Risk Analysis and Waste Management for Construction and Demolition Projects in the Gaza Strip

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ABSTRACT

The demolition industry poses many risks and dangers to people and the environment. Thus, safety in demolition works has become a matter of concern and a real challenge for urban developers and environmentalists .This study aims to enhance the ways of assessing the risks associated with demolition works in the Gaza Strip and to identify the best ways to manage construction and demolition waste. A field questionnaire survey was used for collecting data from people experienced in demolition contracting in the Gaza Strip. To get in-depth information about the actual demolition operations and related risks and to test the results of the quantitative approach, two demolition projects were investigated as case studies. Results showed that most of the demolition works in the Gaza Strip are small- to medium−sized projects. Owing to a large population and overcrowding in housing, the most used demolition techniques are demolition by hand or by cranes with long arms. The top-ranked causes of accidents at demolition sites are related to workers' attitudes and experiences. The study revealed that the lack of safety knowledge and awareness is the major barrier to implementing an effective environmental management plan for demolition projects in the Gaza Strip. Further, the lack of governmental provisions and specifications to control the recycling process is considered the main obstacle to demolition recycling in the territory.

KEYWORDS: Demolition projects, Risk assessment, Waste management, Gaza.

INTRODUCTION

Structural demolition is defined as "dismantling, razing, destroying or wrecking any building or structure or any part thereof by a pre-planned and controlled method" (Building Department Hong Kong, 2004). When a structure is no longer suitable for use or poses a threat to public safety and the surrounding environment, it should be demolished to make way for a new structure by using the materials taken from demolished structures. The demolition process is complex in nature, wherein a structure is intentionally destroyed to form a variety of structural components and materials.

In the building demolition industry, the deconstruction process allows for maximizing the recovery of components and materials for reuse and recycling. Essential materials and components are manually removed to be used later before the remains of the structure are demolished and mixed together. In some cases, the entire building is disassembled piece by piece with the primary goal of reusing those pieces (Jeffrey, 2011).

Basically, three methods of structural demolition are used: progressive demolition, deliberate collapse mechanism and deliberate removal of elements/deconstruction (Rakhshanifar et al., 2015). Progressive demolition is the most used method and is particularly useful in restricted areas, whereas the deliberate collapse mechanism requires sufficient space to enable equipment and personnel to be placed at a safe distance (British Standards Institution, 2011). Until the 1950s, the most used demolition technique was

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demolition by hand, wherein old unsafe buildings were dismantled at the end of their lives (Roodman and Lenssen, 1995). Today, demolition equipment and techniques are constantly improving as a result of the continued development in construction technology. Demolition techniques have improved from the use of hand tools to the use of chemical agents, water jetting, wrecking ball, advanced machinery and tower cranes (Abdullah and Anumba, 2002; Abdullah et al., 2008; British Standards Institution, 2011; Rathi et al., 2014). The selection of the appropriate demolition technique depends on different factors, including the building's structural characteristics, site location and conditions, safety, permitted level of nuisance, budgeted cost, available time and availability of equipment and reuse and recycling of wastes (Kasai, 1988; Alhazmi and McCaffer, 2000; Abdullah and Anumba, 2002).

Demolition works should be carefully planned to be carried out safely. Planning should involve identifying and assessing all potential risks and hazards involved and determining the appropriate control measures before commencing (Australian Capital Territory, 2018). The demolition plan must be developed in consultation with the demolition contractor, structural engineer and health and safety specialist. Moreover, the plan should be accompanied by a report assessing the stability of the surrounding buildings, structures, land and facilities that may get affected (Building Department Hong Kong, 2004).

Demolition work involves many hazards, including the risk of serious injuries and accidents among workers and even to the public, potentially resulting in human suffering and unnecessary expenses. These serious injuries may result from accidents, such as unexpected collapse, falling objects, overloading and exposure to noise, dust, vibration and hazardous chemicals (Anumba et al., 2003; Abdullah et al., 2008). The reasons for these accidents are incorrect use of demolition tools, unsafe and poor site conditions, availability of hazardous materials on site, lack of safety awareness among workers, workers' lack of commitment to occupational safety and health requirements, workers' unsafe attitude and unavailability of personal protective equipment (PPE) (Abdullah et al., 2008; Rathi et al., 2014; Rakhshanifar et al., 2015).

The demolition process demands a high level of skills, experience and care to ensure safe and efficient operations (Bin Abas, 2010). Therefore, the hazard identification and elimination process and the use of safe demolition techniques are essential to achieve zero injuries (California Department of Industrial Relations, 2012). Different factors should be considered during the assessment of the risks associated with demolition work, such as the building's structural integrity, demolition technique and equipment to be used, layout of the workplace, skills and experience of workers involved and local weather conditions (California Department of Industrial Relations, 2012; Australian Capital Territory, 2018). Some control measures can be considered for public safety, including the use of crosswalk closures, separate pedestrian walkways, security fences, overhead protective systems, shoring underpinning adjoining structures, warning signage, adequate lighting, adequate PPE, dust control measures and sound suppression devices on heavy equipment (Victorian Government Legislation, 2017).

Demolition works produce large quantities of waste over a short period, depending on the demolition technique used. At least, an amount of 10 billion tons of construction and demolition waste is generated globally every year (Aslam et al., 2020). This waste contributes to 35-40% of the total solid waste generated worldwide, which includes metal, concrete, bricks, tiles, limestone, ceramic, timber, roofing materials, plastic and glass (Jian, 2021; Umar et al., 2021). In particular, the total quantity of waste generated from demolition works in the USA between 1960 and 2000 was estimated to be 20 to 30 times the amount of waste generated from construction projects in the same period (Franklin, 1986). In China, demolition waste contributed to 93% of the total annual generation of construction and demolition waste from 2003 to 2013 (Zheng et al., 2017).

