750,000	441477.3	1.89
Sand (m3)	2.68	1.06	25,000	17	425,000	11397.7	
Concrete (m3)	1.95	0.71	176,000	300	52,800,000	1032000.0	
Cement (tons)	3.23	0.35	3500	450	1,575,000	50829.5	
Reinforcement steel (tons)	0.00	0.00	14,000	5000	70,000,000	0.0	
Tiles (m2)	3.59	1.41	14,500	500	7,250,000	260340.9	
Bricks/blocks (m3)	2.95	0.71	180,000	400	72,000,000	2127272.7	

Table 6
Evaluation of different CDWR factors at the firm executed the industrial project.

Factor	The composite index of the factor	Standard deviation among respondents' evaluations	Interpretation of the index	The total final score of the project's waste management (WM)	Interpretation of the score
Awareness	0.63	0.09	Very good	0.63	Very good
Practices	0.54	0.06	Good		
Culture & behaviour	0.83	0.04	Excellent		
Legislation	0.50	0.00	Good		

Table 7
Qualitative analysis of the residential project.

Theme	Subtheme	Response
Project description	Size	The project consists of six buildings. Each building consists of 11 floors with a built-up area (BUA) of 1250 m^2. The total number of units is 337 apartments.
	Specifications and challenges	Both managers stated that this project's main challenge was its location near the Nile River, so the underground water was a significant problem. Accordingly, they constructed large piles and caps. Moreover, huge retaining walls were constructed to avoid any deterioration to the near old buildings.
	Duration	The project started in 2008, and it was delivered in 2013.
	Contractual agreement	The apartments were delivered semi-finished.
Materials procurement models	Adopted materials procurement model/s	• GCPM
	Reasons behind choosing the adopted model/s	Both managers stated that most of the financial profit is in this model. The firm calculated its overhead and profit based on the procured materials. They added that this model helped in executing the project on a fast track. They stated that using this model helped in tracking the usage and procurement of materials. Accordingly, materials were procured and used economically and efficiently to increase the firm's profit margin.
	Relationship between the adopted model/s and CDWR	Both managers confirmed that the adopted model was the best option as it helped reduce CDW to maximise the firm's profit.
Materials procurement measures	Adopted materials procurement measures	• Suppliers' flexibility in supplying small quantities or modification to products in conformity. • Supply of quality and durable products. • Usage of minimal packaging (without affecting materials safety). • Purchase of quality and suitable materials. • Correct materials purchase. • Effective protection of materials (during transportation, loading & unloading). • Effective on-site access (for ease of delivery). • Accurate materials take-off. • Prevention of over/under ordering. • Reduced waste allowance.
	Sufficiency of adopted materials procurement measures towards CDWR	Both managers stated that the adopted measures were sufficient for CDWR compared to the complexity of the project, its large size, location, and the unstable political conditions during its execution. Political conditions at this time in Egypt were unstable, so the project was exposed to several interruptions. The main focus was on delivering the project as fast as possible without considering every single measure. They believe that the CDWG rates could be have been greater, but they tried hard to minimise them by applying these measures as much as they could.
Green building practices	Application of green materials procurement approach	Both managers stated that the different criteria were not adopted in the project. They claimed that these criteria are not applicable in their firm. They believe that these are also not applicable in most of the construction projects in Egypt. Moreover, they said that they are slightly aware of them.

(*continued on next page*)

Table 7 (*continued*)

Theme	Subtheme	Response
CDW problem in the Egyptian construction industry	Different reasons for CDWG	Both managers stated that the main reason behind the CDW problem is that the culture of CDWR does not exist within most of the Egyptian construction firms. The awareness of people towards the severity of the problem and developing innovative solutions to face this problem is lacking. They claimed that recycling and reuse strategies for CDW reduction does not exist in Egypt. This could help in reducing CDW significantly. They added that the Egyptian construction firms do not adequately adopt waste-efficient practices of dealing with materials.Moreover, they said that labours in Egypt are not dealing carefully with materials. Additionally, they stated that the nature of project execution affects CDWG. If the project's timeline is compressed, and the project is executed on a fast-track basis, it can be expected to have a high rate of CDWG. They claimed that this is the nature of construction projects nowadays in Egypt. Most of the projects are executed on a fast-track basis. Furthermore, they said that the Egyptian legislation are weak towards solving this problem. No strict laws exist in the industry to enforce construction firms to minimise CDW.
	Negative impacts of CDW problem	Both managers stated that the CDW problem has severe adverse effects on society, the environment, and Egypt's economy.

