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ARTICLE (PEER REVIEWED)

A Project Life-Cycle Readiness Approach to Manage Construction Waste in Jordan

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Abstract

The construction industry is well-known for generating the largest amount of waste amongst other industries, which significantly pollutes the environment. This study, therefore, examines the causes and sources of waste in construction projects, considering activities, inputs, and outputs of each phase of the construction projects' lifecycle (i.e., concept, definition, deployment, and transition). Thirty semi-structured interviews were conducted with professionals in construction projects in Jordan, including architects, contractors, and project administrators. The findings reveal that waste resulting from construction projects passes across several organized operations from generation to final disposal. Furthermore, waste is generated in small amounts at the early stages of the project construction but grows as the project progresses towards the end. This paper's key contribution is to supplement the literature on waste management solutions by providing a holistic approach to tackling waste at its root by including waste management strategies across the project lifecycle phases, not only during the construction phase. This is done with a management readiness view to develop a suitable strategy for construction waste minimization and improve the management of construction projects. This study's practical implication is providing a holistic waste management framework for practitioners to adopt in the early stages of the project.

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Keywords

Construction Projects; Waste Management; Environmental Sustainability; Sustainable Project Management; Project Lifecycle

Introduction

The high volume of waste generated by construction projects is a serious economic, environmental and social challenge (Sarhan, et al., 2019). Construction waste results from construction activities, such as site mobilization, excavation, new building, renovation, refurbishment, deconstruction, demolition, and destruction (Lu, Yuan and Xue, 2021). It is primarily clustered into physical and non-physical waste. Physical waste is mainly broken concrete, bricks, metals, and other materials. The non-physical waste includes non-value-added activities in the project design, execution, procurement, and material handling (Foo, et al., 2013).

Despite the abundance of research on waste management, construction projects still generate large amounts of waste in different forms, such as wood, plastics, paper, metals, concrete, stone, rubber, and gypsum (Tam, Soomro and Evangelista, 2018; Mahpour and Mortaheb, 2018). In 2016, the EU generated 2,538 million tons of waste, of which 25%-30% was construction waste. In the UK alone, construction waste generated 66 million tons in 2016 (Government Statistical Service, 2019). In Jordan, construction projects generated 30 million tons of waste received at the landfills. Moreover, the construction sector accounts for 40% of energy consumption and 12% of freshwater usage and produces up to 40% of annual solid waste. A high percentage of this waste might have been seared on location or transported to landfills (Alawneh, et al., 2019).

The increased interest in construction waste research comes with realizing that construction activities use 50% of natural resources, which comprise 15% of water and up to 45% of power and energy. In addition, around 50% of construction materials are mined from the ground, and 25% of lumber is used in construction projects (Yeheyis, et al., 2013). Thus, managing construction waste is a critical issue for policymakers, researchers and practitioners worldwide (Dolla and Laishram, 2019).

This paper uses the project lifecycle approach to better manage the waste of construction projects. The project lifecycle provides a structured approach to project progress (Association for Project Management, 2019). Despite the interconnection and high dependability between the project lifecycle phases, each phase of the project lifecycle has clearly defined activities, inputs, and outputs (Zighan, 2020). Each phase of the project lifecycle generates different types of waste for different reasons and from different sources (cf. Ding, et al., 2018; Tam, et al., 2007).

According to Akinade, et al. (2018), the main objective of managing construction waste is to use construction materials to their fullest potential, reduce consumption, minimize disposal, and at the same time ensure a proper level of environmental protection and sustainability. In previous years, several research studies on waste-connected construction have been carried out. Osmani (2011) suggests that most of these studies are reactive and oriented toward recycling and reusing waste when it is generated. These studies investigated waste quantification and on-site waste recycling in order to divert construction waste away from landfill. Hence, methods, tools, and techniques have been advanced to better handle and deal with the waste of construction projects (Akinade, et al., 2018, Davis, et al., 2021, Ding, et al., 2018). Several attempts have also been made to outline construction waste and decode its management practices, intending to minimize the quantity of waste and increase recovery rates (Herrera, et al., 2020). McGrath (2001) proposed a waste minimization instrument known as "SMART Waste." This instrument was developed as a standard to review, decrease and mark the waste of construction projects to improve the recovery of construction project materials. (Yuan 2013) used SWOT analysis to analyze construction waste in Shenzhen, China, and suggested several strategies to manage waste while considering internal and external factors that contribute and/or limit the operability of these strategies. Ding, et al. (2018) used a system dynamics approach to assess construction waste reduction during the project design and implementation phases and suggested several practices to alleviate construction waste generation. Mak, et al. (2019) used system dynamics to inform policymakers on the optimal charging fees for construction waste disposal. Using technological approaches, specifically BIM, Akinade, et al. (2018) suggested several factors that stakeholders expect from this technology to reduce construction waste. Nevertheless, the research trend of construction waste management is mainly directed by the hierarchy values of waste, controlled by the 'end-of-pipe' subject (Hamid, Skinder and Bhat, 2020).

Some studies also attempted to minimize construction projects' waste by focusing on preventing waste during the project design phase (cf. Mak, et al., 2019; Wang, Li and Tam, 2015). These research endeavours have been focused either on generic construction management and the design phase or a scattered focus on project phases. However, there has been very little research on managing construction waste from the cradle to the grave (from the conception phase to the project's closing phase). Few studies have considered the project's characteristics, especially the transition of project activities from phase to phase during the project lifecycle - i.e., initiating, planning, building, and closing, given that each phase could generate different types of waste for different reasons. For example, Osmani (2013) presented a framework detailing sources and causes of waste across the project lifecycle. However, and more importantly, amongst the very few research articles that aimed to provide a project lifecycle approach to waste management, there is no attempt to provide a readiness lens that shows how projects can be prepared at each phase to manage the various types of wastes that may arise and proactively tackle the causes of such wastes. Therefore, this study relies on the project management approach to analyze construction waste management across the phases of the project lifecycle to improve the management of construction waste by outlining causes for waste and strategies to tackle them at each phase along the project lifecycle. In determining the scope of this study and guiding the research process, three main questions have been posed.

