AN INVESTIGATION OF MATERIAL WASTE MANAGEMENT IN PREFABRICATED CONSTRUCTION INDUSTRY AND DEVELOPING AN INTEGRATED WASTE MANAGEMENT TOOL

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ABSTRACT

AN INVESTIGATION OF MATERIAL WASTE MANAGEMENT IN PREFABRICATED CONSTRUCTION INDUSTRY AND DEVELOPING A TOOL FOR EFFECTIVE MANAGEMENT OF WASTE

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In order to formulate effective waste reduction strategies in construction projects, it is essential to continuously monitor and analyze the waste generation and improve the existing processes continuously. This requires to establish a waste benchmark, based on the previous experiences in the organization, to assist the project team in taking efficient and timely actions to prevent the waste at source, and enhance the corporate waste management capability. The current study is carried out to explore the waste management in prefabricated steel structure construction companies in Turkey and develop a process model using an integrated waste management tool, to facilitate and improve the efficiency of existing waste management procedures. A classified set of materials and potential waste causes were listed through detailed literature review, studying real project records and interviewing with experts in the sector. A questionnaire survey has been carried out in collaboration with the Turkish prefabricated steel structure building companies to investigate the current performance of companies in material waste management and identify the most waste-prone materials and the main causes of waste generation. Also, the existing deficiencies in waste management processes were explored and factors plugging the way of effective waste management were identified. An integrated waste management process model and a supporting application were developed for the Turkish prefabricated building companies, in order to facilitate waste estimation, management, monitoring and controlling. Finally, the developed tool, the “Waste Tracker”, was tested and verified by the sector professionals. The testing and verification process gave favorable results. Although the findings on waste-prone materials and waste management practices reflect the situation in the Turkish prefabricated construction industry, it is believed that the proposed process model as well as the tool are generic and be modified to other countries and industries after some modifications.

Keywords: Construction, Material Waste, Prefabrication, Waste Causes, Waste Management Process, Lean Construction

ÖZ

PREFABRİK YAPI ENDÜSTRİSİNDE MALZEME ATIK YÖNETİMİNİN İNCELENMESİ VE ENTEGRE ATIK MALZEME YÖNETİMİ İÇİN BİR ARACIN GELİŞTİRİLMESİ

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İnşaat projelerinde atık azaltma stratejilerinin geliştirilmesi için, atık üretiminin sürekli olarak izlenmesi ve analiz edilmesi ve mevcut süreçlerin sürekli iyileştirilmesi esastır. Bu, proje ekibinin kaynakta israfı önlemek ve kurumsal atık yönetimi bilgisini geliştirmek ve verimli ve zamanında harekete geçmesine yardımcı olmak için kuruluştaki önceki deneyimlere dayanan bir atık kriter oluşturulmasını gerektirmektedir. Bu çalışma, Türkiye'deki prefabrike çelik yapı inşaat şirketlerinde atık yönetimini araştırmak ve mevcut atık yönetimi prosedürlerinin verimliliğini kolaylaştırmak ve geliştirmek için entegre bir atık yönetim aracı kullanarak bir süreç modeli geliştirmek ilkesini hedeflemektedir. Sınıflandırılmış bir malzeme seti ve potansiyel atık nedenleri, ayrıntılı literatür taraması ile belirlenip, gerçek proje kayıtları ve sektördeki uzmanlarla görüşme yoluyla listelenmiştir. Türk prefabrike çelik yapı inşası şirketleri ile işbirliği içinde, malzeme atık yönetiminde firmaların mevcut performansını araştırmak ve en çok israfa yol açan materyalleri ve atık üretiminin ana nedenlerini belirlemek için bir anket çalışması yapılmıştır. Ayrıca, atık yönetimi süreçlerindeki mevcut eksiklikler araştırılmış ve etkili atık yönetimi yolunun tıkandığı faktörler belirlenmiştir. Öngörülen süreç modelini kullanarak atık tahminini, izlenmesini ve kontrolünü kolaylaştırmak amacıyla, Türk prefabrike yapı şirketleri için entegre bir atık yönetim süreci modeli ve destekleyici bir uygulama geliştirilmiştir. Son olarak, geliştirilen araç sektör profesyonelleri tarafından test edilmiş ve doğrulanmıştır. Doğrulama ve test etme süreci olumlu sonuçlar vermiştir. Atıklar ve atık yönetimi ile ilgili bulgular Türk prefabrike yapı sektörünü yansıtmakla birlikte, geliştirilen süreç modeli ve araç, gerekli uyarlamalar yapıldıktan sonra, diğer ülkeler ve sektörler için uygun hale getirilebilecektir.

Anahtar Kelimeler: İnşaat, Malzeme Atıkları, Prefabrikasyon, Atık Sebepleri, Atık Yönetimi Süreci, Yalın İnşaat

This thesis is dedicated to my beloved family

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INTRODUCTION

The waste generation in construction industry is considerably high in all countries, as well as in Turkey, and the industry consumes the finite natural resources inefficiently. Although it is difficult to quantify or estimate the exact numbers of construction related waste generation in a region or even in a typical construction project, however there are several studies demonstrating the huge amounts of construction wastes in developing and industrial countries all around the world. Xiao et al. (C. Wang & Xiao, 2012) declares that China is the largest producer of construction and demolition waste in last decades. It is reported that about 38% of total solid waste generation in Hong Kong arising from construction industry (*Hong Kong Government Environmental Report*, 2006). It has been estimated that the US has generated 136 million tons of construction waste in 1996 (Ding & Xiao, 2014), and 170 million tons in 2003. It is estimated that more than 450 million tons of construction wastes is generated every year in the EU; which includes 180 million tons of core material waste and 270 million tons arising from soil and road materials (European Commission - Directorate General for Environment, 2006). Generally, it is estimated that construction material waste accounts for about 30% of the total weight of building materials delivered to a typical construction site (Osmani, 2011). A study carried out by Bossink and Brouwers (Bossink & Brouwers, 1996), reveals that approximately 9% of purchased materials were being wasted in the Netherland. Pinto and Agopyan (Pinto & Agopyan, 1994) reported the waste rate of construction materials in Brazil, ranging from 20% to 30% in the weight of total project materials. According to a report published by European Commission, 75%

of material wastes generated by construction activities in EU region is being disposed in landfills (European Commission - Directorate General for Environment, 2006). Poon et al. (C. S. Poon, Yu, & Jaillon, 2004) reported that about 40% of landfill capacity in Hong Kong is used for construction material waste disposals. The composition of disposed materials is extremely variable including bricks, blocks, mortar, timber, packing, metals, plastics, tiles and glasses. In addition to environmental impacts, the cost impacts of construction wastes are also considerable, due to the major share of material cost in total project budget and waste disposal costs. Yu et al. (Yu, Poon, Wong, Yip, & Jaillon, 2013), reported that material involves 50% to 80% of total project cost in building projects. Further negative impacts on time, productivity, social and economic issues are associated with high percentage of waste generation in construction industry. The diversity and severity of direct and indirect impacts of waste in construction, lead the industry stakeholders and governments to seek ways of waste minimization and management. One of the initial steps in this stream is the environmental protection legislations, passed by governments. Along with legislations, financial rewards have been also proposed by authorities as an incentive to confine the waste generations and landfill disposals. Training, efficient waste management in construction sites and construction process improvements are other recommended ways of waste minimization and efficient waste management. Accordingly, lean manufacturing principles have been disseminated in construction industry in recent years (Koskela, 2000). The aim of lean construction is to maximize the value of the final product by minimizing the waste in production process, from design stage to construction completion and even project maintenance period. The waste elimination with concentration on process improvements is the main objective of lean construction. Unlike to manufacturing industry, in which the material waste is not a major issue due to the implementation of best practices in optimized production processes, material waste has a considerable impact on total project cost in construction industry, because of the uniqueness of construction projects. Although the ultimate aim of the lean manufacturing is to eliminate the all types of waste, however achieving zero waste in construction projects is not possible. Therefore, being more realistic, minimizing the waste of material would be the main objective of efficient waste management in construction. Consequently, process improvement in waste minimization and management is a prerequisite for implementation of lean principles in construction industry.

One of the recommended strategies to develop lean concept in construction and minimize the material waste generation in projects, is to enhancing the share of industrial production methods in overall project construction processes and industrialization of construction projects. The optimized and standard production processes in manufacturing industry simplifies the lean principles implementation in this sector; therefore, shifting the construction industry to industrial manufacturing of projects will enhance the applicability of lean construction. Prefabrication is the major method of industrial construction, which is the shifting of construction activities from traditional practices, with high level of waste, to industrial production processes with minimum waste generation. Prefabrication reduces the waste generation by minimizing the share of wet-trade and labor-intensive activities and increasing the industrial production ratio in compare with traditional methods. Prefabrication also facilitates the implementation of lean production by providing the integrated design and production processes which is the main distinction between construction and manufacturing industry. Prefabrication and industrialization of construction activities, along with the waste minimization in project execution, provides various advantages over conventional construction, including time and cost savings and quality and safety improvements. However, the prefabrication itself is associated with significant amount of material waste; which increases the total project cost and time and reduces the final product quality with various environmental impacts. In case of poor waste management in prefabrication, the relative advantages of cost, time and quality will be lost; besides, due to the type of materials used in prefabrication, the recycling and disposal of wasted materials will be more costly and hazardous, in compare with traditional construction. Wet-trade construction method mostly consumes traditional and inert materials; however, the prefabrication generally uses modern construction materials which are mostly the product of complex chemical refinement processes on raw materials. These types of materials although has valuable properties, however, they contain chemical admixtures to provide their enhanced performance and service life; therefore, the recycling or disposal process of these kinds of materials will be more expensive and environmentally hazardous. Considering the above-mentioned issues and with respect to the fact that, time saving and environmental advantages, are generally the main factors of giving preference to prefabricated building systems by clients, the importance of efficient waste management with tangible minimization of wasted material becomes more prominent in this sector.

Two concepts are generally used in construction waste management including "waste minimization" and "waste management". Osmani (Osmani, 2011) defines "waste minimization" as the action of reducing the waste generation at source by identifying the root causes and improving the current processes and practices; whereas, he describes the "waste management" as the process involved in dealing with waste, once the waste has arisen. Separating the "waste minimization" and "waste management" concepts has led the construction professionals to focusing on the managing waste without considering the waste minimization in their practices. As a result, the existing waste management efforts in construction industry are mainly concentrating on waste disposal management rather than on waste minimization or eliminating. This approach of waste management indicates that material wastage in construction is mostly accepted by sector stakeholders and their efforts are mainly focusing on the proper disposal of the generated wastes. This point of view can be found in academic studies either, meaning that, there are numerous studies investigating the waste disposal and quantification, whereas there is a big gap in studying the waste minimization and efficient management of waste generation at source. Contrarily, the lean production concept encourages the prevention of waste rather than relying solely on reactions dealing with negative impacts of waste generation (Womack & Jones, 1997). It also recommends to improve the waste management processes continuously to achieve the highest productivity and most efficient results. This approach requires to assess the waste management performance and identify the root causes of wastes to eliminate them or alleviate their impacts by implementation of proper tools and techniques. Measuring and monitoring of waste generation is an effective way to evaluate the performance of waste management system; because it usually allows to identify the potential areas of improvement and main causes of inefficiencies in the system (Carlos T. Formoso, Soibelman, De Cesare, & Isatto, 2002). Accordingly, construction companies should attempt to investigate and identify the main causes of the waste during the project lifecycle and eliminate them using the various tools and techniques proposed by lean construction. For this purpose, it is essential to establish a waste management system which enables the project team to monitor and investigate the waste generation by addressing the root causes of waste. The aim of this study is to investigate the construction waste management in prefabricated construction industry in Turkey by studying the current status of waste management and minimization procedures and re-engineering the waste management processes with the aim of waste reduction at source and developing a waste management tool to assist the project team in implementation of efficient waste management process.

1.1. Research Background and Motivation

1.1.1. Literature Review

Limited studies are available on material waste management in construction industry. Most of the available studies have been focused on waste quantification, source investigation and recycling, and few studies have been done on waste reduction. Moreover, the existing studies are mainly focusing on traditional construction methods and rarely studies the waste management in prefabricated construction. Skoyles (Skoyles, 1976) carried out the first extensive study on material wastage in UK building industry by direct on-site observations and investigating of project records of 114 building projects from 1960 to 1970. They examined the waste generation rate for 37 different materials and reported that the percentage of material wastage in weight ranged from 2% to 15% according to the estimated amount of materials in design stage. The study revealed that the actual material losses are mostly higher than initial estimations; also, the waste rates for each material are extremely variable in different construction sites indicating that most of the existing wastes are avoidable. They also concluded that the major material wastes arise from poor material management on site, incorrect material unloading, poor ground conditions, inadequate transportation equipment and unsuitable packaging. They either reported that the wastes are generally the result of occurrence of multiple causes, rather than single events. In order to reduce the environmental impacts of construction wastes and restrict the rising demand for limited disposal areas in Hong Kong, a study was conducted by The Hong Kong Polytechnic and Hong Kong Construction Association (C. Poon, Yu, & Ng, 2001) investigating the ways of waste reduction at source. The construction processes with high potential to waste generation in 32 construction sites were monitored during June 1992 to February 1993 and discussed the relative importance of the waste of six different materials including: premixed concrete, steel reinforcement, mortar, bricks and blocks, ceramic tiles, and wood. They also declared that the average waste of premixed concrete in 14 sites were 11% varying from 2.4% to 26.5%. A research was conducted by Bossink and Brouwers (Bossink & Brouwers, 1996) in The Netherlands and investigated the waste of seven materials in five housing projects between April 1993 and June 1994; and reported that direct wastes were ranged from 1% to 10% in the weight of purchased material. Gavilan and Bernold (Gavilan & Bernold, 1994) reported the results of an empirical study in US on analyzing three processes including masonry foundations, timber frames and sheetrock drywall in five homes at four construction sites. Residual scraps of bricks, blocks, lumber and sheetrock panels remaining from cutting, non-reusable consumables of wood and packaging and improper handling were identified as the major sources of waste. Pinto (Pinto, 1989) carried out a single case study on direct and indirect waste of materials on a residential building project in Brazil using the project records; and found that the percentage of wasted materials varies from 1% to 102% in weight, based on the estimated amounts in design stage. The results also revealed the importance of indirect wastes in compare with direct wastes, for instance the indirect waste of mortar were found as much as 85% of the designed quantities. In Brazil, a detailed study were conducted by Formos et al. (Carlos T. Formoso et al., 2002) in two time phases to explore the main causes of material wastage as well as to investigate the guidelines for waste prevention. The first study monitored 7 materials in 5 projects during 1992-1993 and the second study investigated 18 materials in 69 construction sites during 1996-1998. Some values for the waste rate of investigated materials were found, and the main causes of waste generation in the sector were discussed. The results indicated that the waste of materials in the Brazilian building industry was fairly high and varies significantly across different projects.

