Smart Tourism (2023) Section Collection: Climate Challenges and Urban Tourism
doi:10.54517/st.v4i1.2195

ORIGINAL RESEARCH ARTICLE

Significant guidance for the effective management of construction waste in North Africa and the Middle East countries

Nivin Ghaboun

Department of Civil Engineering, Civil and Environmental Engineering Faculty, Near East University, 99138 Nicosia, Cyprus; nivinahmedhassan.ghaboun@neu.edu.tr

ABSTRACT

Developing countries in North Africa and the Middle East have a low rate of waste recovery (15%) compared with developed countries (90%). The study aims to investigate the main reasons behind this lag. A literature review was conducted to design a questionnaire for scrutinizing waste management plans applied during design, waste mitigation techniques during construction and government support of this sector. The results indicated that there is lack of updated regulations, 74% of stakeholders still sending waste for landfill disposal, whereas other waste hierarchy processes (recycling and reduction) accounts only 7% and weak support of government. In conclusion, the current situation of waste management is not effective, so quick actions from both government and stakeholders were proposed to improve waste management practices.

Keywords: waste management; retrieval rate; waste hierarchy; recycling and reduction; sustainability; taxes and penalties

1. Introduction

Although, construction industry is a significant sector for the economic growth of both developed and developing countries, material waste resulting from these activities threatens both human beings and the environment. These threats include but not limited to resource depletion, greenhouse gas emissions, energy consumption, disruption of ecosystem and soil and groundwater contamination. Construction material waste represents from 30% to 50% of the total solid municipal waste generated worldwide; in the United States, 30% of total waste is related to construction projects, while construction waste in the United Kingdom accounts 59% of the total solid waste generated, 44% in Australia and 70% in Spain[1,2]. Approximately 90% of construction waste is inert, such as soil, earth, bricks, rubble and concrete, these wastes are suitable for site formation and land replacement, whereas non-inert material waste including timber, metal, packaging and other organic materials ends up in landfills. The generation rate of construction waste depends mainly on the construction method, design complexity, labor skills, site layout, supervision, population, urbanization, gross domestic product, regulations and integration between municipalities and governmental authorities which affect waste generation to a great extent[3]. Material waste can be defined as any material or product resulting from construction, renovation, refurbishment and demolition that has no value and can't be used in other applications due to damage, deterioration, excess and inconsistency with specifications[4]. Construction waste can be minimized through different strategies such as zero waste approach, design for deconstruction, waste sorting,

ARTICLE INFO
Received: 25 April 2023 | Accepted: 30 May 2023 | Available online: 25 June 2023

CITATION
Ghaboun N. Significant guidance for the effective management of construction waste in North Africa and the Middle East countries. *Smart Tourism* 2023; 4(1): 2195. doi: 10.54517/st.v4i1.2195

use of prefabricated units, circular construction, charging schemes, new construction technologies, applying Building Information Modeling (BIM) and 5R's regulations. The use of Prefab construction methods instead of conventional methods can diminish the generation of material waste from 40% to 100% in addition, this helps improve the standardization of design, and increase efficiency[5]. Many studies have elucidated the importance of reducing, reusing and recycling waste to protect the environment and humans[6–8]. Communication and collaboration between different parties involved in the construction industry can reduce waste generation and the operational costs of construction projects[9]. Waste management is a long process since it includes quantification, sorting, monitoring, storage, collection, transport to plants, processing and final disposal of non-recyclable waste at landfills. Developed countries have succeeded in formulating laws and policies, investing in sorting and recycling facilities leads to high rates of waste diversion into reusable products. The Waste Framework Directive (WFD) applied by the European Union's states requires that 70% of construction and demolition waste should be retrieved by 2020. The United Kingdom, Germany, Nordic countries and Ireland succeeded in exceeding this target with a (90%) recovery rate, while Poland, Spain and Greece still have low retrieving rates of waste (20%)[10]. Alternatively, construction industry in North Africa and Middle East countries is fast growing due to population growth, urbanization and increasing standards of living, this generates a huge amount of waste. The quantity of waste varies from one country to another, in the Gulf Cooperation Countries, which ranked as the top waste generators in the world where 55% of generated waste is related to construction and demolition activities[11]. In the United Arab Emirates construction waste represents 75% of total solid waste[12], whereas 32% of solid waste in Bahrain is from construction activities and 40% of total waste in Egypt and Libya is related to construction industry[13]. Although, the awareness of stakeholders has been increased during the last years about waste impacts, still the recovery rate of waste is ineffectual compared with developed countries.

2. Literature review

A detailed review of the main legislation, environmental acts and waste management practices applied in some developed countries and countries in North Africa and Middle East will be mentioned. Scopus journals, Web of Science (WOS), international journals and conferences were used to collect related articles using the following keywords: construction waste management in developed countries, construction waste laws and acts in developed countries, construction circularity and sustainability in developed countries, construction waste management in Middle East and North Africa, construction circularity and sustainability in North Africa and the Middle East, construction waste regulations in North Africa and the Middle East. A total of 180 articles were collected from different countries, the screening filters used for the final selection of related articles include:

1) Only articles written in English and Arabic will be considered.
2) Published date: from 2010 to 2022 (discarded articles = 30, $N = 150$).
3) Country restrictions: specific developed countries were selected in waste management field which include (USA, UK, Canada, Germany and Australia) due to their success in retrieving waste and some countries from North Africa and the Middle East, which are active and contribute effectively in academic research of waste management (Egypt, Libya, Jordan, United Arab Emirates, Saudi Arabia and Lebanon) (discarded = 50, $N = 100$).
4) Exclusion: articles related to municipal solid waste management and renovation waste (discarded = 16, $N = 84$).
5) Detailed assessment of the remaining articles based on waste legislation and management strategies (discarded = 16, $N = 68$).

A total of 68 articles were chosen for the final review to investigate the current status of waste management in some developed and developing countries in North Africa and the Middle East.

2.1. Status of waste management in developed countries

Waste legislations, norms and management techniques used in the United States, Canada, European Union, Germany, United Kingdom and Australia were studied to find out the current status of this sector.