Table 8
Quantification of CDW in the residential project.

Material type (unit)	Weighted mean value (%)	Standard deviation (%)	The quantity used in the project (unit)	Cost per unit (EGP/unit)	The total cost of procured material (EGP)	Cost of wasted material (EGP)	Percentage of total wasted materials cost (%)
Timber (m3)	7.05	1.06	2200	800	1,760,000	124000.00	3.34
Sand (m3)	6.74	1.77	60,000	121	7,260,000	489500.00	
Concrete (m3)	3.89	1.41	80,000	150	12,000,000	467272.73	
Cement (tons)	2.50	0.00	50,000	500	25,000,000	625000.00	
Reinforcement steel (tons)	2.65	0.35	25,000	3950	98,750,000	2618371.21	
Tiles (m2)	4.05	1.06	2000	25	50,000	2022.73	
Bricks/blocks (m3)	4.35	0.35	80,000	640	51,200,000	2226424.24	

Table 9
Evaluation of different CDWR factors at the firm executed the residential project.

Factor	The composite index of the factor	Standard deviation among respondents' evaluations	Interpretation of the index	The total final score of the project's waste management (WM)	Interpretation of the score
Awareness	0.57	0.13	Good	0.54	Good
Practices	0.36	0.06	Fair		
Culture & behaviour	0.70	0.11	Very good		
Legislation	0.50	0.00	Good		

5.2.3. Commercial project

See Tables 10-12.

5.2.4. Infrastructure project

See Tables 13-15.

Table 10
Qualitative analysis of the commercial project.

Theme	Subtheme	Response
Project description	Size	The project is an investment bank which consists of two basements and four floors on a BUA of 4400 m2.
	Specifications and challenges	It consists of high specifications and advanced technology for electromechanical systems.
	Duration	The project started in 2009, and it was delivered by 2011.
	Contractual agreement	The project was delivered on a turnkey basis.
Materials procurement models	Adopted materials procurement model/s	• GCPM
	Reasons behind choosing the adopted model/s	Both managers stated that the owner delegated their firm for procuring all the materials of the project. This step occurred without any interference from his side or a speciality contractor.
	Relationship between the adopted model/s and CDWR	They claimed that it was the best option because the firm is more involved in the project execution and more aware of its requirements. Moreover, they added that this model enabled maximising the firm's profit and reducing CDWG.
Materials procurement measures	Adopted materials procurement measures	• Suppliers' flexibility in supplying small quantities or modification to products in conformity. • Supply of quality and durable products. • Usage of minimal packaging (without affecting materials safety).

Table 10 (*continued*)

Theme	Subtheme	Response
		• Purchase of quality and suitable materials. • Correct materials purchase. • Effective protection of materials (during transportation, loading & unloading). • Effective on-site access (for ease of delivery). • Accurate materials take-off. • Prevention of over/under ordering. • Reduced waste allowance.
	Sufficiency of adopted materials procurement measures towards CDWR	Both managers confirmed that the adopted measures were sufficient in terms of CDWR.
Green building practices	Application of green materials procurement approach	Both managers stated that these criteria were not adopted in the project. They claimed that these criteria are not widely applicable or known in Egypt. Moreover, it was not a requirement by the project owner to apply them. Finally, they said that they are not familiar with green building rating systems.
CDW problem in the Egyptian construction industry	Different reasons for CDWG	Both managers stated several reasons for such a problem. They said that the main reason behind CDWG is the carelessness of people in the Egyptian construction industry on different levels, especially labours. They claimed that reusing of materials is not applied at all. They added that the inefficient storage of materials and inadequate materials management on-site play a crucial role in CDWG. Additionally, they stated that there is an inaccuracy in taking off materials on-site. Also, they believed that inadequate supervision of superintendents on-site plays an essential role in CDWG. Moreover, they blamed legislation in Egypt for being inadequate and ineffective in solving the CDW problem.
	Negative impacts of CDW problem	Both managers said that CDW problem has adverse effects on society, the environment, and Egypt's economy. It may change the project profit into a loss, especially in mega construction projects. Moreover, it deteriorates the quality of life and the natural environment.

Table 11
Quantification of CDW in the commercial project.

