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Enhancing Construction and Demolition Waste Management Using SWOT and Quantification Systems

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Keywords:
Circular economy; Construction and sustainability; Construction waste management; Solid waste management; SWOT analysis; Waste recycling.

Highlights:

- Construction waste management is essential in Jordan and developing countries.
- Construction waste constitutes a significant amount of the solid municipal waste generated.
- SWOT analysis and activities-based classification improve C&D waste management.
- The amount and category of C&D waste generated depend on the type of construction conducted.

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Abstract: Construction waste management and inventory are lacking in the Jordanian construction sector. With the dramatic population growth, the construction sector plays a significant role in developing the Jordanian economy. This article aims to develop a model to quantify construction and demolition (C&D) waste based on either project hyper-categorization or waste type, and to measure the degree of awareness and readiness of local contractors to benefit from C&D waste. Therefore, it classified projects further into construction and infrastructure projects. The construction project is also classified as new construction, renovation, or rehabilitation. These classifications help improve the management of construction waste. Moreover, a survey was conducted among construction stakeholders to increase awareness and assess their perceptions and readiness to adopt C&D waste management activities in their current or future projects. Finally, a strengths, weaknesses, opportunities, and threats (SWOT) analysis was conducted to heighten major stakeholders' awareness about the challenges of C&D and to develop an effective C&D waste management plan. The results of this research can help both decision-makers and stakeholders in the construction sector properly classify their waste, reduce and manage generated C&D waste, and lower overall costs. Finally, the SWOT analysis identifies hidden opportunities to promote and develop a future C&D waste management at all levels. Meanwhile, revenue from recycling C&D waste is expected to be about US$4.2/m² of construction.

تعزيز إدارة نفايات الإنشاء والهدم باستخدام أنظمة التحليل الرباعي (SWOT) والقياس الكمي

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الخلاصة

تفتقر إدارة ومخزون النفايات الإنشائية في قطاع البناء الأردني إلى التنظيم الفعال. ومع النمو السكاني الكبير، يلعب قطاع البناء دورًا مهمًا في تطوير الاقتصاد الأردني. تهدف هذه المقالة الى تطوير نموذجًا لإدارة وتقدير كميات نفايات البناء والهدم (C&D) بناءً على تصنيف المشروع أو نوع النفايات كما وتقيس درجة وعي واستعداد المقاولين المحليين للاستفادة من نفايات البناء والهدم. لذلك قدمت تصنيف موسع وشامل للمشاريع الانشائية حيث قسمتها إلى مشاريع بناء أو مشاريع بنية تحتية. كما قسمتها ايضا إلى مشاريع جديدة، أو تجديدية، أو تأهيلية. ستساعد هذه التصنيفات في تحسين إدارة النفايات الإنشائية بشكل كبير. علاوة على ذلك,تم إجراء استبانة بين أصحاب المصلحة في قطاع البناء لزيادة الوعي وتقييم تصوراتهم واستعدادهم لتبني أنشطة إدارة نفايات البناء والهدم في مشاريعهم الحالية أو المستقبلية. أخيرًا، تم إجراء تحليل نقاط القوة والضعف والفرص والتهديدات (SWOT) لتعزيز وعي الجهات المعنية الرئيسية بالتحديات المتعلقة بنفايات البناء والهدم، وذلك لوضع خطة فعالة لإدارتها . ستساعد نتائج هذا البحث صانعي القرار وأصحاب المصلحة في قطاع البناء على تصنيف نفاياتهم بشكل صحيح، وتقليل وإدارة النفايات الناتجة عن البناء والهدم، وخفض التكاليف الإجمالية. كما سيظهر تحليل SWOT الفرص الخفيفة لتعزيز وتطوير إدارة نفايات البناء والهدم في المستقبل على جميع المستويات. وفي الوقت نفسه، من المتوقع أن تصل الإيرادات الناتجة عن إعادة تدوير نفايات البناء والهدم إلى حوالي ٤,٢ دولار أمريكي لكل متر مربع من البناء.

الكلمات الدالة: الاقتصاد الدائري، إدارة النفايات الإنشائية، الإنشاء والاستدامة، إدارة النفايات الصلبة، تحليل SWOT, إعادة تدوير النفايات.