2.1.1. United States

One of the leading countries in construction waste management is the United States, with a high waste recovery rate of 90%. The current practices of construction waste management in the USA considering safety, economic and environmental aspects was investigated to illustrate the main pitfalls of these practices[14]. US has strong policies and regulations regarding waste minimization, compared with China which still lack effective policies and practices regarding waste management[15]. Quantifying construction waste is an essential step toward developing plans for reusing, recycling and final disposal of nonrecyclable waste. A quantification method called CDD (Construction and Demolition Debris) of seven types of waste (steel, wood, bricks and clay tiles, plaster, asphalt shingles, concrete and asphalt concrete) was developed to assess the environmental life cycle impacts and benefits of sustainable management of these wastes[16]. Construction waste of institutional buildings using hauling tickets was quantified to compare the actual and estimated quantities of waste and determine the actual quantity that can be recycled to new products[17]. It was found that governmental regulations varied from state to another, some states take strong actions to protect human and environment while other states provide minimum surveillance to these wastes[18].

2.1.2. Canada

Even though construction waste in Canada represents 25% of total municipal solid waste, the Canadian authorities succeeded in retrieving most of this waste. The ministry of environment in Ontario developed the first regulation (102/94) for all types of wastes (construction, renovation and demolition). The current methods applied for reusing and recycling of construction and demolition waste in Canada to increase the rate of waste recovery were studied, in addition to the main policies and regulations applied to minimize waste sent to landfills[19]. Another study evaluated current regulations, acts and legislation of construction, renovation and demolition waste management in Ontario to determine the main challenges toward reliable sustainability of construction projects[20]. A framework to increase the use of the 3R s regulations (reduce, reuse and recycle) to minimize waste disposal throughout the project life cycle was developed[21]. The contractual clauses that generate material waste in commercial projects was analyzed and found that causes related to quality, labors' skills and field control are the main sources of waste and provided suggestions to improve waste management practices[22].

2.1.3. United Kingdom

Huge amount of construction and demolition waste had been generated in United Kingdom due to urbanization and industrialization. The recovery rate from non-hazardous construction and demolition waste in 2020 was 93.2%, which put the UK ahead of all European Union states along with Germany. The governmental legislation regarding recycling and reusing waste can improve the circularity of the construction industry, in addition logistics problems was selected as the main barrier to recycling construction waste[23]. Construction waste can be minimized at the design stage through standardization, modern construction methods, employing BIM for design coordination and end of life deconstruction of the building[24]. In addition, construction waste can be minimized during the procurement process through suppliers' commitment, low waste purchasing plan, just in time delivery of materials and reliable estimation of materials' quantities, as well as the promotion of 3R's regulations and minimum packaging[25]. A method for cost estimation of material

waste before the start of the construction phase was presented to provide decision-makers with a reliable tool to select the best disposal method and diminish waste impacts on the total cost of the project[26]. The current regulations consider waste minimization during the construction phase, while it's critical to consider the waste reduction during the design stage through designing out waste[27].

2.1.4. European Union

The high rate of waste recovery in European States (89%) indicates strong application of policies and good integration between public and private sector. The sustainability of construction and demolition waste management using materials stock analysis, cost benefit analysis and multicriteria analysis was evaluated to find the optimal scenario of waste management to support circular economy concept[28]. A comparison of waste management techniques between member states of European Unions based on generation and recovery rates, policies and practices were made, the study confirmed that the lack of waste data, low quality of recovered waste and poor logistics are the main barriers behind effective waste management[29]. Another study of construction and demolition waste data for each member state in European countries, which include quantity of waste generated, recovery rate, main drivers and barriers for sustainable waste management was presented[30]. There is a difference between European countries in terms of waste treatment methods and the markets developed for recovered waste[31]. The current status of construction waste in Russia was studied and mentioned that the effective management of waste is the result of integration among local, regional and federal authorities with construction organizations[32]. Waste management practices in Turkey were studied through multiple case studies and found that design changes, storage problems and irregular cutting of materials are the main problems of waste generation, the study revealed that there is no specific waste plan applied on site and steel waste is the most important waste retrieved through recycling and reusing[33].

2.1.5. Germany

Waste management hierarchy of prevention, reduction, reusing and recycling were applied successfully and resulted in high recovery rate of 90%. Construction and demolition waste management strategies were compared in Australia and Germany using SWOT analysis to provide recommendations for more effective waste minimization[34]. The main techniques used for waste management according to the waste type to estimate the amount of waste[35]. Waste management strategies were investigated to identify the main barriers of waste collection and recycling, the study indicated that infrastructure facilities for incineration (energy recovery), mechanical and biological treatment of waste are sufficient to handle generated waste, but the main problems reside in the varying prices of recycled waste, mis-integration between public and private sector and financial problems to support waste treatment sector[36].

2.1.6. Australia

The average waste recovery rate was estimated to be 78%, whereas masonry materials have the highest recovery rate of 81% and metals (76%). The management of waste is different from one territory to another based on provisional legislation and policies applied. The first approach to waste management was undertaken in 1992 by the Council of Australian Governments under the National Strategy for Ecologically Sustainable Development and later on many acts were established to reduce waste and increase construction sustainability. Critical factors for effective management of waste, which include proper design and documentation, innovative technologies, applying waste minimization plans, team building and supervision[37]. The barriers of waste minimization were studied which include lack of incentives, contradicting project priorities, cost and time of waste handling[38]. Positive attitudes of construction practitioners, strong motivation, robust legislation and promoting the use of recovered materials can enhance the effectiveness of waste retrieval[39]. Regional transportation logistics were presented to develop effective waste management plans[40]. Effective federal

regulations should be applied to enforce the application of waste management plans early during the preliminary phase of big construction projects[41]. Extended producer responsibility policy considering the barriers affecting this policy were investigated, the main barriers identified are the diversity of stakeholders, regulations, identifying producers' responsibility, materials' life cycle, safety, design modification, time and cost of applying EPR policy[42]. Appendix A illustrates the main regulations and norms regarding waste management in some developed countries.

2.2. Status of waste management in North Africa and the Middle East countries

The status of waste laws and management techniques used in some North Africa and Middle East countries will be demonstrated in this section.