Material Type (unit)	Weighted mean value (%)	Standard deviation (%)	The quantity used in the project (unit)	Cost per unit (EGP/unit)	The total cost of procured material (EGP)	Cost of wasted material (EGP)	Percentage of total wasted materials cost (%)
Timber (m3)	9.8	3.54	700	800	560,000	54,880	3.43
Sand (m3)	6.69	1.06	28,000	12	336,000	22478.4	
Concrete (m3)	3.46	0.71	12,800	150	1,920,000	66,432	
Cement (tons)	2.77	0.35	233	500	116,500	3227.05	
Reinforcement steel (tons)	2.50	0.00	1200	3950	4,740,000	118,500	
Tiles (m2)	2.04	0.71	3450	50	172,500	3519	
Bricks/blocks (m3)	3.42	1.41	800	640	512,000	17510.4	

Table 12
Evaluation of different CDWR factors at the firm executed the commercial project.

Factor	The composite index of the factor	Standard deviation among respondents' evaluations	Interpretation of the Index	The total final score of the project's waste management (WM)	Interpretation of the Score
Awareness	0.54	0.13	Good	0.47	Good
Practices	0.30	0.06	Fair		
Culture & behaviour	0.65	0.00	Very good		
Legislation	0.38	0.00	Fair		

6. Discussion

After analysing the four projects investigated in the comparative case study, it is obvious that the infrastructure project was the most wasteful in terms of percentage of total wasted materials cost in relation to total procured materials cost and CDWG rates as shown in Fig. 2 and Fig. 3 respectively. The analysis revealed variations in CDWG rates of the most common construction materials among the different construction projects, as shown in Fig. 3. The variability in CDWG rates is obvious as follows: timber (7.05% – 11.77%), sand (2.68% – 6.69%), concrete (1.95% – 5.96%), cement (2.50% – 6.41%), reinforcement steel (0% – 11.69%), tiles (2.04% – 6.69%), and bricks/blocks (2.95% – 7.09%). These variations seem to depend on the differences in projects' nature, size, and complexity on the one hand, and the level of adoption of practices, culture & behaviour, awareness, and legislation on the other hand.

On average, among the four projects, it was found that "timber" is the most wasteful material with an average CDWG rate of 8.96%. This is followed by "sand" with an average CDWG rate of 5.70%, and "bricks/blocks" with an average CDWG rate of 4.45%. These results coincide with the previous studies for CDWM research in Egypt, in which "timber" was stated as the most wasteful material in the studies carried out by Hany and Dulaimi [12] and Garas et al. [13]. On the other hand, Ragab et al. (2001), as reported in El-Desouky et al. [14], claimed that "sand" is the most wasteful material in the Egyptian construction sector. Besides, El-Desouky et al. [14] stated in their study that "bricks" is the most wasteful material in the Egyptian construction sector. The results of this study, along with the results of previous studies about CDWM in Egypt,

Table 13
Qualitative analysis of the infrastructure project.

Theme	Subtheme	Response
Project description	Size	The project is a thermal power plant in Egypt with an electric power production capacity of 650 megawatts (MWs).
	Specifications and challenges	The project had very high specifications and technical requirements. It is one of the most leading and complex megaprojects in Egypt. However, the firm was awarded a certificate for an excellent performance of 10 million working hours with zero accidents.
	Duration	The project started in 2012, and it was delivered in 2017.
	Contractual agreement	The firm executed the project among other 18 different firms. Each firm has its scope of work. The firm was responsible for many civil works and buildings' construction to be delivered fully finished.
Materials procurement models	Adopted materials procurement model/s	• GCPM
	Reasons behind choosing the adopted model/s	Both managers said that it was a contractual agreement, and it was a requirement stated by the project owner. The project was based on a lump sum contract in which the general contractor was responsible for procuring construction materials.
	Relationship between the adopted model/s and CDWR	Both managers recommended that it would have been better to use another model than the adopted one. They explained that saying millions and billions of pounds are spent on materials in construction megaprojects like this infrastructure project. The project was massive, and many construction firms, with different performances, culture & behaviour, and adopted practices, shared its execution. They concluded that this might have resulted in less control over materials wastage. From the managers' point of view, they recommend choosing between SCPM and OPM or maybe an integration between these two models as the speciality contractor is hired and controlled by the project owner. They stated that nobody would care about financial resources as the project owner. They claimed that If these two models were adopted, strict measures would have been taken differently among the construction firms, financial resources would have been saved, and environmental pollution resulting from CDW would have been reduced.
Materials procurement measures	Adopted materials procurement measures	• Supply of quality and durable products • Purchase of quality and suitable materials • Correct materials purchase • Effective protection of materials (during transportation, loading & unloading) • Accurate materials take-off
	Sufficiency of adopted materials procurement measures towards CDWR	Both managers complained that the adopted measures were not sufficient compared to the project size and complexity. They believed that many materials had been wasted in this project that could have been saved if the firm implemented serious materials procurement measures. They felt that their firm haphazardly executed this project. The reasons may be the unstable political conditions during this period and interruptions, owner willingness to deliver the project as fast as possible, and lack of interest and culture regarding CDWR among stakeholders.
Green building practices	Application of green materials procurement approach	Both managers stated that these criteria were not adopted in the project. Moreover, they said that they have no idea about green building rating systems.
CDW problem in the Egyptian construction industry	Different reasons for CDWG	Both managers stated several reasons, from their point of view, towards such a problem in Egypt. Examples of these reasons are as follows: weak and ineffective legislation, lack of waste-efficient practices due to inadequate knowledge, lousy behaviour of construction labours, absence of CDW reduction culture, and lack of awareness towards the severity of the problem and its adverse effects. Moreover, they added that legal dumpsites are scarce, making it difficult and expensive for the contractors to dispose the CDW at the assigned legal dumpsites properly. Therefore, it is easier for them to dispose the CDW near their construction sites on residential roads and agricultural lands.
	Negative impacts of CDW problem	Both managers stated that CDW is a severe problem in Egypt. It leads to deterioration of infrastructure like roads, and it leads to road closures and congestions. Moreover, it negatively affects the citizens' health and well-being in addition to air, water, and soil pollution.