Recently, demolition waste management has emerged as a trending topic because of the significant environmental impacts associated with disposal methods (Liu et al., 2003; Pun et al., 2006; Jian, 2021). Demolition waste can be recycled, reused or disposed of in landfills. The European Commission estimates that 60–80% of the demolition and construction waste produced annually in Europe is currently being recycled (BIO Intelligence Service, 2011). However, developing countries face several economic and logistic constraints and limitations when it comes to choosing the method of demolition waste disposal (Madebwe and Madewe, 2006). Therefore, the common waste disposal method in developing countries is landfilling (Negash et al., 2021). Although 80% of construction and demolition waste has a high potential of being reused or recycled, massive quantities of waste have been disposed of by landfilling in China, which threatens ecological communities (Zheng et al., 2017). As such, the increasing quantity of construction and demolition waste leads to an increased demand for landfills. Moreover, if demolition wastes containing chemical hazards are sent to landfills, they create a risk of underground water pollution (Weber et al., 2002).

Owing to the high risks associated with construction and demolition wastes, it has become essential to utilize sustainable waste management (SWM) systems in demolition and construction projects. However, there are obstacles to implementing these systems. Negash et al. (2021) and Mahpour (2018) agreed that the barriers to implementing SWM systems in demolition and construction projects can be technical, social, economic, environmental or regulatory. Technical weakness of contractors poses significant problems to the implementation of SWM systems and must be solved (Negash et al., 2021). Moreover, the economic uncertainty of the recycling process is considered as the most significant barrier in this regard (Tura et al., 2018). Further, the lack of contractor and community awareness and collaboration is considered a significant social barrier (Blaisi, 2019), the lack of policies and waste management regulations is a regulatory barrier (Mahpour, 2018; Blaisi, 2019) and the lack of waste treatment facilities acts as an environmental obstacle (Jin et al., 2018).

The Gaza Strip has undergone a remarkable progress in infrastructure development over the past few decades (Tayeh et al., 2019; Alhammadi et al., 2021). Nevertheless, this progress is hindered by the existence of many ageing structures. The perfect solution to this problem is to demolish existing old structures such as low-rise buildings and replace them with new multi-story buildings.

However, the Gaza Strip has been a theatre of conflict for decades and has been exposed to several wars in the last 15 years. These wars have resulted in numerous partially and completely destroyed buildings (Tayeh, 2019). The most obvious impact of these wars is the large quantities of debris caused by the destruction of buildings and infrastructures. The total quantity of demolition debris produced during the 2008–2009 war was close to 600,000 tons (United Nations Environmental Programme, 2009). In addition, a total of 1,335 and 1,800 houses were completely destroyed and 12,800 and 16,800 houses were partially destroyed in the recent wars in 2014 and 2021, respectively (Abo Don, 2021; Hass, 2021). During the war on Gaza in 2014, an amount of two million tons of demolition waste was created, which included 1.8 million tons of residential buildings (Thöni and Matar, 2019). Such a huge amount of demolition debris caused environmental, social and economic problems in the Gaza Strip (Ghuraiz et al., 2011).

The limited size of municipal dumping sites and the lack of sufficient open lands in the Gaza Strip are considered the main obstacles to accommodating the large quantities of demolition debris, representing one of the challenges faced by researchers and local authorities (Alfaqawi, 2012).

In the Gaza Strip, there exists a lack of guidelines and standards to govern the practices at demolition sites (Abu Aisheh et al., 2021a; Mahfuth et al., 2019). There are no safety procedures to be followed to ensure a safe working environment for employees and labors (Maliha et al., 2021) and the demotion practices rely only on the knowledge and experience of engineers (Mahfuth et al., 2020).

Thus, identifying and assessing the risks associated with demolition works in the Gaza Strip and finding ways of managing demolition wastes are necessary. Therefore, this study aims to develop a guidance for demolition works in the Gaza Strip. This general aim will be achieved through the following objectives:

- Examining the existing practices and techniques applied in demolition projects in the Gaza Strip and the factors affecting the use of these techniques.
- Presenting a comprehensive analysis of the risks associated with demolition works and the safety measures implemented in the Gaza Strip.
- Identifying the major types of demolition wastes and providing practical suggestions and recommendations for minimizing these wastes and benefiting from them, which will help decision-makers identify the most effective methods for waste management and eliminate the barriers to implementing them.

Given that limited research has been conducted in this field in the Gaza Strip, this research work is fully comprehensive and the results are compared with findings of previous studies in other countries.

METHODOLOGY

Quantitative and qualitative approaches were used in this research study. An extensive review of the previous studies on the research topic was conducted to collect the necessary information used in designing the questionnaire. The questionnaire was used as a quantitative research method to gather information in numerical form in order to convert the data into applicable statistics. Questionnaire forms were distributed to people experienced in demolition contracting in the Gaza Strip: project managers, engineers, contractors and sub-contractors. Data analysis was conducted using the relative importance index (RII) method; more details on this method are covered in the following sections. Further, a pilot study was conducted with the questionnaire prior to using it to collect data in order to ensure that the survey questions are clear and that respondents are able to understand these questions and respond to them. Additionally, to get in-depth information about the research topic and to test the results of the quantitative approach, two demolition projects in the Gaza Strip were investigated as case studies.