2.2.1. Egypt

The waste recovery rate in Egypt is very low (10%–15%), the reasons behind that are the lack of waste laws, lack of awareness of waste impacts, non-supportive governmental actions and shortage of waste processing and recycling facilities. The Waste Management Regulatory Authority (WMRA) was established in 2015 through the cabinet of ministers to monitor all waste management processes by preparing strategies and action plans to diminish waste generation and attracting investment for this sector. Adding up the Housing, Building National Research Center (HBRC) of Egypt had developed engineering codes for green buildings and sustainability to increase the recycling rate of waste to 40% by 2030. The causes of waste during the procurement stage were examined to include lack of planning, late delivery of materials to the site, purchasing of non-standard and low-quality materials and mentioned that effective procurement should include planning, conducting, administering and closing to reduce the total cost of the project[43]. The management of waste depends mainly on the experience of the contractor and site conditions, this makes the management process a complex task due to the uniqueness of each project[44]. Designing out waste strategy to increase construction sustainability by considering the economic, environmental and social impacts of waste was applied[45]. Poor planning and scheduling, low experience of contractors, poor storage and handling of materials were specified to cause waste formation[46]. Effective management of waste entails establishing policies, increasing processing facilities, integration between public and private sector and applying advanced construction techniques[47].

2.2.2. United Arab Emirates

UAE is one of the biggest generators of waste around the world, where 75% of solid municipal waste is from construction activities, this forces the government of the UAE to take serious actions to increase the public awareness of the environmental impacts of waste and apply innovative practices to minimize waste generation. The government in 2008 established a center for waste management to handle all waste matter in Abu Dhabi Emirate. In 2010, UAE established its own rating system (Estidama) that requires at least 30% of waste to be diverted from landfill disposal using 3R's regulation. In 2011, Dubai created Green Building Regulations and it became mandatory for all construction projects since 2014. Poor design, lack of awareness, reworks and poor procurement were identified as the main reasons behind waste in construction activities, this waste can be minimized through advanced construction methods, logistics management, labor training, contractor's motivation and developing policies for waste mitigation[48]. Sustainable regulations of construction waste in UAE with the United nations' plan for 2030 were compared through case-studies and found there is still a lack of awareness among small contractors regarding the financial benefits of waste recycling[49]. The main pillars of waste management were examined to include legislative rules, environmental actions and economic incentives, while the barriers include resistance to the use of new construction methods, time limitations and high cost of investment in recycling and reusing[50]. The legislative rules in UAE require submitting waste management plan before construction activity and 30% diversion of waste into new

products[51], also the study revealed that most companies are looking to obtain Estidama certificate not to apply sustainability rules. Training of employees, good storage conditions and transportation of materials, integration between contractors and sub-contractors and use of prefabricated units can increase productivity and efficiency of construction industry[52].

2.2.3. Jordan

Waste recycling rate is approximately from 5% to 10% due to lack of waste management plans and weak regulations. Despite that the government has realized the importance of increasing the awareness of construction stakeholders about the negative impacts of waste, still the legislative enforcement by authorities and communities feeble. Recently, the Ministry of Environment has approved the Green Growth National Action Plan of 2021–2025 to achieve sustainability in construction projects. Poor contract documents, incorrect quantity estimation, bad transportation and storage are the main sources of waste generation at the site[53]. Waste causes during design stage were checked to include lack of architect's experience in construction methods, unfamiliarity with process sequence, lack of designer's knowledge about material availability and intervention of the owner during construction[54]. The aspects of sustainability were summarized to include regulations, guidelines and technologies, regulations can be achieved by promoting green building concepts and investment in recycling, while guidelines include establishing technical specifications for designers and architects to consider waste management early at the design stage finally the use of BIM and 3D printing technologies can help reduce waste generation dramatically[55]. Waste recovery problem was discussed and indicated that the involvement of stakeholders at the design stage, regulation enforcement, motivations and incentives can help retrieve most of the waste generated[56].

2.2.4. Libya

The majority of research related to construction waste management proved that there is a lack of awareness between engineers, contractors and sub-contractors, lack of legislation and impotent role of municipal authorities in supervising and controlling waste generation, this was confirmed by the low rate of recycling of 6%. The Environment General Authority (EGA) established in 1982, is the main entity responsible of natural resource conservation, developing policies and environment protection. Recently the waste management topic attracts the attention of many researchers to increase the economic, social and environmental benefits. Lack of penalties due to illegal dumping and absence of waste processing and recycling facilities were the main reasons for disposing and burning waste in open sites[57]. The integration between government and private sector in addition to establishing waste handling authorities is the best strategy for waste management, including the enforcement of policies and regulations. Successful procurement of construction materials depends mainly on the experience of the contractor, which requires reliable communication skills with all stakeholders, quick decision making, good awareness of the building process and use of advanced technologies such as Building Information Modeling (BIM) to reduce waste creation[58].

2.2.5. Saudi Arabia

Due to high population growth, industrialization and fast urbanization, waste generation has been increased seriously in the Kingdom of Saudi Arabia, adding up most landfills are unsanitary and are expected to reach their full capacity soon this force the government and authorities to develop action plans for waste control, enhance the awareness of public and stakeholders regarding waste impacts and formulating laws and acts suitable to local conditions of the country instead of depending on foreign regulations. The recycling rate of construction waste is 13.6% while 86.4% is sent to landfills. A study searched the economic benefits of waste recovery through waste hagiarchy to minimize resource depletion and generate revenues[59]. The quantity of waste from construction projects was estimated and transformed into new products to apply the circular

economy concept[60]. It was found that insufficient motivation to minimize construction waste, absence of waste policies, shortage of integration between public and private sector and lack of processing and recycling facilities decreases the sustainability of the construction industry[61].

2.2.6. Lebanon

Political problems, weak support from the government and insufficient waste legislation create serious pollution problems in certain areas of Lebanon. The low-recycling rate of (8%) encourages researchers to investigate the current waste management strategies applied by contractors for more development. Sustainability practices in construction projects were through a case study and indicated that high cost of green design and recycling plus lack of interest from construction professionals are the main barriers to sustainability implementation[62]. The enforcement of governmental regulations and incentives such as tax breaks and increasing landfill fees can encourage contractors to consider waste reusing and recycling[63]. The main barriers of waste recycling were studied to declare that the advanced technologies in addition to the integration between governmental authorities and stakeholders can promote waste recycling practices[64]. A study showed that sustainability issues still infancy due to weak support from the government and lack of legislative rules[65]. The successful management of waste depends on government supervision, contractor's awareness and motivation[66]. Appendix B summarizes the main regulations and norms in some countries of North Africa and the Middle East.

2.3. Study objective

This section is divided into two sub-sections as shown below:

2.3.1. Research gap

It's very obvious that the recovery rate in North Africa and the Middle East (NAME) countries is very low compared with developed countries. The researchers in (NAME) countries have started conducting studies to improve waste minimization practices, however still there is no tangible development in this sector. So, the focus of the study is to attract the attention of construction stakeholders and governmental authorities in North Africa and the Middle East countries towards the economic, social and environmental benefits of waste management.

