SITE LOGISTICS FACTORS AFFECTING RESOURCES ON CONSTRUCTION SITES AND THEIR RELATIONSHIP WITH EMBODIED ENERGY

A Thesis

by

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ABSTRACT

Green buildings are the new norm in the construction industry. Owners and designers alike continue to look for ways to optimize the life cycle of buildings/spaces through design and construction. Construction managers strive to maximize project performance by reducing construction waste, managing specified materials installed, and maintaining indoor air quality. Construction rework, material movement, material storage, material damage, and waste management can all directly affect a construction project's initial embodied energy and overall energy consumption.

Among research studies published so far, very little has been published addressing how site logistics planning may impact construction resource use on construction sites and how it may relate to a project's initial embodied energy. Embodied energy is sequestered in building materials, as well as in all processes of production, on-site construction, and final demolition and disposal (Dixit 2010). Embodied energy can be categorized as either direct or indirect energy. Direct energy is consumed in various on-site and off-site operations like construction, prefabrication, transportation, and administration (Ding 2004; Fay et al 2008; Treloar 1998). Indirect energy represents the sum of the embodied energy of all construction materials used in a building. For the purpose of this research, I focus on initial embodied energy, particularly related to building materials, understanding that an efficient construction site logistics plan assists with significantly reducing initial embodied energy.

This study seeks to enable reducing initial embodied energy by decreasing the use of material and other resources on construction sites. The main goal is to identify and rank factors related to site logistics that which may affect the use of resources on a construction site. To successfully achieve a reliable consensus, the Delphi method was applied to obtain opinions from a selected panel of experts. In this process, I discovered what material aspects of site logistics (location, circulation, and sequencing) may impact resource use on a construction site and therefore initial embodied energy. As the industry moves toward maximizing the energy, economic, and environmental benefits of construction, the significance of this research is more important than ever in attempting to reduce energy consumption, which directly correlates to a reduction in cost and time.

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NOMENCLATURE

C&D	Construction and Demolition
CSLP	Construction Site Layout Planning
EE	Embodied Energy
EPA	Environmental Protection Agency
IEE	Initial Embodied Energy
IJCIET	International Journal of Civil Engineering and Technology
JIT	Just In Time
KSCE	Korean Society of Civil Engineers
LEED	Leadership in Energy and Environmental Design
MMRS	Mixed-Methods Research Synthesis
MSW	Municipal Solid Waste
REE	Recurrent Embodied Energy
SPSS	Statistical Package for the Social Sciences
WMD	Waste Minimization Design

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CHAPTER I

INTRODUCTION

The construction industry has been a main target for the global sustainability agenda, as it consumes a significant portion of materials taken from nature and generates the largest amount of construction and demolition (C&D) waste (Ajayi et al. 2017; Paine and Dhir, 2010; Anderson et al., 2003). The Environmental Protection Agency (EPA) has estimated that 569 million tons of C&D debris was generated in the United States in 2017, which is more than twice the amount of generated municipal solid waste (MSW). MSW, or trash, comprises various items usually thrown away by consumers, including packaging, food, yard trimmings, furniture, electronics, tires, and appliances. MSW does not include industrial, hazardous, or C&D waste (EPA 2019).

The building industry is constantly looking for ways to construct buildings efficiently while attempting to lower cost and maintain quality. Business owners are now not only interested in the schedule and cost of construction projects, but also in the overall life-cycle management of the building and environmental impacts. The industry has focused primarily on the design end of creating sustainable, cost-efficient buildings without much emphasis on the planning aspect of a construction project. The planning aspect of any construction project is critical to the success of the project. Proper sequencing of labor, materials, and equipment is one of the key factors in the success of a construction project. Construction managers are responsible for managing resources such as construction materials, labor, and equipment to ultimately provide a quality building on time, within budget, and without incidents. How efficiently such resources are used on a construction site may influence a project’s environmental sustainability, as each resource contains embodied energy (EE).

EE is sequestered in building materials, as well as all processes of production, on-site construction, and final demolition and disposal (Dixit 2010 et al.). Initial embodied energy (IEE) is the energy used during the production of materials and components of a building, including raw material procurement, building material manufacturing, and final product delivery to a construction site (Dixit et al. 2010). IEE can be classified as either direct or indirect energy. Researchers have determined that direct energy is consumed in various on-site and off-site operations like construction, prefabrication, transportation, and administration and that indirect energy is mostly used through building materials, assemblies, and equipment installed in the building. Indirect energy is mostly used during the manufacturing of building materials, in the main process, upstream process, and downstream process, and during renovation, refurbishment, and demolition. More specifically, Initial embodied energy (IEE) is the energy used during production of materials and components of a building, including raw material procurement, building material manufacturing, and final product delivery to a construction site (Dixit et al. 2010). The management of resources affects both the direct and indirect aspects of IEE. For example, proper planning can prevent a task like rework, requiring (direct energy) more energy to complete the construction task, and (indirect energy), ordering more material to complete the construction task. The mismanagement of multiple tasks can adversely affect energy consumption on construction sites.

Studies have shown that, on average, 90% of IEE is attributed to building materials (Dixit, 2017). Therefore, reducing materials’ EE, site energy, and construction energy would reduce overall IEE (Dixit et al. 2010).

Purpose of the Study

The aim of this research is to help reduce construction waste, material damage, additional equipment use, additional transportation, and additional movement of material causing rework on construction sites. The goal is to enable IEE reduction in a construction project by efficiently managing construction resources. The objectives of the study were as follows:

1. Identify what site logistics factors can help reduce the use of construction materials.
2. Considering the factors, determine their rank in terms of their influence on material use/wastage and IEE.

Significance of the Study

The research is of significance for multiple reasons. First, this research examines and analyzes how EE may be impacted by a site logistics plan. Second, the Delphi method has been applied in other fields, but its application in construction engineering and management has rarely been explored; this work presents a process through which the Delphi method can be applied to a construction site. This proposed Delphi method model can demonstrate how to create a weight table for panel of experts.

Delimitations

The study is delimited to construction industry professionals who have worked in the State of Texas.

Definitions

Adequate forecasting/planning. The planning, organizing, and controlling of the execution of a project (e.g., preconstruction meetings, site logistics plan).

Demolition energy. Energy necessary for deconstruction of building materials and disposing of building materials;

Initial embodied energy (IEE). Energy used during production of materials and components of a building, including raw material procurement, building material manufacturing, and final product delivery to the construction site.

Just-in-time (JIT) delivery/construction. An inventory management approach designed to eliminate waste by receiving goods only as they are needed for production processes. While JIT delivery is most often correlated with combating the issue of inventory waste, it is also perfectly applicable to the elimination of downtime and all eight waste elements as defined by Lean construction.

Location. A particular place or position (e.g., location after transportation delivery).

Material packaging. Product and material protection element during transport, distribution, and storage (e.g., shrink wrap, cardboard, plastic).

On-site construction waste supervision system. Constriction jobsite material waste system used to separate material debris. (e.g., Leadership in Energy and Environmental Design [LEED], Lean construction).

Prefabrication. The practice of assembling components of a structure in a factory or other manufacturing site and transporting complete assemblies or subassemblies to the construction site where the structure is to be located (e.g., preassembled walls/bathrooms).

Recurrent embodied energy (REE). Energy used in various processes for maintenance and refurbishment of buildings (building materials and building components) during their useful life.

Site conditions. The condition of a site, including but not limited to climatic, hydrological, hydrogeological, ecological, environmental, geotechnical, topographical, and archaeological conditions (e.g., hardscape, rough muddy terrain).

Storage system before installation (material usage). The provision of adequate space, protection, and control for materials, components, and equipment that are to be kept on a construction site during the building process (e.g., outside/inside a building).

Superintendent/site manager leadership/execution experience. The years of experience as a site manager. Site managers are required to keep within the timescale and budget of a project and manage any on-site delays or problems encountered during a construction project.

Technology/equipment. A set of tools used for a single purpose (as opposed to individual tools, which are instruments that are generally used by hand, such as a pallet jack). Equipment, which may be mobile, semi-permanent, or permanent, is intended for heavy work such as earth-moving, lifting containers or materials, drilling holes in earth/rock, or concrete/paving application (e.g., forklift, crane)

Waste management governmental regulations. The reduction of solid waste in accordance with federal, state, and local regulations such as EPA requirements.

Weather conditions. High temperatures, low temperatures, precipitation in all forms, wind conditions, and humidity conditions (e.g., rain, snow, hail).

CHAPTER II

LITERATURE REVIEW

Concepts in the Literature

Site Logistics

Efficient management of construction sites is usually subjected to constraints that often jeopardize the efficient utilization of valuable construction resources by the site manager (Fapohunda et al 2014). Logistics involves planning, implementation, and controlling of construction resources in terms of supply, storage, processing, and handling (Regassa 2015). Taking this idea and implementing it on a construction site requires great skill and a deep knowledge base. Logistics in the context of construction can be described as a management function involving the procurement, transportation, handling, storing, and efficient use of materials on site (Tunji-Olayeni, et al. 2017). Waste, particularly from materials, stems from inefficient logistics and may result in time and cost overruns (Tunji-Olayeni, et al. 2017). Minimizing waste, on the other hand, stems from identifying the causes of waste (Hoe, 2006).