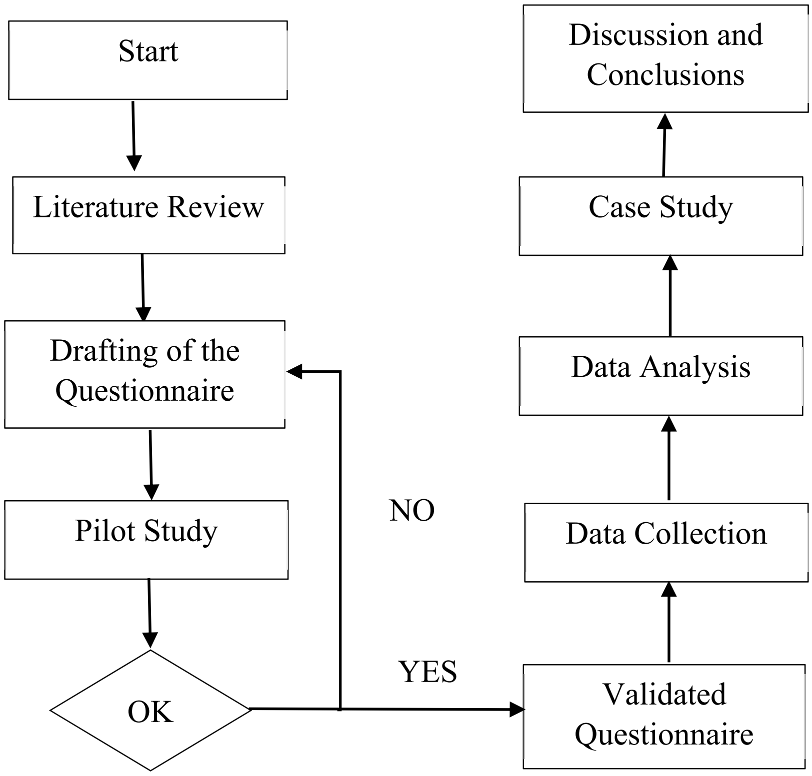

Figure (1): The research flowchart

Research Location, Population and Limitations

In terms of risk analysis, this research work is limited to the demolition projects in the Gaza Strip, but it covers the waste management prospects for both construction and demolition wastes. The respondents were engineers (site/supervision/project), sub-contractors, upper management working in the construction industry in addition to contractors who had worked on removing buildings and facilities damaged by Israeli strikes during the recent wars on the Gaza Strip.

The sample size was calculated using Eq. 1:

$$\text{sample size} = \frac{\frac{z^2 p\,(1-p)}{e^2}}{1+\frac{z^2\, p\,(1-p)}{e^2 N}} \qquad (1)$$

where, z = Z-score (1.96 for 95% confidence level),

p = population proportion, expressed as a decimal (0.50 used for sample size needed),

e = margin of error (7%) and

N = population size.

As per the Palestinian Contractors Union, the number of first- to third-class contracting companies in the Gaza Strip in 2019 was 122 (Abu Aisheh et al., 2021b). Therefore,

$$\text{sample size} = \frac{\frac{1.96^2 \times 0.5 \times (1-0.5)}{0.07^2}}{1 + \frac{1.96^2 \times 0.5 \times (1-0.5)}{0.07^2 \times 122}} = 76$$

The total number of the distributed questionnaire forms was 137 and the total number of collected questionnaire forms was 117, representing a response rate of about 85%.

Questionnaire Design

The questions were developed from the literature review to support the discussion and recommendations of this research work. The questionnaire has 22 closed- and open-ended questions divided into five sections, as follows:

- Section 1 covers the respondents' general information, such as designation, educational level and years of experience.
- Section 2 covers the size and nature of the demolition projects and the reasons for demolition.
- Section 3 covers the demolition techniques used and the factors affecting the selection of the appropriate technique.
- Section 4 covers the causes of accidents at demolition sites, the health and safety control measures implemented to minimize them and the obstacles to implementing an effective environmental management plan in the Gaza Strip.
- Section 5 aims to assess the demolition waste management system applied in the Gaza Strip using different techniques, such as reuse, recycling and disposal and to investigate the obstacles to demolition recycling as well as the best ways to benefit from solid demolition waste.

A five-point Likert scale was used to measure the level of agreement of respondents on a proposed question/factor. The levels of agreement were: 1 = "strongly disagree," 2 = "disagree," 3 = "do not know," 4 = "agree" and 5 = "strongly agree."

Pilot Study

The survey questionnaire was pre-tested before being used to collect data. The pilot study aimed at ensuring that the survey questions are clear and that respondents are able to understand and respond to them. Four copies of the questionnaire were distributed to expert engineers. On the basis of the results of the pilot study, some minor changes were recommended and the questionnaire was modified accordingly.

Data Analysis

Collected data were statistically analyzed and the findings were discussed and compared against the literature reviewed. The responses were analyzed using mean index and RII. Eq. 2 was used to calculate the RII (Muhwezi et al., 2014).

$$\text{RII} = \frac{\sum W}{AN} \quad (2)$$

where, W = weight given to each factor by the respondents, ranging from 1 to 5,
A = highest response weight (5) and
N = total number of respondents.

Case Study

To test the results of the quantitative approach, two demolition projects in the Gaza Strip were investigated as case studies:

- The first case study was the demolition of "Ministries Complex," a six-story building that was attacked by Israeli rockets and partially damaged during the 2014 war. The government decided to replace the building with a new one. The United Nations Development Programme (UNDP) implemented and supervised the project in coordination with the Ministry of Housing, the Ministry of Local Government and the Ministry of Economy.
- The second case was the demolition of "Carinos" restaurant, a three-story building, with a floor area of 250 m^2. It was removed as a part of the expansion of Al-Rashid Road to 40-m dual carriageway.

The actual demolition activities were investigated and the related risks were identified. The findings are presented in the next section.

RESULTS AND DISCUSSION

General Information

The respondents comprised one sub-contractor, 76 site engineers, 17 project engineers, 16 upper managements and seven others, as shown in Table 1. In terms of total work experience in the construction industry, 15% (n = 18) of the respondents had more than 15 years of work experience, 19% (n = 22) had 10–15 years, 27% (n = 31) had 5–10 years and 39% (n = 46) had less than 5 years of work experience. A total of 31% of the respondents had worked in companies that have executed major demolition projects (more than 500 tons). Therefore, the respondents were adequately qualified to answer the distributed set of questions, providing a good indicator for the quality of the information obtained.