From the literature review, it can be observed that the current data on material waste in the building industry is relatively scarce and comparing the results of these studies is difficult due to the locational and technical differences between studies, which strongly affects the outcomes. However, it is clearly notable that the level of waste generation in traditional construction methods are significantly high and variable meaning that the wastes in most cases are avoidable. Several studies suggest taking actions to reduce the waste generations at source by improving the processes rather than dealing with generated wastes by recycling or reuse. Some studies (Vivian W Y Tam & Tam, 2006) (V W Y Tam, Kotrayothar, & Loo, 2009) reported that, concerns about the extra cost of recycling and the quality of recycled materials are the key barriers to promotion of recycling practices in construction.

Modular design and prefabricated construction is proposed as one of the effective and feasible methods for process improvement and waste reduction at source in some studies. Baldwin et al. (Baldwin, Poon, Shen, Austin, & Wong, 2009) confirm that off-site prefabrication of building elements can effectively reduce the waste generation on site. Lachimpad et al. (Lachimpadi, Pereira, Taha, & Mokhtar, 2012) compared the waste generation by three different construction methods in high-rise buildings in Malaysia and found that Industrialized Building Systems are most waste efficient method with a waste generation rate of 0.016 tons/m^2. Wang et al. (J. Wang, Li, & Tam, 2014) investigated the factors affecting construction waste minimization at design stage and suggested to develop modular design and prefabrication of building components as one of the more effective ways in waste minimization. Vivian et al. (Vivian W Y, C.M., & L.Y., 2004) also compared the average waste level of materials in two groups of projects, adopting conventional construction and prefabrication, and found that the wastage level in several trades including: concreting, rebar fixing, bricklaying, tiling and plastering have been reduced, however new wastes have been occurred due to the utilization of new kinds of materials in prefabrication (e.g. drywall). A study by Tam et al. (Vivian W.Y. Tam, Tam, Zeng, & Ng, 2007) suggested that construction waste generation can be fully avoided by using prefabrication technologies. Although the prefabrication promotes the project performance in time, cost, quality and safety; however, waste production may not be completely avoided if the material wastage would not be managed properly. This concern is revealed by Jaillon et al. (Jaillon, Poon, & Chiang, 2009) reporting that prefabrication can only provide about 52% reduction in average waste rates. Therefore, it is obvious that shifting the construction industry from traditional methods to industrialized prefabrication would not be adequate in waste minimization, but it is essential to implement an efficient waste management system to identify the waste generation sources and measure the quantity of waste continuously. Thus, investigation of root causes of waste would be inevitable in development of efficient waste management system. There are several studies on waste causes carried out in different countries and have been explained in section 2.3.

Limited studies exist on construction waste management in Turkey; Polat and Ballard (Polat & Ballard, 2004) assessed 14 factors in their study to identify the main causes of material waste in Turkish construction industry. Esin and Cosgun (Esin & Cosgun, 2007) conducted a survey among 180 homeowners from different parts in Istanbul to investigate the construction material waste generation due to modifications on residential buildings and proposed to use standard and modular structures for building materials to be easily dismantled without damaging. They also find that one of the sources of frequent modifications is the poor material and labor quality. Polat et al. (Polat, Damci, Turkoglu, & Gurgun, 2017) carried out a study to explore the importance of the root causes of material wastage during new construction projects in the Turkey. They carried out an extensive literature review on construction waste and identified 34 waste causes. They found that "frequent design changes and change orders", "design and construction detail errors", and "waste from cutting uneconomical shapes" have "High" importance level for C&D waste generation. They also reported that none of the 34 predefined factors had "Medium-Low" or "Low" importance level.

In addition to above mentioned researches, there are some studies on developing computerized waste estimation in construction projects. Li and Zhang (Li & Zhang, 2013) have developed a Web-based Construction Waste Estimation System (WCWES) as shown in Figure 1-1, which provides an online waste estimation platform for building construction projects at project level by integrating data input modules and online analytical modules. Data input modules comprise material management, project management, WBS management and material quantity takeoff. The online analytical modules allow analysis of construction waste from three dimensions: waste origin, waste stream and work package. The WCWES is able to track the origins of construction waste streams, identify construction waste categories, and determine the most significant construction waste streams. Analytical results can be presented in both graphical and non-graphical formats for easy understanding and effective communication.

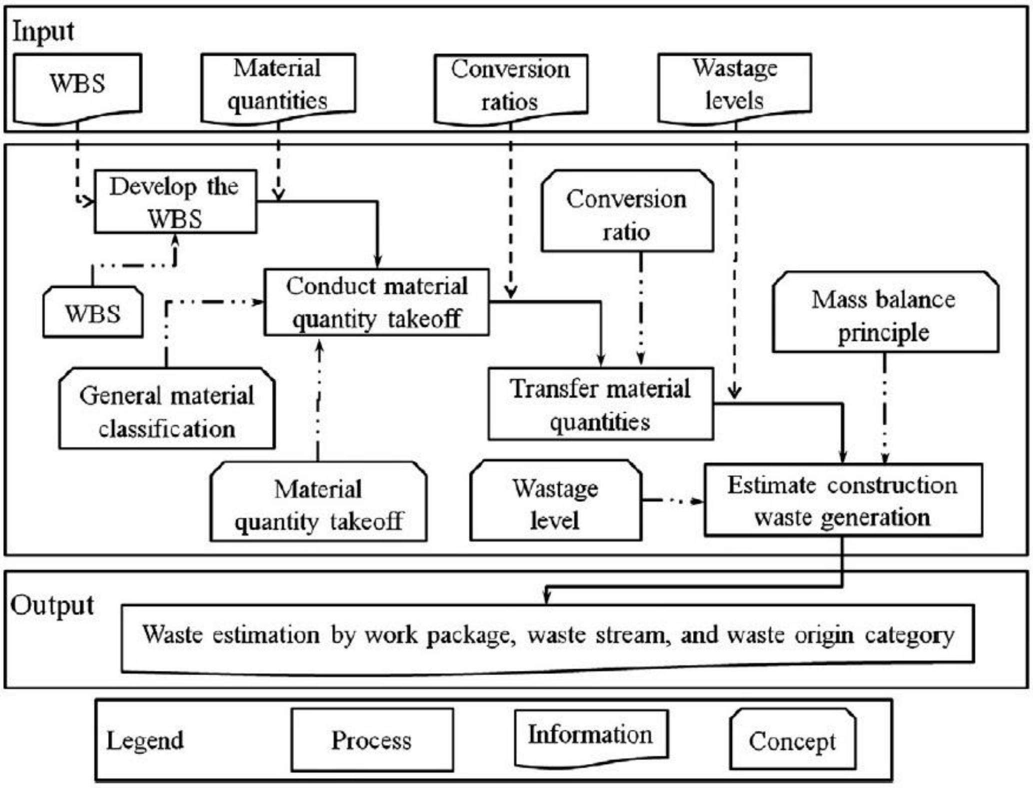


Figure 1-1: Web-based waste quantification model proposed by Li and Zhang

Moreover, Cheng and Ma (Cheng & Ma, 2013) presented a Building Information Modeling (BIM) based system for estimating and planning of Demolition and Renovation (D&R) waste as shown in Figure 1-2. BIM allows multi-disciplinary information to be superimposed within one digital building model. This system can extract material and volume information through the BIM model and integrate the information for detailed waste estimation and planning. Waste recycling and reuse are also considered in the system. Extracted material information can be provided to recyclers before demolition or renovation to make recycling stage more cooperative and more efficient. Pick-up truck requirements and waste disposal charging fee for different waste facilities will also be predicted through the system. The results could provide alerts to contractors ahead of time at project planning stage.

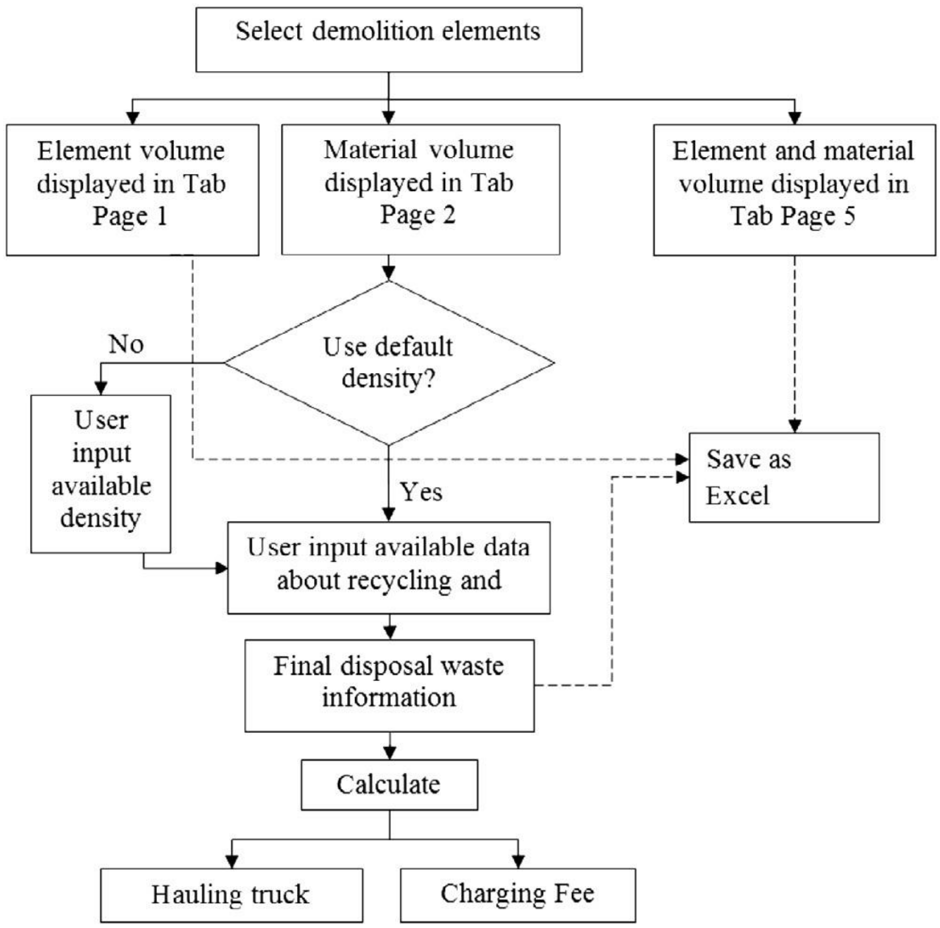


Figure 1-2: BIM-based demolition waste estimating system operation flowchart

1.2. Lean Construction and Waste

Lean Construction is derived from the manufacturing approach developed by Toyota after World War II, which is focusing on waste minimization within the manufacturing system while maximizing the productivity. Ohno (Ohno, 1978) have categorized the waste in seven groups as follow:

1- Overproduction,
2- Waiting,
3- Transporting,
4- Over-processing,
5- Inventories,
6- Moving,
7- Making defective parts and products;

In traditional production concept, a process is viewed simply as a conversion of an input into an output that can be divided into sub-processes, which are also conversion processes (Koskela, 2000). On the other hand, Lean Production concept, explains the production as a combination of both conversion and flow activities. Conversion activities are the direct actions which affect raw materials to make a value for the final product. Whereas, flow activities are the input actions for a conversion activity including information flow and resource flow (Koskela, 2000). According to the lean concept, only conversion activities can add value to the final product. In this concept, the waste is directly associated with the use of resources that do not add value to the final product. Meaning that there are two approaches to improving processes. One is to improve the efficiency of both value-adding and non-value-adding works, and the other is to eliminate waste by removing non-value-adding activities in the process (Carlos T. Formoso et al., 2002).

The main concept of lean in construction is maximizing the value of the final product by minimizing the waste. The studies on lean construction feature various types of waste relating to processes and operations including lead time and variability (Ohno, 1978). The material waste is not highlighted in the existing Lean Production studies, probably due to the fact that material waste is not a major issue in manufacturing which representing the best practices in repetitive production model, such as car manufacturing industries. However, the material waste is an important issue for the construction industry, because of the uniqueness of final products in construction and less amount of repetitive and modular production model. Waste is defined as the loss of any kind of materials, that generate direct or indirect costs but do not add any value to the final product from the point of view of the project owner. As proposed by Ohno, (Ohno, 1978), the incidence of waste is associated with any inefficiency that results in the use of resources in larger quantities than those considered necessary.

Lean construction is considered as an opportunity to address the problems of waste generation in construction projects and to estimate the impacts of waste on the overall project performance (Khanh & Kim, 2014). Unfortunately, the construction project participants often think that wastes are generally associated with waste of materials in the construction processes while non-value-adding activities such as delays, inspection, material transportation, and other types of waste are not recognized as wastes (Khanh & Kim, 2014).

1.3. Problem Statement and Motivation of Study

Considering the existing studies in waste management, the following limitations can be listed:

- Despite the significant importance of efficient waste management in prefabricated construction industry, there is not adequate studies on waste management in this field.
- There is a great limitation of studies on waste management processes with focus on waste avoidance or minimization at source, in compare with waste quantification and source analysis.