1.INTRODUCTION

The construction industry is one of the world's essential economic drivers. It consumes about 40% of global raw materials and about 50% of global energy. Thus, sustainable construction activities significantly enhance environmental protection, reduce costs, and generate a positive reputation for responsible construction practices [1]. Due to rapid population growth and an increase in the demand for housing and infrastructure, thousands of tons of C&D waste are being generated in the country annually [2, 3], usually as a result of the clearing of construction sites, building of new structures or infrastructure, and renovation and maintenance activities for both current structures and infrastructure. Construction projects generate significant quantities of various types of waste as a result of construction activities, such as mobilization of materials, excavations, rehabilitation and renovations, deconstruction, refurbishment, and demolition [4, 5]. Recently, there has been a significant increase in C&D waste generated due to population growth and rapid urbanization, especially in developing countries [6]. Moreover, due to political instability, especially in the Middle East, a massive amount of structural debris has created an urgent demand to properly manage and protect the environment and conserve resources [7]. The amount of C&D waste varies significantly from one country to another due to its various definitions [8]. Often, it is disposed of in landfills. For instance, C&D waste represents about 30% of total solid waste volume at landfills in the US, while it occupies one-third of Canadian landfills and 65% of landfill space in Hong Kong [8]. Most of the generated C&D waste can be reused or recycled [6, 9]. For instance, according to the EU Waste Directive 2008/98/EC, at least 70% of C&D waste should be recycled. In addition, it calls for exploring and using more sustainable materials and implementing the principles of a circular economy in the construction industry [10]. However, the lack of proper monitoring and law enforcement, especially in developing countries, may encourage illegal disposal of C&D waste, with significant environmental impacts. For instance, the scouring of water channels and the banks of water bodies may cause flooding, resources depletion, and the leaching of hazardous materials into water resources (ground or surface water). Moreover, illegal dumping along roadsides may cause accidents, traffic congestion, and flooded pavements [11]. According to Rahim et al., the illegal dumping of C&D waste is due not only to increasing demand, economic growth, rising living standards, population growth, and urbanization, but also to other factors, such as the distance to treatment or disposal facilities, education, renovations, and a lack of law enforcement. The C&D waste generated by the demolition of small houses generally ends up in municipal bins [12], and this issue significantly impacts treatment facilities at receiving landfills and requires specialized transportation facilities [13]. Thus, attention must be given to proper C&D waste management, the use of additives, and the development of regulations to increase and improve the recycling of C&D debris [14]. However, proper quantification and management of C&D waste enable government agencies, industries, and stakeholders to better

understand the current situation, identify major challenges, and propose actions and measures to protect human health and the environment [15, 16]. Finally, it guides the planning and monitoring efforts of the C&D sector in both the short- and long-term [17, 18]. Furthermore, waste generation at construction sites may result from laborers' daily activities, the improper sizing of required materials, poor application of materials, and contractors' lack of interest, thereby leading to damaged or wasted materials. Other factors include poor-quality materials and/or improper handling [19]. Issues concerning sustainable construction and development, priorities, workers' skill levels, and required interventions vary between countries. However, this study aims to develop a quantitative model and improve perceptions of C&D waste and its sustainable management, including the methodology and tools for surveying and developing a C&D waste management plan. It will highlight the major factors hindering efficient C&D management and present the required measures and elements to improve C&D waste management in a construction project. Moreover, there is a lack of data and no official records on C&D waste and its management in Jordan. Therefore, this research aims to bridge this gap and to employ a strengths, weaknesses, opportunities, and threats (SWOT) analysis to demonstrate the importance and evaluate the benefits of initiating an effective C&D waste management plan in the country.