Table 1. Respondents' general information

Aspect	Category	Response/ Percentage
Position	Sub-contractors	0.9%
	Site engineers	65.0%
	Project engineers	14.5%
	Upper management	13.7%
	others	5.9%
Years of Work Experience	less than 5 years	39.3%
	5-10 years	26.5%
	10-15 years	49.6%
	more than 15 years	17.9%
Your company has experience in executing major demolition projects (more than 500 tons of waste)	Yes	30.7%
	No	60.8%
	Don't know	8.6%

Demolition Overview

The respondents classified the demolition works carried out in the Gaza Strip into three categories: minor demolition work with less than 250 tons of waste, intermediate work with 250 to 500 tons of waste and major work with more than 500 tons of waste. The weight of two floors of house debris with an average floor area of 150 m^2 was estimated to be 250 tons. A total of 32.5% of the demolition work projects in Gaza were minor, whereas 49.6% and 17.9% of them were intermediate and major projects, respectively. Moreover, a total of 74% of decisions taken to demolish any structure in the Gaza Strip were based on the recommendations received from consultants and contractors, whereas the remaining decisions were based on the owners' requests and other factors.

As depicted in Table 2, infrastructure projects (RII: 0.628) contributed the most to demolition works undertaken in the Gaza Strip, followed by residential, commercial and industrial projects with RIIs of 0.476, 0.442 and 0.43, respectively. This finding indicated that demolition works are mostly minor to intermediate works, which is in line with the above-mentioned classification of demolition works.

The respondents were asked to rate reasons for the demolition works in the Gaza Strip based on their experience. The study results, presented in Table 2, indicated that road infrastructure development is the major reason, with RII of 0.66, followed by the physical deterioration of the building, with RII of 0.6. This finding is consistent with the finding that most demolition works carried out in Gaza are infrastructure works, as previously explained. In this context, many projects were executed in the Gaza Strip, such as construction of Salah al-Din Street and the expansion of Sea Street; at present, 30 public infrastructure projects funded by the European Union and the Palestinian Authority are running in the Gaza Strip, including the construction and rehabilitation of 26 roads and sewerage networks (European Union, 2020).

Table 2. Demolition overview in the Gaza Strip

Aspect	Category	Response/Percentage		
Demolition Decision is Made Based on:	Consultant's Advice	38.4%		
	Contractor's Proposal	36.7%		
	Owner Decision	16.5%		
	Others	8.2%		
Classification of Demolition Work in Gaza	Minor Demolition Work (<250 tons)	32.5%		
	Intermediate Demolition Work (250-500 tons)	49.6%		
	Major Demolition Work (>500 tons)	17.9%		
Aspect	**Category**	**Mean**	**RII**	**Rank**
Types of Structures Demolished	Infrastructure & Others	3.14	0.628	1
	Residential	2.38	0.476	2
	Commercial	2.21	0.442	3
	Industrial	2.15	0.43	4
Reasons for Demolition	Road Infrastructure Development	3.29	0.66	1
	Building's Physical Deterioration	3.01	0.6	2
	Demolition of Society Property for Redevelopment	2.97	0.59	3
	Noncompliance with Allowable Building Setback and Height	2.81	0.56	4
	Refurbishment of Older Housing	2.78	0.56	5
	Demolition of a Fire Damaged Structure	2.65	0.53	6
	High Maintenance Cost	2.63	0.53	7
	Lack of Competent Restoration Expert	2.57	0.51	8
	Building without a Permit	2.56	0.51	9
	Demolition of New Houses That Do Not Comply with Design and Material Specifications	2.43	0.49	10
	Outdated Design and Appearance	2.19	0.44	11

Outdated design and appearance and non-compliance with design and material specifications were ranked the least important reasons for demolition works in the Gaza Strip, with RIIs of 0.44 and 0.49, respectively. This trend could be attributed to the economic situation in the Gaza Strip and the lack of regulations in the territory to control the general view, making deciding on demolition works difficult.

Demolition Techniques

Demolition Methods, Tools and Equipment

Abdullah et al. (2008) stated that the most popular method used in demolition works in Malaysia is progressive demolition, whereas the least used method is the deliberate removal of elements. This finding is consistent with the results of the present study, as summarized in Table 3. Progressive demolition is the most common demolition concept used in the Gaza Strip, with an RII of 0.67, followed by deliberate collapse mechanism and deliberate removal of elements, each with an RII of 0.49.

As explained, most of the demolition works in the Gaza Strip are minor to intermediate works, with the majority of them being renovations of deteriorated buildings. Due to huge population, overcrowding in housing and the sensitivity of the neighborhood, these conditions demand a manual/hand demolition technique. Table 3 shows that manual demolition, in which hand tools such as hammers, picks, ripping bars and jackhammers are used, is the most common technique used in the Gaza Strip (RII: 0.66), followed by cranes with long arms (RII: 0.65). The respondents agreed that the demolition by chemical agents (RII: 0.26) and water jetting (RII: 0.23) are rarely used in the Gaza Strip.

Demolition was carried out using cranes with 10 m long arms in projects executed by the Palestinian Ministry of Public Works and Housing, such as the expansion of Al-Rashid Street, for which many buildings were demolished for non-compliance with the minimum setback as per municipal regulations. These cranes, with 10 m long arms, were used in demolishing buildings that were impacted by war and were partially damaged and rendered unsafe.