Construction Site Layout Planning

Part of project planning in construction is coordinating the project site layout. An optimal construction site layout improves the productivity of a construction project and the safety level of a construction site. Therefore, effective construction site layout planning (CSLP) is critical to the success of a construction project (Ning et al. 2010). No major project can be successful without a well-thought-out site logistics plan. A site logistics plan can be defined as a set of activities that need to occur in a certain sequence to assist in the avoidance of disruption. The project team must be able to maneuver people, equipment, and material efficiently and safely. CSLP has been recognized as a critical step in construction planning by practitioners and researchers. CSLP is a decision-making process that involves identifying problems and opportunities, developing solutions, choosing the best option, and implementing it (Ning et al. 2011). The project team must be able to think critically about current issues that present themselves and also be able to forecast project progress. For example, storing materials on site can have a negative impact on project outcomes. Materials can be damaged by weather, moving equipment, or people (Fei, 2014). Efficient material logistics requires the use of innovative techniques like just-in-time (JIT) delivery in order to minimize the negative impacts of storing materials on site. Construction activities are usually performed in stages. Each stage depends on completion of the previous activity. Late completion of one activity affects the start time of the next activity. Hence, adequate activity planning is required for efficient material logistics on site. (Tunji-Olayeni, et al. 2017).

Waste

Construction waste is caused by the inefficient use of equipment, manpower, resources, or capital, that is, using a larger quantity than that required for production (Formoso et al. 1999). Ohno (1988) defined seven types of waste in manufacturing that Lean construction has adopted: overproduction, conveyance, inventory, waiting, processing, motion, and correction. Lean construction case studies have reported these seven manifestations in the production of buildings. Koskela (2004) observed that the first five refer to the flow of material and the last two to human work.

Discrete waste, that is, material waste, is classified by type, weight (Gavilan and Bernold 1994), volume (Alwi et al. 2002; Ekanayake and Ofori 2004), and cost (Love and Li 2000; Love et al. 1999). Discrete waste exists at the task level. National Research Council (NRC) (2009) has stated that task-level metrics are leading indicators and are commonly used by contractors and subcontractors who must evaluate the efficiency of their workforces on a daily or weekly basis and make adjustments so that problems on active projects can be detected and corrected quickly. “Task” refers to specific construction-related activities, such as placement of concrete or the installation of mechanical systems. Most task-level metrics include explicit measures of output for specific tasks and the labor hours required to complete the task. Most waste measurements are at the discrete level (Fernández-Solis et al 2015). For the purpose of this work, only discrete waste is discussed. Ohno (1998) identified the following seven types of waste, of which the first five refer to the flow of materials and the last two to human work:

- overproduction
- correction
- material movement
- processing
- inventory
- waiting
- motion

Construction Waste Management

Construction waste has been identified as one of the major problems in the construction industry (Park and Tucker, 2016; Udawatta et al., 2015). How to reduce the generation of construction waste and prevent the “garbage siege” phenomenon has become an important issue for governments around the world. From the perspective of sustainable development, effective waste management must focus on generating sources and the implementation of waste reduction management (Tan, 2011).

A contractor's C&D waste management performance significantly contributes to waste minimization in C&D activities (Wu et al., 2017). Ding et al. (2016a) developed the system dynamics model of construction waste reduction management at the construction stage; simulation results from their study showed source reduction to be an effective waste reduction measure, reducing 27.05% of total waste generation. For instance, a United Kingdom report of waste generated by industry showed that while the construction industry contributes 44% of waste in landfills, commercial activities generate as low as 14% and domestic waste contributes only 13% (DEFRA, 2013). This huge proportion of construction waste has prompted various legislative and fiscal provisions, as well as substantial research efforts, seeking to unravel both causes of construction waste and strategies for mitigating construction waste (Ajayi 2017). Despite these efforts, waste generated by construction activities is continuously increasing, irrespective of decrease in those generated by other activities (Ajayi et al., 2015a). A significant portion of generated waste can be attributed to construction sites. The industry has looked for ways to reduce construction waste on construction project sites. Some of the most significant sources of construction waste are design changes, leftover material scraps, waste from packing/no reclaimable consumables, design/detailing errors, and poor weather conditions. Proposed actions for reducing or eliminating waste are also very diverse. Some papers have described attempts to change practices by implementing Lean techniques (Nahmens et al, 2011).

Among the solutions to reduction, waste minimization design (WMD) is commonly identified as a key strategy for effectively minimizing waste (Baldwin et al., 2009).

Damage and Rework

Rework continues to plague the construction industry. Rework requires trades to reperform tasks that should have already been completed. This effort ultimately affects cost and schedule. Previous research has shown that the overall cost of rework is between 2% and 3% of the contract value (Love et al, 1999). Some factors that cause rework are design changes, design errors, construction damage, changes, errors, and omissions. Several researchers have discussed the incidence of rework in construction projects (Love 2002). However, none of them contains much discussion of the concept of rework, nor a clear definition from the industrial engineering point of view. Moreover, the source of data has not always been fully described, and there has been little contribution on how to measure rework or investigate its root causes. The major general cause of rework is variability associated with uncertainty (missing or unstable information). Damaged material on a jobsite can also contribute to project delays. Factors that lead to material damage include improper packaging, improper equipment to offload material, poor staging conditions, and improper staging placement.

Material Movement on the Jobsite

Material movement on a construction site should be reviewed and executed properly. The project team’s goal is to get the material on site and immediately installed. The JIT system was promoted in the early 1950s by Mr. Taiichi Ohno of Toyota Motor Corporation and the creator of the Toyota Production System. JIT concepts have been used in the manufacturing sector of Toyota Motor Corporation and have proved to be a success because the cars manufactured have been better quality and reliability, productivity has been improved, costs have been reduced, and storage space has been achieved by maintaining inventory levels (Pheng et al, 1999). This system can be very beneficial to a project team. The procurement process needs to align with the JIT system for construction material movement to be efficient.

Embodied Energy (Initial Embodied Energy)

EE has been referenced in published literature as early as 1963. Much of the literature has discussed the economic aspects of EE in terms of goods and services. The works referencing EE, though, did not analyze or discuss buildings and construction in detail until the mid-1990s to early 2000s. The emergence of LEED and “green” construction has forced the industry to take a closer, more analytical look at construction and how the industry manages its resources. In order to understand EE, one must first understand the life-cycle energy of a building. The total life-cycle energy of a building includes both EE and operating energy (Ding 2004; Crowther 1999). EE is sequestered in building materials and all processes of production, on-site construction, and final demolition and disposal (Dixit 2010). Dixit explained (as cited by Koskela [4]) that the energy consumed in production is called the “embodied energy” of the material and is of concern for energy consumption and carbon emissions (Dixit 2010). Buildings are constructed with a variety of building materials, and each material consumes energy throughout its stages of manufacturing, use, and deconstruction. These stages consist of raw material extraction, transport, manufacturing, assembly, and installation. The final stage consists of its disassembly, deconstruction, and decomposition (Dixit 2010). Dixit created an EE model for the life cycle of a building. As shown in Fig. 1, EE is categorized as either direct or indirect energy. Direct energy is consumed in various on-site and off-site operations like construction, prefabrication, transportation, and administration (Ding 2004; Fay et al 2008; Treloar 1998). On-site direct energy includes energy consumed during the assembly of building materials and components on a construction site. Off-site direct energy consumption includes building components that are prefabricated at a location off the construction site. Direct energy can also be in the form of the transportation activities involved in on-site construction and assembly and off-site prefabrication.

For the purpose of this paper, the focus is on indirect energy. Dixit explained indirect energy (Dixit 2010) as energy mostly used during the manufacturing of building materials in the main process, upstream process, and downstream process and during renovation, refurbishment, and demolition. Demolition energy, specifically, is the energy necessary for deconstruction of building and disposing of building materials.

This work more specifically focuses on recurrent embodied energy (REE), which is a type of indirect energy used in various processes for maintenance and refurbishment of buildings (building materials and building components) during their useful life. As previously mentioned, IEE is energy used during production of materials and components of a building, including raw material procurement, building material manufacturing, and final product delivery to the construction site. Dixit explained that IEE is consumed during the upstream process of material production, including raw material mining, processing, and delivery, and the downstream process, consisting of manufacturing, packing, and delivery. IEE is also consumed in facility activities affecting construction, fabrication, transportation, and administration. It is noteworthy to mention that EE is measured in GJ/m^2.

Gonzalez and Navarro asserted that building materials possessing high EE could possibly result in more carbon dioxide emissions than would materials with low EE (Gonzalez et al.2006). Dixit created an EE model for the life cycle of a building, as shown in Fig. 1. Based on the detailed definitions presented, the efficient use of resources would reduce IEE.