Q1: What kind of waste can be produced during the construction project lifecycle?

Q2: What are the sources of this waste?

Q3: How can this waste be managed at its various sources?

As a response to these questions, qualitative-based research has been adopted. The paper starts with a review of the existing literature; then, the research method is described. The main findings are then presented through an examination of the collected data. Finally, the outcomes of this examination will be discussed, the study questions will be answered, and the study's conclusion will be drawn. In the next section, a brief outline of the construction industry and its characteristics are presented.

Literature Review

THE LIFECYCLE OF THE CONSTRUCTION PROJECT

Project management is seen as a reflection of management functions, which involve planning, organizing, leading, and controlling the project phases to achieve a specific goal within exact pre-defined specifications (Atkinson, Crawford and Ward, 2006). Each project goes through a chain of recognizable phases, where it is born, develops, and then delivers (Zighan, Bamford and Reid, 2018). While there might be some overlap throughout the phases, the work usually moves from the primary phase to the final phase. One single-phase provides the base for work conducted in the phase that follows the project lifecycle (Renuka, Umarani and Kamal, 2014).

In the project management literature, there are various views regarding the number of phases that a project goes through, varying from at least three phases to six phases (Zighan, 2020). In such a lifecycle, each phase involves a collection of demarcating rituals before it transitions into another phase (van den Ende and van Marrewijk, 2014). While this linear transition has been criticized for being incapable of dynamically engaging with complex projects, the project lifecycle remains a powerful tool to visualize transitioning projects from concept to handover (Javed, Bamford and Abualqumboz, 2020). Traditionally, a typical construction project consists of four main phases: initiating, planning, construction, and closure. Each phase has its own schedule of tasks, resources, characteristics, and purposes, with varying degrees of definition (van den Ende and van Marrewijk, 2014). Figure 1 below shows the different phases of the construction project lifecycle.

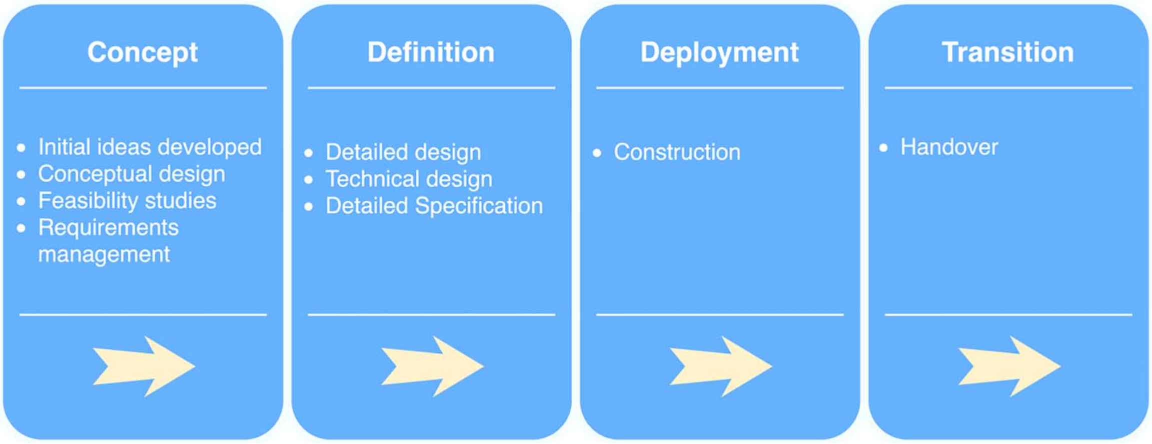

Figure 1. Project Lifecycle Adapted from APM Body of Knowledge 7th Edition (Source: Association for Project Management, 2019)

CONSTRUCTION WASTE MANAGEMENT

Construction waste arises from renovation, construction, and the demolition actions of public, residential, and industrial construction projects. Waste can be classified according to the type of materials used or by the various operational activities in the project (Ding, et al., 2018). Generally, the term waste refers to a substance or material that is discarded or is to be discarded. Waste is also referred to as a by-product that is removed or rejected due to it being no longer valuable or essential after construction operations have ended (Davis, et al., 2021). Waste may also take the form of excess and ruined goods and ingredients that result from construction work or materials used temporarily through the process of on-site actions (Poon, Ann and Ng, 2001). From another perspective, waste can also be defined as unnecessary activities, extra effort, unproductive use of time, along with costs or resources that have been expended extravagantly, carelessly, or to no ultimate aim (Lu, Yuan and Xue, 2021). Thus, construction waste can be grouped into either physical or non-physical waste (Foo, et al., 2013).

Physical waste is a combination of non-inert and inert materials arising from building, makeovers, excavations, road repairs, destruction, and other construction-related actions. For example, some of this waste constitutes actual wreckage, diverse kinds of blocks and bricks, many kinds of plastic materials, tiles, wood, paper, steel reinforcement, and glass, in addition to soil and stones (Nagapan, Rahman and Asmi, 2012). On the other hand, non-physical waste refers to non-value-added actions. The term non-value-added actions separates on-site physical construction waste and other waste produced by the project lifecycle and construction preparations (Foo, et al., 2013). This kind of waste is also known as imperceptible waste, non-physical waste, or in-direct waste (Nagapan, Rahman and Asmi, 2012). Womack and Jones (1997) define this waste as any human action that captivates properties but creates no value, such as errors that involve alteration, the construction of objects that no one needs, procedure phases that are not required, underutilization of workforces, and time wasted waiting for the conclusion of upstream activities.