- The concentration of academic studies and real project efforts is on the waste disposal management rather than the implementation of waste minimization procedures.
- Currently the majority of construction companies incur from the lack of predefined and structured waste management processes and plans with the aim of waste minimization at source.
- The focal point of existing waste management studies is on traditional construction method; whereas, the industrialized construction sector is passed over. Therefore, the results of studies cannot be generalized in prefabrication sector and it is essential to carry out new studies in this field.
- Due to the various specifications of construction materials, the waste causes for each material type is extremely different, however existing studies mostly investigated the waste generation sources as a whole for all material types or for most critical type of material. Therefore, generalization of study results to other material will not be reliable.
- The existing waste management studies have been carried out in typical geographic location or on particular projects that cannot be generalized for other locations or projects. Therefore, the results of the studies are mostly project-based or location-based and will not be entirely reliable for prefabricated projects in Turkey.
- On-site processes and the basic materials used in prefabricated building projects are mostly different than those in traditional constructions, which have been investigated in previous studies. Therefore, it is required to identify the wasted materials and related waste causes in this sector.
- Although Turkish construction industry has a prominent position in international market and is a leader sector in national economy, there are limited number of studies on waste management in Turkish construction industry.

- There are limited number of studies on barriers of implementation of efficient waste management in construction and the success factors of waste management systems in companies.
- There is no study on development of a process model and a tool for management of waste in Turkish construction industry, which is highly needed.

1.4. Scope and Objectives

In the light of above-mentioned limitations of existing studies on waste management, and with concern to the investigations of waste management in prefabricated construction companies in Turkey, the scope and objectives of the study is developed as follows.

1.4.1. Scope of the Study

As mentioned before, the efficient way of waste management in construction projects is to avoid or minimize the waste generation at source. Therefore, with respect to the lack of studies on this field, mainly in Turkey, this study is concentrating on the investigation of waste management with the aim of waste minimization and controlling at source. On the other hand, as it is explained in previous sections, prefabrication is the main method of industrialization of construction industry and there is a great gap of waste management studies in this field. Besides, from the literature review, it can be observed that the current data on material waste in the construction industry is relatively scarce and comparing the results of these studies is difficult due to the locational and technical differences between studies, which strongly affects the outcomes. Thus, the focal point of the study is the prefabricated steel structure building projects in Turkey.

1.4.2. Objectives of the Study

Based on the lean construction principles, several studies recommended to concentrate on waste elimination or reduction at source by improving the waste management processes, rather than dealing with generated wastes by recycling or reuse. On the other hand, on-site and off-site processes, and basic materials used in prefabricated building projects are mostly different than those in traditional constructions, which have been investigated in previous studies (Rahmani, Dikmen, & Birgonul, 2018). Therefore, it is necessary to investigate the waste management in prefabricated construction industry independently to be able to develop any process improvements. On the other hand, as mentioned by Gavilan and Bernold (Gavilan & Bernold, 1994), it is assumed that the importance of identified waste causes are varying not only from project to project, but also from material to material. Therefore, it is required to develop a system for waste management and minimization based on the material and project specifications. Consequently, the objectives of this study can be summarized as follows:

- Investigating the current state of waste management in prefabricated construction industry in Turkey to explore the quality and efficiency of waste management processes in companies and identify the barriers of implementation of efficient waste management.
- Identifying the most waste prone materials in prefabricated construction projects to develop a material based waste management system.
- Investigating the sources of waste generations in prefabricated construction projects in Turkey to develop a classified list of most prevalent waste causes.
- Developing a waste management process based on the needs of the industry and existing deficiencies of implementation of efficient waste management system in companies.

1.5. Research Methodology

In order to take efficient measures in reducing the amount of waste at source, which is the initial step in waste management, it is essential to identify the most waste-prone materials and investigate the main causes of waste generation (Rahmani et al., 2018). An investigation has been carried out in collaboration with the Turkish prefabricated steel structure building companies to identify the most waste-prone materials and the main sources of waste generation. A mixed research method incorporating qualitative and quantitative approaches were adopted in this study. An overview of research method process is illustrated in Figure 1-3 and detailed explanation of the research method is given in Figure 1-3.

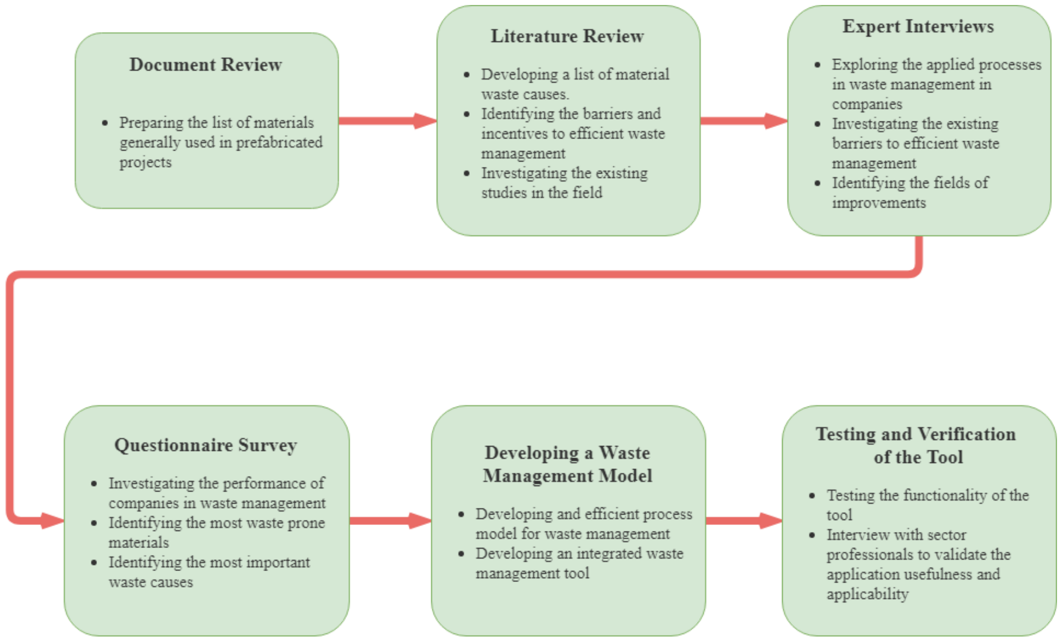


Figure 1-3: Overview of the research method process

1.5.1. Project Document Review

Since the existing academic literature were mostly dealing with traditional construction materials, it is required to prepare a list of prevalent materials used in prefabricated steel structured projects. For this purpose, the documents of four different prefabricated projects were investigated and an initial list of materials were prepared.

1.5.2. Literature Review

A detailed literature review has been conducted to investigate the causes of material waste generation in existing studies and preparing a classified list of potential waste causes in prefabricated construction projects. Moreover, the obstacles and incentives to implementation of efficient waste management were explored in previous studies.

1.5.3. Expert Interviews

In order to explore the current state of waste management in prefabricated construction industry in Turkey, and understand the existing processes of waste management and reduction, oral interviews were carried out by nine professionals working in the sector. The barriers and deficiencies of existing processes were discussed and the potential fields of improvements were identified.

1.5.4. Questionnaire Survey

A multi-phase questionnaire survey has been administrated to more than 30 professionals to learn about their perceptions on waste-prone materials, their sources and factors plugging the way of effective waste management within the prefabrication sector in Turkey.

1.5.5. Developing a Waste Management Process Model and Tool

After analyzing the outputs of questionnaire surveys and interviews with sector professionals, and with respect to the variable sources of waste, an integrated waste management process model a supporting tool is developed in order to facilitate the waste estimation, monitoring and controlling stages.

1.5.6. Testing and Verification of the Tool

After developing the waste management tool, the functionality of the application and the accuracy of output results were examined by entering a portfolio scenario in the system. Besides, the usefulness and applicability of the tool were discussed with sector professionals to complete the verification process of the tool. The methodology and findings at each step will be explained in detail in the forthcoming chapters.

CHAPTER 2

MATERIAL WASTE AND WASTE MANAGEMENT IN CONSTRUCTION

2.1. Concept of Waste

There is no commonly accepted definition for waste in literature (Osmani, 2011). Various definitions have been proposed for waste in literature, Formoso et al. (Carlos Torres Formoso, Isatto, & Hirota, 1999) defines the waste as any inefficiency in the utilization of equipment, materials, labor or capital which leads to the use of quantities larger than necessary amounts. The concept of waste in construction covers a wide range of subjects including operations and resources; however, the focus of this study is on the waste of material. Cheung (Chi Sun Poon, Yu, Wong, & Cheung, 2004) defined construction wastes as the byproduct generated and removed from construction, renovation and demolition work places or sites of building and civil engineering structures. Shen et al. (Shen L., Tam V., Tam C., 2002), defines the building material wastage as the difference between the quantities of materials delivered on construction site and those properly used according to designs and measured accurately in the work. Koskela (Koskela, 2000) express that waste adds costs but does not add value to the work. Likewise, Formoso et al. (Carlos Torres Formoso et al., 1999) classifies the waste to avoidable and unavoidable wastes. Unavoidable wastes are those the costs of reduction for them are higher than the economy produced, whereas, avoidable wastes are those that the required investment to manage the produced wastes are higher than the costs to prevent or reduce them. The best definition of waste is giving in the lean concept; where the waste is defined as activities that increase costs directly or indirectly but do not add value to the project.

2.2. Construction Material Waste

Construction industry produces significant amount of waste arising from construction activities in diverse form of debris including inert and organic materials or a mixed combination. The common perception about the material waste in construction is generally focuses on the direct material disposals from construction sites as debris (Carlos T. Formoso et al., 2002), however there is a significant type of waste, known as indirect waste, that should be taken into account when studying the material waste in construction industry. Skoyles (Skoyles, 1976) categorizes wastes in two principal types, including direct and indirect wastes. According to this classification, direct wastes are the physical loss and unrepairable damages of material which incorporates both physical and monetary losses, and generally needs disposal and replacement of wasted material. On the other hand, indirect wastes are generally originating from unnecessary material substitutions, excessive use of material and errors during constructions, which only cause monetary losses without physically damage of material. Construction and Demolition (C&D) wastes are divided into three categories according to the generation phase by Wu et al. (Wu, Yu, Shen, & Liu, 2014): Construction Wastes (CW), Renovation Waste (RW) and Demolition Waste (DW) which generally composed of inert materials with little damage to the environment (e.g., concrete, bricks, etc.). These inert materials are generally wasted in traditional construction methods by wet trade activities; however, some hazardous material components are also generated which requires properly recycling or disposal processes with more cost and environmental effects. The prefabricated industry produces less inert wastes and more hazardous materials therefore waste reduction at source should be more considered.

2.3. Material Waste Causes

There are several studies carried out in different countries to identify the sources of wastes in construction; but the focal point of these studies are traditional construction methods. Bossink and Brouwers (Bossink & Brouwers, 1996) investigated the sources of construction waste in The Netherlands by categorizing 31 sources of waste under 6 main categories as shown in Table 2 1. They identified that the main causes of material wastage are related to design, material supply, poor handing in transportation and storage. Adewuyi and Odesola (Adewuyi & Odesola, 2015) assessed the level of contribution of several factors to construction material waste generation in Nigeria. They identified 74 waste causes and grouped them under 8 main categories. The results revealed that reworks due to non-conformance to specifications as demonstrated in Table 2 2, Table 2 3 and Table 2 4, waste from cutting uneconomical shapes, and design changes and revisions were the first three highest contributors to material waste. Umar et al. (Aminu Umar, Shafiq, Malakahmad, Fadhil Nuruddin, & Umar Salihi, 2016) identified 40 causes of waste in Malaysian residential projects and grouped them into seven categories as shown in Table 2-5 and Table 2-6, and revealed that on-site operation activities rank as the most important sources of waste. In addition to above-mentioned studies there are various researches on waste causes investigation and classification. For instance, Gavilan and Bernold (Gavilan & Bernold, 1994) reported 12 factors as main causes of construction waste categorized under 6 main groups including: Design, Procurement, Handling of materials, operation, residual and other factors that not listed. Ekanayake and Ofori (Ekanayake & Ofori, 2000) have also examined and discussed 27 factors as causes of construction waste. Poon et al. (C. Poon et al., 2001) conducted a research in Hong Kong and identified 13 factors that cause material waste in construction. Garas et al. (Gara, Anis, & Gammal, 2001) also considered 10 important factors in the generation of construction waste in Egyptian construction industry.

In Turkey, Polat and Ballard (Polat & Ballard, 2004), conducted a survey between contractors and consultants and evaluated the frequency of occurrence of 14 waste causes classified in 6 groups as it is shown in Table 2-7. The study reveals that 86% of respondents believe that “ordering of material that do not fit in terms of quality, type and dimensions” causes to waste generation. On the other hand, 61% of the respondents identified the “imperfect planning of construction” as the root cause of waste in construction projects.