Table 14
Quantification of CDW in the infrastructure project.

Material type (unit)	Weighted mean value (%)	Standard deviation (%)	The quantity used in the project (unit)	Cost per unit (EGP/unit)	The total cost of procured material (EGP)	Cost of wasted material (EGP)	Percentage of total wasted materials cost (%)
Timber (m3)	7.23	0.71	10,000	1200	12,000,000	867567.57	7.50
Sand (m3)	6.68	1.77	160,000	45	7,200,000	480648.65	
Concrete (m3)	5.96	1.41	65,000	1200	78,000,000	4648378.38	
Cement (tons)	6.41	1.06	22,750	800	18,200,000	1165783.78	
Reinforcement steel (tons)	11.69	2.12	6400	6000	38,400,000	4488648.65	
Tiles (m2)	6.69	2.12	25,000	120	3,000,000	200675.68	
Bricks/blocks (m3)	7.09	1.06	136,000	180	24,480,000	1736756.76	

prove that "timber", "sand", and "bricks/blocks" are the most wasteful materials in the Egyptian construction sector.

The CI devised in this paper reflects the actual evaluation of WM in each project. The percentage of total wasted materials cost in relation to total procured materials cost in the four projects are as follows: industrial (1.89%), residential (3.34%), commercial (3.43%), and infrastructure (7.50%). According to Shamseldin [10], it is unacceptable that the waste in total materials cost exceeds

Table 15
Quantification of CDW in the infrastructure project.

Factor	The composite index of the factor	Standard deviation among respondents' evaluations	Interpretation of the index	The total final score of the project's waste management (WM)	Interpretation of the score
Awareness	0.42	0.04	Good	0.28	Fair
Practices	0.25	0.00	Fair		
Culture & behaviour	0.33	0.07	Fair		
Legislation	0.13	0.00	Poor		

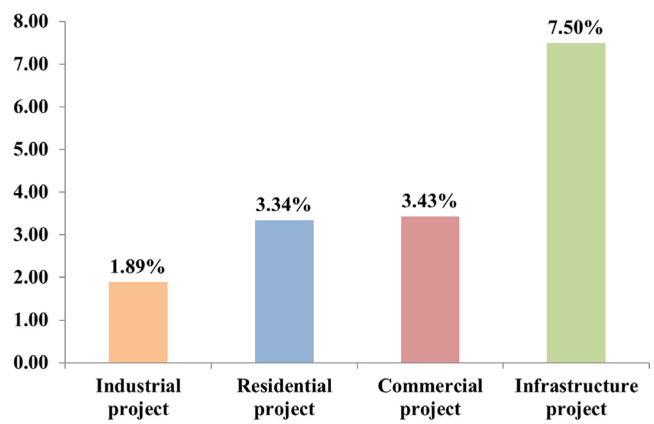

Fig. 2. Percentage of total wasted materials cost in relation to total purchased materials cost in different construction projects – a comparison.