In order to map waste in construction projects, various techniques have been developed to classify the root causes of construction waste. For example, Davis, et al. (2021), using a deep learning tool that scans digital images of construction waste bins, classified construction waste into the operational, design, management of materials, and determining the waste's origin. Saleem, et al. (2018) describe waste in the design phase resulting from errors in contract clauses or due to incomplete contract documents. Inefficient procurement management was found to be the primary source of pre-construction waste since it generates the most waste during the construction phase. Mak, et al. (2019) identified several causes of

Table 1. Summary of waste management research

Main Focus	Key Findings/main contribution	Representative research
Sustainable Building	Introduced sustainable waste control practices, including reduction, recovery, reuse, and recycling	Lu, et al., 2019; Chi, et al., 2020
Factors Affecting the Project's Waste	Explored the critical waste factors affecting the construction projects performance during the construction phase	Nikmehr, et al., 2017; Yuan, Wu and Zuo, 2018
Using System Dynamics	The study simulated the environmental benefit assessment of construction waste during design and construction phases	Ding, et al., 2018
Waste Quantification Models	A BIM-based waste prediction tool that largely depends on analytical waste quantification models to compute the waste quantity generated from construction projects, mainly during the design phase	Guerra, et al., 2019
Zero Waste to Landfill	An environment-friendly philosophy involving reducing the amount of waste that ends up in landfills during the construction phase. The zero-waste journey involves a strong commitment to waste eliminating and treating	Hamid, Skinder and Bhat, 2020.
Circular Economy	Better resources management through a regenerative system aiming at keeping materials in a closed loop at their highest value. In this model, materials at the end project should be reused and deconstructed to act as banks of material banks for new projects, keeping the components and materials in a closed loop	Esa, Halog and Rigamonti, 2017; Mahpour, 2018
Lean Construction Management	Lean construction is concerned with designing and managing construction projects in reducing waste using continuous improvements and value stream mapping in the construction phase	Nikakhtar, et al., 2015
Critical Design Factors	Minimizing waste during the design phase by standardizing the material size and using modern methods of construction.	Ajayi and Oyedele, 2018; Akinade, et al., 2018

project waste, including construction project complexity and communication and coordination difficulties. These difficulties result from the multi-penalizing nature of construction projects where the data that goes to contractors is adjustable and open to misunderstanding, which inevitably generates waste. Likewise, Osmani, Glass and Price (2008) stated that 'waste [is] accepted as inevitable' and a 'lack of training' results in challenges for architects in managing waste. Yet, many researchers have barely concentrated on the root causes of waste and its effects in both a holistic and proactive approach (Esin and Cosgun, 2007; Kofoworola and Gheewala, 2009; Saleem, et al., 2018). Besides, prior studies have concentrated on waste administration (e.g., Lockrey, et al., 2016) and effectively offered rules for waste recycling and reclaiming as a method of waste administration.

Nevertheless, they generally focused on rules for handling waste after it has been produced. Table 1 below shows that while there have been many studies on construction waste, Osmani (2011) could only be noticed to have presented a project lifecycle approach to waste management in the UK. Therefore, these research endeavours, while plausible, offered a path for decreasing waste to landfills instead of stopping or proactively reducing waste production. Other studies have also studied waste minimization from a quantity perspective, focusing on reducing construction projects' waste in large quantities (Yuan, 2013). Therefore, this paper is set to provide a holistic approach to view the causes of waste at project lifecycle multiple phases with a readiness lens that aims to proactively show the key strategic enablers and mitigating actions to tackle those wastes identified at each phase.

Research Methodology

In this paper, a qualitative approach was adopted since it provides a detailed account of people's behaviours and perceptions and facilitates studying their opinions on a particular subject in more detail (Sarhan and Manu, 2021). As this research is exploratory, a qualitative approach based on interviews was adopted to explore the key causes of construction waste based on the project lifecycle.

The study has been conducted in the Jordanian construction industry, which faces significant macro-level challenges (e.g., socio-economic problems) and micro-level challenges (e.g., ineffective management) (Albalkhy and Sweis, 2019). With a population of 10 million and an area of 34,495 sq mi, the Jordanian economy is one of the smallest economies in the Middle East. The construction industry contributes 4.4% to Jordan's GDP (Department of Statistics, 2017). Jordan has three regions (Northern, Central, and Southern) of which, Amman (the capital), Irbid, and Zarqa are the most populous cities. The construction industry in Jordan produces significant amounts of waste (most notably concrete and steel) as a result of poor quality, significant rates of rework, and a shortage of skills (Al-Rifai and Amoudi, 2016). Recent studies (e.g., Sweis, et al., 2021) show that Jordanian construction companies do not prioritize construction waste. As the purpose of the study is to elicit expert views on construction waste across phases of the project lifecycle, construction management professionals were approached through a purposive sampling method. This sampling method is appropriate for qualitative research as it allows researchers to effectively choose data-rich participants who are likely to have a comprehensive understanding of the topic in question.

Consequently, the research participants are professionals from contractor and consultant sides alike. The criteria for the research participants were such that (1) the participant must work in the construction industry (e.g., architects, public/operational engineers, sub-contractors, contractors, project or construction administrators), (2) their work could be on-site or in office and (3) the individual must have at least 5 years of experience. This criterion was followed to ensure the participants have relevant knowledge and experience in the construction industry.