Table 2-1: Waste causes classification by Bossink and Brouwers (1996)

Source	Cause
Design	Error in contract documents Contract documents incomplete at commencement of construction Changes to design Choices about specifications of products Choice of low-quality products Lack of attention paid to sizes of used products Designer is not familiar with possibilities of different products Lack of influence of contractors and lack of knowledge about construction
Procurement	Ordering error, over-ordering, under-ordering, and so on Lack of possibilities to order small quantities Use of products that do not fit
Materials handling	Damaged during transportation to site/on site Inappropriate storage leading to damage or deterioration Unpacked supply Throwaway packaging
Operation	Error by tradesperson or laborer Equipment malfunction Inclement weather Accidents Damage caused by subsequent trades Use of incorrect material, requiring replacement Method to lay the foundation Required quantity of products unknown due to imperfect planning Information about types and sizes of products that will be used arrives too late at the contractor
Residual	Conversion waste from cutting uneconomical shapes Offcuts from cutting materials to length Overmixing of materials for wet trades due to a lack of knowledge of requirements Waste from application process Packaging
Other	Criminal waste due to damage or theft Lack of on-site materials control and waste management plans

Table 2-2: Waste causes classification by Adewuyi and Odesola (2015)

Source	Cause
Design and Documentation	Design changes and revisions Lack of attention paid to dimensions of product Selection of low quality product Ignorance about types and sizes of materials on design documents Specifying materials and dimensions without considering waste Complexity of detailing in the drawings Waiting for design documents Ambiguities, mistakes, and changes in specifications Errors in contract documents Incomplete contract documents Ambiguities, mistakes, and inconsistencies in drawings Reworks contrary to specifications Contractor's non-involvement Supplier's non-involvement Manufacturer's non-involvement
Materials procurement	Poor schedule of materials procurement Ordering of materials that do not fulfil project requirements Incorrect estimated quantity Over ordering or under ordering Impossibility to order small quantities Purchase of materials contrary to specification Substitution of a material by more expensive ones
Materials management on site	Damage of materials on site Waste from uneconomical shapes Unnecessary inventories on site Overproduction Manufacturing defects Theft and vandalism Poor quality of materials Lack of on-site materials control Poor storage of materials Over-sized of building elements during execution Using excessive quantities of materials more than the required

Table 2-3: Waste causes classification by Adewuyi and Odesola (continued)

Source	Cause
Materials handling, storage and transportation	Wrong handling of materials Unnecessary material handling Insufficient instructions about handling Poor and wrong storage of materials Inadequate stacking and insufficient storage Insufficient instructions about storage and stacking Inappropriate storage leading to damage or deterioration Double handling of materials Damage during transportation Bad road condition Accident Inappropriate equipment Breakdown of equipment Poor technology/malfunction of equipment
On-site operations	Rework due to workers' mistakes Damage to work done caused by subsequent trades Use of incorrect material Poor workmanship Lack of skilled subcontractors Difficulty in performance and professional work Interaction between various specialists Wrong construction method Accidents due to negligence Using untrained labors Lack of coordination among crews
Environmental conditions	Severe weather conditions Effects of subsurface conditions Site conditions significantly different from contract documents Restiveness Labor unrest Difficulties in obtaining work permits Government authority instruction/policy

Table 2-4: Waste causes classification by Adewuyi and Odesola (continued)

Source	Cause
Site Management and Practices	Lack of waste management plan Lack of a quality management system aimed at waste minimization Lack of strategy to waste minimization Poor site layout Incompetent contractor's technical staff
Site Supervision	Inadequate supervision Incompetent consultant's resident engineer Slow response from consultant engineer to contractor inquiries Change orders

Table 2-5: Waste causes classification by Umar et al. (2016)

Source	Cause
Site Operation Related Factors	Use of incorrect material, thus requiring replacement Poor craftsmanship Required quantity unclear due to improper planning Accident due to negligence Equipment malfunctioning Unused materials and products Time pressure
On-site Management and Planning Related Factors	Improper planning for required quantities Lack of on-site waste management plans Lack of supervision Lack of on-site material control
Material Storage and Handling Related Factors	Waste resulting from cutting uneconomical shapes Damage to materials on site Materials supplied in loose form Unnecessary inventories on site leading to waste Poor method of storage on site Inappropriate site storage space Manufacturing defects
Design and documentation Related Factors	Overlapping of design and construction Design and construction detail errors Lack of attention paid to standard sizes Design changes Poor coordination and communication Designer's unfamiliarity with alternative products Unclear/unsuitable specification Design and detailing complexity
Transportation Related Factors	Damage during transportation Difficulties for delivery vehicles accessing construction sites Inefficient method of unloading Insufficient protections during unloading

Table 2-6: Waste causes classification by Umar et al. (Continued)

Source	Cause
Procurement Related Factors	Ordering errors Inappropriate methods used for estimation Purchased products that do not comply with specification Supplier errors Changes in material prices
External factors	Weather Theft Vandalism

Table 2-7: Waste causes classification by Polat and Ballard (2004)

Source	Cause
Design	Lack of information about types and sizes of materials on design documents Design changes and revisions Error in information about types and sizes of materials on design documents Determination of types and dimensions of materials without considering waste
Procurement	Ordering of materials that do not fulfill project requirements defined on design documents Over-ordering or under-ordering due to mistakes in quantity surveys Over-ordering or under-ordering due to lack of coordination between warehouse and construction crews
Material Handling	Damage of materials due to deficient stockpiling and handling of materials
Operation	Imperfect planning of construction Workers' mistakes Damage caused by subsequent trades
Residual	Conversion waste from cutting uneconomical shapes
Other	Lack of on-site materials control Lack of waste management plans

2.4. Impacts of Material Waste in Construction

High level of material wastage, results in several side effects in projects, including cost overrun, environmental impacts and project delays. Considering that the main causes of contractual conflicts in construction arises from cost and time overruns, it can be concluded that poor management of waste will increase the probability of raising conflicts in projects. Many other indirect effects can also be considered for material waste in construction. Therefore, waste is one of the major problem of construction industry all around the world. The impacts of material waste are varying from country to country and from project to project. The following sections explains the various types of material waste impacts in construction industry.

2.4.1. Environmental Impacts

It is obvious that the construction industry, due to its nature, is environmentally unfriendly (Yu et al., 2013),(Yuan, Chini, Lu, & Shen, 2012) meaning that the majority of construction and side activities, from material extraction and production to handling and execution, have inherently environmental impacts, which can be escalated with inefficient management of waste (Rahmani et al., 2018). The construction industry consumes energy and nonrenewable natural resources, directly or in the course of production of the construction materials. Udayangani et al. (Udayangani, Dilanthi, Richard, & Raufdeen, 2006) claim that 40% of raw stone, gravel and sand as well as 25% of virgin wood are consumed in construction industry every year in the world. Therefore, the waste of material leads to depleting theses resources during a medium or long-term period and converts them to the construction debris which in turn results in soil and water contamination. Nowadays, environmental impacts of material waste, due to the wide range of its side effects, are significantly emphasized by researchers in compare with other negative results. The environmental impacts of wasted materials can be reduced by proper disposal methods. However, the majority of generated wastes mainly in prefabricated construction industry cannot be disposed easily and are mostly disposed by faulty methods in landfill without any further processes. Guthrie and Mallett (Guthrie & H. Mallett, 1995), classifies the C&D wastes into three categories as follows:

1- Potentially valuable materials in construction and easily reused/recycled, e.g. stone masonry, concrete, tiles, bricks, pipes, soil and asphalt;
2- Materials which are not capable of being directly recycled but may be recycled elsewhere, including timber, glass, paper, plastic, oils and metal
3- Not easily recycled or which present particular disposal issues, including chemicals (i.e. paint, solvents), asbestos, plaster, water and aqueous solutions.

The environmental impact of material wastage is the prominent effect of waste that is considered by companies and authorities and therefore is the main and initial cause of taking preventive actions in waste minimization in regional scale by governments.

2.4.2. Delay or Time Waste

Material waste in projects generally ends up with new purchases for recovering the losses arising from waste. The procurement process generally affects the work schedule and cause to waiting times in work packages. This time might be extended if the wasted materials consist of long lead items, the procurement process would take longer time and consequently greater impacts on schedule. In addition, transportation might be time consuming if the project located in a remote location. The waiting time due to procurement and transportation might be affected the project success at completion. The time impact of material waste in prefabricated projects are mostly greater than traditional construction projects due to the manufacturing processes required for some prefabricated elements. Arditi et al.

(Arditi, Akan, & Gurdamar, 1985) investigated the main causes of project delays in public construction projects in Turkey. They reported that, delay in material supply is the most important reason for total project delay with average relative weight of 17.46%. Project delay is the most frequent cause of claims in construction projects, therefore, efficient waste management will reduce the number of disputes and contractual conflicts.

2.4.3. Cost Overrun

Materials are the major components of construction projects and constitute the significant portion of project budget. Yu et al. (Yu et al., 2013) declare that material involves 50% to 80% of total cost in building projects. Ameh and Daniel (Ameh & Itodo Daniel, 2013) found that the material wastage contributes about 21% to 30% of cost overruns in construction projects. When waste occurs, usually new purchases should be done to cover the lack of wasted materials, therefore, any direct and indirect costs associated with material procurement will be reflected as cost overrun in total project budget. In addition, the cost associated with wasted material will be also loss in the case of waste occurrence, hence, the related cost will be doubled. Moreover, the wasted materials must be disposal, in some cases the disposal costs are significantly higher than the original material costs. Therefore, if the waste generation would not be controlled in the source, the imposed cost overruns maybe escalate the total project cost and significant financial losses.

2.4.4. Social Impacts

Environmental pollutions due to the poor waste management and wrong waste disposal in the nature will lead to soil and water contaminations and environmental pollution in residential and urban areas (Udayangani et al., 2006). The high amount of construction material disposal and arising contaminations effects the social health and destroys the public image of construction industry (Yuan et al., 2012).

These environmental contaminations in some cases leads to social protests and crisis.

2.4.5. Productivity Loss

Waste usually cause extra efforts and rework activities therefore activity delays due to unplanned waiting time for material repurchasing and reworks may be occurred in projects. Any reworks or waiting times will affect the productivity rates of the project resources including manpower and equipment. Low productivity rates will increase the project cost and time extensions. Several studies demonstrate the material waste as the major source of schedule delays and low productivity in construction projects (Makulsawatudom & Emsley, 2003),(Bell & George Stukhart, 1987),(Bell & Stukhart, 1986).

2.5. Material Waste Management in Construction

"Waste minimization" and "waste management" are two concepts which are generally used in construction waste management. Osmani (Osmani, 2011) defines "waste minimization" as the action of reducing the waste generation at source by identifying the root causes of waste and improving the current processes and practices. On the other hand, "waste management" is defined as the process involved in dealing with waste, once the waste has arisen. Separating the "waste minimization" and "waste management" concepts has led the construction industry to focusing on the managing waste without considering the waste minimization. As a result, the existing waste management efforts in construction industry are mainly concentrating on waste disposal management rather than on waste root analysis and waste minimization or eliminating at source. This approach of waste management indicates that material wastage in construction is mostly accepted by sector stakeholders and their efforts are mainly focusing on the proper disposal of the generated wastes. This point of view can be found in academic studies either, meaning that, there are numerous studies investigating the waste disposal and quantification, whereas there is a big gap in studying the waste minimization and efficient management of waste generation at source. Waste management is defined as all efforts dealing with waste estimation, monitoring and controlling the waste generation at source, with the aim of waste minimization or elimination; and investigating the root causes of waste generation, as well as dealing with wasted materials, once generated, in order to make a safe final disposal and avoid the repeated waste generation from the same source.

2.5.1. Basic principles of waste management

Various methods for managing the construction waste have been practiced in construction industry worldwide (Zhang & Li, 2012). To achieve the optimal resource-saving and environmental-friendliness results in waste management processes, a generic waste management approach is used to lead the plans and efforts in prioritizing the waste management practices. Waste hierarchy is the generalized waste management method which is developed in a descending order (Peng, Scorpio, & Kibert, 1997) as shown in Figure 2-1, consists of 5 different steps as avoiding, reducing, recycling, classification, and disposal. Avoiding or prevention is the most efficient method to restrict the waste generation at source and prevent waste disposal problems. Reducing is the minimizing the waste amount for inevitable waste generation cases. Recycling means reprocessing materials into useable products and using them in other applications and is viewed as the most desirable waste management method after waste reduction. Classification is the process of separating the materials according to their composition to be able for choosing proper disposal methods. Landfilling is the traditional waste disposal method that buries the wasted materials in safe places. The prior methods are the most environmentally-friendly methods that are encouraged internationally however the landfilling is the most environmentally damaging method. Landfilling, is the cheapest and easiest way of waste disposal method which is the most widely-used method.

Most of the countries and regional authorities have developed their own construction waste management hierarchies generally similar to each other. The European Commission (European Commission - Directorate General for Environment, 2006) suggested a five step hierarchy including: prevention, reuse, recycling, recovery and disposal. Later, the five step hierarchy was expanded to a seven step hierarchy as: prevention, reduction, on site reuse, on site recycles, off site reuse, off site recovery and landfill. The US Environmental Protection Agency recommends a waste management hierarchy in as prevention and reuse, recycling or composting, energy recovery, and disposal. The Australian government developed a waste management hierarchy including: avoiding, reducing, reusing, recycling, recovering, treating and disposal. The Hong Kong Environmental Protection Department also prepared a hierarchy for waste management with the order of avoidance, minimization, recycling, treating, and disposal (Xiao, 2013).

Considering the waste hierarchy shown in Figure 2-1, waste must be avoided if possible to the greatest possible extent. Therefore, the initial step in developing an efficient waste management system is to developing the waste management plans and processes in accordance to this philosophy.

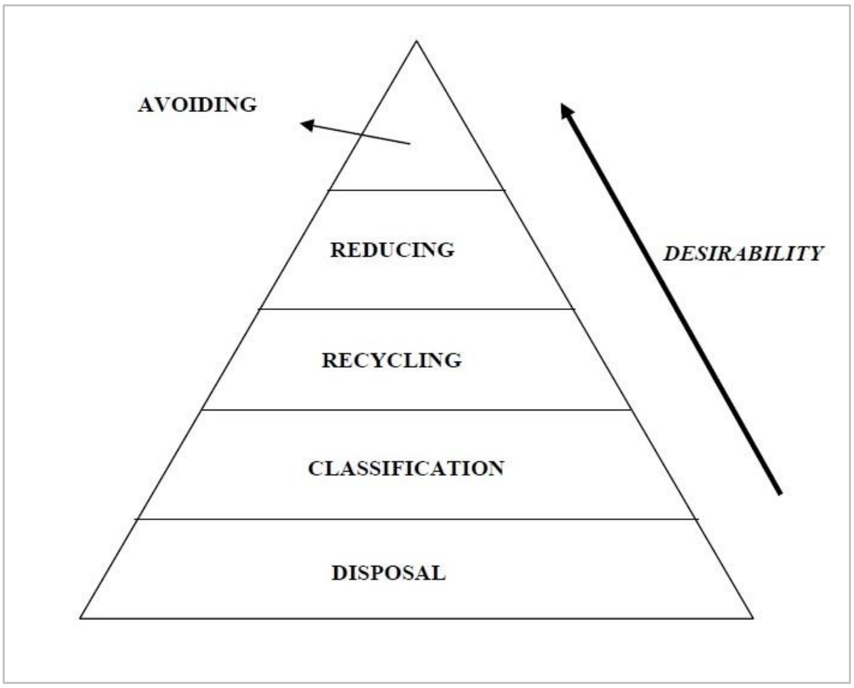


Figure 2-1: Construction waste management hierarchy

2.6. Importance of Material Waste Management

Construction industry is the leading sector in global and regional economies, especially in developing countries; and contributes in large portion in economic growth and direct and indirect employment of workforce. Therefore, profitability and sustainability of this sector is significantly important in establishing a sustainable economic growth in any country. Today construction companies get into global markets therefore they have to compete in a global scale with lowest possible costs and higher performances. The before-mentioned impacts of poor waste management on total corporate performance is demonstrating the importance of efficient waste management in achieving the maximum benefits of cost, time and environmental efficiencies. Hence, it is obvious that, efficient management of waste in construction projects will ensure the strategic advantage for any construction company working in regional and global markets. Accordingly, construction companies have begun to find ways of increasing their competitiveness in global markets by removing all kinds of inherent or tangible waste in their construction processes by means of implementation of lean construction techniques (Polat & Ballard, 2004).