2.METHODOLOGY

Waste minimization and recycling, including waste identification, inventory, classification, and disposal, are not official practices in the construction sector in Jordan, although there are unofficial efforts to collect precious metals generated by C&D activities in the country. A literature review was conducted to summarize the major C&D classifications and procedures worldwide to develop a proper inventory and management model for C&D waste. According to the results of the review, C&D waste can be divided either according to (i) the nature of the waste or (ii) the type of structural activities [17, 20]. Figure 1 shows the research methodology implemented and the results obtained at each step. The research was divided into three phases: a literature review, data collection, and analysis of regulations and focus group discussions, which resulted in the identification of regulatory gaps and stakeholders' inventory and classification. A SWOT analysis was conducted to develop a roadmap for an effective C&D management plan, improve the perception of stakeholders of the current situation, and highlight the essential measures required [21]. Such analyses were conducted to highlight and propose a strategic action for managing C&D waste in Suzhou city [22] and to develop a C&D waste management plan [21, 23]. In this study, a survey questionnaire was developed and distributed to local stakeholders, namely, local contractors, consultants, NGOs, academia, and public officers in charge of regulations and monitoring, to assess their perceptions of C&D waste and its management. Finally, an inventory was implemented on a current project to classify the waste. This inventory aimed to demonstrate the potential economic savings and resource conservation achievable through the recycling of C&D waste.

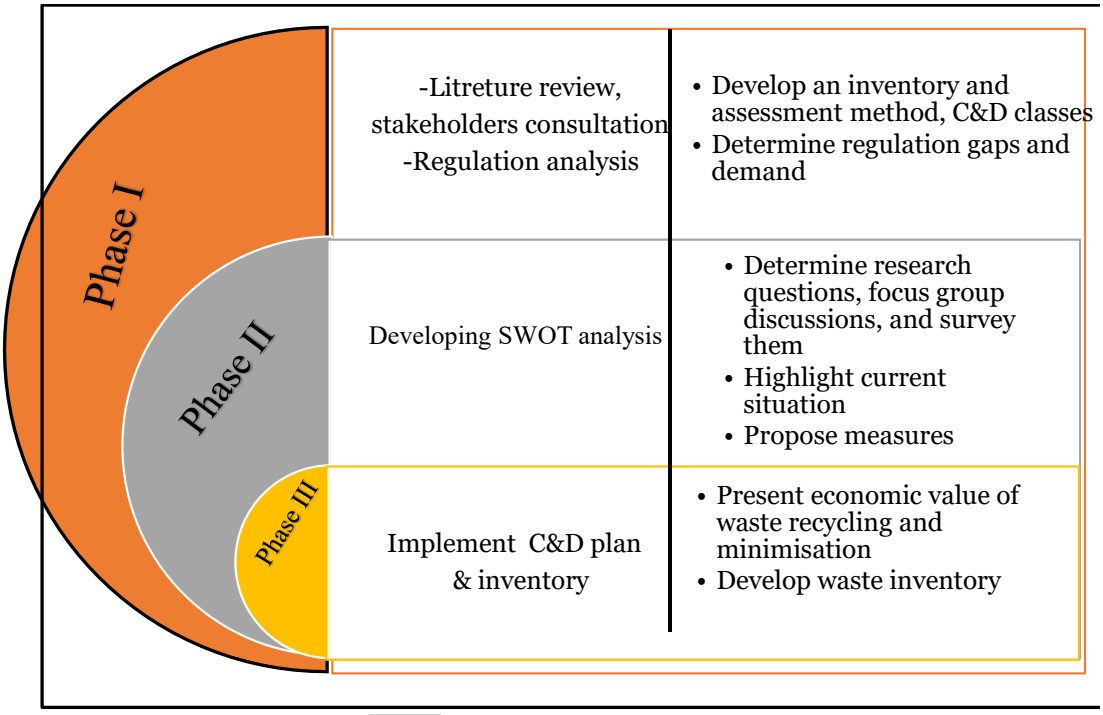

Fig. 1 Research Methodology.

3.RESULTS AND DISCUSSION

In Jordan, C&D waste is classified as special waste, which also includes used tires and oils, electrical and electronic waste, dried sludge, and acid and hybrid car batteries. The current collection rate for municipal solid waste is about 90% in urban areas, while this number decreases to only 70% in rural areas [24]. However, although C&D waste is solid waste, it is partially covered by waste management regulations and policies in Jordan, as shown in Table 1. There are no dedicated regulations or strategies for dealing with C&D waste. In the absence of dedicated regulations for C&D management and official records of waste generated, C&D waste still poses a major threat to human health and the environment in the country. Moreover, C&D is controlled by various implementing and government agencies, further complicating the situation and monitoring procedures. Moreover, there is no legal obligation to submit a manifest or an estimate of waste quantity or to produce a disposal receipt before construction licenses are issued (approved), thereby increasing the risk of illegal dumping.