Thirty semi-structured interviews were conducted with professionals in construction projects, including architects, contracting companies, and project administrators. The research participants have more than 6 years of experience and knowledge in construction projects. Further, they have been involved in various construction projects in the previous 5 years and have knowledge or experience in reducing waste in construction projects. Table 2 below shows the characteristics of the 30 participants based on the type of construction projects they were primarily involved in.

Table 2. Research participants

Type of construction project	No of Experts	Participants
General buildings, such as house building projects, commercial building projects, and industrial construction projects.	17	8 Architects 2 Structural/Civil Engineers 4 Project Managers 3 Contractors
Engineered construction projects, i.e., public construction projects that are funded by the Jordanian government.	13	4 Architects 1 Structural/Civil Engineers 4 Project Managers 4 Contractors

Data were collected between May 2019 and February 2020 based on semi-structured interviews. The interviews were face-to-face in the central region due to the high intensity of public and private construction projects in the region. The interview questions were developed to explore the key reasons why construction waste is generated across the different phases of the construction project lifecycle. As shown in the Appendix, the interviews comprised 15 questions covering 5 sections background information, construction project lifecycle, waste origin, sources and causes of waste during the project lifecycle, construction waste minimization strategies, and further thoughts and opinions. Each interview lasted between 50 minutes and 90 minutes. The entire recorded interview is 10 hours and 24 minutes, while the average for each interview was 1 hour and 8 minutes. Data were recorded via digital recorder and transcribed manually by the authors.

A thematic analysis approach (Braun and Clarke, 2006) has analysed the collected data. The initial phase focused on discovering and reading the data to maintain data consistency and isolate discrepancies. This was followed by coding the data and concluded by labelling and segmenting the data scripts. To develop themes, similar codes were gathered before they were carefully examined to check suitability and combine them with interrelated themes (Braun and Clarke, 2006). The thematic analysis culminated in a basic readiness model (See Table 3 below) that captures four levels at which waste minimization strategies have been operationalized and a set of factors that informed the key features of strategy implementation.

To establish the credibility of this qualitative study, a triangulation of data analysis (Creswell and Miller, 2000) has been conducted by using three main tactics to analysing data. Firstly, the research team analysed the data separately; then, researchers met and reviewed each other's suggestions, discussed, defined, and justified their codes, and agreed on initial themes for application to the full dataset. This was to ensure the interviewees' voices are maintained across the data analysis processes (Abualqumboz, et al., 2021). Secondly, credibility was also addressed during the data analysis phase by operationalizing an external peer review of themes by one expert academic in the field to address discrepancies in their organization, cross alignment, and track-ability (Creswell and Miller, 2000). The peer reviewer is an expert academic in the built environment and qualitative research methods, who assisted in reviewing the interview guide before the data collection commenced, examined themes and codes after the first iteration of data analysis, and verified the themes matching with interviewees' transcribed accounts in the final iteration of data analysis. In addition, the research team conducted one Zoom call with the expert in August 2020 to discuss any comments, suggestions raised throughout the peer review process to remove any discrepancies and agree on the themes

Table 3. Four Levels of readiness model

Level	Factors
Environmental (Contextual)	Regulatory requirement Risk-based regulations Market Drivers Stakeholder awareness
Organizational	Learning and knowledge Top management support Business strategy Competitive advantage
Project	Project scope Project plan Value for money
Technology	Ease of Use Compatibility Availability

and coding structures. Finally, the results of data analysis were also sent to the study participants (Five participants have agreed to complete this exercise of trustworthiness check) for verification and validation (Lincoln and Guba, 1985).

Findings

The outcomes of the thematic data analysis concerning the sources and causes of waste throughout the construction project lifecycle are identified and presented below.

WASTE CAUSES AND SOURCES DURING THE CONCEPT PHASE

The interview questions and the data analysis were oriented toward identifying the causes and sources of construction wastes during the pre-project phase. A lack of early collaboration and engagement among the project stakeholders was the most frequently mentioned cause of waste during this phase. Table 4 below shows the participants' perceptions of the most impactful causes of waste during the project's concept phase (i.e., initiation phase).

One of the most critical causes of waste participants focused on in the project's concept phase was that waste is not a part of project selection's main criterion. For instance, one architect said that "*waste minimization is not one of the main pillars of the project selection process or a main aspect of the project selection criteria.*" The participants also mentioned several causes that limit the ability of project management to develop plans and scenarios to manage waste during the project's concept phase, such as unclear project features throughout this phase. For instance, one architect said, "*The quality of instructions that engineers get from a client is normally vague and un-structured at this phase. This makes it very difficult to look at the project waste problem at this point*". Participants emphasized issues surrounding the low level of cooperation and

Table 4. Participants' perceptions on waste causes during the project concept phase

Causes of waste at concept phase	Details of the cause	Strategic Readiness Enablers	Proactive Mitigating Actions
Lack of initial waste minimization and management consideration.	• Waste minimization has not been established as one of the project's objections and criteria. • No feasible studies of waste minimization and management have been conducted. • The waste minimization plan is not a requirement for the construction project.	**Environmental**: Regulatory requirements **Organizational:** Business strategy **Project:** Project scope	• Project Assessment • Stakeholder analysis
Insufficient incentives and enablers.	• Inadequate prior communication accompanied by minimal cooperation efforts amongst the project stakeholders. • Waste management is not client-driven. • The client lacks awareness of waste management benefits. • Waste management is not a legislative requirement for designers.	**Environmental:** Regulatory requirements **Environmental:** Stakeholder awareness **Organizational**: Top management support	• Stakeholder analysis • Scope monitoring

communication between the project's main stakeholders during the concept phase. The client, designer, contractor, and project manager are responsible for reducing the project's waste. According to one project manager, "*the responsibility for managing the project's waste is a collective effort, and not the individual responsibility of a particular person or group in the project. It requires coherence of effort between all the project stakeholders*". This, according to several respondents, signals the importance of having a coordinated and distributed responsibility among stakeholders to work towards an improved collaborative environment in the early phases of construction projects.