4% under any circumstances. This coincides with the devised CI representing WM evaluation in different projects as follows: industrial (very good), residential (good), commercial (good), and infrastructure (fair) as shown in Fig. 4. It is worth mentioning that these percentages of total wasted materials cost are for projects executed by first grade firms, the most capable ones in the Egyptian construction sector, in which they are approaching the maximum recommended limit of total wasted materials cost. It is expected that the situation would be worse for lower performing firms, mostly sixth and seventh-grade firms, in which the percentages of total wasted materials cost could approach 40% as stated by Shamseldin [10]. According to El Ehwany [42], more than 80% of the Egyptian construction firms belong to the sixth and seventh grades. This statistic means that most Egyptian construction firms are small-sized ones with low capabilities and shortage in advanced construction techniques, leading to high CDWG.

Based on the analysis of the managers' responses in the different projects, it can be concluded that the CDWG is affected by several factors such as adopted practices, level of managers' awareness, quality of culture & behaviour in the firm, and applicability of legislation. On average among the four projects, it was found that "practices" and "legislation" are the least applied factors towards CDWR with average evaluation scores of 0.36 (i.e., fair) and 0.38 (i.e., fair) respectively, which means that these factors need careful attention and improvement to be better applied for better CDWR results. This is followed by "awareness" with an average evaluation score of 0.54 (i.e., good), and "culture & behaviour" with an average evaluation score of 0.63 (i.e., very good). The WM score, which depends on the four CDWR factors, varies from one project to another. The highest WM score is awarded to the industrial project with a value of 0.63 (i.e., very good). In contrast, the lowest WM score is awarded to the infrastructure project with a value of 0.28 (i.e., fair) as shown in Figs. 4 and 5. By comparing Figs. 2 and 4, it can be found that the percentage of total wasted materials cost decreases when the WM score increase. This highlights the inverse relationship between CDWG and WM score. Moreover, this indicates the importance of careful and considerate implementation of the four factors towards efficient WM and CDWR during project execution.

More specifically, CDWG increased in the projects which adopted a low number of waste-efficient materials procurement measures and did not apply any of the green materials procure-

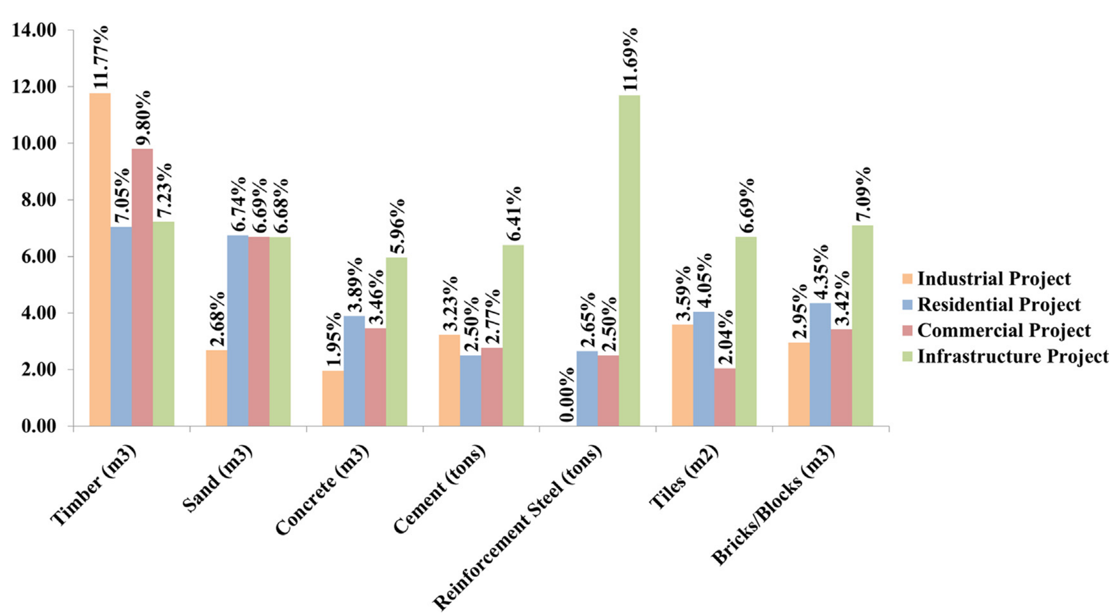

Fig. 3. Percentage of waste in each type of most common construction materials in different construction projects – a comparison.