Table 1 Comparison of C&D Waste- and Domestic Waste-related Legislation in Jordan.

Waste Stream Regulation Name (Type)	Domestic Waste	C&D Waste	Regulating Authority
Solid Waste Framework Law (2020)	Fully	Partially	Ministry of Environment
Environment Protection Law No. 6 (2017) and related regulations	Partially	Partially	Ministry of Environment
Solid Waste Management Bylaw No. 27 (2005)	Fully	Partially	Ministry of Environment
Environmental Information and Monitoring System For Waste Management Bylaw No. 85 (2020)	Partially	Partially	Ministry of Environment
SWM Instructions (2019)	Fully	Partially	Ministry of Environment
Municipality Law No. 41 (2015) and amendments	Partially	Partially	Ministry of Local Administration
Nuisance Prevention and Waste Collection Fees for Greater Amman Municipality Law No. 83 (2009)	Fully	Partially	Greater Amman Municipality
Joint Services Council Regulation No. 75 (2009)	Fully	Partially	Joint services councils
Environment Protection Bylaw No. 21 (2001)	Partially	Partially	ASEZA
The National Strategy to Improve the Municipal Solid Waste Management Sector in the Hashemite Kingdom of Jordan	Fully	Partially	Ministry of Local Administration

The generated C&D waste in the country is usually collected and disposed of either by main contractors or subcontractors. Usually, construction companies manage the collection, transportation, and disposal of C&D waste themselves at landfill sites allocated to each region. For instance, the municipality of Amman has allocated a special site, known as the Al Baida C&D Waste Landfill, for the disposal of C&D waste. However, in this study, C&D waste is classified by nature or construction activity type. The classifications of C&D waste based on the nature of the waste are:

a) *Inert waste:* These results are mainly from excavations and/or building demolitions. It mainly consists of soil, bricks, wood, tiles, and milled asphalt from road rehabilitation. However, it is the largest component of C&D waste and is generally managed and handled by contractors. Moreover, its quantity depends mainly on the depth and area of the dredging sites, the topography of the land, regulations, and specifications. In practice, to estimate the amount of dredged waste (soils and rocks) for a project, various dredging depths are considered. Then, the average depth of these points is used to estimate the waste. However, a significant amount of dredged material may be used to fill and level the uneven areas at the project site, especially for road construction.

b) *Domestic waste:* This is generated as a result of labor activities during the construction project. It is related to the workers living, working, and consuming products at the site. This waste is usually handled by the service provider at the municipality or through a special contract. It is estimated based on the number of workers at the construction site. The generation rate is about 40-60% of the local domestic solid waste generation rate of the city where the construction project is located.

c) *Non-hazardous construction waste:* This mainly includes the packaging used for construction materials, such as glass, plastic, paper, and metals. Furthermore, it includes damaged, wasted, and unused construction materials, such as nails, wires, and steel. However, such waste is usually recyclable and can be sent to recycling facilities or managed with solid domestic waste.

d) *Hazardous construction waste:* This is generated through the use of certain construction materials. However, it should be handled and managed by the waste generator under the supervision of the relevant regulatory authorities and in accordance with the regulations. Figure 2 shows an example of C&D waste that is classified based on its nature. It includes inert waste, domestic waste, packaging of non-hazardous waste, and hazardous waste generated as a result of construction activities.

On the other hand, C&D waste may be classified based on the construction type (activity) into (i) new structures, including both new construction and infrastructure projects; and

(ii) rehabilitation and innovations, which can be further categorized into construction and infrastructure rehabilitation. Finally, demolition activities can be further classified into residential and non-residential buildings. Figure 3 shows the main categories and subcategories of C&D waste classifications based on the construction type. However, such classifications aim to organize and facilitate quantification of generated solid waste at construction sites, as well as to motivate the construction industry to contribute more efficiently to sustainability and the circular economy. Moreover, it facilitates the estimation and quantification of generated waste based on activities. The construction codes and specifications differ between residential and non-residential commercial buildings. Consequently, the quantity and quality of the C&D waste generated either from new or rehabilitation construction activities also vary. For instance, residential buildings have specific sanitary fixtures that differ from those in non-residential, commercial, or public buildings. It has been reported in some literature that new residential buildings generate about 21-30 kg of non-hazardous waste per m^2 of construction; in comparison, this amount may reach about 19 kg/m^2 for non-residential buildings [25, 26].