The client's lack of awareness of waste management benefits (particularly those linked with savings from waste minimization) was brought up in the interviews. When respondents were asked to explain the lack of cooperation between engineers and consultants when advising the client regarding waste management, most respondents stressed that engineers are accountable for calculating the benefits of waste management and communicating this to the customer. For instance, one contractor said, *"architects have an essential role in informing customers of waste management in order to maintain certain levels of environmental protection."* Finally, it is essential to point out that most participants considered waste as an inevitable and natural aspect of construction projects. According to one project manager, "*waste is a normal issue in construction projects and is dealt with as one of the project outputs and handled promptly.*"

WASTE CAUSES AND SOURCES DURING THE DEFINITION PHASE

According to the participants, the definition phase (i.e., the design phase) seems to be the primary source of waste in construction projects, affecting the following phases. According to one of the project managers, *"the project design is the fundamental aspect for a low or free project. At this phase, the amount of waste is few, but the*

Table 5. The impactful causes of waste in the definition phase

Causes of waste at the definition phase	Detail of causes	Strategic Readiness Enabler	Proactive Mitigating Actions
Lack of (or poor) waste management system	• No waste management plan • Waste minimization is not one of the project's main deliverables and is not considered a basic constraint of the project. • A lack of pre-defined waste minimization targets and no definite governance boundaries of waste management.	**Environmental:** Regulatory requirements **Organization**: Top management support **Project**: Project plan **Technology**: Availability	• Stakeholder consultations • Project planning • Interface analysis
Project documents and contracts	• Waste management is not included in the contracts. • Poorly categorized waste management duties and responsibilities confuse the delivery and accountability of waste management. • Waste is not an aspect of the material's specifications.	Environmental: Market drivers **Organization**: Business strategy **Project**: Project plan **Technology**: Compatibility	• Interface analysis • Process improvement (e.g., cause and effect analysis) • Configuration management
Lack of initial cooperative arrangement	• Poor client-designer coordination. • Poor coordination and communication within the design team • Poor communal collaboration and coordination in waste minimization.	**Environmental:** Regulatory requirements **Organization**: Top management support **Project**: Project plan **Technology**: Compatibility	• Stakeholder consultations • Interface management • Communication management
Waste management related knowledge	• The ability to specify suitable and compatible materials. • An awareness of the quality and durability of materials. • Limited reviews of waste management research and best practice. • Insufficient waste management know-how. • Limited-knowledge and guidance.	**Environmental:** Regulatory requirements **Organization**: Learning and knowledge **Project**: Value for money **Technology**: Ease of use	• Updating industry guidelines • Training and workshops • Access to industry exhibitions and know-how repositories

Table 5. continued

Causes of waste at the definition phase	Detail of causes	Strategic Readiness Enabler	Proactive Mitigating Actions
Lack of commitment from architects to waste management	• No significant financial incentives for designing a waste-free project. • Waste management is not institutionalized in design regulations. • Waste management is not a design priority. • Design complexity and limited time. • No assessment of project design on waste generation. • A lack of appreciation of waste generated by poor design. • Tight work schedules lead to off-the-shelf design solutions.	**Environmental:** Regulatory requirements **Organization**: Top management support **Project**: Project plan **Technology**: Availability	• Establishing quality circles • Incentivization • Promoting professional ethics

reasons for waste arising in the next phases of the project are high". Based on the interviews, several causes were thematized and grouped into five categories which have been divided into sub-categories. Table 5 below summarized the most impactful causes of waste in the project design phase.

The research participants suggested that the project design phase is critical in preventing and reducing waste in construction projects. According to one of the project managers, "*considerations in project design and planning toward waste-free construction projects are the basis of waste management*." Furthermore, the participants were asked whether waste minimization is considered one of the main construction project's constraints (i.e., scope, time, and cost) or, at least, if waste is considered a significant component when formulating and planning these three constraints. The data analysis reveals an agreement between nearly all the respondents, that waste is not considered within the project's three main constraints, and that waste is not usually considered the main component of project planning and design; for instance, one project manager said:

> **…usually, when formulating a project plan to reach the project's specified goal within specific activities, time and costs, waste is not considered. It is possible to add it to the project's costs, but there is no advanced plan for waste management similar to other project plans, such as plans for risk management, conflict management or stakeholder management.**

Most participants suggested that waste-linked leadership is needed at the beginning of a project and that this leadership needs to tackle this challenge at its roots.

Another main issue that participants emphasized is that there are no pre-defined waste minimization targets and no definite responsibility structure or governance boundaries of waste management. For instance, one project manager said that *"waste management duties and responsibilities are poorly categorized, which confuses the delivery and accountability of waste management."* The participants also acknowledged that architects have no legal accountability to calculate waste. Nevertheless, most contractors and project managers claimed that proactive activities would require architects to go above and beyond their legal obligations. For instance, a project manager said that *"waste considerations should be a standard responsibility of architect works with no incentivizing policies."*

Furthermore, there was a consensus between contractors that design waste resulted from not implementing a waste management plan during the design phase. Designers re-emphasized the role of communication and cooperation to plan waste-free projects. One architect suggested that *"waste management is a chain made up of several stakeholders."*

WASTE CAUSES AND SOURCES DURING THE DEPLOYMENT PHASE

The quantity of waste will be at its peak during the deployment phase (e.g., construction phase). Reflecting on this, one of the contractors said, *"There may be few reasons, but waste is high at this phase."* The main causes and sources of waste during the construction phase, as pinpointed by respondents, are summarized in Table 6 below.