2.7. Challenges of Waste Management

The uniqueness of construction projects makes the process improvement efforts harder than in manufacturing industry with mass production and optimized methods. Therefore, in order to improve the implementation of lean concept in construction industry it is recommended to transfer the construction processes to the more industrialized methods with minimum amount of uncertainties. Due to the uniqueness of construction projects, learning from past experiences would be less efficient than manufacturing industry. Considering the fact that knowledge management in construction industry is mostly ignored by companies, the learning and knowledge transferring procedures are considerably inefficient in improving the construction processes. The lack of reliable documents about waste generation from past projects is another challenge of waste management in construction projects. Moreover, unavailability of waste benchmarking to assist the waste monitoring and controlling processes is the great deficiency in implementation of successful waste management system in construction companies.

Unintegrated processes mainly in waste management stage make the waste controlling efforts unsuccessful in achieving minimum waste generation in construction projects. Inefficiency of waste control processes are mostly due to the high degree of uncertainties associated with construction projects, in compare with manufacturing industry, and due to the variety and dynamism of interrelated waste causes.

Considering the distinct characteristics of construction industry and the ultimate goal of the lean concept that is the eliminating the waste in processes and achieving "zero waste", it is obvious that reaching the "zero waste" in construction processes is not a realistic target, at least in case of material. Therefore, being realistic the aim of lean construction in material management in construction projects would be avoiding the waste incidents and minimization the waste generation at source according to the "waste management hierarchy" demonstrated in Figure 2-1. This requires to:

1- Establish a real-time waste monitoring system,
2- Develop a reliable and realistic waste benchmark for analyzing the waste generation,
3- Establish a waste database to record the information of waste in past projects and enhance the corporate knowledge on waste management.
4- Integrate the waste estimation, monitoring, analyzing and documentation processes to enhance the efficiency if the waste management efforts.

This study aims to develop a waste management model to feature the above mentioned issues with the aim of waste minimization and controlling ant source. The upcoming chapters explains the study methodology and details of the findings

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Data Collection

The objective of data collection stage is to prepare an initial data for investigating the waste management state in prefabricated construction companies in Turkey. As demonstrated in Figure 1-3, three sources have been used for collecting initial data including: project documents, previous studies in literature, and professional experiences. The following sections explains the details of these stages.

3.1.1. Document Review

On-site processes and the basic materials used in prefabricated building projects are mostly different than those in traditional constructions, which have been investigated in previous studies (Rahmani et al., 2018). Therefore, it is required to prepare a list of most prevalent materials used in prefabricated steel structured projects before starting to investigate the most waste-prone materials and root waste causes. For this purpose, a list of basic material groups was prepared using the data collected from 4 prefabricated steel structure building projects, undertaken by Turkish companies within Turkey and 2 other countries, as shown in Table 3-1. Company 1 is a Turkish prefabricated construction company ranked in ENR contractors list and is working in this sector for more than 36 years. They have several projects in domestic and international market with majority of international

EPC projects. The Company 2 is also a Turkish prefabricated company but with mostly domestic projects. They have 27 years of experience in the sector.

Table 3-1: List of projects in document review stage

Project	Company	Area (m2)	Contract Type	Project Location
A	1	55,780	EPC	Qatar
B	1	41,360	EPC	Kazakhstan
C	2	18,750	PC	Turkey
D	2	26,930	EPC	Turkey

The bill of quantities and material purchase lists were investigated and a primary list of 47 material groups was prepared considering the relative cost of each group to total material cost, and also with regarding to the material potential for being wasted. The identified materials were classified under 3 different categories including: building materials, mechanical materials and electrical materials. The number of material groups was reduced to 42 by excluding 5 sets from the initial list, considering the minor waste potential or minor cost effect in projects, after interviewing with 9 professionals from prefabricated construction industry. As it is shown in Table 3-2 Table 3-3, and Table 3-4 the final material list includes 27 building materials, 9 mechanical materials and 6 electrical materials.

Table 3-2: Building material groups

Ranking	Building Material Group
1	Sealing materials (silicon, etc.)
2	Gypsum board
3	Fiber cement board
4	Heat insulation (Rockwool - XPS - glass wool)
5	Paint
6	Fasteners/ connection elements
7	Plaster (gypsum & others)
8	Ceramic tile
9	Un-structural concrete (screed & others)
10	Door handles and accessories
11	Waterproofing material
12	PVC flooring
13	Window handles and accessories
14	Wood (OSB - timber & plywood)
15	Premixed structural concrete
16	Carpet flooring
17	Sandwich panels
18	Cast/cut stone
19	Steel reinforcement
20	Laminated parquets
21	Aluminum board/tiles
22	Vapor barrier
23	Wooden doors
24	Steel profiles/ structural elements
25	Laminated separation panels
26	PVC window
27	Aluminum window

Table 3-3: Electrical material group

Ranking	Electrical Material Group
1	Cables (LV - LC - MV)
2	PVC cable conduits & pipes
3	Cable trays
4	Switch, sockets and electrical installations
5	Electrical equipment
6	Lighting units

Table 3-4: Mechanical material group

Ranking	Mechanical Material Group
1	PVC pipes and fittings
2	Pipe heat insulations
3	PPRC pipes and fittings
4	Sanitary/ bathroom accessories
5	HDPE pipes and fittings
6	Air ducts and fittings
7	Sanitary wares
8	Steel pipes and fittings
9	Mechanical equipment

In addition to material list preparation, the reported waste causes were also investigated during document study stage. Since there were not any structured and predefined process of material waste reporting process in these companies, therefore, the waste causes were extracted from material purchase orders prepared by construction sites and transportation and construction nonconformity reports. The detailed list of waste causes is given in Table 3-5.

Table 3-5: List of waste causes found in document review stage

Project	Company	Waste Causes
A	1	Poor estimation Poor Packaging for transportation Locational access roads quality Construction errors
B	1	Design errors Multiple shipment destinations Poor estimation Poor storage and protection Poor Packaging for transportation
C	2	Production Error Design changes and revisions
D	2	Poor Packaging for transportation Construction errors Poor estimation Production Error

Although two companies and four projects are not enough to conclude the list, it is believing that this investigation provides a significant source. Literature review have also be conducted to identify the causes of waste which are explained in the next section.

3.1.2. Literature Review

A detailed literature review has been conducted to investigate the causes of material waste generation in existing studies and preparing a classified list of potential waste causes in prefabricated construction projects. A categorized list of potential waste causes, including 49 items were identified through a detailed literature review and classified under 5 categories. The prepared list was discussed by 9 sector professionals and some specific waste causes that were not identified in literature review were added and some causes with same concepts were merged together. In addition, the list of waste causes were revised with considering the findings of document review stage, demonstrated in Table 3-5. Ultimately, the final list of waste causes with 46 waste cause factor and 6 different categories was prepared as shown in Table 3-6.

Table 3-6: Categorized material waste causes

Waste category	Waste cause
Design	Poor design and details
	Poor estimations
	Poor specifications
	Changes in designs and specifications
	Complexity and low constructability of design
	Poor interdisciplinary design integration
	Improper/ wrong material selection or substitution
	Ignorance of material specifications in designs
Procurement	Ordering errors (quality/quantity errors, wrong selection/substitution)
	Supplying errors by suppliers (quality/quantity errors)
	Early or late delivery
	Defective/rejected products
	Ordering limitations applied by suppliers (quantity/quality limitations)
Transportation	Poor loading and unloading
	Inappropriate packing for transportation
	Multiple shipment/ transportation points
	Accident during transportation
	Poor site accessibility/ road condition
Storage and distribution	Poor/improper handling and distribution on site
	Poor/improper storage and protection
	Unpacked/ improper packaging of materials
	Multiple/ unnecessary relocating or Handling
	Excessive/ unnecessary inventories
	Poor site storage capacity
	Accidents during storage and distribution
	Handling equipment failure (breakdown or malfunctioning)
	Untraceable/ left-over materials on site
	Poor stock management

Table 3-7: Categorized material waste causes (Continued)

Waste category	Waste cause
Construction	Using poor quality/ wrong material
	Poor/ wrong execution of work
	Damages by subsequent trades
	Excessive/ un-optimized cutting (conversion waste)
	Accidents during construction
	Excessive use of material
	Overproduction
	Ignorance of designs/ method statements during construction
	Unavoidable process waste
External waste affecting factors	Poor planning and scheduling
	Poor waste management
	Poor supervision and control
	Poor project contracting/ subcontracting
	Unfavorable weather conditions
	Natural/ manmade disasters (e.g. earthquake, floods, war, etc.)
	Unknown site conditions
	Theft and vandalism
	Unskilled/ unexperienced labor

Moreover, the obstacles and incentives to implementation of efficient waste management were explored in existing studies. Osmani (Osmani, 2011), reported the key drivers for waste reduction and management in the UK construction industry in four major groups as environmental, legislative, economic and business factors. He also divided waste minimization strategies in two main groups including: design strategies and on-site strategies as shown in Table 3-8. He reported that few attempts were being made to reduce the waste generation in design stage and 92% of survey participants declared that they did not carried out any feasibility study for waste reduction in design stage. According to on-site strategies it is reported that the 88% of participants reported that they used “appropriate storage of materials” and 77% declared that they “provided easy access for delivery vehicles” in their projects. However, they confirmed that few efforts were made to segregate and reuse wasted materials.

Table 3-8: Waste minimization strategies in UK provided by Osmani (2011)

Category	Waste Minimization Strategy
Design	Feasibility study of waste estimation Rarely Designing for deconstruction Specifying reclaimed/recycled materials Use of standard dimensions and units Use of prefabricated units Avoidance of late variations in design
On-site	Appropriate storage of materials Provide easy access for delivery vehicles Waste Segregation Recycle waste materials Set waste reduction targets On-site reuse of waste materials offsite reuse of waste materials

Osmani (Osmani, 2011) also identified four incentives for construction waste minimizations as “waste management policy in place”, “ legislation”, “training” and “financial rewards”. He also identified the barriers of waste minimization in construction industry including: “lack of interest from client”, “Poor defined individual responsibilities”, “lack of training” and “waste accepted as inevitable”. Ameh and Daniel (Ameh & Itodo Daniel, 2013) declared that “Negligence and care free attitude of management”, “Lack of integration of waste reduction- plan in the design and construction process” are the barriers to efficient waste management. There are several studies investigating the barriers to implementation of efficient waste disposal and recycling in construction industry. These studies reveals that low cost of landfilling, lack of recycling facilities, lack of appropriate technology for recycling, lack of policies and financial incentives are the main barriers to successful waste recycling in construction industry.

3.1.3. Interview with Professionals

In order to explore the current state of waste management in prefabricated construction industry in Turkey, and understand the existing processes of waste management and reduction, face to face interviews were carried out by 9 professionals from 5 prefabricated companies. The profile of companies and interviewees are demonstrated in Table 3-9, and Table 3-10 respectively. The barriers and deficiencies of existing processes were discussed and the potential fields of improvements were identified. A set of 7 questions given in Table 3-11 have been prepared and were discussed with interviewees.

Table 3-9: Interview participant's company profile

Company ID	Company Size	Company Experience
A	Large (> 250 employees)	36 years
B	Large (> 250 employees)	29 years
C	Medium (50 < employee < 250)	24 years
D	Large (> 250 employees)	43 years
E	Medium (50 < employee < 250)	27 years

Table 3-10: Interview participant's profile

Participant	Company	Experience	Job Designation
1	B	9	Project Monitoring and Reporting Responsible
2	B	14	Manager of Construction and Project Management Department
3	A	12	Lead Planning and Project Control Professional
4	A	18	Director of Project Management Office
5	C	21	Senior Project Manager
6	C	9	Design Group Chief
7	E	7	Project Manager
8	D	6	Project Control Engineer
9	D	13	Design and Technical Office Manager

Table 3-11: Interview questions and answers

	Questions	Answer	#	%
1	Do you have a waste management plan in your company	Yes	6	67%
		No	3	33%
2	Do you have a waste estimation and reporting procedure in your company	Yes	2	22%
		No	7	78%
3	What is the focal point of your waste management plan	Avoidance	0	0%
		Minimization	0	0%
		Recycling	2	33%
		Disposal	4	67%
4	Which strategy do you generally apply as on-site waste management strategy	Avoidance	0	0%
		Minimization	2	22%
		Recycling	1	11%
		Disposal	6	67%
5	Do you apply a waste management concept in design stage	Yes	2	22%
		No	7	78%
6	Do you have a classified lessons learned archive on material waste in previous projects	Yes	1	11%
		No	8	89%
7	Does waste management performance assessment apply in your company	Yes	0	0%
		No	9	100%

According to the answers as demonstrated in Table 3-11, 67% of respondents expressed that there is no waste management plan in their company. This shows that most of the companies are not aware of the importance of planning for waste management in their projects. 78% of participants answered that they do not have any waste estimation and reporting procedure in their company meaning that only 22% of respondents have waste estimation and reporting system in their company. Question 3 and 4 demonstrates that the concentration of existing waste management plan and waste strategies are on waste recycling and disposal. This confirms that waste minimization or avoidance is ignored by waste management plans and is less important for on-site personnel. This is a confirmation of the fact that the majority of companies have accepted the inevitability of waste generation in projects and are concentrating the waste management efforts on recycling and disposal. According to the given answers 78% of respondents confirmed that waste management principles were not applied in design stage in their companies. Moreover, 89% of respondents declared that there were not any classified lessons learned archive in their company on waste management in past projects. According to the answers to the last question the waste management performances were not measured in their companies. The overall assessment of these interviews provided a general vision about waste management state in prefabricated construction companies and illustrated that waste management is mostly ignored in these companies. It is obvious that developing a waste management plan for estimation, monitoring and controlling of waste generation in prefabricated construction companies is a prominent and needs to more investigation and improvements.