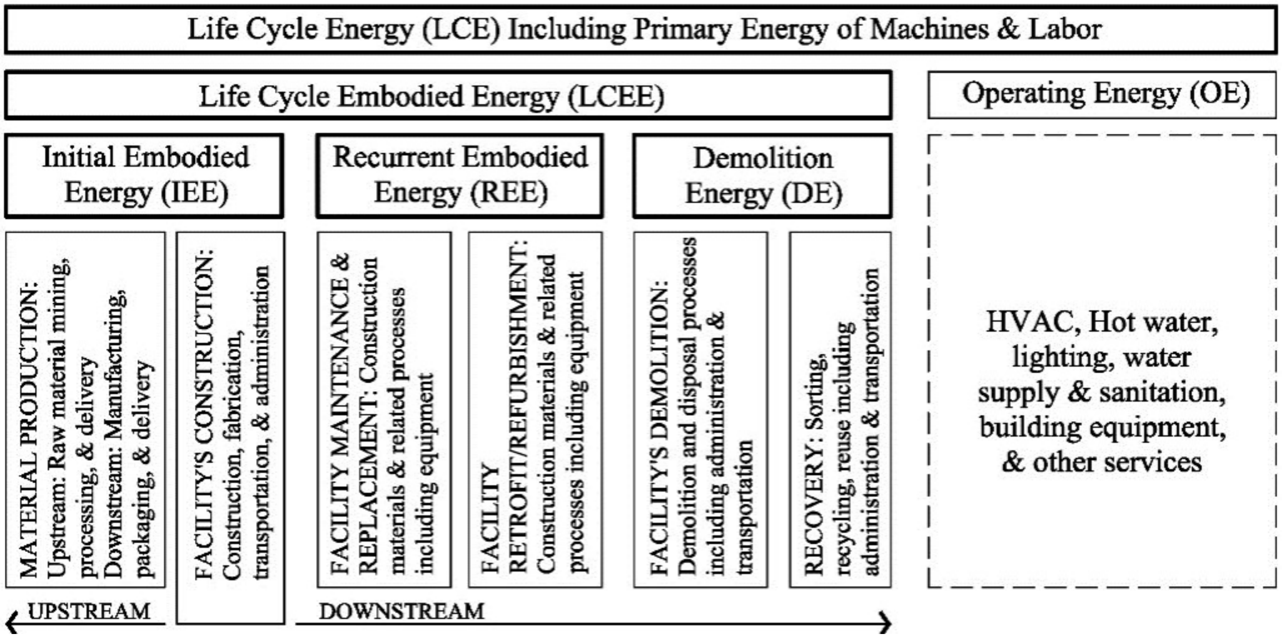

Fig. 1. Life-cycle energy model for a building.

Literature Analysis

Data Collection

This study adopted a four-step process for data collection, as modeled by Borrego et al. (2014), to ensure that data represented the posed research questions. The four steps involved were as follows:

1. Define the research question
2. Define the scope of inquiry
3. Find sources
4. Apply appropriate exclusion criteria

Defining the Research Question

This work aimed to address the following research objectives:

1. Identify what site logistics factors can help reduce the use of construction materials.

2. Considering the factors, determine their rank in terms of their influence on material use/wastage and IEE.

Defining the Scope of Inquiry and Finding Sources

Peer-reviewed research papers published after 1990 were extracted from various databases:

- *African Journal of Environmental Science and Technology*
- *Asian Conference on Real Estate 2011*
- *Earthscan Publications Ltd.*
- *International Journal of Advances in Applied Sciences*
- *International Journal of Civil Engineering and Technology (IJCIET)*
- *International Journal of Construction Management*
- *Journal of Construction Project Management and Innovation*
- *Journal of Engineering and Technology*
- *Journal of Engineering Design and Technology*
- *Journal of Sustainable Development*
- *Korean Society of Civil Engineers (KSCE) Journal of Civil Engineering*
- *Procedia - Social and Behavioral Sciences*
- *Trans Tech Publications Ltd.*
- *Waste Management*

Articles in peer-reviewed journals and conference papers constitute a primary source of reviewed information. To narrow the scope of search results, articles in the literature review were chosen based on the following criteria:

- language
- text availability
- article type
- publication date

Additionally, technical reports from famous effective local and national research institutes, government documents, and other literary sources were also gathered to obtain a holistic literature review. Keywords used in search engines included the following:

- factors + construction waste
- waste + minimize + construction
- construction + material damage
- re-work + construction
- Delphi method + construction
- embodied energy + construction + site logistics
- site logistics + material movement

Applying Appropriate Exclusion Criteria

Inclusion and exclusion criteria were developed by accounting for the research questions. In particular, the focus was on construction sites. As a result, articles focusing on time wastage, cost wastage, or design factors were excluded. Eventually, 16 articles were identified—12 quantitative studies, 3 qualitative studies, and 1 mixed-methods study. Article descriptions can be found in Table 1, and the process followed in the literature analysis is presented in Fig. 2.

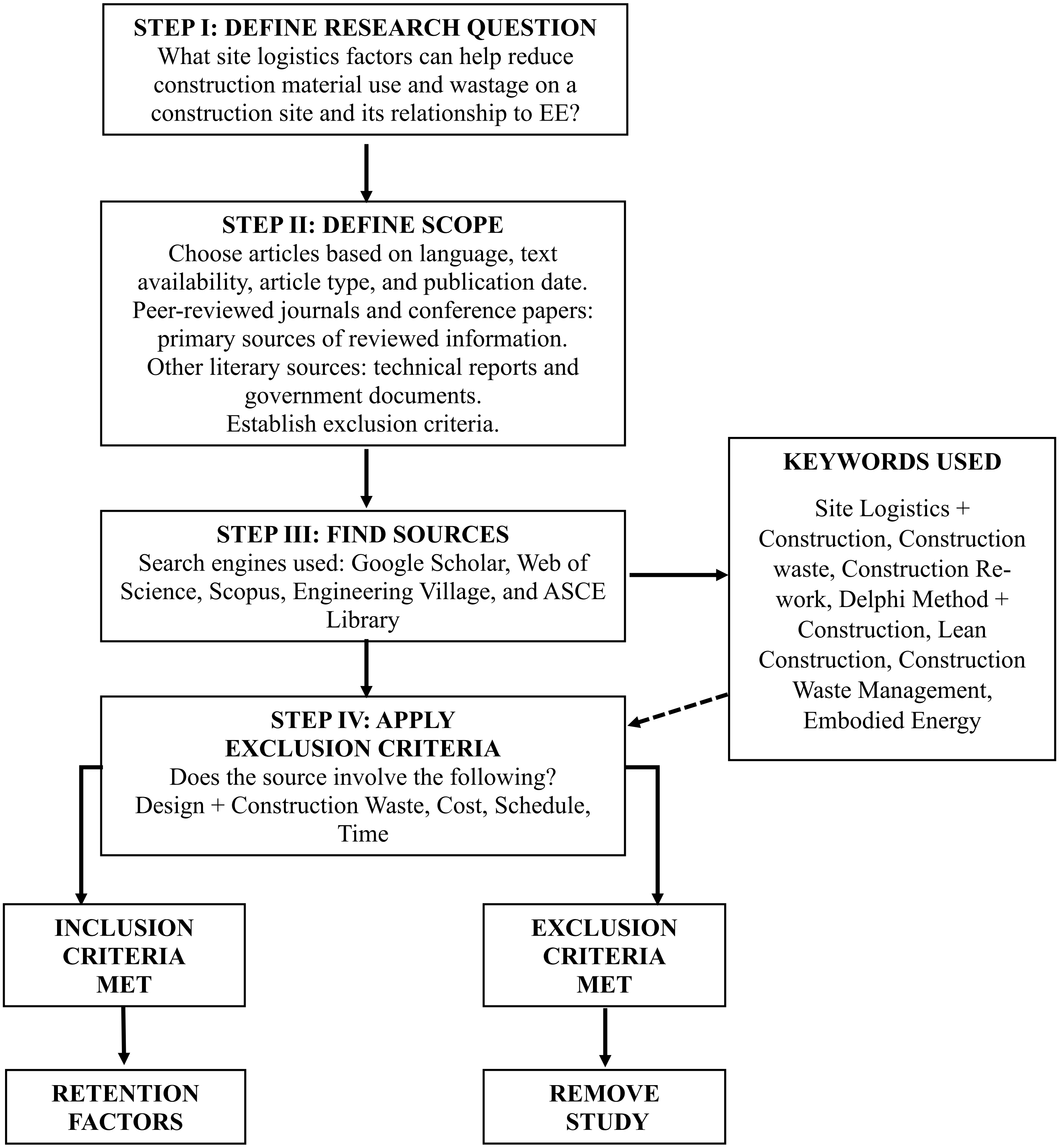

Fig. 2. Flowchart of systematic literature review process (adopted from Hurwitz et al., 2016).

Table 1. Article descriptions

#	Author(s)	Year	Title of the study	Article source	Research method	Factor(s)	Summary
1	Tunji-Olayeni et al.	2017	Impact of logistics factors on material procurement for construction projects	*IJCIET*	Quantitative method	1. Late delivery of materials and components 2. Inability to forecast activity period with accuracy 3. Delivery inaccuracies 4. Transportation 5. Storing materials on site 6. Increase waiting time between activities	Performed research based on a quantitative research design with the use of a questionnaire. Convenience sampling was used to distribute 85 questionnaires to contractors in Abuja, Nigeria. A total of 55 questionnaires were properly filled and returned, representing a 65% response rate. Data collected were analyzed using Statistical Package for the Social Sciences (SPSS) version 21.
2	Chileshe, Nicholas, et al.	2012	Construction management and a state of zero waste	Earthscan Publications Ltd.	Quantitative method	1. Materials 2. Site management 3. Machinery 4. Production information 5. Manpower 6. Lean designing 7. Inefficient labor use 8. Inefficient machinery use 9. Total quality management techniques, “zero defects” 10. Lack of training 11. Changes to organizational culture	Identified several issues affecting the implementation of waste strategies at the mesolevel.
3	Adebowale et al.	2015	Analysis of construction-related factors affecting the efficiency construction labor	*Journal of Construction Project Management and Innovation*	Quantitative method	1. Rework due to construction error 2. Site manager’s coordinating skill 3. Effective site-planning ability 4. Planning ability of site managers 5. Rework due to unclear instruction from supervisor 6. Level of education of site managers	Provided factors affecting construction workforce efficiency, as explored from the review of literature produced by previous research and exploratory studies conducted at the early stage of the study. A majority of the questionnaires were hand-delivered to respondents, and the remainder were administered through email. Sixty-two were retrieved and analyzed with SPSS version 22.