(a) **(b)** **(c)** **(d)**

Fig. 2 Classification of the C&D Waste Based on Type (a) Inert Waste, (b) Domestic Waste, (c) Non-Hazardous Construction Waste, and (d) Hazardous Construction Waste.

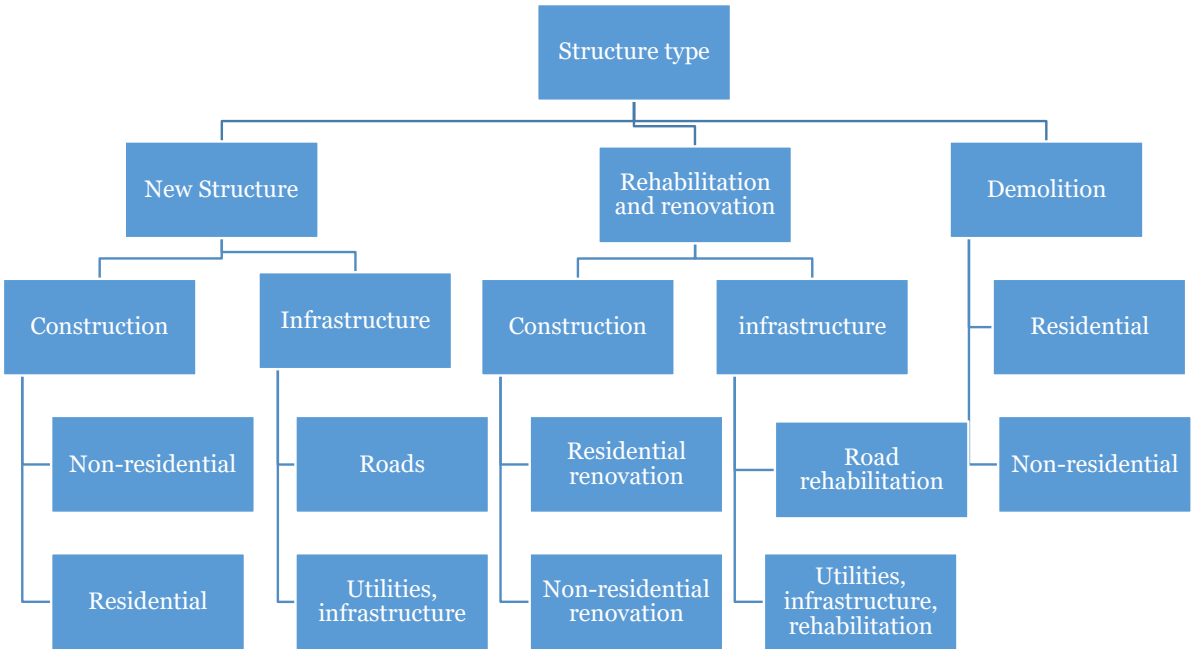

Fig. 3 Structure of the Activities Classification Chart.