3.2. Questionnaire Survey

A multi-phase questionnaire survey has been administrated to more than 30 professionals to learn about their perceptions on waste-prone materials, their sources and factors plugging the way of effective waste management within the prefabrication sector in Turkey.

3.2.1. Questionnaire Design

Arranging the final results of interviews, and considering the length of the surveys, a two-phase questionnaire was designed and distributed between sector professionals to learn about their perceptions about wasteful materials and waste causes. The first phase of survey was designed to elicit the perception of respondents about the most waste-prone materials and similarity attributes used in similarity analysis. The second phase were seeking the answers for most critical waste causes and company performances in waste management. The questionnaires consisted of two sections, the first section was related to the general information of respondents and their company profile; like, company size and their experience in prefabricated construction industry. In second section, the respondents were required to identify their perceptions about most waste-prone materials, similarity attributes and waste causes in first and second phases respectively.

3.2.1.1. Investigating the Most Waste-Prone Materials

The first phase of the survey asks the respondents to evaluate the 42 identified materials (Table 3-17, Table 3-18, Table 3-19) according to their level of waste-proneness using a five-point Likert system ranged from 1 to 5; representing: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; and 5 = Very High.

3.2.1.2. Factors Affecting the Level of Waste in Different Projects: Similarity Survey

This part of questionnaire aims to identify the project similarity attributes and their weights for similarity analysis in next stages. Five project attributes were identified as follows during interviewing with sector professionals to form the survey framework:

1- Project location
2- Client
3- Project area
4- Contract type
5- Building type

Adding new project attributes to the existing list were possible for participants, if they found any important attribute to be included in the list. However, only one attribute was added to the existing list by two persons. The proposed attribute was “project duration” or “project schedule” which were defined in two different ways by two persons but they were pointing out one concept. The proposed attribute has not been accepted; since “project duration” is generally interrelated with project area and project complexity which both of them are represented by existing attributes, where project area is directly addressed and project complexity factor is represented by building type. Therefore, the predefined list of attributes has been found adequate for similarity analyzing. In order to define the weight of each attribute in similarity assessment, a questionnaire surveying was designed including the above-mentioned attributes, and respondents were asked to evaluate the importance degree of each attribute in project similarity assessment. To evaluate the respondent’s opinion about the proposed attributes, a Likert system, ranged from 1 to 5, was developed which is representing: 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High; and 5 = Very High. This questionnaire is part of first step surveying and 34 respondents were accomplished the survey. The results of survey are represented in next sections.

3.2.1.3. Waste Causes Investigation

After the results of the first phase were analyzed and the most wasteful materials were identified for each discipline; the respondents required to evaluate the waste causes in general and for most wasteful material groups in each discipline. The survey in second phase were asking the respondents to rank the degree of contribution of 46 identified waste causes (Table 3-6 and Table 3-7) in waste generation based on their experience in prefabricated steel structure projects according to the given five-point Likert scale representing 1 = Very Low; 2 = Low; 3 = Moderate; 4 = High ; and 5 = Very High.

3.2.1.4. Waste Management Performance Assessment

The respondents were also asked in second phase of questionnaire survey to evaluate the performance of their company in waste management by answering the 18 expressions given in Table 3-24, in accordance to the given scale of five-point Likert scale representing 1 = Very Poor; 2 = Poor; 3 = Moderate; 4 = Good; and 5 = Excellent. The expressions were defined according to the literature review and interview results and aims to point out the actual state of waste management in companies.

3.2.2. Sampling and Data Collection

A representative sample is a small set of a larger group that adequately reflects the characteristics of its population as a whole. Statistical methods are generally used for designing the representative sample in questionnaire surveying, to enable the generalization of findings to the entire population (De Vaus, 2014). For this purpose, 11 Turkish companies with national and international experiences in steel structure prefabricated building projects were identified using information obtained from Turkish Contractors Association (TMB). 73 questionnaires were sent by Email to professionals from these companies which were specified using business network connections and professional social networks such as “Linkedin”. 34 responses for first phase and 45 replies for second phase were collected from 5 participant companies.

As it is shown in Table 3-12, the majority of companies (60%) are large companies with more than 250 employees; and the remaining (40%) are medium size companies with employees between 50 to 250 people. Table 3-13, demonstrates that 80% of companies have more than 20 years of experience in national and international prefabricated building projects which demonstrates their understanding of the construction waste in Turkey and other countries. Figure 3-1, illustrates the participant company's profile. Moreover, as it is shown in Table 3-15, 67% of participants have more than 10 years of experience in prefabrication which means that they are professionals with significant knowledge about material wastes and sources of waste generation in construction sites. Regarding to the profile of targeted companies and respondents as shown in Figure 3-1, Figure 3-2, it is obvious that the representative sample has a uniform and homogenous composition. In addition, it is expected that the responses will be adequately consistent. Therefore, as it is declared by De Vaus (De Vaus, 2014), the relatively small sample size can suffice in a homogeneous population in which most people will answer a question similarly. Besides, the more uniform and consistent a population is, the smaller a sample that can be drawn from it for a research purpose will be (Carmichael, Edwards, & Holt, 2007). Considering the level of participation from 45% of targeted companies (46.6% in phase 1; 61.6% in phase 2) and the uniformity of the respondents and expected consistent answers from participants, this level of participation for sample study would be sufficient.

Table 3-12: Company profile - Company size

Company Size	%	Number
Micro (< 10 employee)	0%	0
Small (10< employee < 50)	0%	0
Medium (50 < employee < 250)	40%	2
Large (> 250 employee)	60%	3
Total	**100%**	**5**

Table 3-13: Company profile - Company experience

Company Experience	%	Number
0-5	0%	0
5-10	0%	0
10-15	0%	0
15-20	20%	1
20-25	40%	2
25+	40%	2
Total	**100%**	**5**

Table 3-14: Participant profile - Job designation

Job Designation	%	Number
Project/Construction Manager	27%	12
Technical Manager	24%	11
Engineer	29%	13
Technician	7%	3
Tech. Supervisor and Inspector	11%	5
Other	2%	1
Total	**100%**	**45**

Table 3-15: Participant profile - Field of experience

Field of Experience	%	Number
Civil/Architectural	62%	28
Mechanical Engineering	20%	9
Electrical Engineering	18%	8
Total	**100%**	**45**

Table 3-16: Participant profile - Personal experience

Personal Experience	%	Number
0-3	7%	3
4-6	9%	4
7-10	18%	8
11-13	20%	9
14-16	16%	7
17-20	18%	8
20-25	11%	5
25+	2%	1
Total	**100%**	**45**

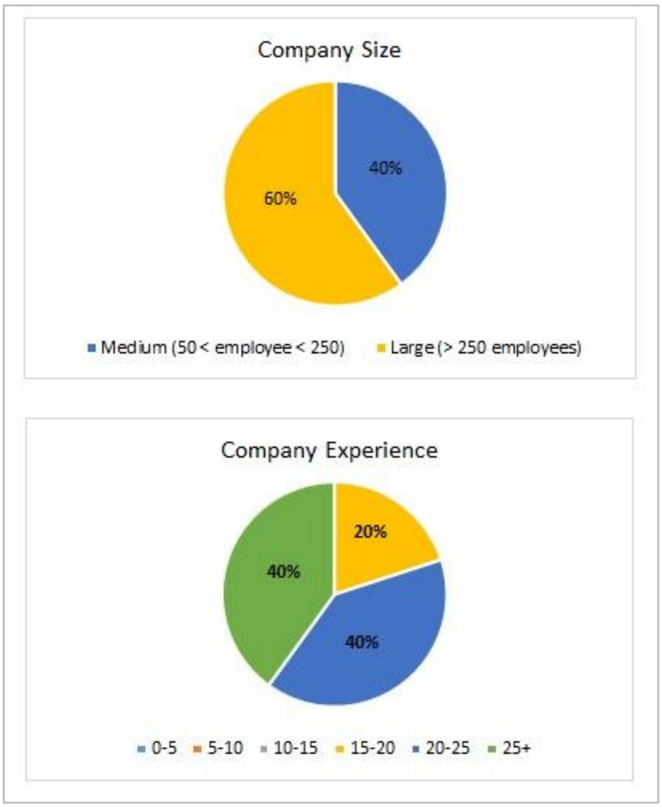


Figure 3-1: Company profile in questionnaire survey

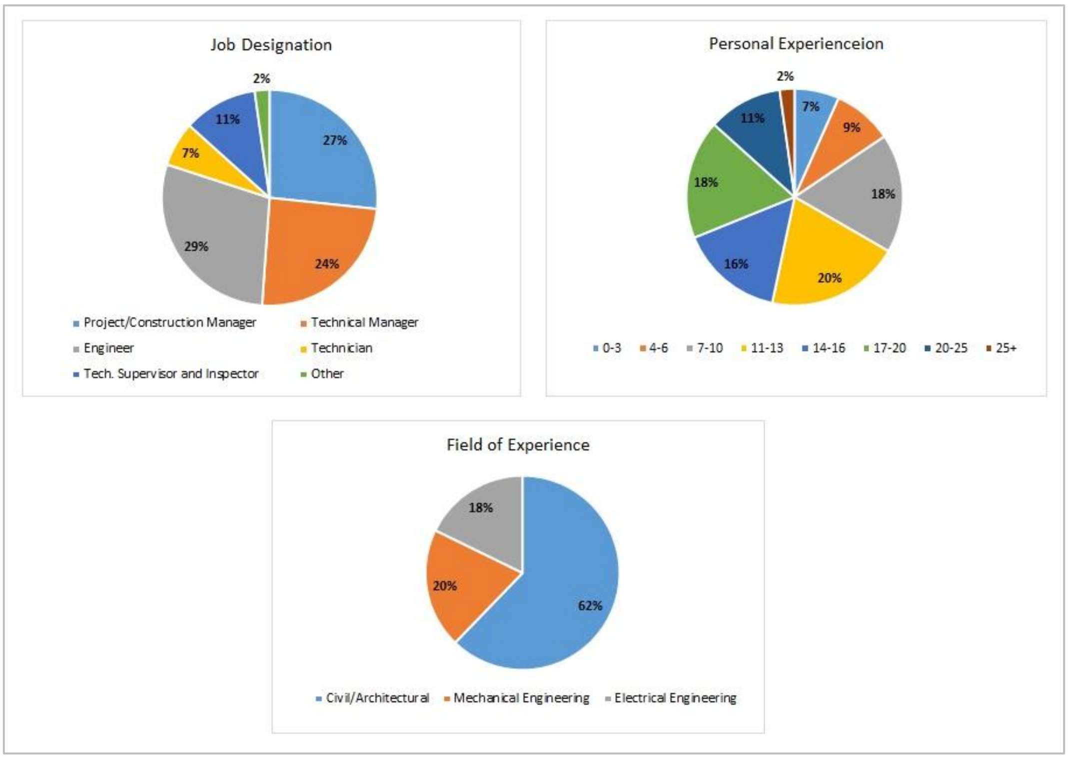


Figure 3-2: Participant profile in questionnaire survey

3.3. Data Analysis

To determine the relative ranking of the most waste-prone materials and waste causes, and also to identify the relative importance of project similarity attributes, the responses collected from surveys were evaluated according to the Relative Importance Index (RII) using the following equation:

$$RII = \frac{\sum W}{A \times N} \quad (0 \leq RII \leq 1) \tag{3.1}$$

Where:

W: The weight given to each factor by the respondents (from 1 to 5),

A: The highest weight and,

N: The total number of respondents

3.3.1. Most Waste-Prone Material Analysis

The Relative Importance Index (RII) is calculated for each material type and for each cause. Then the materials and causes were ranked according to the value of RII. The results of material ranking, based on RII, are demonstrated for building, electrical and mechanical materials in Table 3-17, Table 3-18, and Table 3-19, respectively. According to the results, sealing materials, wall and ceiling boards (gypsum and fiber cement boards), heat insulation materials, and paint, are the most five waste-prone building materials in prefabricated steel structure projects. In addition, cables in electrical material group and PVC pipes and fittings in mechanical material group has the greatest RII and are evaluated as the most wasteful materials by respondents. Based on the results of first phase of survey, one material from each discipline including “wall and ceiling boards”, “pipes and fittings”, and “cables” were selected considering their RII value and cost and quantity in prefabricated projects, to investigate the related waste sources in second phase of survey.

Table 3-17: Relative Importance Index of building material groups

Ranking	Building material group	∑w	RII
1	Sealing materials (silicon, etc.)	132	0.78
2	Gypsum board	116	0.68
3	Fiber cement board	104	0.61
4	Heat insulation (Rockwool - XPS - glass wool)	102	0.60
5	Paint	98	0.58
6	Fasteners/ connection elements	96	0.56
7	Plaster (gypsum & others)	96	0.56
8	Ceramic tile	96	0.56
9	Un-structural concrete (screed & others)	94	0.55
10	Door handles and accessories	92	0.54
11	Waterproofing material	92	0.54
12	PVC flooring	88	0.52
13	Window handles and accessories	88	0.52
14	Wood (OSB - timber & plywood)	84	0.49
15	Premixed structural concrete	84	0.49
16	Carpet flooring	84	0.49
17	Sandwich panels	80	0.47
18	Cast/cut stone	78	0.46
19	Steel reinforcement	78	0.46
20	Laminated parquets	78	0.46
21	Aluminum board/tiles	76	0.45
22	Vapor barrier	74	0.44
23	Wooden doors	74	0.44
24	Steel profiles/ structural elements	66	0.39
25	Laminated separation panels	64	0.38
26	PVC window	56	0.33
27	Aluminum window	52	0.31

Table 3-18: Relative Importance Index of electrical material groups

Ranking	Electrical material group	∑w	RII
1	Cables (LV - LC - MV)	102	0.60
2	PVC cable conduits & pipes	98	0.58
3	Cable trays	88	0.52
4	Switch, sockets and electrical installations	86	0.51
5	Electrical equipment	78	0.46
6	Lighting units	74	0.44

Table 3-19: Relative Importance Index of mechanical material groups

Ranking	Mechanical material group	∑w	RII
1	PVC pipes and fittings	98	0.58
2	Pipe heat insulations	96	0.56
3	PPRC pipes and fittings	90	0.53
4	Sanitary/ bathroom accessories	84	0.49
5	HDPE pipes and fittings	82	0.48
6	Air ducts and fittings	82	0.48
7	Sanitary wares	82	0.48
8	Steel pipes and fittings	78	0.46
9	Mechanical equipment	58	0.34

3.3.2. Similarity Attributes Analysis

As it mentioned before, 34 respondents were answered to similarity related questions. The responses distribution is demonstrated in Table 3-20.