Table 1. Continued

#	Author(s)	Year	Title of the study	Article source	Research method	Factor(s)	Summary
4	Fapohunda & Chilese	2014	Essential factors towards optimal utilization of construction resources	*Journal of Engineering Design and Technology*	Quantitative method	1. Bad workmanship 2. Inadequate supervision 3. Improper planning 4. Poor organization of project site by the site manager 5. Budgeting for construction resources waste syndromes 6. Attitudinal behavior of construction participants to work 7. Weather condition 8. Technological change during work in progress 9. Legal and local authority regulations 10. Resources procurement system	Evaluated problems associated with the site managers' project delivery and establishes essential factors toward efficient resource utilization. It identified these intrinsic hindrances and established facilitators that will ultimately enhance the site manager's efficient performance. In all, 102 completed questionnaires were obtained. The information collected was analyzed using SPSS version 13 and presented in tables and figures
5	Fapohunda et al.	2012	Critical evaluation of allowance for resources wastefulness in the construction industry	*Journal of Sustainable Development*	Quantitative method	1. Construction project location 2. Lack of skilled manpower 3. Environmental and weather conditions 4. Lack of new innovative skilled workers 5. Subcontractors' carefree attitude 6. Site management	Identified the behavioural features of site participants in resource wastefulness and provides an incentive framework for achieving efficient utilization of construction resources. Questionnaires totalling 102 were collected and analyzed using SPSS.
6	Tam & Hao	2014	Prefabrication as a mean of minimizing construction waste on site	*International Journal of Construction Management*	Qualitative method	1. Prefabrication	Revealed the status of construction waste, investigated the effectiveness of prefabrication in terms of waste reduction in replacing traditional on-site production, examined the factors that help minimize construction waste by adopting prefabrication, and explored the areas of waste reduction after adoption of prefabrication in comparison to traditional on-site production.

Table 1. Continued

#	Author(s)	Year	Title of the study	Article source	Research method	Factor(s)	Summary
7	Wang et al.	2008	An investigation of construction wastes: An empirical study in Shenzhen	*Journal of Engineering, Design and Technology*	Quantitative method	1. Enforcement of legislation 2. Lack of training and education 3. On-site waste management system involving environmental consideration in tendering reports 4. Improvement of communication	Analyzed 17 construction projects in Shenzhen to investigate the existing waste situation and to improve waste minimization methods. These projects were rebar-concrete structures, with project costs ranging from 70 million to 3 billion yuan. Three of these projects were selected to trial-implement on-site waste sorting for three months. These three project costs cost about 79 million, 90 million, and 0.21 billion yuan. These data were recorded on site by contractors and collected once a week by the research team.
8	Tam et al	2006	Cutting construction wastes by prefabrication	*International Journal of Construction Management*	Quantitative method	1. Prefabrication 2. Poor workmanship 3. Damage during transportation 4. Lost during installation 5. Overorder 6. Excess after cutting	Conducted an interview survey with 31 construction senior practitioners' observations and opinions on wastage levels when comparing prefabrication with the traditional wet-trade approach. The practitioners included senior project managers, project managers, architects, senior quantity surveyors, and engineers with around 15 to 25 years of on-site experiences. The interviewees were asked to comment on the levels of wastage reduction and reasons for the reduction by comparing prefabrication with other wet-trade activities including in-situ concreting, timber form work, brick laying, plastering, screening, tiling, rebar fixing, and bamboo scaffolding.

Table 1. Continued

#	Author(s)	Year	Title of the study	Article source	Research method	Factor(s)	Summary
9	Jaillon & Chiang	2009	Mentoring experiences and Latina/o university student persistence	*Waste Management*	Quantitative method	1. Form work 2. Packaging and protection 3. Finish work 4. Masonry work 5. Scaffolding 6. Concrete work 7. Material handling 8. Hoarding	Aadministered questionnaire survey to experienced professionals and conducted case studies of recently completed building projects. The results revealed that construction waste reduction is one of the major benefits when using prefabrication compared with conventional construction. The average wastage reduction level was about 52%.
10	Nagapan	2012	Factors contributing to physical and non-physical waste generation in construction industry students	*International Journal of Advances in Applied Sciences*	Quantitative method	1. Handling 2. Workers 3. Management 4. Site conditions 5. Procurement	Developed a matrix of causative factors of construction waste generation. The matrix was developed based on past research articles published worldwide. This factor matrix was then validated by construction experts to detect the relevant factors in the local construction industry. The process was done through interview sessions of selected experts involved in construction. The interview was conducted with seven personnel to cross-check the contributory factors.
11	Nagapan et al.	2011	A review of construction waste cause factors	Asian Conference on Real Estate 2011	Quantitative method	1. Damage during transportation 2. Worker mistakes 3. Poor planning 4. Leftover materials on site 5. Ordering errors	Analytically reviewed construction waste causes from the beginning to the end of construction activity. This information will help researchers and construction industry players to identify the main causes of construction waste contributing to generated waste.

Table 1. Continued

#	Author(s)	Year	Title of the study	Article source	Research method	Factor(s)	Summary
12	Adewuyi & Odesola	2015	Factors affecting material waste on construction sites in Nigeria	*Journal of Engineering and Technology*	Quantitative method	1. Over/underordering 2. Waste from uneconomical shapes 3. Lack of on-site material control 4. Poor storage of materials 5. Double handling of materials 6. Poor workmanship	Used a questionnaire survey to elicit the perceptions of consultants and contractors for a period of six months about the factors affecting the generation of material waste on a building site in the south-south zone of Nigeria comprising six states (Akwa Ibom, Bayelsa, Cross River, Delta, Edo, and Rivers). Questionnaires were sent randomly; 85 selected consultants and contractors responded.
13	Roseline et al.	2016	Factors influencing waste generation in the construction industry in Malaysia	*Procedia - Social and Behavioral Sciences*	Quantitative method	1. Inappropriate storage leading to damage 2. Lack of on-site material control 3. Damage caused by subsequent trades 4. Offcuts	Carried out a quantitative study to investigate the perception of selected contractors concerning the construction waste issue. From the recognized factors, a structured questionnaire was developed and distributed to contractors. From the total of 500 questionnaires distributed, only 306 (61%) of the respondents duly filled and returned the questionnaires. Information was analyzed with SPSS.
14	Khanh & Kim.	2013	Identifying causes for waste factors in high-rise building projects: A survey in Vietnam	*KSCE Journal of Civil Engineering*	Quantitative method	1. Poor planning and scheduling 2. Lack of trade skills 3. Poor site layout 4. Poor equipment choice or ineffective equipment 5. Overallocated/unnecessary materials on site	Identified the main waste factors and their causes in current construction performance. Responses were received from 159 professionals. After filtering these, only 128 numbers of responses were found usable. Thus, rate of response in this study was 43%.

Table 1. Continued

#	Author(s)	Year	Title of the study	Article source	Research method	Factor(s)	Summary
15	Mokhtar et al.	2010	Factors that contribute to the generation of construction waste at sites	Trans Tech Publications Ltd.	Quantitative method	1. Untidy construction sites 2. Poor handling 3. Overordering 4. Method of material packaging 5. Prefabrication	Conducted in collaboration with a Malaysian-based construction company. Three construction sites were selected for this study, which adopted different types of construction methods with different types of buildings and project sizes. Additional interviews with construction workers and site engineers were conducted to provide additional information.
16	Wahab & Lawal.	2011	An evaluation of waste control measures in construction industry in Nigeria	*African Journal of Environmental Science and Technology*	Quantitative method	1. Overconsumption of resources 2. Material damage due to weather and inappropriate storage 3. Material damage on site due to mishandling or careless delivery 4. Rework/improve 5. Materials availability	A total number of 80 questionnaires were administered and 78 were retrieved; this ought to be useful to depict issues concerning waste generation during the construction process. The author recommended that the use of prefabricated elements must be encouraged among contracting firms so as to reduce the amount of waste that may be generated.

CHAPTER III

METHODOLOGY

The goal of this research is to reduce the EE of construction material, surplus waste, material damage, additional equipment use, additional transportation, and additional movement of material causing rework on construction sites. After reviewing many studies, not much background knowledge on the research topic was found. Therefore, the need was felt to create this background knowledge by expert opinion using the Delphi method. The Delphi method is a systematic and interactive research technique for obtaining the judgment of a panel of independent experts on a specific topic. Individuals (panelists) are selected according to predefined guidelines and are asked to participate in two or more rounds of structured questionnaires. For this study, questionnaires were sent out via email and/or were read aloud to panelists through conversation via mobile contact. This method proved most feasible given the limited time restrictions of the panelists. Responses were sent back via email and/or were read aloud to the questionnaire administrator through conversation via mobile contact.

After each response round of the Delphi method, the facilitator provides an anonymous summary of the experts' input from the previous survey as a part of the subsequent survey. In each subsequent round, participants are encouraged to review the anonymous opinions of the other panelists and consider revising their previous response. The goal during this process is to decrease the variability of the responses and achieve group consensus about the correct value. Finally, the process is concluded after a predefined criterion, such as number of rounds or achievement of consensus, is met; a statistical aggregation of the responses in the final round determines the results (Hallowell et al, 2009).

The Delphi method is a systematic procedure to evoke expert opinion. Its intended outcome is to achieve a reliable consensus among a selected panel of experts. Based on the current state of knowledge, this proved to be the most appropriate method for this study. To successfully achieve a reliable consensus, the Delphi method was used to solicit opinions from a selected panel of experts. The expert panel for this study was constituted of professionals/practitioners from the construction industry. The term “expert” refers to a person who is very knowledgeable about or skillful in a particular arena. The term “panelist” refers to an expert individual who is part of a larger group of construction industry professionals.