Factors Affecting the Selection of Demolition Technique

Bhuvaneswari et al. (2017) posited that the selection of the demolition method depends upon factors, such as site condition, type, age and height of the building. The most important factors are the building's structural stability and proximity to its surroundings. Other factors include project conditions, site constraints, sensitivity of the neighborhood and availability of equipment (Building Department Hong Kong, 2004). These findings match the findings of the present study, wherein the respondents confirmed that the proximity to adjacent buildings (RII: 0.8) and the availability of equipment (RII: 0.77) are the two top factors affecting the selection of demolition techniques in the Gaza Strip. As discussed, the Gaza Strip has a huge population and buildings lie in close proximity, so closeness of adjacent buildings is an important factor to consider for selecting the appropriate demolition technique.

No regulations in the Gaza Strip govern and regulate the demolition activities and assess their environmental impacts. Further, stakeholders' awareness of the importance of using more environment-friendly demolition methods remains low. In this context, the research findings indicated that the environmental considerations and permissible noise level are the two least significant factors affecting the selection process.

Table 3. Demolition techniques in the Gaza Strip

Aspect	Category	Mean	RII	Rank
Demolition Methods	Progressive demolition	3.37	0.67	1
	Deliberated collapse mechanism	2.46	0.49	2
	Deliberate removal of elements	2.46	0.49	3
Demolition Techniques (Tools and Equipment) Used	Manual demolition (by hand)	3.31	0.66	1
	By cranes with long arms	3.27	0.65	2
	By advanced machineries and wrecking ball	2.03	0.41	3
	By chemical agents	1.28	0.26	4
	By water jetting	1.15	0.23	5
Factors Affecting the Selection of Demolition Technique	Proximity to adjacent buildings	4.01	0.80	1
	Availability of equipment	3.85	0.77	2
	Strength and stability of the structure	3.5	0.70	3
	Health and safety considerations	3.44	0.69	5
	Ease of site accessibility	3.44	0.69	4
	Cost constraint	3.38	0.68	6
	Contractor's experience in similar projects	3.37	0.67	7
	Type of demolition (minor/major)	3.32	0.66	8
	Ease of transporting demolition waste	3.1	0.62	9
	Time constraint	2.92	0.58	10
	Permissible noise level	2.74	0.55	11
	Environmental considerations	2.65	0.53	12

Demolition Health and Safety Considerations

Causes of Accidents and Injuries at Demolition Sites

Hazards occur because of different reasons and may result in human suffering and unnecessary expenses. Bhuvaneswari et al. (2017) revealed that unsafe workplaces, unprotected openings, falling objects and sudden building collapse are the main causes of accidents at demolition sites, whereas Abdullah et al. (2008) found workers' unsafe attitude and negligence as the primary causes. Moreover, Gebreamlak (2016) found that the lack of PPE kits, dearth of safety netting to protect workers from falling objects and workers' negligence are the top-ranked reasons. The findings of the present study demonstrated that the three top-ranked reasons are related to workers' attitude and experience. Table 4 shows that workers' unsafe attitude, refusal to wear PPE and lack of knowledge and experience are the main causes. Therefore, safety induction should be conducted for all workers before starting the demolition work and safety meetings should be held regularly to make sure that all workers are committed to the safety procedures at the work site.

Furthermore, poor site conditions and lack of safety measures and tool maintenance also were considered important reasons. Although fire and unexpected explosions were ranked as the least important reasons for accidents, the possibility of unexpected explosions during debris removal from buildings destroyed during the recent wars on the Gaza Strip is high. As of May 2021, Gaza police have neutralized 300 unexploded shells and missiles found in the rubble of houses damaged by Israel during its recent attack on the Gaza Strip (Mahmoud, 2021).

Safety Measures Taken at Demolition Sites

Any project should obtain a demolition permit from municipal authorities prior to commencing the work. A demolition permit must be obtained to demolish any structure that required a building permit to construct (City of Portland, 1997). The Australian Capital Territory (2000) recommended that project management prepares a demolition plan before starting the actual work on site. The plan should include information about the demolition technique selected, health and safety plan and site management plan. The demolition plan should include the location and condition of aboveground and underground essential services that may be affected by the demolition work. The Australian Capital Territory (2000) also advised to conduct an engineering investigation before starting the actual work. The investigation should consider the as-built details, current load-carrying capacity and stability of the structure. Bhuvaneswari et al. (2017) claimed that building surveys must be carried out carefully before starting the work to avoid any severe damage to the workers, public, environment and adjacent properties. Moreover, safety precautions must be taken to protect the people working on the site and those in the vicinity.

The results of this research reflect the importance of these recommendations and indicate that the contractors in Gaza are aware of all the procedures that must be taken before starting work. The respondents confirmed that important safety measures are being implemented at demolition sites in the Gaza Strip. Obtaining the demolition permits (RII: 0.67) and conducting the engineering investigation (RII: 0.66) were found to be the two top-ranked health and safety control measures implemented in Gaza projects. In addition, inspection of the surrounding area and preparation of comprehensive health and safety management plan were found to be important measures already being implemented.

Conducting a pre-demolition hazardous materials' survey as well as ensuring that the site is free from dangerous substances and flammable gases were rated as the least common activities. A possible reason for this is that demolition projects in the Gaza Strip are small to intermediate projects, where owners and contractors usually remove all reusable materials. Furthermore, as per the respondents, primary survey for toxic gases and harmful substances should be conducted for buildings that were attacked by Israeli rockets.

Types of Pollution Resulting from Demolitions

Noise, vibration and air pollution are considered the primary types of pollution caused by demolition projects (Chartered Institute of Environmental Health, 2016; Bromley Council, 2017). Abdullah et al. (2008) insinuated that noise is the major type of pollution caused by demolition projects, whereas Gebreamlak (2016) found that dust (air pollution) was ranked first, followed by noise and vibration. The findings of this research study corroborate the above-mentioned findings, with noise, air pollution and vibration as the top-ranked reasons with RIIs of 0.81, 0.75 and 0.68, respectively. As protection against these pollutions, all workers are recommended to use PPE, such as hearing protection, masks and eye face protection, while working at demolition sites (Arthur-Aidoo et al., 2014).