2.3.2. Study aim

The study aims to find the impediments affecting waste mitigation and set the guidelines for efficient recovery of waste. The research questions have been set as follows:

- What are the plans applied to reduce waste generation during design?
- What are the techniques used at site to handle generated waste and minimize it?
- What are the main restrictions facing construction parties to take over waste control?
- How can governments and authorities boost waste management?

3. Materials and methods

The questionnaire was designed using an online platform called (survey planet) to facilitate the participation and selection of answers by the respondents in addition considerable attention was paid to make the survey as short as possible to save participant's time. To increase the number of responses to the survey, it was translated into two languages (English and Arabic). The questionnaire was distributed using two methods.

3.1. LinkedIn website

A keyword of project managers, site engineers, architects, contractor, sub-contractors and MEP engineers in North Africa and Middle East countries were searched using the LinkedIn search bar to find people working in the construction field, the search results were evaluated based on their profiles, education, experience in the construction field and interest in waste management, based on these criteria a list of qualified engineers who has experience between 5 and 25 years has been prepared to send them the survey link with a small introduction about the research using the messaging option in LinkedIn.

3.2. Social media websites and services

The second method for distributing the questionnaire is by sharing survey links on Engineering Forums, Facebook, Instagram, Twitter and WhatsApp.

The total questions of the survey are 18 questions divided into two parts. Part (A) collects general information about the respondents and their organizations, including type of the organization, job title, educational background, years of experience in the construction field. Part (B) illustrates current waste plans, techniques used for construction waste mitigation, impediments facing stakeholders, and government role in waste management.

4. Results and data analysis

The questionnaire was distributed to 150 professionals in construction industry, only 130 respondents participated in the questionnaire from different countries including Egypt, Libya, Jordan, United Arab Emirates, Palestine, Saudi Arabia, Tunisia, Morocco, Kuwait, Qatar, Lebanon, and Iraq, with a response rate of 87%. The data were analyzed using SPSS software to obtain descriptive statistics about waste management. **Figure 1** illustrates the distribution of the participants from targeted countries in North Africa and the Middle East.

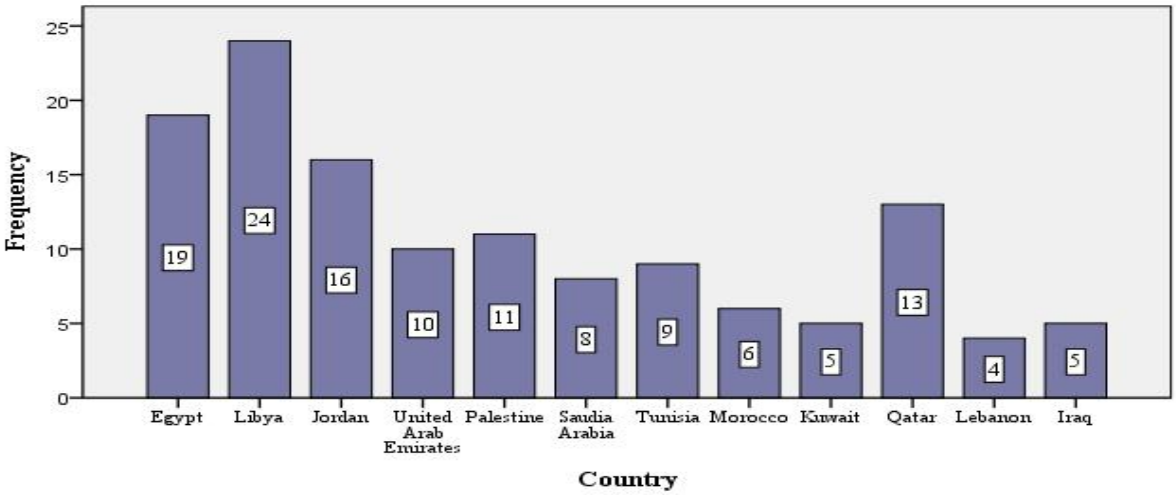

Figure 1. Frequencies of participants' countries.

4.1. Respondents' general information

Different disciplines participated in the questionnaire as follows: project managers (41 participants), design engineers (36 participants), architects (33 participants), site engineers (17 participants), while the lowest responses were from MEP and environmental engineers (5 and 1 participants respectively) as shown in the figure below.

The respondents work for different types of organizations: Contractors, Management Consultancy, Architectural and Design, Sub-Contractors, MEP and waste companies, the frequencies of participants' organization types are shown in **Figure 2**. The majority of the participants (79 respondents) work in Residential and Commercial building projects, while (21 respondents) work in infrastructure projects, (15 respondents) work in road projects, (8 respondents) work in industrial projects, (4 respondents) work in bridges and (3 respondents) work in airport projects, as shown in **Figure 2**. A wide variety in work experience among the participants were observed, where (33 participants) have experience between 1 and 5 years, (30 participants) have experience between 6 and 10 years, (22 participants) have experience between 11 and 15 years and (20 participants) have experience above 25 years. It was found that 46 respondents work for companies with an experience from 1 to 5 years in construction field, while 27 respondents work for companies with an experience from 6 to 10 years, 23 respondents work for companies with 11–15 years and 16 respondents only work for companies with more than 25 years.