The majority of the participants contended that the primary source of waste at this phase is the limited use of modern construction methods. According to the participants, waste is twofold, through the use of old or traditional construction methods and/or using old or traditional construction materials. According to one project manager, "*Works must be carried out using methods and materials that are compatible with the environment and generate less waste. Failure to do this is likely to result in a large amount of waste at the end of the project*". Thus, the participants were asked why modern construction methods are not used. The data analysis has identified several reasons for this. For instance, one contractor said that *"the project design and specifications are not compatible with modern building systems."* Further, a project manager said, *"…sometimes it is difficult to persuade the client to use modern construction methods and materials, especially if those methods and materials were not presented to the client during the design phase"*. Another contractor argued that *"sometimes the contractor does not know about these modern methods or does not have relevant experience in these methods."*

On the other hand, the contractual provisions and the contractors' dedication to minimizing waste was also emphasized as one of the main pillars of waste minimization during the construction phase. A designer stated that "*the lack of contractors' waste minimization abilities, know-how, and practices, are the main causes of waste in the construction phase.*" Here, contractors clarified that architects are in a better position to demonstrate a high-level engagement waste minimization specific design, resulting in improvements in on-site waste management by contractors and subcontractors.

WASTE CAUSES AND SOURCES DURING THE TRANSITION PHASE

There was agreement among the participants that waste during the transition phase is the product of previous phases' activities. Nevertheless, according to the participants, waste at this phase is usually limited but comes with high risk. A designer said, *"the greatest waste at this phase may be in the client's refusal to receive the project due to different specifications than agreed, or as a result of apparent defects in the quality of works."* According to a project manager, *"at this phase, an inspection of the whole building needs to be done. If everything is done correctly, these inspections are fairly simple to pass"*. There is also the problem of waste sorting - one of the contractors said, "*at the end of the project there are two types of waste, reusable materials, which could be used in other projects or recycled to be used in other industries, and non-reusable materials, which cannot be used or recycled and should be moved to landfill.*" Nevertheless, a project manager argues that *"most of the time, these leftover materials that are reusable or non-reusable are sent to the landfill."* According to a project manager, *"creating a sorting system from the starting point of the project is essential for the effective management of these materials."*

Table 6. The main causes and sources of waste during the deployment phase

Causes of waste at the deployment phase	Detail of causes	Strategic Readiness Enabler	Proactive Mitigating Actions
Limited use of modern methods of construction	• Construction techniques and strategies leading to higher waste projects. • Lack of knowledge of modern construction methods and sequences. • Low deconstruction ability and poor reusability technique. • Waste-efficient formworks. • Less reliance on prefabrication and offsite production.	**Environmental**: Market drivers **Organization**: Top management support **Project**: Value for money **Technology**: Ease of use	• On-site management and coordination • Proper material selection • Training and workshops
Poor contractual relationships and commitment	• A low readiness among contractors for low waste projects. • No thorough check of design information prior to construction. • Lack of recommendations related to waste minimization. • Oversight of project activities that allow for reusable materials to be used in construction • Incompatible project delivery approach to that contracted	**Environmental:** Regulatory requirements **Organization**: Competitive advantage **Project**: Project scope **Technology**: Compatibility	• Government subsidization • Managerial intervention • Managing contractual relationships

Table 6. continued

Causes of waste at the deployment phase	Detail of causes	Strategic Readiness Enabler	Proactive Mitigating Actions
Poor Site Management Procedures	• Lack of site planning for low waste material • A lack of logistic management and waste segregation strategy.	**Environmental:** Regulatory requirements **Organization**: Learning and knowledge **Project**: Value for money **Technology**: Ease of use	• Proper transportation of materials • Effective control of material usage • Kanban boards for materials (dynamic pull planning)
Cultural barriers	• Cultural barriers for driving low waste projects. • Excessive project interfaces leading to team confusion of requirements • Communication gaps between project stakeholders	**Environmental:** Regulatory requirements **Organization**: Learning and knowledge **Project**: Value for money **Technology**: Ease of use	• Resilient team support • Training and workshops • Promoting Sustainable solutions
Design changes and rework	• Rework due to mistakes in project design. • Rework due to mistakes in project execution. • Rework due to dynamic customer needs.	**Environmental:** Regulatory requirements **Organization**: Learning and knowledge **Project**: Value for money **Technology**: Ease of use	• Training and workshops • On-site management and coordination • Improved change management system

Discussion

Construction projects generate both physical and non-physical waste during the different phases of the project's lifecycle. The extant literature provides a plethora of research on waste management but less conclusive studies on a holistic approach of project dynamics (from concept phase to the transition phase) on the origin of the waste, its causes, and key enablers of mitigating actions. These research endeavours have varied both in-depth and breadth of analysis. Several studies demonstrated an in-depth analysis of the waste at a specific project stage, while others spanned more than one phase to engage with various sources of waste; for the definition phase (See, for example, Lu, et al., 2019; Chi, et al., 2020; Guerra, et al., 2019; Mahpour, 2018; Ajayi, and Oyedele, 2018; Akinade, et al., 2018); for the deployment phase (See, for example, Nikmehr, et al., 2017; Yuan, Wu and Zuo, 2018; Nikakhtar, et al., 2015) for the definition and deployment phases (See, for example, Ding, et al., 2018) and for the full lifecycle (See Osmani, 2013). Nevertheless, in parallel with extant research (cf. Davis, et al., 2021, Lu, Yuan and Xue, 2021, Mak, et al., 2019). This paper argues that the sources and causes of construction waste are interconnected and interrelated since the outcome of a previous phase (or phases) affects the next phase (or phases).