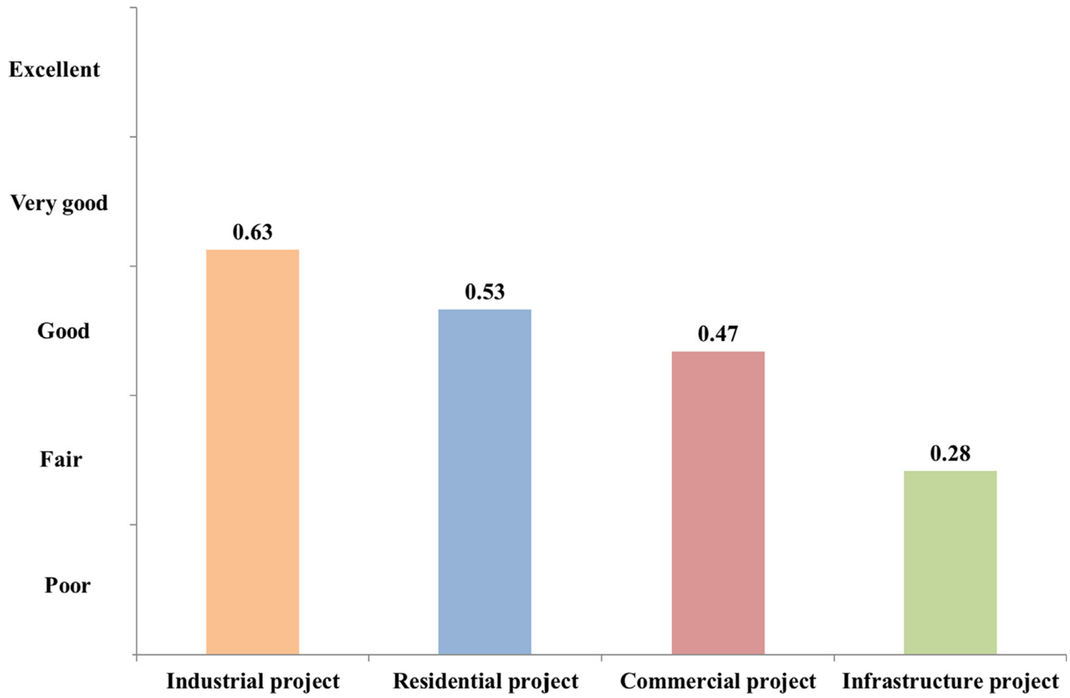

Fig. 4. Waste management (WM) score in different construction projects – a comparison.

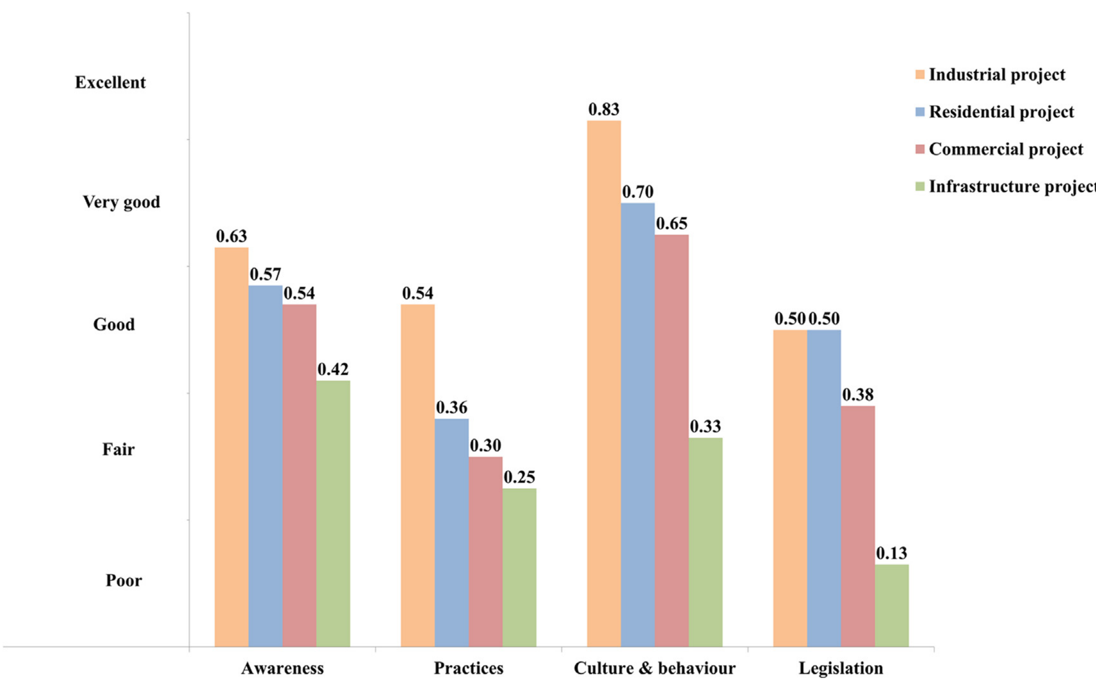

Fig. 5. Different CDWR factors affecting waste management (WM) score in different construction projects – a comparison.