However, Figure 4 presents a procedure for properly establishing and implementing a C&D waste management plan. This schematic plan is designed to help contractors properly classify and determine the activities and the expected quantity of C&D waste that may be generated. It is based on the classification of C&D waste according to the type of project. Then, an inventory as well as a model of the system are developed to estimate the amount of C&D waste that could be generated. Next, an implementation plan and procedures are established. However, these measures should satisfy local regulations, considering the available resources, such as financial and human resources, and the logistics. For instance, the availability of space, either within the construction site or storage facilities, should be considered. Furthermore, the human and economic resources required should be determined together with details of their allocation. However, to market the plan, the costs and benefits should be highlighted, and the minimization of the negative impact on human health and the environment through proper management of the generated C&D waste should be emphasized. Finally, the plan should include a detailed time sheet linking the activities with the expected quantity and quality of the waste since each phase of the project generates various types of C&D waste and requires dedicated measures to collect and manage them [27]. Table 2 shows the quantity of C&D waste generated from the demolition and reconstruction of a two-story workshop administration building with a total area of 1347 m^2 in the Jordan Valley. The building comprised an administrative office, restrooms for workers and technicians, and an equipment repair hall. The quantity column describes the estimated materials generation that may be recycled. The prices of the recycled items collected were based on a survey of local market prices at the time of the study. However, as there was no market for the tiles and blocks, they were not considered. Moreover, the total expected income was about JOD$3370 (Jordanian dinars), not including the expected savings on transportation and the disposal of these items, since such costs mainly depend on the location of the disposal site and the size and type of the used dumping trucks. On the other hand, construction rehabilitation generates more waste from ceramics and tiles than new construction; thus, the construction activities may be classified into rehabilitation and new construction to provide an estimate of the quantity of generated waste. Furthermore, infrastructure projects that include road construction, water and wastewater supply and collection networks mainly generate soil and rocks (inert waste) that are usually used for filling and levelling activities at the same sites, thus classifying the construction project, as shown in Fig. 3, facilitates further C&D waste management. Generally, the contractors are responsible for the handling, management, and disposal of the generated waste during the construction period [28]. However, their responsibility and commitment continuously decrease at the latest project life span, thus they tend to leave the debris or illegally dump it at any nearby locations.

Classification based on physical status (solid and liquid) with emphasis on solid that may classify as: 1-domestic like SW 2-Hazardouse SW that carries one of the hazardous characteristics Inert waste it is resulted mainly from the excavation and/or building demolition; it mainly consists of soil, bricks, wood, tile asphalt from road Non-hazardous waste this waste category may include the packaging materials	Developing inventory system: how to develop the inventory system What are the indicators based on building type: A-New construction 1- Residential 2- Non residential (x kg of waste per m² of building area) B-Existent building 1-Maintenance 2-Demolition C-Excavation works	Actions categorized into: 1-Regulatory (develop regulation, law enforcement, criteria for site allocation) 2-Finanacial (budget allocation, fees collection, incentive for recycling) 3-Capacity building (lack of skilled personnel, training, awareness) 4-Recycling program planning 5-Social involvement and cooperation	Impacts can classified into: a-Impacts of waste on human health and environmental elements b-impacts of actions: financial impacts, impacts on job, impacts on energy, impacts on materials (saving)	When and how to implement?
What	**How**	**How**	**What**	**When**

Fig. 4 Planning Construction Waste Management in a Project.

Table 2 Estimated Quantities and Prices of the Recyclable Items in the Building.

#	Item	Unit	Quantity	Price (JOD/unit)	Total (JOD)
1	Interior tiles	m²	340	NA	-
2	Block works	m²	1556	NA	-
3	Windows	Pcs	21	50	1050
4	Doors	Pcs	23	40	860
5	Windows' steel protection*	m²	105	10	1,050
6	Handrails*	M	12	10	120
7	False ceilings	m²	340	NA	-
8	Exterior tiles	m²	277	NA	-
9	Curb stones	M	175	1	175
10	Sanitary fixtures (western and eastern-style water closets)	Pcs	4	10	40
11	Sanitary fixtures (faucets)	Pcs	5	5	25
12	Sanitary fixtures (bathroom and kitchen sinks)	Pcs	5	10	50

*Price based on the scrap market's price per kg for recyclable items.