Despite the key contributions that extant research has provided, the results of these studies are disjointed and produce fragmented knowledge that is broken down into several perspectives and did not provide a proactively holistic conceptualization. In response to this gap, this study took a proactively holistic approach to manage construction waste. Our study has found that waste has several causes that are predictable, quantifiable, and manageable (Ding, et al., 2018; Guerra, et al., 2019; and Lu, et al., 2019) and accordingly suggested a readiness framework to enable construction projects to tackle construction waste (physical and non-physical) institutionally and strategically.

The findings show that the various participants in construction projects (clients, designers, contractors, and project managers) are responsible for reducing waste throughout the project's lifecycle. This echoes previous research (e.g., Nikakhtar, et al., 2015; Ajayi and Oyedele, 2018; Akinade, et al., 2018) that signposted the need to improve the effectiveness and efficiency of cooperation and collaboration throughout the ongoing construction projects by improving information flow and improved communication between the project's stakeholders in the project's early phases.

Moreover, during such phases, an awareness of the project waste and a consideration of the feasibility of waste management in the project are essential to decrease the waste, which this study found out can be facilitated by the strategic readiness enablers that project stakeholders have. According to Osmani (2011), two main causes of waste during the deployment phase (i.e., construction) are ineffective communication amongst project stakeholders and incomplete information and complexity of the design. Nevertheless, effective waste management starts at the concept phase and planning out the project waste (Mak, et al., 2019).

While the definition phase is considered the critical phase to minimize construction waste, the deployment phase is considered the primary phase in which a large amount of waste is generated (Ding, et al., 2018). The on-site organization and management were considered the most significant factors that produced waste with the absence of a waste reduction process, given they have no consideration for reducing, recycling, or reusing waste. During the deployment phase of a project, waste can be generated from any inadequacy, resulting in the use of equipment, materials, labour, or capital in larger amounts than those calculated as being necessary for the construction procedure. According to McGrath (2001), a waste-efficient project is characterized by maximizing materials used and reused during construction activities. This requires adopting efficient and modern construction methods, especially an adequate segregation system of different materials (cf. Davis, et al., 2021, Lu, Yuan, and Xue, 2021). In fact, efficient and modern construction methods were another key enabler identified by this research as a key underlying strategy for minimizing waste during construction. Lu, et al. (2021) argue that prefabrication techniques such as the use of pre-set modules and parts are more efficient than other techniques in decreasing waste from construction projects. Resorting to offsite construction, waste due to bad weather, offcuts, material breakage, and alteration can be avoided (Dainty and Brooke, 2004).

A waste minimization culture that is part of the contractors' competencies, awareness, and commitment to the project is crucial for driving waste minimization in the construction phase. This agrees with previous studies, for instance, Osmani, Glass and Price (2008) found that the traditional construction culture and opposition to change are obstacles for effective waste minimization. Ajayi, et al. (2016) argue that regardless of adopting various waste management methods and introducing several legislative measures, decreasing the amount of waste produced by the industry remains a challenge. This is mainly caused by cultural factors contributing to the industry's waste intensiveness, thus preventing the effectiveness of adopting existing waste management strategies. In line with the above argument, our research suggests that waste management strategies will not be effective without commitment and dedication from all project stakeholders (particularly contractors, as they are more involved in the operations phase). Even so, such dedication can be produced by contractual and regulatory requirements that punish and reward waste production and minimization correspondingly.

The study has concluded a basic framework (presented below in Figure 2) for low waste project strategies for each phase of the construction project.

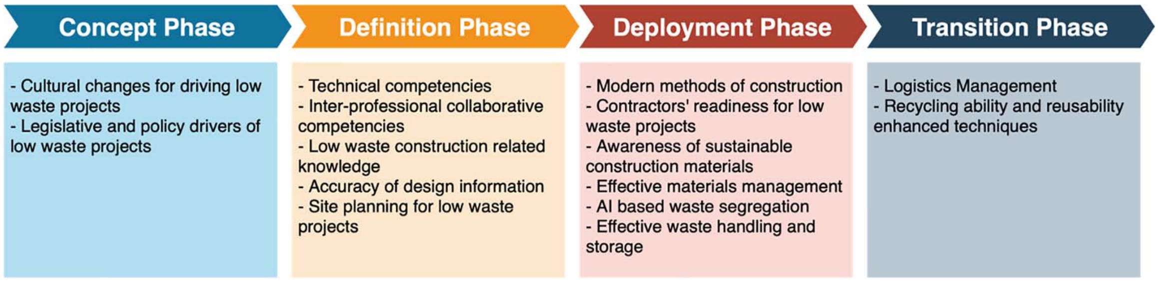

Figure 2. Low Waste Project Strategies across the project lifecycle

This conceptual framework suggests that key measures underlie waste-efficient construction, including coordinating design from the project's stakeholders and producing coherent and comprehensive design information, respectively, and further produce waste and error-free design. This can be accomplished through regulation and dimensional cooperation, collaborative design procedures, modern methods of design for construction, and the waste being included as a design certification. Other than designer duty capabilities, construction linked knowledge, and inter-professional skills as basic leaders of a low-waste design, along with designers' behavioural competency, are seen as the key drivers regarding their efforts in designing ways of avoiding waste.