Concrete and tile demolition waste can affect the soil and water quality if disposed of in landfills (Ministry of Environment and Forest-Government of India, 2004). It was found that soil contamination and water pollution caused by disposal of concrete and tile demolition waste in landfills were considered the least significant types of pollution in this regard, with RIIs of 0.64 and 0.60, respectively; however, the RII values of more than 0.6 suggest that these types of pollution are still significant.

Barriers to Improving Environmental Performance of Demolition Projects

The demolition process and management of demolition waste should be carried out as per national and international environmental standards (UNDP, 2013). Moreover, contractors in construction and demolition projects should comply with the applicable national and municipal safety laws and regulations. They should develop, implement and enforce a comprehensive health and safety program that complies with all health and safety regulations, standards and rules (The University of Michigan, 2010). Most countries have their own regulations and standards in this regard; however, some developing countries, such as the Gaza Strip, do not have or do not comply with such regulations.

Gebreamlak (2016) and Abdullah et al. (2008) agreed that lack of safety knowledge and awareness, lack of commitment to health and safety regulations, the nature of demolition project itself and inadequate contract provisions and specifications on environmental management are the main obstacles to implementing an effective environmental management plan for demolition projects. Moreover, Buniya et al. (2021) found that poor safety commitment followed by poor safety knowledge and awareness are the main obstacles. These findings are partially consistent with the current results, in which lack of adequate contract provisions and specifications on environmental management, lack of environmental knowledge and awareness and the nature of the demolition project are the significant barriers, with RIIs of 0.63, 0.63 and 0.58, respectively. Although the above-mentioned research studies agreed that the lack of commitment to health and safety regulations is a significant barrier, the present study showed that this barrier is not one of the top five barriers in the present context.

Table 4. Demolition Health and Safety

Aspect	Category	Mean	RII	Rank
Causes of Accidents and Injuries at Demolition Sites	Workers’ unsafe attitude	3.98	0.80	1
	Workers not wearing the personal protective equipment (PPE)	3.97	0.79	2
	Workers’ lack of knowledge and experience	3.79	0.76	3
	Use of incorrect demolition method and tools	3.54	0.71	4
	Poor site management	3.53	0.71	5
	Lack of safety netting to protect workers from falling objects	3.39	0.68	7
	Lack of regular maintenance of tools and equipment used	3.39	0.68	6
	Availability of unprotected dangerous places and hazardous materials at the site	3.23	0.65	8
	Lack of cooperation between workers and management	3.2	0.64	9
	Fire and unexpected explosion	2.94	0.59	10

Aspect	Category	Mean	RII	Rank
Safety Measures Taken at Demolition Sites	Getting demolition permits before starting the demolition	3.33	0.67	1
	Conducting an engineering survey and structural evaluation of the building for stability check	3.29	0.66	2
	Inspection of the surrounding area where workers, public or properties may be at risk	3.16	0.63	3
	Make a comprehensive health and safety management programme for workers, visitors and the passing public at the demolition site	3.06	0.61	4
	Make sure that there is no dangerous substances and flammable gases at the site	2.79	0.56	5
	Conducting a pre-demolition hazardous materials' survey	2.58	0.52	6
Types of Pollution Resulting from Demolitions	Noise pollution	4.06	0.81	1
	Air pollution	3.74	0.75	2
	Vibration	3.38	0.68	3
	Soil contamination	3.22	0.64	4
	Water pollution	2.99	0.60	5
Main Obstacles to Implement an Effective Environmental Management Plan	Inadequate contract provisions and specifications on environmental management	3.17	0.63	1
	Lack of environmental awareness	3.16	0.63	2
	The nature of the demolition project	2.92	0.58	3
	Cost implication	2.9	0.58	4
	Weather conditions	2.78	0.56	5
	Lack of commitment to HSE by all project parties	2.72	0.54	6
	Archaeology and cultural heritage	2.69	0.54	7

Further, according to Abdullah et al. (2008), weather conditions represent the least significant barrier faced during the implementation of the environmental management plan, but the current results showed that weather conditions represent a barrier with medium importance and impact.

Regarding archaeological and cultural heritage, heritage sites in the Gaza Strip are well known, managed and protected by the Palestinian Ministry of Tourism and Antiquities. A permit must be obtained from the ministry to carry out any work, such as demolition or renovation, in these areas. For this reason, the respondents did not rate archaeological and cultural heritage as an important barrier.

Demolition Waste Management

Use of Deconstruction (Building)

Deconstruction is a construction-in-reverse process where existing elements and materials are disassembled and extracted with great care to be recycled and reused later in creating new structures (Dantata et al., 2004). The deconstruction method has many advantages, such as reducing the amount of waste disposed of in landfills, increasing the ease of recycling and enhancing environmental protection (Kibert and Chini, 2000).

Gaza has been under siege since 2007 and there is a shortage of essential construction materials. Therefore, recycling and reusing of demolition waste are in high demand. The total quantity of demolition debris produced from Israel's attack on private houses, public buildings and infrastructure in 2008 was close to 600,000 tons (United Nations Environmental Programme, 2009).

This study revealed the awareness of stakeholders in the Gaza Strip to the importance of applying the deconstruction process in demolition projects. A total of 44.4% of the respondents always used the deconstruction method in demolition projects (Table 5). Most of the materials, which were removed to be reused later, were wood, bricks, tiles, gypsum, steel bars and light fixtures. A total of 24.8% of the respondents had applied the deconstruction methods a few times, whereas 30.8% of the respondents never used the deconstruction method in any demolition project, potentially due to the lack of knowledge and experience in demolition projects, possible delay caused by the application of the deconstruction method and high cost of the project. A total of 56.4% of respondents had applied on-site separation of demolition debris and waste materials, whereas 33.3% did not, probably due to the need for special places on site to conduct it and the expected high cost to do so.