However, the amount of waste that is generated during road rehabilitation depends on the standards and required pavement milling activities. In addition, pavement scraping activities are still being practiced, making the reuse of scrapped pavement layers unfeasible and causing noise at the dumpsites. Finally, demolition activities for both residential and non-residential buildings generate a larger amount of solid waste. Usually, the valuable removable items, such as windows, doors, kitchen closets, and sanitary fixtures like faucets, are stripped down and collected separately for recycling. There are special markets for used, stripped construction items in all major cities in Jordan. However, the prices of the recycled items are not fixed and mainly depend on the quality of the stripped items and the international price of raw materials. Furthermore, the survey results

highlighted the importance of proper C&D waste management and the need to raise awareness among construction stakeholders in the country to establish a culture of C&D management. Figure 5 shows the significant challenges that may be encountered at construction sites regarding the proper management of generated C&D waste. The significant challenges are the limited space at the site, the absence of regulations, and the demand for qualified manpower and logistics to manage the waste. However, the limited quality of the recycled products and the absence of industrial standards also hinder the proper management of C&D waste. Finally, to strengthen the C&D management process, a SWOT analysis was performed. Pairing the strength with the opportunities improves the competitiveness and highlights the required measures to improve C&D management [23]. On the other hand, determining the weaknesses and threats motivates innovation to transform them into business opportunities and helps the decision-makers to better understand the challenges and prepare for them. The results of the SWOT analysis for C&D waste management in Jordan are shown in Table 3. It presents the significant elements of the SWOT analysis. For instance, the percentage of highly educated people in Jordan may be regarded as a significant opportunity for it to be developed into an innovation hub in the region, especially with the high regional demand for reconstruction activities due to political instability in the region. Furthermore, the availability of infrastructure, the government's capacity to raise awareness and enforce regulations, and the existence of basic legal frameworks all drive the need to reduce and reuse the C&D waste while also fostering a new market for recycled C&D materials. Meanwhile, as indicated in this research, the absence of obligations and dedicated regulations increases the risk of illegal dumping and reduces the reuse potential of C&D waste. Moreover, as the generation of new jobs for the young population is a very important priority of the government, the recycling of C&D waste and the development of innovative products from it can be a source of materials and jobs. Finally, increasing awareness among contractors and construction workers could improve the management of C&D waste and reduce its impact. Additionally, while Jordan has an existing market for recyclable materials collected from domestic solid waste, there remains a significant need to develop a similar market for recycled materials from construction activities, particularly concrete and bricks.