Moreover, because experts might have differing opinions or perceptions on the ranked benefits due to their levels of experience, exposure, region, and professional background, Zahoor et al. (2017) argued for the need for consensus among the experts, as well as validation of their agreement level. In construction-related research, there has been a limited number of studies utilizing Delphi. Based on critical review of the literature, discussions with researchers in construction management, and experience applying the method, it has been observed that limited awareness of Delphi and lack of clear guidance in the literature related to how it operates could be among the contributing factors to the limited use of Delphi in construction management research (Sourani et al, 2015). A flowchart of the Delphi method as employed in this study is shown in Figure 3.

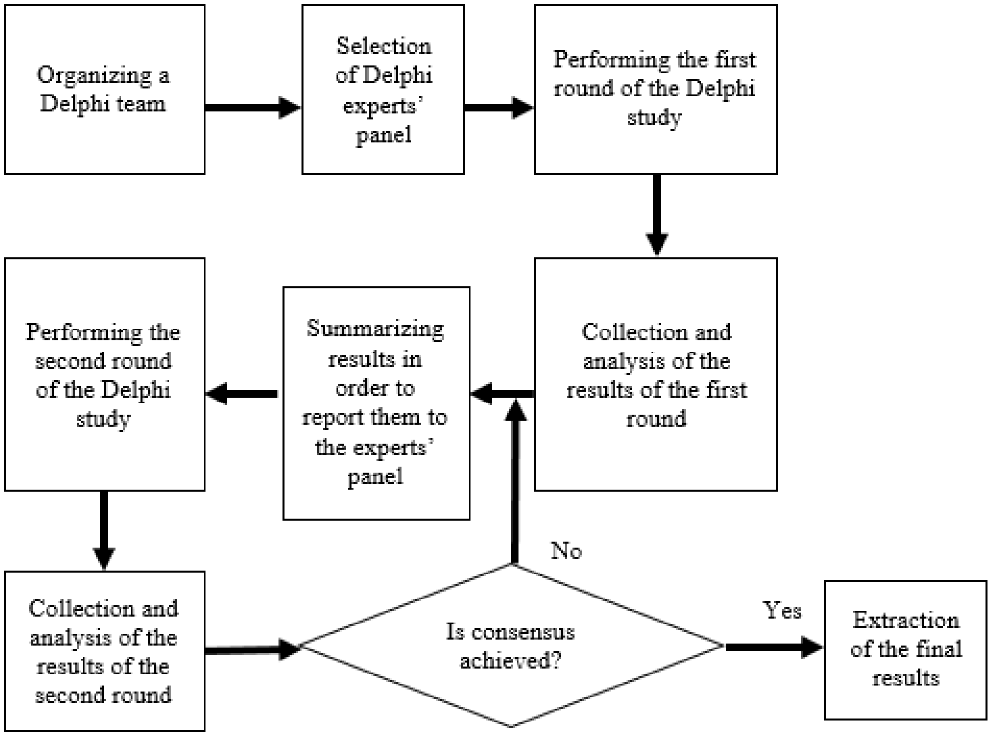

Fig. 3. Delphi method process (adopted from Mozaffari et al., 2012).

Justification for Using the Delphi Method

- Compared to questionnaire surveys, the Delphi method offers better interaction with respondents and could potentially provide more understanding of complex problems (MacCarthy & Atthirawong, 2003; Mullen, 2003).
- By reviewing relevant literature, Sourani and Sohail (2015) concluded that the Delphi method can be useful when there is a need to
  - "study or define areas where there is considerable uncertainty and/or a lack of agreed knowledge or disagreement

  - allow for combining fragmentary perspectives into a collective understanding
  - model a real-world phenomenon involving a range of viewpoints and for which there is little established quantitative evidence
  - highlight topics of concern and assess uncertainty in a quantitative manner
  - obtain accurate information that is unavailable or expensive to obtain
  - handle complex problems that require more judgmental analysis."
- The Delphi technique is useful when the opinions and judgments of experts and practitioners are necessary. It is especially appropriate when it is not possible to convene experts in one meeting (Kirun &Varghese, 2015).
- The Delphi method has seen increased use for construction engineering and management research since the early 1990s (Ameyaw et al., 2016, Hallowell & Gambatese, 2010).

Delphi Panelists

Selection of Panelists

Selecting well-qualified, well-rounded, and diverse panel members is one of the most critical facets of the Delphi method in order to ensure minimal bias and increase internal and external validity. For the academic level, this study employed criteria recommended by Hallowell and Gambatese (2010) to qualify an individual as a panel expert. Specifically, an identified academic expert scored a minimum of 11 total points on an expert evaluation system, shown in Table 2, to qualify for participation in the academic level of the study. Characteristics of this study's Delphi panelists for the industry level are presented in Table 3.

Table 2. Expert evaluation system

Achievement or experience	Points (Each)
Professional registration	3
Years of professional experience	1
Conference presentation	0.5
Member of industry organization	1
Professional certification	3
Peer-reviewed journal article	2
Writer/editor of an article/blog	1
Advanced degree:	
BS	4
MS	2
PhD	4

Table 3. Industry expert characteristics

Industry expert ID	Years working in the field of construction	Background	Education	Project size ($)	Gender
P1	18	Project manager	BS	250M	Female
P2	1.5	Superintendent	High school	50M	Male
P3	18	Superintendent	BS	17M	Male
P4	15	Project manager	BS	195M	Female
P5	12	Superintendent	MS	12M	Male
P6	17	Superintendent	High school	30M	Male
P7	10	Lean specialist	BS	50M	Male
P8	13	Superintendent	High school	50M	Male
P9	9	Superintendent	B.S.	63M	Male
P10	14	Superintendent	High school	500M	Male
P11	19	Assistant superintendent	BS	80M	Male
P12	32	Superintendent	BS	40M	Male
P13	5	Superintendent	High school	60M	Male
P14	15	Professor	BS	50M	Male
P15	15	Project manager	High school	49M	Male
P16	8	Superintendent	High school	256M	Male
P17	30	Safety manager	BS	69M	Male
P18	18	Material vendor	High school	5M	Male
P19	13	Superintendent	High school	13M	Male
P20	14	Superintendent	BS	75M	Male
P21	28	Professor	BS	26M	Male
P22	12	Superintendent	High school	89M	Male
P23	24	Superintendent	High school	53M	Male
P24	16	Material vendor	BS	7M	Female
P25	11	Superintendent	BS	63M	Male
P26	13	Professor	BS	25M	Male
P27	16	Superintendent	High school	34M	Male
P28	21	Superintendent	BS	18M	Male

Number of Expert Panelists

While previous literature has provided no particular guidelines on the number of Delphi panelists, as shown in Table 4, of 67 studies using the Delphi technique in the area of construction engineering and management, a majority involved 8 to 20 members (Ameyaw et al., 2016). In contrast to traditional statistical surveying, the goal of the Delphi technique is not to select a representative sample of the population, but rather to yield more accurate results by experts in their field (Kirun & Varghese, 2015). The panel sizes for construction industry professionals are shown in Table 5.

Table 4. Panel size in identified Delphi papers (Ameyaw et al., 2016)

Panel size	3–7	8–20	21–30	31–40	41–50	51+	Total
Frequency	7	41	9	5	4	1	66

Table 5. Panel sizes of the study

Delphi panelist type	Round one	Round two	Round three
Construction industry professional	28	25	21

Number of Delphi Rounds

The goal of performing multiple rounds in the Delphi method is to obtain consensus among panelists (Sourani & Sohail, 2015), along with improving precision by using controlled feedback and an iterative process (Hallowell & Gambatese, 2010). While literature has been inconclusive on the optimal number of rounds for the Delphi method, this study included three rounds for the academic level and two rounds for the industry level for the following reasons:

- After reviewing 88 papers in construction engineering and management, Ameyaw et al. (2016) reported that 40 reached desired consensus after two or three rounds.
- Studies involving only two rounds are not sufficiently capable of identifying outlying viewpoints, obtaining justification, or sharing this information with other panelists (Hallowell & Gambatese, 2010).
- Responses are more likely to obtain consensus on the correct value rather than conforming to an incorrect opinion after the second round (Hallowell & Gambatese, 2010).
- Hasson stated that the researcher should take into account participant fatigue, attrition rate, time, and cost if the research involves more than three rounds (Ameyaw et al., 2016). In addition, research has shown that the number of experts participating in a study decreases after round two (Chan et al., 2001; Rajendran & Gambatese, 2009; Xia et al., 2011).

Round One

This round aimed to further refine the retention factor list identified through the literature review with open-ended interviews with construction experts. Round one intended to use interview data as an indication of nonpublished perspectives by the board of experts on establishing site logistics factors that can influence and reduce material waste and material damage on construction jobsites. The aforementioned themes are either associated with material damage or construction waste. The factor list identified through the literature review was not refined or changed. Panelists were made aware of 11 site logistics factors from literature affecting material waste and damage on construction job sites. There were asked if they agreed with the original 11. If not, they could add up to four additional factors. The four most-frequently-replied factors were compiled on the list, totaling 25 factors. This round took 27 days.

Round Two

This round asked panelists to rank the level of importance of each factor impacting the reduction of material waste and material damage on construction jobsites. By analyzing the literature review findings and the results obtained from round one, the round two questionnaire was developed. Data in this round were gathered using a self-administered, researcher-designed survey instrument. The survey questionnaire was divided into two sections. Section one collected key demographic information such as professional background, gender, job title, and years of experience in the construction industry. The survey was administered using Microsoft Word, email, and phone conversations. Participation was voluntary, and participant information remained confidential. This round took 20 days.