Types of Waste

Masonry (brick) forms the major portion of construction and demolition waste in Australia, followed by concrete and timber (Kibert and Chini, 2000). The total quantity of construction and demolition waste generated in the European Union exceeds 700 million tons per year. Countries with high populations, such as France and Germany, contribute to more than 50% of total waste generated in the European Union countries together (Iacoboaea et al., 2019).

In 1996, concrete was the main building material being recycled in Australia with 50% of the total recycled quantities, followed by steel, brick, timber and plaster with 42%, 7%, 1% and 1% share, respectively (Kibert and Chini, 2000). Most of the recycled materials in European Union countries are concrete, bricks and asphalt. The recycling rates are different among the European countries. The highest recycling rates were noticed in countries that have specific regulations for construction and demolition waste, whereas the lowest rates were noticed in countries that have plenty of natural materials at low prices (Iacoboaea et al., 2019).

The results of this study shown in Table 5 revealed that concrete is the most recycled and reused material, followed by steel bars, whereas wood and asphalt are the least recycled materials in the Gaza Strip. Asphalt and wood are the most commonly disposed of materials. Concrete is mainly recycled into fine and coarse aggregates, which are used for infrastructure projects such as the development of Al-Mina Road. Steel bars, which are separated from demolished structural elements, such as columns, slabs, beams and footings, are cleaned and then reused or sold to manufacturers of melting steel scrap. Other metals, such as aluminum and copper, are collected and recycled to be reused in the manufacturing of windows, cooking utensils and wiring. Most structures in the Gaza Strip are concrete structures. Wood is used for only doors, decorations or covering roofs. If the wood waste is in good condition, it can be reused for similar purposes. Moreover, wood can be recycled into a mulch or fuel product. Owing to the limited quantities of wood produced after demolition, recycling of wood is a time-consuming and costly process, so contractors prefer to dispose of it. This finding matches the response of the respondents who agreed that wood is a disposable and non-recyclable waste material in the Gaza Strip. Further, recycling of asphalt waste needs high techniques and experience, so in most infrastructure demolition projects in Gaza, contractors prefer to remove the damaged asphalt and dispose of it into landfills. In 2009, asphalt of part of Salah al-Din Street was removed, treated, re-molten with additions and then reused in paving the same road (United Nations Environmental Programme, 2009).

Common Ways to Benefit from Solid Demolition Waste

Landfill is not a recommended method to dispose of construction and demolition waste, since it takes up considerable space, is a major source of pollution and has a high negative environmental impact. Further, increased disposal costs and fewer landfill sites worldwide have led to an urgent need to look for an effective waste management system.

The construction and housing sector in Lebanon is almost similar to that in the Gaza Strip. Lebanon is suffering from heavily populated areas, shortage of spaces needed for landfills and high production of waste, but no clear waste management plan is in place.

Knowledge among Lebanese contractors on the economic and environmental benefits of recycling construction and demolition waste is lacking (Tamraz et al., 2011). In China, most construction and waste materials are recycled and reused. The most common way of benefitting from construction and waste management in China is by recycling and converting the waste into a recycled aggregate that can be used in low-strength concrete for nonstructural applications (Ma et al., 2020). The results of this study showed that most demolition waste in Gaza is recycled or reused in new construction projects. The quantities of waste disposed of in landfills are limited in the Gaza Strip, potentially due to the economic and political situation; for example, because Israel is imposing a siege on the occupied territory and limiting the import of construction materials. The limited open areas in the Gaza Strip to build landfills is another important factor that forces Palestinians to obtain benefits from construction and demolition waste and consider it a new source of building materials.

The results shown in Table 5 indicated that the most common way of obtaining benefits from demolition waste is by using recycled concrete as coarse and fine aggregates for concrete mixtures. Recycled concrete and bricks have been used extensively in road and infrastructure projects for base course layering and backfilling. The least common way of using recycled materials in the Gaza Strip is reusing asphalt in new paving projects. Recycled asphalt was reused in the UNDP's project of developing Salah al-Din Street (United Nations Environmental Programme, 2009).

Obstacles to Demolition Waste Recycling

The deconstruction process worldwide faces several challenges. The main ones include failure to take into account the ease of future disassembly while formulating original design of a building, lack of essential tools for deconstruction, more time required for dismantling and a dearth of codes and standards to regulate the reuse of building components (Kibert and Chini, 2000). Ma et al. (2020) found that the lack of government support for recycling activities, dearth of regulations on recycling, unregulated landfill activities and high cost of land used for onsite sorting are the main challenges for waste recycling. The main obstacles facing the recycling industry in European countries are the lack of confidence in the quality of recycled materials and potential health risks for workers involved in recycling (Iacoboaea et al., 2019). According to Zou et al. (2015), lack of space for separation, high cost of recycling processes, dearth of government policy to drive recycling and absence of confidence in recycled materials are some important challenges in this regard.

Jordan, as an example of the developing countries, is suffering from the generation of tons of construction waste per year. The Jordanian construction industry does not pay considerable attention to waste management and waste minimization is not considered a priority. This is most likely due to the lack of legislations regarding construction waste management in Jordan (Al-Rifai and Amoudi, 2016; Sweis et al., 2021).

The results of the current study confirmed that, to date, no governmental provisions and specifications are in place to control the recycling process; this limitation is considered the main obstacle to demolition recycling in the Gaza Strip. This finding matches the findings of Kibert and Chini (2000) and Ma et al. (2020). As a result of the Israeli siege, there is a clear shortage of recycling equipment, tools and facilities; this shortage is considered the second significant challenge facing demolition waste recycling in Gaza. Further, many types of waste materials are generated from the same demolished building, making recycling operations more difficult. The presence of a variety of waste materials is considered the third significant challenge. Respondents disagreed that the long time needed for recycling waste materials may delay project completion and considered it as the least significant obstacle to the application of demolition recycling. According to them, to save time, recycling containers can be labeled and placed closer to work locations where wastes are generated, recycled and reused. Some obstacles were found of moderate importance, such as insufficient space on site to recycle demolition waste, high costs of recycling and insufficient financial return/profit from the recycling process, matching Zou's findings (Zou et al., 2015).