Table 3-20: Responses distribution for similarity attributes

Project Attribute	Very Low	Low	Moderate	High	Very High	Total
Contract type	0	2	8	12	12	34
Project area	0	3	9	8	14	34
Project location	2	5	7	11	9	34
Building type	1	6	9	10	8	34
Client	4	10	9	8	3	34

To determine the weight of each project attribute, the responses were analyzed using (eq.4-1). The results are presented in Table 3-21.

Table 3-21: Relative importance of similarity attributes

Ranking	Project Attribute	∑w	RII	RII %
1	Contract type	136	0.80	22.26%
2	Project area	135	0.79	22.09%
3	Project location	122	0.72	19.97%
4	Building type	120	0.71	19.64%
5	Client	98	0.58	16.04%
	Total		**3.59**	**100.00%**

3.3.2.1. Project location

"Project location" is considered as a decisive attribute of a project which affects the waste generation due to the specific local conditions. Projects in different locations may be exposed to various types of local conditions with different effects on waste generation, whereas, projects in same locations experience similar factors that may cause to equivalent waste results. The survey participants were asked to evaluate the importance of being in same or similar location in projects similarity. As it is shown in Figure 3-3 and Table 3-20, only 2 persons were evaluated "project location" attribute as "very low", whereas 20 persons were assessed it "high" and "very high" and 12 persons identified it as "low" and "moderate" important factor in projects similarity.

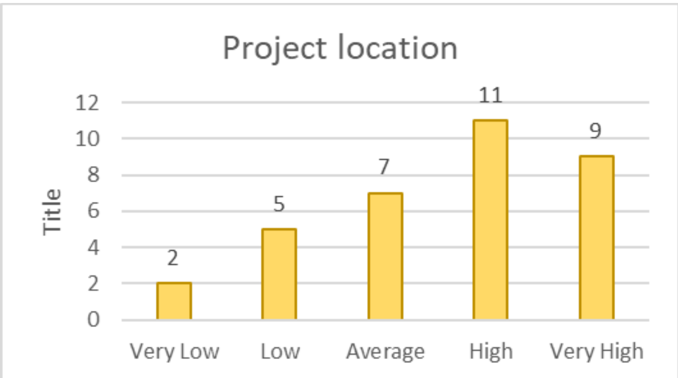


Figure 3-3: Responses for the importance of "Project location" in similarity

Considering the given responses, the Relative Importance Index (RII) is calculated as 0.72 which is equal to 19.97 %.

3.3.2.2. Project area

As it is known, the projects with same or similar sizes generally encountere similar problems related to waste generation originates from project size. For example, the organizational structure for these kinds of projects are mostly similar; therefore, they may encounter same problems related to material lost or site management. Considering the size of project as an important factor in waste management the "project area" were identified as project similarity attribute. The responses for evaluation of the importance of equivalant "project area" in projects similarity are indicated in Figure 3-4 and Table 3-20. the results indicate that, 17 responses are assigned for "moderate" and "high" on the other hand, 14 respondents assessed the "project area" as "very high" important factor in similarity, only 3 persons were considered "project area" as low important attribute.

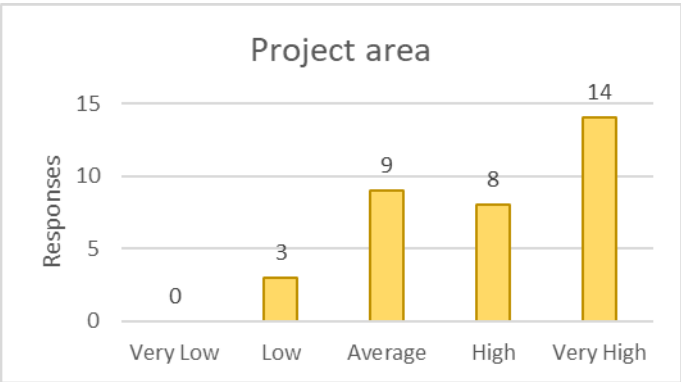


Figure 3-4: Responses for the importance of "Project area" in similarity

According to the data given in Table 3-21, the Relative Importance Index (RII) value for "project area" is calculated as 0.79 which equals to 22.09 %.

3.3.2.3. Building type

Steel structure prefabricated buildings comprise of three general building types as follow:

- Heavy structural steel
- Light steel panelized
- Containerized

Considering the structural, architectural specifications of these buildings, similar problems may be cause to waste genration in these building types. Therefore, same building type is considered as one of the similarity attributes in projects. Considering this issue the respondents were asked to evaluate the importance of "building type" in projects similarity. The responses distribution is demonstrated in Figure 3-5 and Table 3-20. As it is shown, 18 persons are evaluating the "building type" as "high" and "very high" important attribute, and 15 persons as "low" and "moderate", whereas, only 1 respondent assigned this attribute as "very low" important factor in projects similarity evaluation.

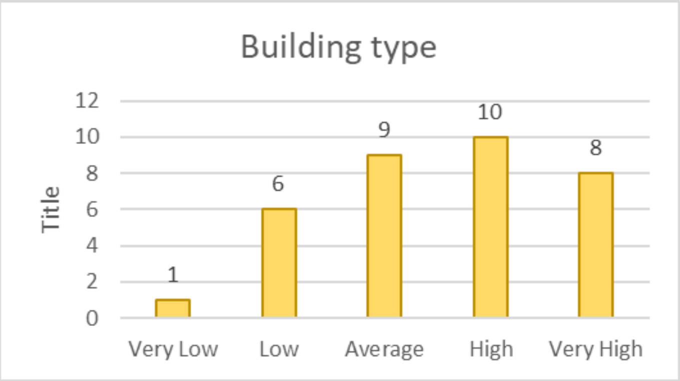


Figure 3-5: Responses for the importance of "Building type" in similarity

Based on the given responses, the Relative Importance Index (RII) for "building type" is calculated as 0.71 which is equal to 19.64 %.

3.3.2.4. Contract type

According to the findings of previous studies on assessing the relationship of contracting type on waste generation in construction projects (Vivian W.Y. Tam, Shen, & Tam, 2007), contract type is represented as one of the influencing factors of waste generation. Therefore, contract type is considered as one of the important project attributes in similarity analysis in “Waste Tracker”. Four types of contracts are generally used in prefabricated construction projects including:

- Lump Sum Contract - EPC
- Lump Sum Contract - PC
- Unit Price Contract - PC
- Cost Plus Contract

Depending on the payment methods and scope of the work, the contract types are varying in prefabricated construction projects, consiquently as it is declared by Tam et al. (Vivian W.Y. Tam, Shen, et al., 2007), based on the type of contract, different level of waste may be generated. As it is experienced in projects and based on the academic investigations as conducted by Tam et al. (Vivian W.Y. Tam, Shen, et al., 2007), Lump sum contracts with EPC scope of the work generates lower amount of waste; whereas Cost Plus contracts leads to a higher waste quantities. Considering this issue, it can be concluded that contract type is one of the important project attributes in projects similarity. The survey participants were asked to evaluate the effect of same contract type in projects similarity analysis. As it is shown in Figure 3-6 and Table 3-20, 24 respondents have identified the “contract type” as “high” and “very high” important attribute whereas, 8 persons assessed it as “moderate” and only 2 persons found it as “low” important factor in projects similarity analysis.

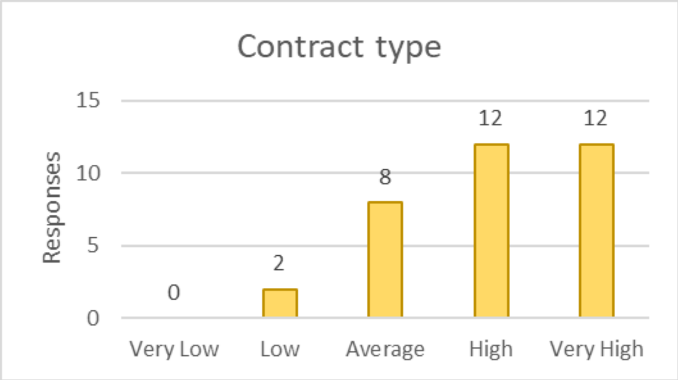


Figure 3-6: Responses for the importance of "Contract type" in similarity

According to the data given in Table 3-21, the Relative Importance Index (RII) value for “contract type” is calculated as 0.80 which is equals to 22.26 %.

3.3.2.5. Client

In most cases, waste management procedures imposed by clients at projects have considerable effects on contractors performance in waste management and waste reduction. Same clients or corporates with similar strategies in waste management, mostly leads to similar results in waste generation, therefore, client factor is considered as one of the five main similarity attributes. The respondents were asked to evaluate the importance level of “client” in similarity analysis of two projects. The result of survey is demonstrated in Figure 3-7 and Table 3-20.

According to the given responses by participants, 79.4 % of total respondents have evaluated the “client” factor in similarity analysis in mid range of importance between “low” to “high”.

Based on the data given in Table 3-21, the Relative Importance Index (RII) value for “client” is calculated as 0.58 which is equals to 16.04 %.

Figure 3-7: Responses for the importance of "Client" in similarity

3.3.3. Waste Causes Analysis

The respondents in second phase, were asked to evaluate the waste causes in general and for selected three materials either. According to the results, demonstrated in Table 3-22 and Table 3-23, “poor site storage capacity” and “poor stock management” are the most critical waste causes in general evaluation. On the other hand, “multiple/ unnecessary relocating or handling” of material is identified as the highest rated waste cause for “wall and ceiling boards” whereas, “unpacked/ improper packaging of materials” and “Damages by subsequent trades” has the highest importance in waste generation of “pipes and fittings” and “cables” respectively.

Table 3-22: General ranking of material waste causes

Ranking	Waste causes	∑w	RII
1	Poor site storage capacity	184	0.82
2	Poor stock management	175	0.78
3	Poor/ improper storage and protection	168	0.75
4	Unskilled/ unexperienced labor	157	0.70
5	Poor estimations	155	0.69
6	Poor design and details	153	0.68
7	Unpacked/ improper packaging of materials	153	0.68
8	Multiple/ unnecessary relocating at site	152	0.68
9	Unfavorable weather conditions	151	0.67
10	Changes in designs and specifications	151	0.67

Table 3-23: Five most important waste causes for three different materials

Ranking	Waste causes	RII
Wall and ceiling boards		
1	Multiple/ unnecessary relocating or Handling	0.73
2	Poor/ improper storage and protection	0.71
3	Poor site storage capacity	0.71
4	Excessive/ un-optimized cutting (conversion waste)	0.70
5	Unskilled/ unexperienced labor	0.69
Pipes and fittings		
1	Unpacked/ improper packaging of materials	0.89
2	Untraceable/ left-over materials on site	0.87
3	Poor interdisciplinary design integration	0.82
4	Ignorance of material specifications in designs	0.82
5	Ordering errors (quality or quantity errors, wrong selection or substitution)	0.78
Cables		
1	Damages by subsequent trades	0.83
2	Ignorance of designs/ method statements during construction	0.83
3	Poor planning and scheduling	0.78
4	Theft and vandalism	0.75
5	Poor/ improper storage and protection	0.70

3.3.4. Waste Management Performance Analysis

According to the results of waste performance data analysis, illustrated in Table 3-24, (1 = Very Poor; 2 = Poor; 3 = Moderate; 4 = Good; and 5 = Excellent) "The awareness of company/project stakeholders about waste management" and "The material traceability at construction sites" are the best evaluated attributes of prefabricated construction companies according to the respondents. "Training and education about waste management and control in projects" and "Using integrated design and estimation software (e.g. BIM software)" are the worst evaluated factors in waste management of companies. They also declared that the waste cost impact analysis is not performed in acceptable level and consequently the magnitude of the cost impact of waste in projects is not known in most cases. The results also revealed that personnel designation for waste management at construction sites is not enough in most cases according to 33% of the respondents.

Table 3-24: Waste management performance analysis

Rank	Expressions	1	2	3	4	5	∑w	RII
1	The awareness of company/project stakeholders about waste management	0%	9%	**44%**	38%	9%	156	0.69
2	The material traceability at construction sites	2%	18%	**36%**	31%	13%	151	0.67
3	The company policies in material waste avoidance or reduction	0%	20%	**42%**	24%	13%	149	0.66
4	Documentation of material wastes and waste sources	9%	18%	24%	**36%**	13%	147	0.65
5	The availability of actual waste data during project construction	4%	18%	**40%**	31%	7%	143	0.64
6	Company knowledge about the actual amount of waste and waste causes	9%	27%	27%	**31%**	7%	135	0.60
7	The efficiency of waste management and control plan in projects	2%	**40%**	24%	27%	7%	133	0.59
8	The quality of systematic waste data capturing for direct and indirect waste	16%	18%	**36%**	24%	7%	130	0.58
9	The accuracy of methods used for waste source and quantity estimation in projects	4%	**44%**	22%	24%	4%	126	0.56
10	The awareness of project team about estimated waste causes and rates for each material	16%	18%	**40%**	27%	0%	125	0.56
11	Considering environmental and waste management issues in design stage	20%	27%	**33%**	16%	4%	116	0.52
12	The evaluation of waste management performance in projects	16%	**36%**	29%	16%	4%	116	0.52
13	The lessons learned process regarding waste management in projects	27%	**31%**	20%	16%	7%	110	0.49
14	Personnel designation for implementation of waste management plan	**33%**	22%	22%	16%	7%	108	0.48
15	The analysis of actual and nominal waste data in projects	**40%**	24%	16%	16%	4%	99	0.44
16	The analysis of cost impact of material waste in projects	36%	**42%**	7%	9%	7%	94	0.42
17	Using integrated design and estimation software (e.g. BIM software)	**38%**	31%	22%	9%	0%	91	0.40
18	Training and education about waste management and control in projects	**47%**	31%	18%	4%	0%	81	0.36
Average Evaluation of Waste Management Performance		**18%**	**26%**	**28%**	**22%**	**6%**	**2210**	**0.55**

3.4. Summary of Findings

Document review in two companies and four projects revealed that since there was not any predefined process for material waste reporting and analyzing, there were not specific documentation in companies for material waste in typical project. All material waste reports were prepared for extra material purchases requested from construction sites. Although this cannot be generalized for all companies but it shows that even these two companies have not established any structured procedure for waste capturing and documentation in their companies. This is mostly because of the unawareness of company stakeholders about the magnitude of waste and waste impacts. Besides, the short term of prefabricated construction projects did not allow the project team to establish and support a proper monitoring and documentation system for material waste generation in projects.