Managerial Implications

The findings of this paper have important implications on construction activities throughout the project's lifecycle. The paper shows that the definition phase is crucial for waste minimization. This paper also argued that a collaborative culture is vital for provoking waste minimization in construction projects. Taking this into consideration, construction companies are encouraged to culturally embed waste management into their design teams. While an inter-professional cooperative capability is mainly required for designers/architects, construction firms should crucially consider proficiency and fundamentalism in rudimentary design duties and knowledge of construction activities and materials across their design teams. Various stakeholders can use the proposed framework to prevent construction waste. It assists in understanding waste sources and making decisions to minimize waste by providing an early warning sign system for waste management strategies during the planning phase of construction projects.

Conclusion

This paper proposes that most construction waste can be avoided by proactively identifying the causes and sources of waste, focusing on value creation either early (or before) waste occurs. The paper presents that this can be done by identifying the key strategic enablers of a set of mitigation actions that tackle the root cause of the waste at each phase of the project management lifecycle. Causes of waste are linked to all phases of the project's lifecycle. Therefore, this waste should be managed throughout all phases of the project's lifecycle. This study argues, in line with extant research, that it is crucial to take measures to identify all waste production activities early on in the concept and definition phases to be able to manage the waste during all project phases. However, in addition to key contributions in the field, this study argues that waste management must consider the whole project's lifecycle and foresee, control, and avoid waste through the strategic readiness enablers of project stakeholders.

This study proposes that a particular set of measures are fundamental. This includes intensifying waste avoidance measures during each phase and proactively employing mitigating actions such as project assessment, stakeholder analysis, and scope monitoring that assist more in the early phases. Consequently, the involvement and incorporation of stakeholders as early as possible have been noted as critical factors towards solving waste problems fundamentally. Factors affecting the application of construction waste management have been identified in this study. The most important elements impacting the application of systematic construction waste management are design, project or corporate culture, regulations, procedural guidelines, and incentives. In concurrence with previous studies, by placing waste in the centre of the definition phase, the focus of addressing waste will move from being an on-site issue to a design issue.

This paper makes a number of contributions that can be described as an incremental contribution (Nicholson, et al., 2018) to knowledge and practice by spotting neglect in the extant literature on waste management and providing a holistic and proactive approach to waste. Firstly, we contribute to knowledge by advancing a lifecycle approach in spotting various causes and sources of waste that span the multiple phases of a project. Extant research has focused on an in-depth analysis of sources of waste, but this has consequently neglected the breadth of that waste that scatters across the project lifecycle. By shining a spotlight on the strategic readiness enablers, the second contribution is to inform academia and practice on the significance of proactively contemplating the various sources of waste as early as the concept phase and the mitigating actions that can be designed to tackle the waste before it emerges. Finally, the third contribution is to inform practitioners on how to create waste-minimal design approaches to minimize waste before it is generated and establish an early warning signs system to tackle waste as soon as it emerges.

Focusing on the Jordanian construction industry as the empirical research setting means that our findings and conclusion are particularly designed for that setting. However, while appreciating generalizations from such research settings is limited, the way the research was conducted may empirically be evaluated in a similar context to either confirm or refute some of the research results and implications. In addition, we are aware that our sample size is small, but this size was decided when we noticed no new information was emerging following the last interviews in order. We are also aware that our sample does not include direct clients. Finally, one limitation can be found in the project lifecycle adopted. This paper used a linear project lifecycle due to restrictions of the collected data, and as a result, we focused on the main four phases of projects and agreed to rule out an extended lifecycle that goes beyond the project handover phase`.

With these limitations in mind, we suggest a number of future researches. Further research could examine the generalizability of the research results by quantitatively examining the causes of waste on a large-scale sample (e.g., cross-country comparison). This may mean cross-sectional research settings across Jordan's three regions, segmenting the data collection to a mixture of small, medium, and large construction companies in Jordan and include clients and government subjects. In addition, future studies in the Jordanian context may investigate variations of waste types and quantities in the different regions of Jordan. Other studies may investigate the applicability of our framework in comparable contextual settings (e.g., regional, cultural, socio-economic). Likewise, as this study covers construction projects, future studies could specifically examine methods for minimizing waste in particular types of construction projects. For example, future research could focus on variations of construction waste in private/business financed projects against government-funded projects to study factors such as compliance, governance, and financing models. This would enable an appraisal of methods of waste minimization between various types of construction projects. Another future research avenue could be using an extended project lifecycle (including operation, decommissioning, and disposal phases) to provide a more holistic view of waste minimization strategies.

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Appendix

1. What is your position (job title)?
2. How many years of experience do you have in construction projects?
3. What are the main types of waste in construction projects?
4. What are the main stages of the construction project lifecycle?
5. What are the main sources of construction waste?
6. Could you link the sources of construction waste to the project lifecycle?
7. Could you link the generated waste to the project lifecycle?
8. What are the main considerations to prevent the waste of construction project?
9. What are the main causes of waste during the project lifecycle?
10. What are the practices and strategies for construction waste minimization at the concept phase?
11. What are the practices and strategies for construction waste minimization at the project definition phase?
12. What are the practices and strategies for construction waste minimization at the project deployment phase?

13. What are the practices and strategies for construction waste minimization at the project transition phase?
14. Do you have further comments or suggestions about the waste origin, causes and sources during the project lifecycle?
15. Do you have further comments or suggestions about the practices and strategies for cost minimization?