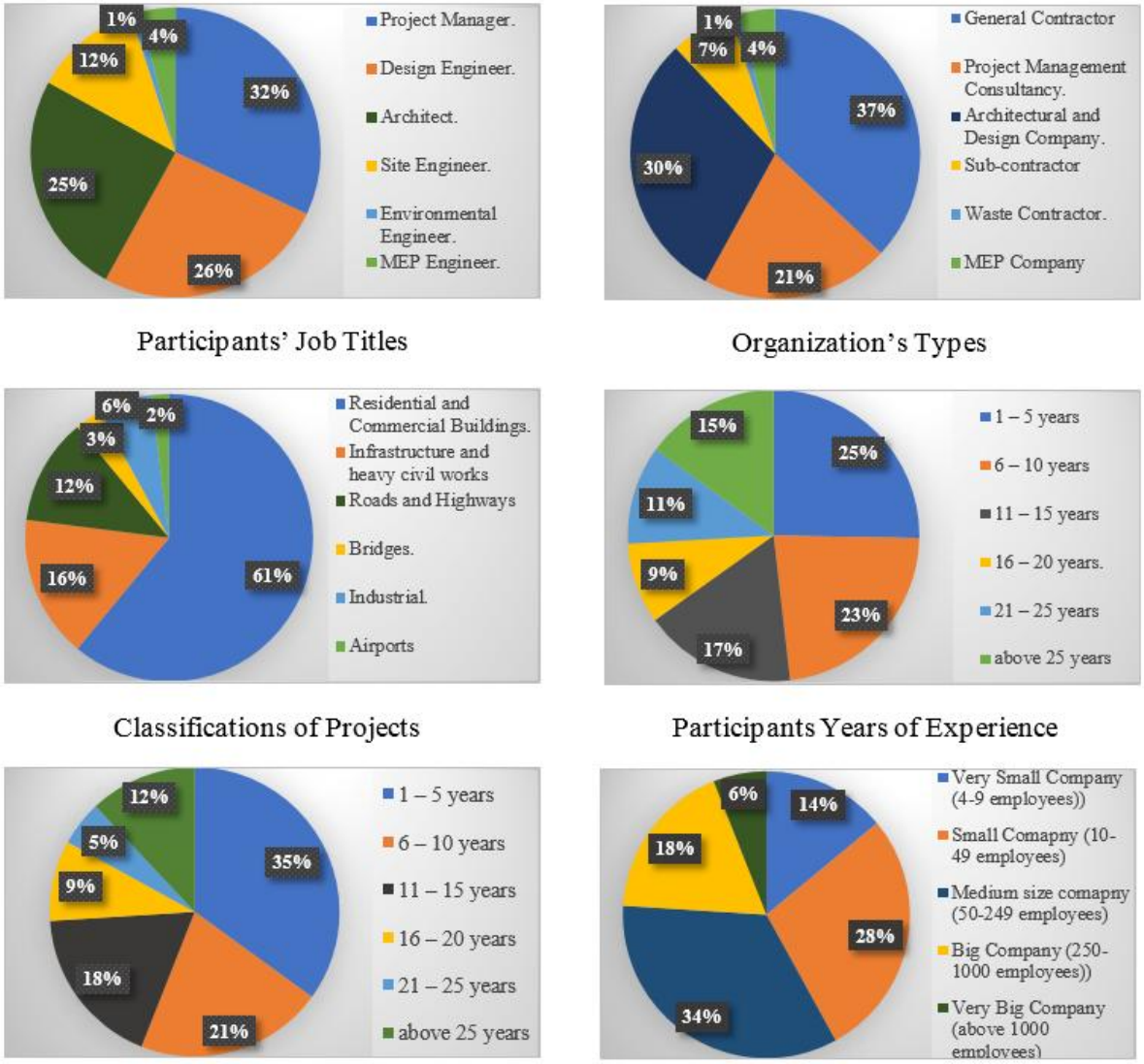

Figure 2. Respondents general information.

The classification of participants based on their company size indicated that 34% of them are working in medium sized company while 28% of the participants are working in small company and 18% are working in big size companies.

4.2. Waste management awareness and practices

The awareness of the participants to the importance of environment protection compared with other critical factors including safety, quality, time and cost was investigated using a Likert scale question. The Relative Importance Index (RII) for each factor was calculated and found that cost has the highest importance index of (0.715), the second important factor is time (0.674), while quality is the third important factor (0.566), safety is the fourth (0.532) and lastly is the environment protection (0.52). The participants agreed that (sand/earth) waste resulting from site clearing activity is the most common waste with a percentage of (25%), while (wood) from formwork activity is the second material wasted (22%), (concrete) from concrete casting and (bricks) from (brick works) were in the third position with a percentage of (16%), then (steel scraps) represents (11%) whereas ceramic tiles are the less wasted material (9%). **Figure 3** illustrates the percentages of waste generation activities and waste handling processes.

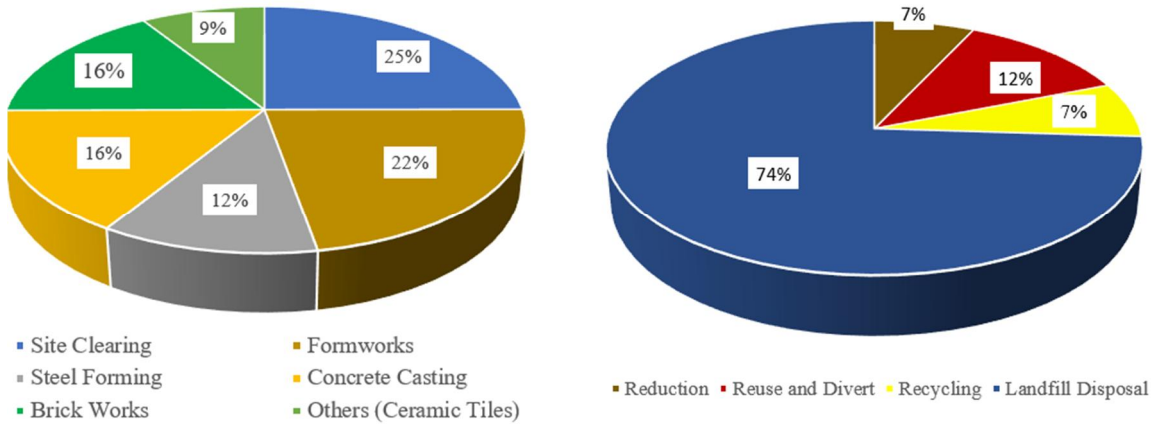

Figure 3. Frequencies of waste generation activities and handling processes.

The most common method of waste handling selected by the majority of participants was landfill disposal (74%), whereas the reuse of generated waste in other projects (12%) was selected as the second preferred technique, finally recycling and reduction (7%) were the last preferred options for waste control. Most participants indicated that local environmental protection acts and green design concepts are the main waste management plans selected during design to control waste generation with 25% for each, while 19% of the participants used site waste management plans (SWMP) with design documents as a mandatory requirement as shown in **Figure 4**.