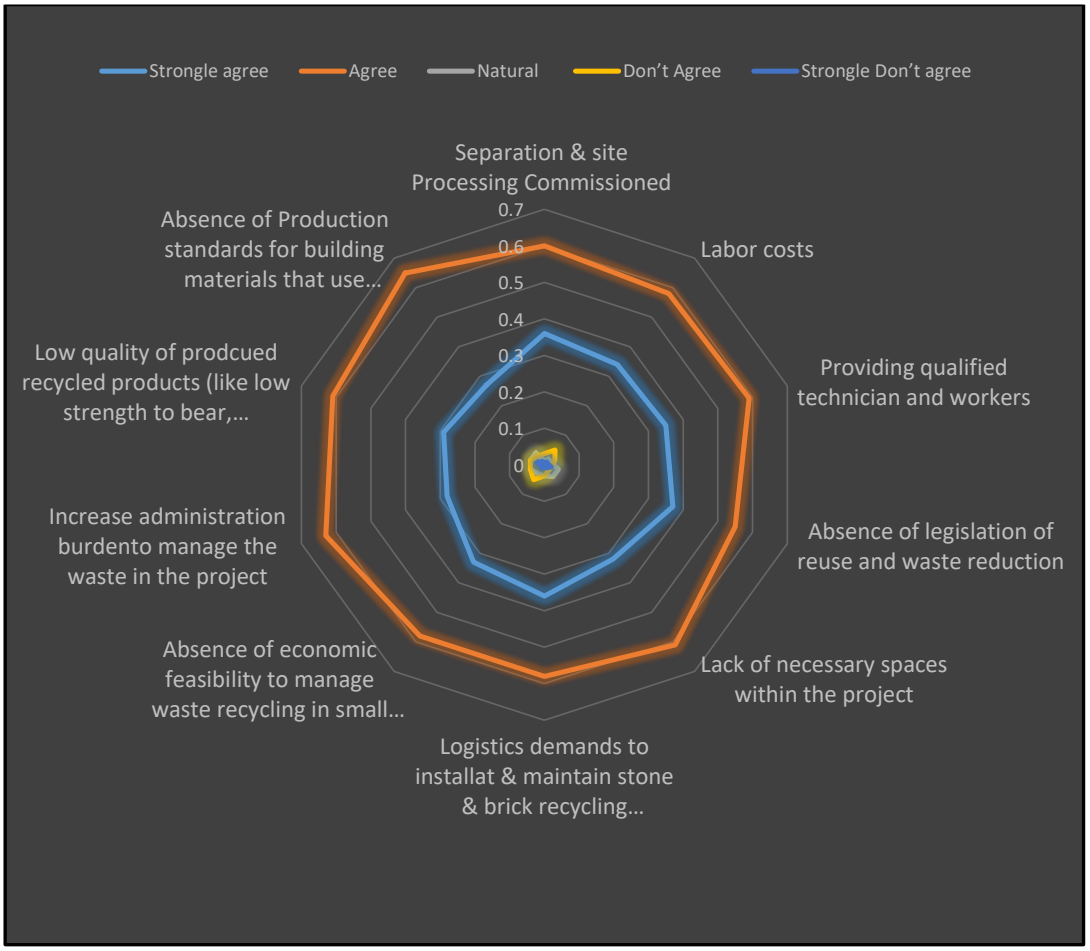

Fig. 5 The Major Challenges that C&D Waste Management Faces in the Jordanian Market.

Table 3 SWOT Analysis of C&D in Jordan.

Strength		**Weakness**	
Description	**Impact**	**Description**	**Significance**
Infrastructure availability, such as dedicated landfills, transfer stations, and involvement of the private sector in the construction sector.	Important	Lack of clear and comprehensive legislation that encourages implementation and investment.	Very significant
Knowledgeable staff that can manage and innovate C&D.	Very important	Lack of an integrated SWM system and marketing of recycled materials.	Significant
Presence of special regulations and policies for dealing with solid waste.	Very important	Lack of specialized management units for C&D waste.	Significant
Capacity of governmental agencies to conduct awareness and monitoring campaigns.	Important	Lack of waste segregation measures and incentives, as well as regulations.	Very significant
Opportunities		**Threats**	
Description	**Impact**	**Description**	**Significance**
Presence of many civil societies and NGOs that are interested in volunteering and youth work.	Important	Lack of marketing of recycled products/materials.	Limited Significance
Economically safe and generates new markets and job positions.	Very Important	Lack of necessary legislation and testing, such as reusing concrete, blocks, and construction materials.	Significant
Receiving support from the government and international donors.	Important	Absence of private sector involvement in C&D recycling	Significant
		Contractors and traders' unwillingness to cooperate.	Very Significant

4.CONCLUSION

The construction industry is one of the most challenging and complex sectors throughout the world. Thus, its improvement and update require the participation of various stakeholders to overcome the conservatism associated with traditional practices, innovations, and the implementation of new construction technology based on materials, recycled materials, as well as C&D waste management principles and classifications to improve the construction sector, minimize costs and waste generation, and save time and consumption of materials. For instance, currently, the expected price for marketable recyclable materials from a 1347-m² building is about JOD 3,370 or JOD 3/m². Moreover, with the growing awareness of issues related to human health and the environment, the demand to minimize and properly manage C&D waste has become a priority for sustainable development programs at all levels. This research presented an inventory model for the estimation of construction waste in Jordan and developing countries. In addition, a management method has been proposed for more sustainable construction activities to reduce the impact of C&D waste on human health and the environment. Furthermore, there is a need to formulate dedicated regulations and policies to make it mandatory for construction companies to register the quantity of C&D waste generated, as well as to recycle and minimize its amount in Jordan. Furthermore, innovative construction technologies and procedures should be introduced to absorb part of the generated waste under the monitoring of relevant authorities to guarantee its quality and sustainability.

5.FUTURE WORK

The adoption of novel legislation and standards is critical to incentivize the implementation of advanced construction technologies, including robotics, IoT, and BIM. These innovations can optimize efficiency, reduce C&D waste, and promote sustainability. Furthermore, the development of a structured recycled C&D waste market, governed by stringent oversight, is essential. Research should focus on evaluating waste streams under these technologies and testing predictive models such as the Pelican Optimization Algorithm. For instance, a WiFi-based robotic camera utilizing this algorithm could enhance object recognition, improving recycling accuracy and worksite safety [29, 30].

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