Table 5. Demolition waste management

Aspect	Category	Mean		Percentage
Use of Deconstruction Technique	Use of deconstruction technique in demolition projects	Always		44.4%
		Never		30.8%
		Sometimes		24.8%
	On-site separation of demolition debris and waste materials	Always		56.4%
		Never		33.3%
		Sometimes		10.1%
Aspect	**Category**	**Mean**	**RII**	**Rank**
Common Reused/ Recycled Materials	Concrete	4.27	0.85	1
	Steel	3.83	0.77	2
	Other metals	3.62	0.72	3
	Masonry	3.56	0.71	4
	Timber/Wood	3.08	0.62	5
	Asphalt	3.07	0.61	6
Common Disposed Materials	Timber/Wood	3.03	0.61	1
	Asphalt	2.63	0.53	2
	Other metals	2.59	0.52	3
	Masonry	2.32	0.46	4
	Steel	2.21	0.44	5
	Concrete	2.13	0.43	6
Most Common Ways to Benefit from Solid Demolition Waste	Using recycled concrete as coarse aggregate for concrete	3.90	0.78	1
	Using recycled concrete and bricks in base course layer for road projects	3.38	0.68	2
	Using recycled bricks/blocks as fine aggregate (sand) for concrete	3.25	0.65	3
	Use of concrete or bricks waste in embankment construction & backfilling	3.23	0.65	4
	Reusing asphalt in new paving projects	3.09	0.62	5
	Demolition waste is disposed of in landfills	2.50	0.50	6
Obstacles to Demolition Recycling	Absence of standards or specifications for waste recycling	3.30	0.66	1
	Inadequate recycling tools and facilities	3.13	0.63	
	Presence of a variety of waste material makes recycling operations complicated	3.01	0.60	3
	Lack of laws for preventing waste disposal at landfills	2.95	0.59	4
	Insufficient space on site to recycle demolition waste	2.87	0.57	5
	Insufficient financial return/profit from the recycling process	2.61	0.52	6
	High cost of recycling	2.58	0.52	7
	Limited demand for recycled content products or materials	2.55	0.51	8
	Lack of qualified contractors for waste recycling	2.33	0.47	9
	Recycling delays the project completion	2.23	0.45	10

Findings from the Case Studies

Case Study 1 (Ministries Complex Demolition)

It was found that some activities were conducted before the start of the actual demolition work:

- Preparation of the demolition safety plan. It covered the identification, evaluation and control measures of the expected hazards that might occur at workplace during the demolition activities.
- Preparation of engineering investigation report, safety awareness programs and emergency plan.
- Implementation of safety measures, such as ensuring street closure, placing warning signs, providing workers with PPE and implementing dust minimization and noise control techniques.

These findings matched with the results obtained from the respondents and are presented in Table 4, which covers the safety measures implemented at demolition sites in the Gaza Strip. The respondents were aware of the importance of applying health and safety measures at demolition sites, such as obtaining the necessary permits, preparing the engineering survey for building and making a comprehensive health and safety plan.

It was found that the majority of demolition debris recycled and reused in this project constituted concrete and steel. The findings also strengthen the results obtained from the questionnaire presented in Table 5.

Case Study 2 (Carinos Restaurant)

From the investigation of this case, it was found that the project was delayed and some accidents happened during the work. The five most important reasons of delay and accidents are as follows:

- The lack of safety plan for all demolition project phases.
- The lack of safety control measures on site.
- Poor site management.
- Workers' unsafe attitude and negligence.
- The lack of workers' knowledge and experience.

These findings strengthen the results obtained from the questionnaire. The questionnaire respondents agreed that workers' unsafe attitude, lack of safety control measures on site and lack of workers' knowledge and experience are the main causes of accidents at demolition sites.

CONCLUSIONS

This study aimed to develop a guidance for construction and demolition works in the Gaza Strip. Identifying and assessing the risks associated with demolition works in the Gaza Strip and finding ways of managing demolition wastes were the main objectives of this study.

Based on the research findings and discussion of the results, the following conclusions can be drawn regarding the demolition works in the Gaza Strip:

- Most of the demolition works undertaken are small- to medium-sized projects that were carried out either for renovation of deteriorated buildings or for infrastructure development.
- The most common demolition method followed is progressive demolition and the common techniques are demolition by hand or by cranes with long arms. These techniques are suitable for areas with high population, housing overcrowdiness and limited facilities.
- The major causes of accidents at demolition sites are related to workers' attitude, awareness and experience. This finding is supported by the questionnaire results and the Carinos restaurant case study.
- Contractors are aware of all the procedures that must be undertaken before starting the demolition work, such as obtaining the demolition permits, conducting the engineering investigation and preparing the safety plan. This finding is supported by the questionnaire results and the Ministries Complex case study.
- Lack of adequate contract provisions and specifications on environmental management, lack of environmental knowledge and awareness and the nature of the demolished buildings are highly significant barriers to implementing an effective environmental management plan.
- Concrete is the most recycled and reused material, followed by steel bars, whereas wood and asphalt are the least recycled materials.
- The most common way of obtaining benefits from demolition waste is by using recycled concrete as fine and coarse aggregates in concrete mixtures.
- Lack of governmental provisions and specifications to control the recycling process and lack of recycling

equipment, tools and facilities are considered the main obstacles to demolition recycling.

Conflict of Interest

The authors declare that they have no conflict of interest.

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