Additionally, 17% of the participants selected new design concepts such as design for deconstruction and disassembly as a way to reduce waste during design and only 13% selected ISO-14001waste standards to reduce waste impacts on human and environment. Lack of awareness of waste impacts on the environment, especially from small and medium sized contractors was selected by (25%) of the participants as the main drawback of not applying any waste management plan, the second factor to be considered is the lack of government enforcement of waste laws and acts (23%), other factors include lack of development in recycling and reusing markets, low quality of recycled waste and insufficient promotion for using wasted materials. Waste sorting and segregation using containers was selected by 35% of participants as the most popular mechanism of waste control at the site, wheares waste contractors were selected as the second option for waste control 24%, transporting waste to dumpsite and processing facilities was selected by 23% of respondents while the least preferred techniques for waste sorting were belt conveyer and magnet technology with a rate of (9%).

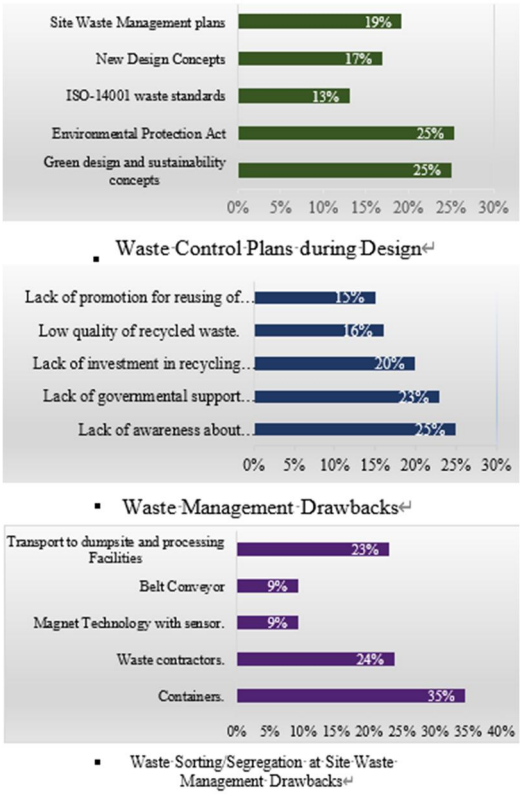

Figure 4. Waste management plans and drawbacks.

Figure 5 illustrates that shortage of waste recycling standards and facilities is the first obstacle facing contractors in managing waste with a percentage of 26%, secondly limited space of site prevents contractors from conducting waste sorting effectively was selected by 25% of the participants. High transportation cost of waste is the third problem that hinders contractors from considering waste management, lack of incentives and support from local authorities are another two factors that reduce the interest of contractors in waste management (16% and 11%).

Taxes and penalties imposed by the government was selected by 35% of the participants as the main rule to make contractors consider waste management in their work, alternatively rewards and bonuses selected by 25% of the participants is another option to encourage contractors for waste control, increasing knowledge and awareness of small and medium sized contractors is another important factor to be considered (15%).

Applying new technologies and integration between public and private sector can help promoting waste management practices. Training of site labors and operators on how to reduce waste during the construction stage was selected as the fundamental strategy with a percentage of 33%, while 26% of the participants agreed that the use of waste hierarchy can help mitigating waste effectively, use of new technologies, modular construction and optimized site layout can help in waste reduction (15%, 14%, and 12% respectively) (**Figure 5**).

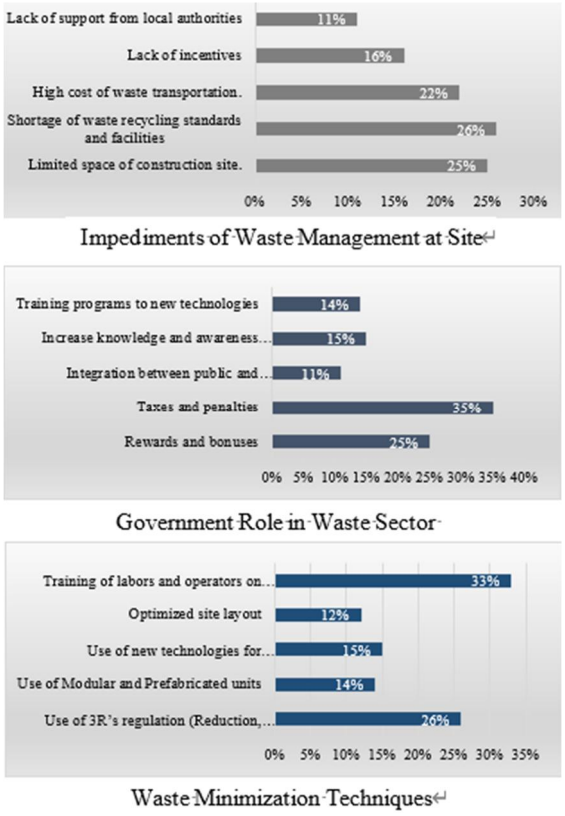

Figure 5. Waste management impediments and minimization techniques.

5. Discussion

It's very obvious that the focus of construction stakeholders is to perform the project with the minimum cost, less time, and high quality since these factors have the highest Relative Importance Indexes compared with safety and environmental protection, this indicates that waste management isn't considered sufficiently and efficiently. The transportation of waste to dumpsites is still the preferred method by most construction stakeholders compared with reduction, reusing and recycling. Although, waste sorting and segregation activities are labor intensive and requires more investment to identify recyclable and non-recyclable materials, they were selected as the common method for waste handling at site. Generally, construction companies in North Africa and Middle East countries transport waste outside cities to keep it clean without considering the negative impacts of these wastes on the long run. Big companies started realizing the importance of sustainability in their work by considering green building concepts such as the use of environmentally friendly construction materials and green procurement, while small companies still lack these concepts in their work. Governmental and municipal authorities must put considerable effort into increasing stakeholders' knowledge through scientific conferences, seminars and research to promote the use of recycled materials and invest in recycling facilities. The questionnaire results indicated that training of labors and operators for new technologies and equipment can reduce waste production. Big and some medium sized companies are carrying waste sorting either on or off site, while small companies still send waste mixtures to dumpsites. Current waste regulations and laws are not sufficient and should be updated and enforced to mandate waste sorting and recycling. Another important aspect to be considered is the limited space of the construction site and nonexistence of clear developed standards and guidelines about recycling and reusing of waste, which hinder contractors from considering these techniques in their work. Imposing of taxes and penalties by the government for illegal dumping of waste along with providing rewards and bonuses will encourage construction stakeholders to consider waste management in their work.