Round Three

This round aimed to provide Delphi panelists with the opportunity to reconsider the responses they provided in round two. By analyzing the results obtained from round two, the round three questionnaire was developed. The round three survey included only one ranking-order question. Based on feedback from the academic experts regarding the ranking-order question in round two, it was difficult for them to compare 15 factors simultaneously. As posited by Miller's law (1956), there are limits on the human mind's capacity for processing information; an individual normally can compare only 7 ± 2 items at the same time. Taking Miller's law into account and consulting with the advisory committee, ranking-order questions in this round comprised eight of the most important retention factors from round two. This round took 15 days.

A mixed-methods research synthesis (MMRS) (Sandelowski, et al. 2007; Heyvaert, et al. 2013) was employed to analyze a body of empirical articles reporting on the factors affecting waste on a construction site. MMRS investigates data collected, analyzed, and interpreted in qualitative, quantitative, and primary-level mixed studies (Heyvaert et al. 2013). By employing MMRS “compared to ‘unmixed’ syntheses more complete, concrete, and nuanced answers can be given to complex research questions” (Heyvaert, et al. 2013,). In MMRS, analysis includes organizing, summarizing, and categorizing data in a form that computes the equivalent of an effect size.

CHAPTER IV

RESULTS

Analysis of the Data

A majority of panelists (89.2%, 25 of 28) were male, and three (10.7%) were female. Over half of respondents (60.7%) reported completing their bachelor's degree or higher, and 39.2% reported a high school diploma as their minimum completed education. A majority of panelists (89.2%) reported working in the construction industry for a minimum of 10 years (Table 3). The majority of respondents (64.2%) were superintendents, followed by project managers (10.7%), professors (10.7%), material vendors (7.1%), lean specialist (3.6%) and safety manager (3.6%).

Data Transformation

The first item investigated in the data was if the respondents had agreement on ratings. Kendall's coefficient of concordance (as known as Kendall's W), a measure of agreement among raters, was applied to answer this question. Kendall's W of the data for round two was equal to 0.0643299, showing no agreement among the raters. Usually, if Kendall's W is smaller than 0.2, there is thought to be no agreement. The larger the Kendall's W, the more unified the raters' opinions. The maximum Kendall's W is 1 (i.e., the raters are in complete agreement).

The second item investigated in the data was the relationship of the raters' covariates to the rank they assigned. Two different methods were used in this step.

Method 1

The author applied a simple setting considering one covariate at a time. First, the author divided the raters into two groups, junior and senior, according to their years of experience.

Then, the author calculated Kendall’s W for each group; the Kendall’s W for the junior group was equal to 0.08908668 and for the senior group was equal to 0.07998236. Similarly, the author divided the raters into two groups according to their education background. The Kendall’s W for the high school diploma group was equal to 0.07420307 and for the bachelor’s degree group was equal to 0.07290223. These numbers show that even within the group, there was still no agreement, indicating that the covariates of raters had no obvious impact on the rank they assigned. In addition, to intuitively explain the conclusion, I dichotomized the data for round two such that if the rank was 1 to 8, the rater was thought to find the corresponding site logistics factor important, and if the rank was higher than 8, the rater was thought to find the corresponding site logistics factor unimportant. Figs. 4 and 5 show the opinions of raters toward the 15 site logistics factors in accordance with raters’ years of experience and education levels. The y axis represents the proportion of raters believing the factor to be important. No obvious discrepancy exists between different groups (junior vs. senior, bachelor’s degree vs. high school diploma).

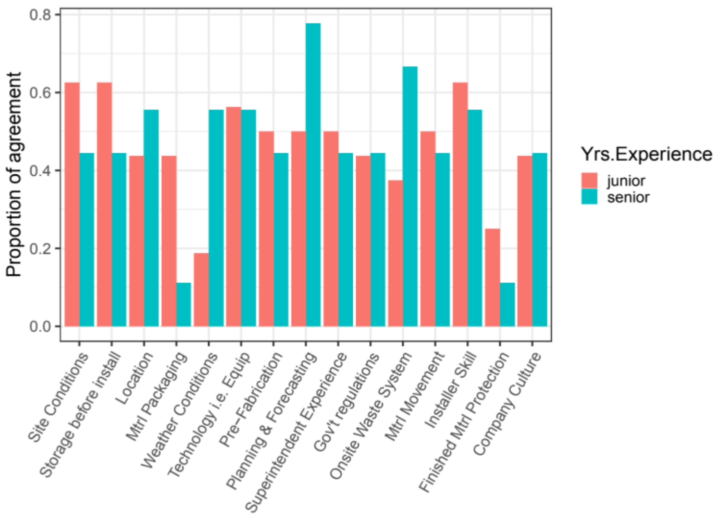

Fig. 4. Proportion of agreement between raters according to industry experience.

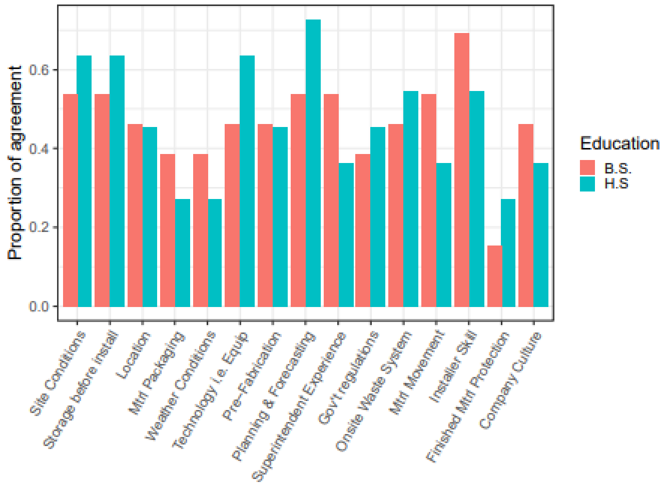

Fig. 5. Proportion of agreement between raters according to education level.

Method 2

To explore the potential for any subpopulation of all the raters reaching agreement, I went a step further and applied the Mallows model.

Model. Ranking data can be modeled by the multimodal Mallows model by dividing the raters into several homogeneous subpopulations. The model is based on Kendall distance, which describes the homogeneity between rank sequences—two rank sequences are more homogeneous if their Kendall distances are smaller. After division using the Mallows model, ranks in the same subpopulation showed more homogeneity and lower total Kendall distance than those between different subpopulations.

In this work, I looked into the offered ranking data with the following steps. First, I implemented the multimodal Mallows model into several subpopulations and checked the improvement of Kendall's W in each subpopulation. Ensuring that each subpopulation did not have too few raters, I divided the raters into three sub-populations. Second, I checked the agreement proportions of every factor in each subpopulation and found out on which factors raters reached agreement. I selected the factors with agreement proportions reaching 70%. Finally, the author looked into the covariates in each subpopulation and identified differences in covariates between different subpopulations.

Results. The author divided the raters into three subpopulations: (R1, R5, R8, R12, R15, R18, R20), (R3, R10, R11, R17, R19, R21, R22, R23, R24, R25), and (R2, R4, R6, R7, R9, R13, R14, R16). Kendall's W rose from 0.0643299 to 0.4399417, 0.3186429, and 0.1806771 in each group, respectively. Then, I checked the agreement proportions in each subpopulation and made a list of factors with agreement proportions reaching 70%. For the analysis, + meant that the subpopulation was in favor of the factors, and − meant not in favor; I assumed that rankings of 1 to 8 meant a favorable opinion.

- The first subpopulation had high agreement on the following factors: location (+, 85.7%), material packaging (−, 100%), planning and forecasting (+, 100%), on-site waste system (−, 100%), material movement (+, 100%), and finished material protection (+, 100%). Selecting the factors with agreement and reranking them, Kendall's W rose to 0.8134.
- The second subpopulation had high agreement on the following factors: storage before install (+, 80%), location (−, 80%), superintendent experience (+, 80%), government regulations (−, 80%), material movement (−, 90%), installer skill (−, 90%), and finished material protection (+, 80%). Selecting the factors with agreement and reranking them, Kendall's W rose to 0.5337.
- The third subpopulation had high agreement on the following factors: storage before install (+, 75%), weather conditions (−, 75%), technology/equipment (+, 87.5%), prefabrication (−,

87.5%), and installer skill (−, 87.5%). Selecting the factors with agreements and reranking them, Kendall’s W rose to 0.4031.

Finally, the author looked into the relationship between subpopulations and covariates. Table 6 shows the covariates in each subpopulation.

Table 6. Subpopulation covariates

	Subpopulation 1	Subpopulation 2	Subpopulation 3
Average (medium) years’ experience	17.86(15)	14.5(13)	14.25(15)
Average (medium) project size	61.71(40)	98.7(66)	94.25(55)
Proportion of high education (at least BS)	0.5714	0.6	0.375
Average (medium) points	17.43(17)	20.2(17)	18.25(17)

Consensus

To determine consensus results, I addressed whether raters expressed a consistent opinion between rounds two and three. The eight factors used in round three were prefabrication, on-site waste system, installer skill, technology/equipment, planning and forecasting, site conditions, material movement, and company culture. To make this part of the process comparable with the results of round three, I dichotomized the data for round two such that ranks between 1 and 8 were understood as the rater finding the corresponding site logistics factor important, and ranks higher than 8 were understood as the rater finding the corresponding site logistics factor unimportant. Table 7. summarizes the number of factors assigned a lower rank (no higher than 8) in round two by round three respondents. Table 8 summarizes the opinions of raters who responded negatively in round three.