ment criteria during the project execution. For instance, it was found that the industrial project, which was the best performing project regarding WM, applied 13 out of the 16 defined waste-efficient materials procurement measures plus additional measure out of the listed 16 measures, and it applied one out of the five defined green materials procurement criteria listed in the GPRS. On the other hand, it was found that the infrastructure project, which was the worst-performing project regarding WM, applied five out of the 16 defined waste-efficient materials procurement measures, and it did not apply any of the defined green materials procurement criteria in the GPRS due to lack of knowledge. The infrastructure project's managers stated that the adopted waste-efficient materials procurement measures in this project were insufficient towards CDWR. This demonstrates the impact of waste-efficient materials procurement measures and green materials procurement criteria on CDWR.

Moreover, it was found that the GCPM is the dominant model being applied in the four construction projects. Based on previous studies carried out by Daneshgari & Harbin [43], it is known that this model is not the best option regarding CDWR compared to

SCPM and OPM. This was demonstrated by the responses of the infrastructure project's managers who recommended choosing between SCPM and OPM or maybe integration between these two models to better control materials procurement in mega construction projects and minimise CDW, which consequently will lead to better financial savings and reduced negative environmental impact. However, the managers of the industrial, residential, and commercial projects stated that the GCPM allowed them to minimise CDWG and maximise their firms' profits. Based on different managers' responses in the data analysis section, it can be concluded that the suitability of materials procurement model is affected by project size and nature, contractual agreement, and culture & behaviour implemented among different stakeholders.

Based on the insights given by the managers' responses, the CDW problem in Egypt is severe, and it is escalating over time. They stated that it results in financial losses, especially in megaprojects. Also, it negatively impacts well-being and the environment. They stated several reasons behind the problem as follows: (1) lack of good practices and especially careful dealing with materials whether during procurement or on-site; (2) poor culture & behaviour towards CDWR; (3) lack of knowledge and awareness among project participants on different levels; (4) lack of coordination among different project parties; (5) absence of efficient and effective WM legislation; (6) absence of recycle and reuse of CDW in Egypt; and (7) scarcity of legal dumpsites which forces contractors to dump CDW illegally on residential roads and agricultural lands.

7. Conclusion

CDW is one of the global challenges which threaten developed and developing nations. It contributes up to 50% of total global annual generated SW, and it represents approximately 10% of the total cost of materials used in construction projects. In Egypt, the problem is serious in which CDW represent up to 40% of total materials cost in construction projects. Moreover, the dominant practice of handling CDW in Egypt is illegal dumping which negatively affects society and the environment. This indicates the negative impact of CDW on sustainable development in Egypt. The main factors behind CDWG in Egypt can be summarised as follows: (1) deficiencies in waste-efficient practices; (2) lack of awareness; (3) absence of appropriate culture & behaviour; (4) lack of strict legislation; (5) lack of coordination among project parties; (6) scarcity of legal dumpsites; and (7) lack of adoption to CDW recycle and reuse.

This study provides a new contribution to knowledge through mixed-methods research by (1) quantifying CDW among various Egyptian construction projects in terms of costs and generation rates; and (2) exploring the relationship between CDWR factors and CDWG. Based on the analysis results among the four projects, it has been noted that "timber" is the most wasteful material regarding CDWG rates followed by "sand" and "bricks/blocks" consecutively. The infrastructure project was the most wasteful in terms of CDWG rates and total wasted materials cost.

Also, it has been indicated that there is an inverse relationship between the different CDWR factors, which represent the WM evaluation in any project, and CDWG. It has been proven that if these factors are better applied, the CDWG decreases represented in a decrease in the total cost of wasted materials. On average, among the four projects, it was found that "practices" and "legislation" are the least applied factors towards CDWR, which need to be better applied for better-targeted CDWR results. More specifically, it has been noted that the project which adopts more waste-efficient materials procurement measures and green materials procurement criteria is characterised by less CDWG than its peers such as the case in the industrial project which is the least wasteful project. Also, it has been noted that all projects adopted the GCPM during project execution which is not the best option regarding CDWR. Some experts in this study recommended adopting either SCPM or OPM or integration between both of them to minimise CDW, especially in mega construction projects.