6. Guidelines for effective waste management

The effective management of construction waste requires two main pillars; firstly, the strong role of the government in formulating and enforcing legislations regarding construction waste. Secondly, the commitment of construction stakeholders to waste mitigation strategies during design and construction. **Tables 1** and **2** illustrate the guidelines of effective waste management.

Table 1. Guidelines of effective waste management.

Governmental actions	**Classification**			
	Legislative	**Administrative**	**Workforces/Institutions**	**Technologies and assets**
	Applying taxes and pay as you throw policy.	Applying circular construction and zero waste concepts for effective reuse of generated waste.	Establishing and empowerment of authorities and environmental councils to supervise and control waste generation and handling.	Introducing new techniques, technologies and equipment's to facilitate material handling and transportation.
	Formulating new regulations and policies considering 5R' waste hierarchy (Refuse, Reduce, Reuse, Repurpose and Recycle).	Fostering green building rating system and sustainable design concepts.	Increase awareness of construction parties regarding waste impacts through education, advertising and training.	Establishing factories for prefabrication and modular construction.
	Penalty fees for illegal dumping.	Providing incentives and motivation schemes to stakeholders who count waste management in their work.	Mandating waste sorting and segregation either at site using waste skips or using a waste contractor.	Provide low rent off-sites for materials' storage, waste sorting and processing.
	Compulsory and reliable implementation of existing and new developed laws and acts.	Setting standards and certified quality management systems for products manufactured from recycled waste.	Promoting the market of secondary materials manufactured from waste.	-
	Providing funds for waste management sector.	Encouragement of Public-Private Partnership to establish waste sorting, processing and recycling facilities.	-	-

Table 2. Waste mitigation strategies.

Design	**Benefit**	**Construction**	**Benefit**
Contractual clauses to prepare a site waste management plan (SWMP).	It considers waste management early before the construction phase.	Use of waste contractor.	Reliable experience in sorting, controlling and supervising waste management.
Dimensions' standardization and avoidance of over-complicated design.	Improve buildability and reduce materials' cutting requirements.	Mechanical handling of materials.	Reduce labors errors and material damage.
Design using Building Information Modeling (BIM).	Reduce design errors, change orders, accurate estimation, clash detection, optimized site layout and effective waste control plans.	Reduce, reuse and recycle of generated waste.	Minimize waste sent to landfill disposal.
Training of cadres for Building Information Modeling (BIM).	Create professionals and facilitate BIM implementation.	Labors and operator training.	Decrease waste generation and improve labors and operators' skills.

Table 2. (*Continued*).

Design	Benefit	Construction	Benefit
Green and circular procurement methods.	Avoid over ordering across the entire life cycle of the products.	Prefabrication and modular construction.	Prevent waste creation.
Just in time delivery of materials to the site.	Eliminate excess inventory at job sites and reduce time delay.	Use products with a high content of recyclable materials.	Promoting the markets of secondary materials.
The involvement of contractors and sub-contractors during the design stage.	To familiarize engineers with construction sequences and avoid over specifications of materials.	Avoid unnecessary packaging.	Reduce paper and packaging waste.
Design for deconstruction (selective-demolition) by developing guidelines and plans.	Facilitate the reuse of construction components and reproduce recyclable waste.	Supplier commitment of take-back scheme.	Reuse of wasted materials in good conditions for new projects.
Establishing a data collection system of construction waste.	Simplifying the waste quantification process and developing management plans.	Waste sorting and separation using colored and titled bins at the site.	Quick categorization of waste for recycling and reusing.
Selection of durable construction materials.	Avoid early renovation and replacement.	Well established and protected storage spaces.	Protect materials from bad weather conditions and theft.
Applying an Integrated Project Delivery (IPD) system.	Increase productivity, improve project quality, enhance collaboration and communication between project parties.	Effective line of communication at site.	Facilitate decision making.

7. Conclusion

The main attributes behind low rates of waste recovery in North Africa and the Middle East are lack of sufficient awareness among stakeholders, negative attitudes towards new technologies, lack of support from governmental and municipal authorities, weak implementation of regulations and acts, lack of incentives, low quality of recycled waste and shortage of recycling standards. Therefore, waste management is a critical issue that requires the collaboration of many parties to control waste and achieve high rates of recovery. A set of governmental actions along with strategies to be applied at design and construction phases were proposed to inform construction parties about the significance of waste management and environment protection and help them take the essential initiatives for better waste management.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not for profit sectors.

Conflict of interest

The author declares no conflict of interest.

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Appendix A

Table A1. Waste management laws and norms (Developed Countries).

Country	Waste regulations	Norms
USA	***Resource Conservation and Recovery Act of 1976 (RCRA):** dictated minimum standards for the maintenance of sanitary landfills to protect humans and the environment, preserve energy and natural resources. ***National Emission Standards for Hazardous Air Pollutants (NESHAP):** It's applied to asbestos waste and paintings contain lead. ***Comprehensive Environmental Response Compensation and Liability Act (CERCLA):** It's known as the Superfund, which applies to any hazardous material in C&D debris. Toxic ***Substances Control Act:** specifically regulates the disposal of debris generated from activities related to renovation and demolition.	Strong awareness of waste impacts on human health and the environment. Reliable enforcement of rules and regulations with strong supervision by local authorities and communities.
Canada	***Waste Reduction Regulations (1994):** The government of Ontario established these regulations as a part of the Waste Reduction Action Plan (WRAP) to make contractors to develop recycling plans of generated wastes. ***Regulation (103/94)**, which requires certain types of waste to be separated during construction or demolition of buildings with an area above 2000 m^2. ***Canadian Environmental Protection Act**, which requires waste reduction plans, a separation system and a cost accounting system of waste. ***Waste audits:** aims at determining the types and quantities of generated waste to apply 5R regulations (Reduce, Reuse, Recycle, Recovery and Residual management). ***Low-L-200**, which bans some construction and demolition waste, including asphalt paving, porcelain and ceramic from being sent to landfills in addition to the enforcement that all C&D waste must be taken to certified processing facilities for recycling.	
European Union	***Waste Framework Directive** (2008/98/EC). ***Federal Environmental Protection Act** 527/2014. *** Waste management, waste disposal, end of waste and the Federal Circular Economy Acts.** ***Waste Classification Ordinance**. ***Separation of Construction Waste Ordinance**. ***End of the Waste Act**: ***Landfill ordinance:** to regulate taxes and fees. ***Environmental Rating Protocols**:	Fair awareness of waste impacts. Strong enforcement of rules and regulations for waste mitigation. European Standards act as a driver for contractors and stakeholders for waste management under the supervision of local authorities.
Germany	***German Federal law of waste:** prevention and disposal. ***Commercial waste ordinance:** for safe and high recovery of waste. ***DIN standards:** to regulate construction and deconstruction works. ***Guidelines for sustainable construction:** throughout the building life cycle. ***Soil and groundwater protection regulations.** ***Green building rules.** ***Circular Economy Act:** work approval by the German sustainable building council.	High awareness and interest of construction stakeholders regarding waste minimization. Robust supervision by municipal authorities for regulations. The German Institute for standards (DIN) acts as a driver for stakeholders to consider waste management in their tenders.