Table 7. Factor agreement between rounds two and three

Rater	Number of factors in the eight factors assigned a lower rank in round two	Agreement with the eight factors in round three
R1	6	No
R3	4	Yes
R4	3	Yes
R5	5	Yes
R6	3	Yes
R7	3	No
R9	5	Yes
R10	6	Yes
R11	5	Yes
R12	5	No
R13	5	Yes
R14	5	Yes
R15	5	Yes
R17	4	Yes
R18	5	Yes
R19	5	Yes
R20	5	Yes
R22	6	Yes
R23	3	Yes
R24	6	No
R25	6	Yes

Table 8. Negative responses in round three

Rater	Remove	Rank in round two	Add	Rank in round two
R1	Site conditions	2	Material packing	12
R7	Company culture	10	Storage system before install	5
R12	Company culture	15	Government regulations	8
R24	Sit conditions	11	Government regulations	14

Table 7 shows that many raters responded positively in round three. However, the eight factors used in round three do not match the eight most favored factors in round two. For example, R3 assigned a lower rank (no higher than 8) in round two to only four factors among the eight used in round three, but he/she still responded with “yes.” Those who responded “no” in round three gave their opinion about which factor to remove and which to add. However, especially for R1 and R24, these raters did not add the factors to which they had assigned a lower rank in round two. Based on these observations, raters were found to have inconsistent opinions between round two and round three.

The final step assigned final ranks to the 15 site logistics factors from round two. To obtain the final rank considering the different weights of raters, I took inverse of the rank as the score given by the rater. Specifically, a rank of 1 received a score of 15, a rank of 2 received a score of 14, and so on. I used the raters’ points as their weights. For each factor, the final score was found as the weighted sum of scores graded by 25 raters. The final ranks ordered from most important to least important were equivalent to the final scores ordered from maximum to minimum. The factors fell as follows from most important to least important:

1. storage before install
2. installer skill
3. prefabrication
4. planning and forecasting
5. location
6. technology/equipment
7. material movement
8. superintendent experience

9. material packaging
10. company culture
11. site conditions
12. on-site waste system
13. weather conditions
14. government regulations
15. finished material protection

CHAPTER V

RECOMMENDATIONS AND CONCLUSIONS

Conclusion

The following conclusion can be drawn from this research: a well-thought-out site logistics plan directly affects resources on a project, as well as a project's schedule, budget, and embodied carbon emissions (EE). Based on the findings, the author recommends taking a critical look at the factors affecting the misuse of resources on construction job sites. Based on results from the study, the consensus agreed that storage before install is most critical factor to minimizing waste and resources on construction sites followed by installer skill and pre-fabrication respectively. The author can agree with these factors based on experience in the field on construction jobsites. Proper storage before install can prevent material from being damaged before it is finally installed. Far too much on jobsites new material is being seen thrown into waste dumpsters due to damage by other trades, weather conditions, etc. Installer skill can prevent to misuse of materials preventing rework and additional material. Pre-fabrication eliminates many logistical factors that encompass the installation of a system (i.e. drywall system, wet wall plumbing system). The Pre-fabrication of system(s) in a controlled environment would eliminate unwarranted resources and unnecessary waste on a construction site.

Limitations

The questionnaire was sent to construction industry workers in the State of Texas only. Opinions from other states or regions may not reflect the opinions stated in this study, as many various factors affect opinions throughout the United States, such as geographical location, seasonal weather, demographics, etc. Limiting the responses to industry professionals in Texas also led to a smaller sample size. Although most Delphi panel sizes range from 8 to 20, a larger sample size across a wider region would further validate the consensus from a national perspective. While some of the research analyzed occurred in the United States, many articles referenced for this study presented projects based in other parts of the world. Finding literature relevant to this particular scope of research work was challenging.

Future Research

For future studies, more vendors should be contacted regarding material damage. Determining greater quantities of materials arriving at landfills would be notable research for others to further address. During the course of this study, the author observed a substantial amount of literature on the effect of design on resource use. I therefore suggest considering the standard size of materials (i.e., 4- × 8-ft sheet rock) during the design process. I also suggest studying general contractors who have eliminated overage buffers to determine the impact on the behaviors of second- and third-tier subcontractors, as well as studying how the Lean approach can be implemented for eliminating the overage process. Finally, I suggest investigating what project managers and superintendents do with project materials on site, including whether there are company policies in place and whether they adhere to them.

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APPENDIX A

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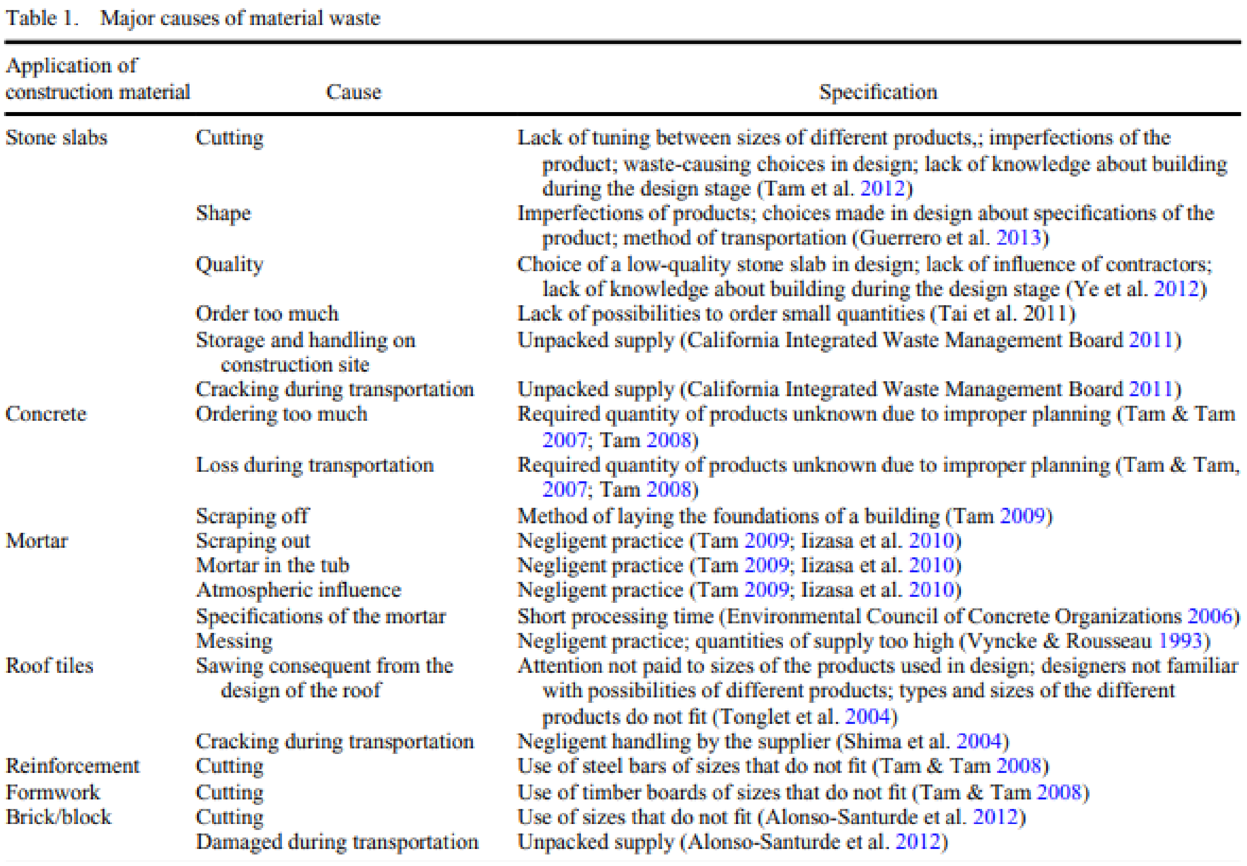

Table 1. Major causes of material waste

Application of construction material	Cause	Specification
Stone slabs	Cutting	Lack of tuning between sizes of different products,; imperfections of the product; waste-causing choices in design; lack of knowledge about building during the design stage (Tam et al. 2012)
	Shape	Imperfections of products; choices made in design about specifications of the product; method of transportation (Guerrero et al. 2013)
	Quality	Choice of a low-quality stone slab in design; lack of influence of contractors; lack of knowledge about building during the design stage (Ye et al. 2012)
	Order too much	Lack of possibilities to order small quantities (Tai et al. 2011)
	Storage and handling on construction site	Unpacked supply (California Integrated Waste Management Board 2011)
	Cracking during transportation	Unpacked supply (California Integrated Waste Management Board 2011)
Concrete	Ordering too much	Required quantity of products unknown due to improper planning (Tam & Tam 2007; Tam 2008)
	Loss during transportation	Required quantity of products unknown due to improper planning (Tam & Tam, 2007; Tam 2008)
	Scraping off	Method of laying the foundations of a building (Tam 2009)
Mortar	Scraping out	Negligent practice (Tam 2009; Iizasa et al. 2010)
	Mortar in the tub	Negligent practice (Tam 2009; Iizasa et al. 2010)
	Atmospheric influence	Negligent practice (Tam 2009; Iizasa et al. 2010)
	Specifications of the mortar	Short processing time (Environmental Council of Concrete Organizations 2006)
	Messing	Negligent practice; quantities of supply too high (Vyncke & Rousseau 1993)
Roof tiles	Sawing consequent from the design of the roof	Attention not paid to sizes of the products used in design; designers not familiar with possibilities of different products; types and sizes of the different products do not fit (Tonglet et al. 2004)
	Cracking during transportation	Negligent handling by the supplier (Shima et al. 2004)
Reinforcement	Cutting	Use of steel bars of sizes that do not fit (Tam & Tam 2008)
Formwork	Cutting	Use of timber boards of sizes that do not fit (Tam & Tam 2008)
Brick/block	Cutting	Use of sizes that do not fit (Alonso-Santurde et al. 2012)
	Damaged during transportation	Unpacked supply (Alonso-Santurde et al. 2012)