8. Recommendations

Based on the findings of this study and the experts' responses, it is recommended to adopt different strategies to solve the CDW problem in Egypt as follows: (1) adopt waste-efficient practices especially waste-efficient materials procurement measures and green materials procurement criteria based on their high impact on the reduction of both CDWG and total project cost; (2) increase the awareness of citizens and professionals towards CDWR; (3) promote the culture and improve the behaviour towards CDWR at workplaces, schools, governmental bodies, and universities; (4) develop strict legislation which offers incentives for CDWR and penalise the construction firms which dump CDW illegally; (5) enhance the communication channels between different project parties; (6) suffice an adequate number of legal dumpsites all over the different Egyptian governorates, and (7) promote the adoption of reuse and recycle of CDW.

As a part of an on-going PhD research, this study represents an exploratory phase to fill the knowledge gaps found in different studies existing in the literature. As a future research step, it is recommended to adopt a confirmatory phase to test and confirm the different hypotheses regarding the relationship between the investigated four main factors and CDWR via rigorous multivariate statistical analysis. This can be carried out by conducting a survey among a representative stratified sample size of the Egyptian construction firms of different grades at the EFCBC. This is needed to include different firms' perspectives and performances rather than the first-grade firms in this study. This survey can help in investigating the applicability and effectiveness of the different investigated factors towards CDWR. The confirmatory study shall help develop a framework to be validated by professionals and academics to help the Egyptian government, academics, construction industry practitioners, and policymakers solve the CDW problem.

Author contributions

The first author initiated this exploratory research using a mixed-methods approach, carried out the complete data analysis, and drafted the whole manuscript. The co-authors supervised the research carried out by the first author and provided guidance given their roles as PhD supervisors. All authors have read and agreed to the published version of the manuscript.

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Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asej.2021.02.039.

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Dr. **Daoud** was graduated in 2013 from the British University in Egypt (BUE) in partnership with Loughborough University in the UK with a dual BSc degree in Civil Engineering. His overall GPA was 4.0 out of 4.0, and his rank was the 1st among his class. In 2011, since he was an undergraduate student, Dr. Daoud introduced the idea of replacing reinforcement steel with chemically treated palm fronds in light-weight concrete elements, which was his graduation project for his BSc degree. He applied this idea in two buildings in upper Egypt. Based on this idea, he was honored in several national and international scientific events. In 2012, Dr. Daoud joined Construction Facilities Laboratory (CFL) at North Carolina State University (NCSU) for a three months' internship. As an intern, he assisted several MSc and PhD students in their experimental work. He helped in: (1) testing FRP materials characteristics; (2) strengthening of composite steel beams with FRP; (3) testing FRP-reinforced concrete sandwich wall panels; and (4) designing of a test set up for pre-stressed concrete dapped end beams. From 2013 to 2014, Dr. Daoud was appointed as a Teaching Assistant in the Civil Engineering department at the BUE. It is worth mentioning that Dr. Daoud has been exposed to many industrial projects in the period between August 2008 to August 2014. During this period, he observed the different construction processes related to industrial, commercial, and residential buildings. In 2014, he assisted in the design and construction of two factories in Cairo. From 2014 to 2016, Dr. Daoud was appointed as a Graduate Research Assistant at the University of Alberta (UofA) in a research group named "Industrial Research Chair in Strategic Construction Modeling and Delivery" (IRC in SCMD). In this period, he carried many research activities related to his MSc degree and other research topics. He has pursued his master's degree at the University of Alberta (UofA) in Construction Engineering and Management. His MSc thesis title

was "A Framework for Evaluating the Impact of Construction Research and Development on University, Construction Industry, and Government". In this research, Dr. Daoud developed a framework for assessing the outcomes and impact of construction R&D on the construction industry and academia. The research outcomes introduce chains of change so that the collaborating party's specific inputs and outputs can be better improved to reach the desired results on the short, medium, and long terms. From 2016 to 2021, Dr. Daoud was working as an Assistant Lecturer in the Civil Engineering department at the BUE. He was enrolled in a PhD program at London South Bank University (LSBU) in January 2017. His PhD thesis title was "Materials Procurement Conceptual Framework for Minimizing Waste in the Egyptian Construction Industry". In this research, he developed a materials procurement conceptual framework for minimising waste in the Egyptian construction industry. This framework provides suggestions for improvement of practices, legislations, culture & behaviour, and public awareness in support of Egypt Vision 2030. Since 2021, Dr. Ahmed Daoud is an Assistant Professor of construction and project management. He has several publications in international conferences and high-rated scientific journals focusing mainly on the development of the construction sector in Egypt.