Table A1. (*Continued*).

Country	Waste regulations	Norms
United Kingdom (UK)	1-**Aggregates levy,** which promotes the use of recycled aggregates and clean neighborhoods. 2-**Environment act 2005:** that contains site waste management plan. 3-**Code for sustainable design and construction:** for new buildings. 4-**Environmental Protection Act (EPA)** and **Environmental Protection Regulations.** 5-**Landfill tax.** 6-**Waste management licensing** and controlled waste. 7-**hazardous waste regulations.** 8-**Waste and Emissions Trading act.** 9-**Producer responsibility obligations**.	Strong awareness of the environmental impacts of waste and willingness of construction professionals in the use of recycled waste. Environmental Authorities are key drivers in supporting sustainability practices of construction industry.
Australia	1-**Environmental Protection Act (EPA) 1993:** was the first introduced act for waste management. 2-**Environmental Management and Pollution Control Act 1994.** 3-**Waste Avoidance and Resource Recovery Act 2001.** 4-**Zero Waste Act 2004.** 5-**Sustainability Act 2005.** 6-**Waste Reduction and Recycling Act 2011.** 7-**National Waste policy:** for less waste and conservation of resources. 8-**National Environment Protection Measures,** which control the identification, handling and transportation of waste. 9-**Product stewardship Act:** to control the impacts of products on the environment and human health.	High knowledge of waste impacts on environment and human. Good integration between environmental divisions and construction stakeholders for implementing waste laws.

Appendix B

Table B1. Waste management regulations and norms (some countries in north Africa and Middle East).

Country	Waste regulations	Norms
Egypt	***Law 38/1967:** for public cleanliness. ***Conservation and Recovery Act 1976:** to clear dumpsites. ***Law 4/1994:** for protecting the environment, it's the main regulations that control solid waste management including construction waste. ***Waste Management Law:** issue licenses for companies working in the construction and demolition waste sector and increase penalties against waste generators violation. ***Egyptian System for Building Sustainability:** (Green Pyramid Rating System-GPRS). ***Egyptian Code of Design Principles:** for solid waste management. ***Egyptian code for recycling.** ***Egyptian code of Smart Cities.**	Started recognizing the importance of waste management as a source of economic benefit, but still there is weak implementation of legislation with non-supportive policies and actions from government and local authorities.
Jordan	***Building and Zoning regulation No. 67 of 1979 and its amendments,** which regulate permit requirements for excavations and renovations to control construction and demolition dumping. ***Solid Waste Management Regulation No. 27 of 2005, which** controls all types of wastes including hazardous waste. ***Environmental Protection Law No. 52 of 2006, which** sets the responsibilities of the Ministry of Environment and the rules for environment protection. ***Waste Management Framework Law No. 16 of 2020.**	Lack of awareness regarding waste effects, shortage of environmental rules and supervision from local authorities.
Libya	***Law No. 106 of 1973:** regulates waste collection and disposal to allocated places by municipalities. ***Decision 142 of 1976:** identified additional ways of waste disposal according to health regulations. ***Law No. 7 of 1982:** for protecting the environment. ***Law No. 13 in 1984,** defines compliance terms of solid waste disposal. ***Law No. 15 of 2003:** to prevent the incineration of waste nearby urban areas and big cities.	Contractors and stakeholders don't have enough familiarity with the adverse impacts of waste on the environment. Lack of regulations regarding waste mitigation. Weak role of authorities in supervising waste disposal and processing.
Lebanon	***Decree No. 8735/1974:** assigns waste management to municipalities. ***Law 444/1988:** regulates hazardous wastes. ***Law No. 444 of 2002:** sets the rules and guidelines of environment protection. ***Decree 9093/2002:** for establishing processing and recycling facilities by municipalities. ***Decree 1117/2008:** to establish sanitary landfills. ***Decree 8471/2012:** considers environment protection due to industrial waste. ***Ordinance 2019/09:** amends solid waste and landfill regulations. ***Law No. 80:** integrated Solid Waste Management (ISWM) that identifies the sustainability principles and waste recovery techniques (reduction, reusing, recycling).	Lack of waste laws and acts. Inadequate knowledge of the environmental impacts of waste. Insufficient support from government and poor enforcement of the laws.

Table B1. (*Continued*).

Country	Waste regulations	Norms
Saudi Arabia	***Decree No. 7/B/13061:** under section 12 regulates waste storage, transport, treatment and disposal considering environmental protection. ***MOMRA regulation:** defines waste materials and sets rules for construction and demolition of waste disposal. ***Solid-waste Law of 2013:** regulates the relation between government and contractors for all types of wastes to reduce waste generation and apply best practices of waste management. ***Decision No. 457 of 2019:** to Create the National Waste Management Center to regulate importing, exporting, collecting, transporting, sorting, treating and final disposal.	Stakeholders started considering waste management as a potential for economic benefits, but still there is a weak implementation of laws and rules in addition to applying foreign rules which are not customized to suit the local conditions of the country.
United Arab Emirates	***Provision of Environment Agency of Abu Dhabi (1996):** for air quality, groundwater and biodiversity protection and enhancement of desert and marine ecosystems. ***UAE Federal Law 24 of 1999** for the protection and development of the environment, which specify the liabilities and compensation for any environmental damage. ***Law No.21 Of 2005:** for waste management. ***Dubai Green Building Sustainable Regulation (2008):** to increase construction sustainability. ***Abu Dhabi Environment Policy Agenda 2014:** to improve waste regulations, promote awareness of waste management ***Federal Law No. 12 of 2018:** for Integrated Waste Management.	High awareness of waste impacts on humans and the environment. Economic benefits and legislation are the main drivers of waste minimization. Government support for local authorities to control waste. Only big companies apply waste management plans to big projects.