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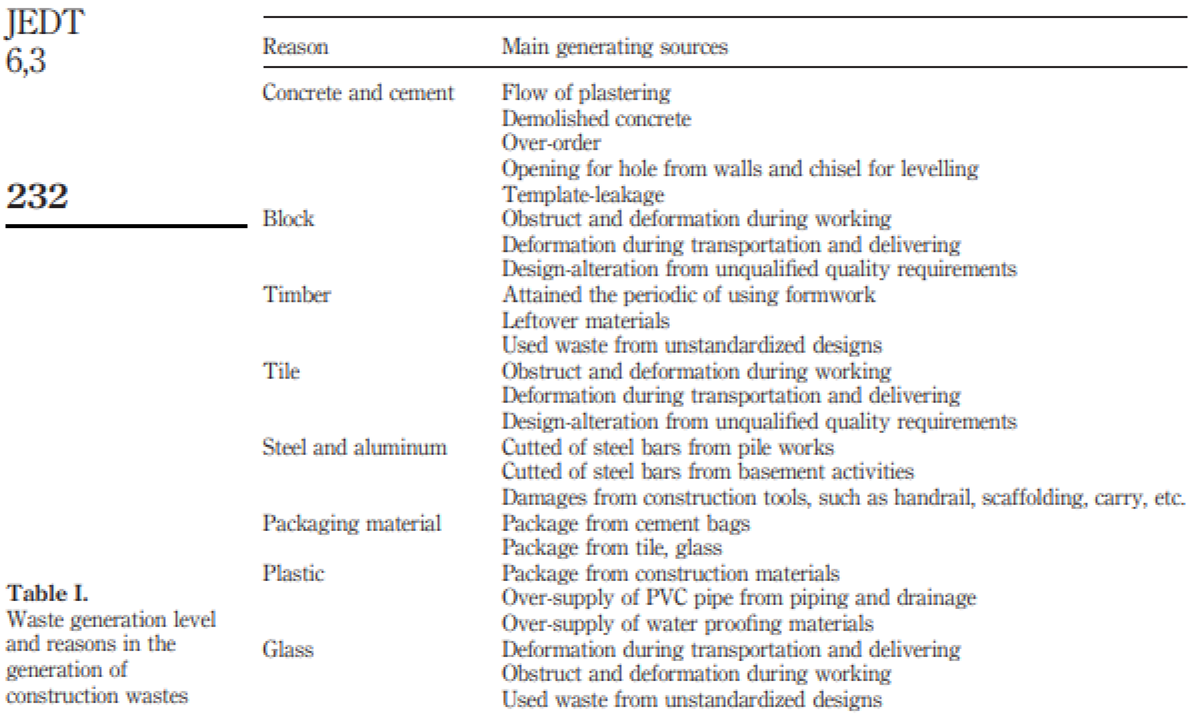

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Table I.
Waste generation level and reasons in the generation of construction wastes

Reason	Main generating sources
Concrete and cement	Flow of plastering
	Demolished concrete
	Over-order
	Opening for hole from walls and chisel for levelling
	Template-leakage
Block	Obstruct and deformation during working
	Deformation during transportation and delivering
	Design-alteration from unqualified quality requirements
Timber	Attained the periodic of using formwork
	Leftover materials
	Used waste from unstandardized designs
Tile	Obstruct and deformation during working
	Deformation during transportation and delivering
	Design-alteration from unqualified quality requirements
Steel and aluminum	Cutted of steel bars from pile works
	Cutted of steel bars from basement activities
	Damages from construction tools, such as handrail, scaffolding, carry, etc.
Packaging material	Package from cement bags
	Package from tile, glass
Plastic	Package from construction materials
	Over-supply of PVC pipe from piping and drainage
	Over-supply of water proofing materials
Glass	Deformation during transportation and delivering
	Obstruct and deformation during working
	Used waste from unstandardized designs

Cement Waste

Waste component

Surplus of reinforcement bar component waste

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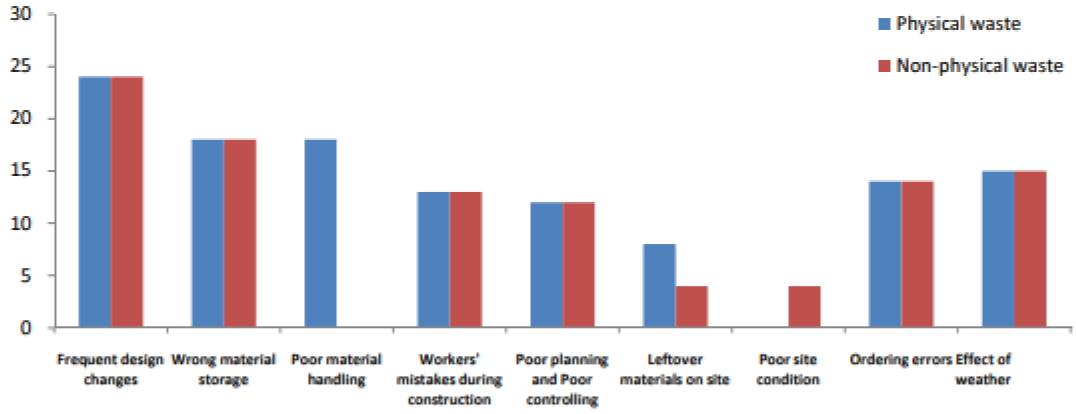
Based on the factors in Table 3, the highest frequency for physical and non-physical waste factors were presented in Figure 8. This factor contributes to both physical and non-physical waste



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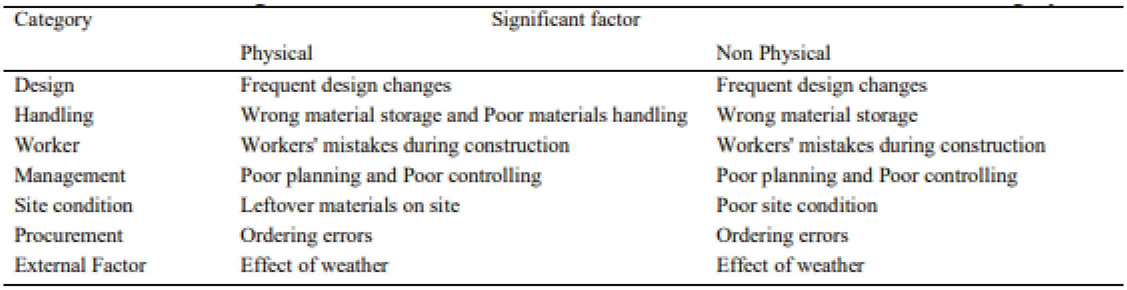
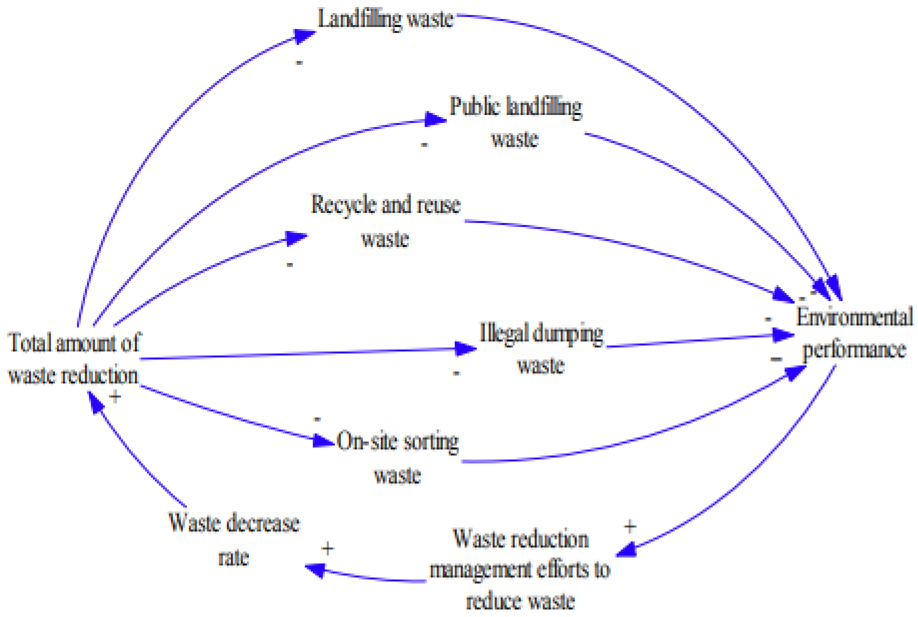


Category	Significant factor	
	Physical	Non Physical
Design	Frequent design changes	Frequent design changes
Handling	Wrong material storage and Poor materials handling	Wrong material storage
Worker	Workers' mistakes during construction	Workers' mistakes during construction
Management	Poor planning and Poor controlling	Poor planning and Poor controlling
Site condition	Leftover materials on site	Poor site condition
Procurement	Ordering errors	Ordering errors
External Factor	Effect of weather	Effect of weather

APPENDIX B



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