Considering the findings of literature review, it is clear that although there are common waste causes between studies, however, the wastes originates from various sources in different studies. Besides, the importance level of waste sources is varying depending on the project type and location. This demonstrates the dynamic nature of the material waste causes in different projects and locations, and requires to be investigated individually for every project depending on the project specifications. Moreover, the studies are mostly considering that each material is affected by several factors and depending on material type, the causes can be changed significantly, therefore, it is essential to come up with waste sources based on the material type.

The professional interviews reveal that, although most of the companies possess a waste management plan, however, none of them addresses the waste avoidance and minimization plans; but they are mostly involving waste recycling and disposal. This means that companies in a large scale have accepted the existence of certain amount of waste in their projects and they do not attempt to eliminate or minimize them. Therefore, it is not expected to implement a systematic waste management plan with the aim of waste elimination or reduction in companies. Unawareness about or ignorance of the waste minimization in construction projects is the main reason behind the unavailability of corporate knowledge on waste management in the form of lessons learned. Consequently, it is essential to promote the corporate awareness about material waste by regular reporting and analyzing the waste generation data and encouraging the project team to enhance the efficiency of waste management processes by considering the waste performance as a total project performance measurement factors.

The results of investigation of most waste-prone materials in prefabricated construction projects, demonstrates that wasteful material types in this sector are totally different than in traditional construction methods investigated in previous studies. Therefore, it is expected that the waste sources and waste management actions must be totally different than in traditional construction method. Considering the types of most waste prone materials in this study, it can be concluded that, due to the chemical compositions of these materials, the waste recycling and disposal costs and the cost of indirect material wastes would be more significant than in traditional construction. Therefore, it can be concluded that the efficient management of waste in prefabrication is significantly important than traditional construction. Consequently, it would be essential to develop a waste management model based on project and material specifications to achieve more efficient results in waste management. Meaning that, the proposed model must be able to track and record the waste sources for every material types in each project independently.

Due to the variability of waste performance in several companies depending on the company culture and organization, it is concluded that, the best method of developing a waste baseline in a project is to investigate the previous performance of the company in past similar projects and compare the current performance with previous results and attempt to improve the efficiency within the company. For this purpose, evaluating the project similarity attributes is performed in this study. Among the five predefined attributes “contract type” and “project area” are identified as the most important attributes in waste performance similarity analysis. The results demonstrate that, due to the unavailability of systematic waste management and reduction strategy within the companies, the waste performances can be varied depending on project contract type and project size. The results also demonstrate that client is the less important attribute in similarity, meaning that client strategies in waste management have minor effect on waste performance of the companies. Therefore, external imposes by clients can not result in process and performance improvement in waste management; whereas, dynamic waste management systems must be able to improve performances by receiving beneficial directions.

Investigating the waste causes in prefabrication demonstrates that the most important waste causes are related to transportation and on-site storage of materials, arising from the off-site manufacturing of building elements, whereas the waste causes in traditional construction are mostly because of the on-site trades and workmanships. The study also reveals the different causes for various materials and demonstrates the magnitude of waste causes variation depending on material type. Therefore, the proposed waste management system must be able to tolerate the dynamic nature of the wastes depending on the material types.

The results of waste management performance assessment are challenging. Although the respondents have declared that the awareness of the company stakeholders about waste management are in acceptable level, however, the evaluation results about waste cost analyzing, personnel training and personnel designation for waste management are in contrast with this assessment. This may originate from misunderstanding of waste management with two different concepts: one with concentration on waste disposal, which is commonly used in industry; and the other with emphasize on waste reduction, which is the main purpose of the question. With reference to average evaluation results of waste management performance, although the calculated value is representing the moderate performance, however, poor assessments are in the second rank. This is an indication of poor waste management performance within prefabricated construction companies according to the sector professionals. Unreliable waste estimation methods, and poor data capturing and sharing within the company, as well as poor data analyzing and recording are the main obstacles in implementation of efficient waste management in companies.

Briefly the following issues can be listed as the findings of exploring the waste management in prefabricated construction companies:

1- Unavailability of predefined reporting and analyzing system for material waste management.
2- Lack of proper documentation for material waste in projects.
3- Lack of waste minimization strategies within the companies and concentrating on waste disposal.
4- Lack of corporate knowledge about waste management due to the poor waste reporting and learning processes.
5- The most waste-prone materials in prefabrication are different than in traditional construction; therefore, the waste causes and waste management methods would be varying either. Meaning that the results of material waste management studies in traditional construction may not be suitable enough for this sector.
6- Vulnerability of waste performance of a typical project to “contract type” and “project area” is an evidence of the lack of waste management strategy within the companies.
7- Different materials are exposed to various waste causes due to the dynamic nature of the waste generation.
8- Total performance of prefabricated construction companies in waste management is not good enough and needs more investigations by researchers.

9- Deficient waste estimation, monitoring, analyzing and recording are the main reason of poor performance in waste management in prefabricated construction industry.

Considering the above mentioned issues, it is required to develop an integrated waste management tool which features the following improvements:

1- Developing a material-based and project-specific waste management model.
2- Integrating the waste estimation, monitoring and analyzing processes.
3- Improving the waste estimation quality based on the realistic data from the previous company performances.
4- Enabling waste data capturing and analyzing within the existing organizational processes in simplest way to enhance the participation of project team.
5- Developing a waste benchmark based on the previous project performances and enable comparisons of current waste data with benchmark information.
6- Establishing waste data recording system for further analyzing and knowledge generation.

CHAPTER 4

DEVELOPING A WASTE MANAGEMENT PROCESS AND TOOL

This study aims to develop a waste management process and tool for prefabricated steel structure construction companies to improve the efficient management of material wastage in companies. Due to the large portion of material costs in projects and limited amount of available resources at construction sites, especially in prefabricated construction projects, poor management of material wastes will cause to significant environmental impacts, cost overruns and delays. Therefore, the efficient management of waste is more critical than it is perceived by project stakeholders. Successful waste management in construction projects requires a comprehensive investigation and monitoring of waste sources and live capturing of waste data for on-time controlling and prevention of waste generation at source; as well as improving the learning process from historical data in past projects for taking proper preventive actions in upcoming projects. The sources of waste are varying for every material as well as for each company and project; so the collected data for a project in a company may not be valid completely for other projects in same or different companies, therefore, the material waste must be monitored and managed separately in any project using the company's waste management system to promote the results of waste reduction strategies. On the other hand, since the construction projects consists of mostly repetitive actions, the lessons learned from previous projects in a company has significant role in developing company knowledge and enhancing the performance of processes; therefore, successful waste management would not be achieved without establishing a comprehensive waste database in a company.

The proposed waste management tool in this study, named as "Waste Tracker" is developed based on the findings of investigation of current state of waste management in prefabricated construction companies in Turkey to overcome the barriers of successful waste management. The following sections explain the objectives of tool development based on the corporate needs for efficient waste management. The topics cover the following subjects:

- Existing deficiencies of waste management processes in prefabricated construction companies.
- Needs and objectives for process improvements.
- Process model for proposed tool for efficient waste management.
- Details of the developed tool including data entry, analysis and reporting processes along with a brief demonstration of tool implementation and authorization of the tool.

4.1. Current Process Model for Waste Management in Companies

In order to identify the needs of prefabricated construction companies in waste management and clarify the main objectives of the proposed process model, the existing processes of material waste management which are generally implemented in these companies should be investigated. According to the PMBOK (Project Management Body of Knowledge), a general management process model requires at least four major steps including: planning, executing, monitoring & controlling and closing. Talking about waste management, planning activities must be generally performed in preconstruction stage during project design and initiating by estimating waste quantities and identifying the sources of waste generation and finally by preparing an integrated waste management plan to perform accordingly. The planned activities with the aim of waste avoidance or minimization, according to waste management plan, must be performed in executing stage including design, procurement, transportation and on-site construction. Tracking of waste management progress, reviewing the performance of project team in waste management and controlling variances from waste management plan must be performed in monitoring and controlling stage. At the end of the project, all waste related data must be analyzed to turn into waste management information with the aim of improving corporate knowledge asset from waste management processes in previous projects; and must be shared and documented properly for future uses in project closing stage. The results of survey and expert interviews about waste management process in prefabricated construction companies in Turkey as explained in section 3.3, reveals that material waste management procedures are not compliant with above-mentioned processes within the companies.

Most of the companies in this study (4 companies) implement a deficient and broken process of waste management within their organization. In some companies, only the waste reporting process is performed in a defective way; whereas in some other companies only the waste estimation stage is executed; waste controlling is mostly neglected due to the lack of waste management plan. Waste estimation and waste monitoring processes are completely separated from each other in all the companies, in a way that project management team, unless quantity estimators, are not aware of the estimated waste rates; and consequently, there is not any reference point to determine variances. Planning, controlling and data analyzing processes for real-time monitoring and prevention, and proper documentation of estimated and realized data are mostly neglected in these companies. In the lack of corporate material waste knowledge, the majority of waste estimations are conducted based on the personal perceptions and experiences of estimators rather than depending on historical project data. On the other hand, waste sources are not identified generally in waste estimation stage. Waste reporting as a part of waste monitoring and controlling process is implemented in a defective way; meaning that a large portion of generated wastes cannot be identified by the means of existing system due to the lack of standard procedures for waste identification and capturing. Since there is no predefined waste management process to be investigated, it would be more sensible to explore the waste estimating, monitoring and controlling, data analyzing and documentation procedures in companies separately. The following sections provide an explanation of existing procedures in the companies.

4.1.1. Waste Estimation Process

The waste quantity and source estimation in design stage is a critical aspect of efficient waste management in construction projects. Since material procurement, transportation and on-site storage planning processes are conducted based on the bill of quantities prepared during design stage. Over or under-estimation of waste can negatively affect the waste management processes in projects. Over-estimation leads to excessive material purchases and finally makes the project more vulnerable for waste generation during transportation, storage and construction stages. On the other hand, under-estimating may cause to material repurchases or substitution with other alternatives, which both are identified as the potential causes of waste production. Therefore, realistic waste estimations represent a critical role in achieving efficient waste management results. There are several ways to make reliable waste estimations, either for quantities and sources of waste. National or international resources, previous project records and previous studies in literature. There are several studies on waste quantification performed in several countries, however, these values cannot be generalized and considered as reliable values for every project in any country. Waste generation is extremely variable for different materials, between various companies and projects, depending on their organizational structure and construction methods. Waste is also affected by various locational, environmental and managerial attributes in projects. Therefore, the most reliable method to make realistic waste estimations is considering the company's historical records from previous projects. Since a systematic waste data collection, analyzing and recording is not available in most of the companies, the majority of waste quantity estimations are performed based on the estimator's personal experiences and perceptions. The waste estimation in prefabricated construction companies in this study involves waste quantity calculation and waste source identification is not included in estimation process. This fact is featured by survey results demonstrated in section 3.3.4. On the other hand, the waste estimation process is completely separated from waste monitoring and control stage in all of the companies, therefore, the project management team is not aware of the estimated waste rates by design team and potential sources of waste generation in their projects. Consequently, they are not able to take appropriate preventive actions prior to waste occurrence to avoid waste generation or waste reduction. This method of waste estimation is not reliable for establishing an efficient waste management in prefabricated construction companies. Therefore, it is essential to develop the process of waste estimation as a part of integrated waste management process.

4.1.2. Waste Monitoring and Controlling Process

The objective of waste monitoring and controlling stage is to facilitate the decision making process for efficient waste controlling by improving the real-time capturing and analyzing of the actual waste generation data and determining the variances from predefined benchmarks during the project lifecycle. This requires a systematic identification of waste quantities and causes as well as existence of a realistic waste baseline. Identifying and reporting the waste generation is the basic part of this process which leads the waste controlling activities. Poor waste identification or defective waste capturing procedures will cause to misleading decisions in taking actions during waste management process.

Considering the current state of waste monitoring and controlling process in prefabricated construction companies in this study, the process is mostly summarized in waste reporting in a deficient and unsystematic way. Due to the lack of systematic waste identification and reporting, as a part of waste management process, the waste controlling activities are generally neglected or delayed. The existing waste reporting procedures, as it is shown in Figure 4-1, are mostly developed as a prerequisite function for material reordering from construction sites, which result in a partial waste identification and are mostly fall into three general categories including: "Damage Reporting", "Nonconformity Reporting" and "Material Requesting". The above-mentioned waste reporting functions are described in following sections.

4.1.2.1. Damage Reporting

Informing project management team about the reasons of additional material purchases due to damages on site is performed using this type of reports in most of the companies in study. Damages reported in this way are generally covering direct wastes with physical losses of material and are mostly used as supporting document of additional material purchase requests rather than a regular waste reporting procedure within the waste management process for project performance measurement. All "Damage Reports" contain waste material type and quantity data and rarely in some companies include the waste causes data, therefore, a simple waste source identification, without any predefined classification of waste causes may be done using these type of reports. However, additional preventive actions proposal is not included in most of the reports. The collected data with this method must be analyzed cumulatively and compared with estimated values to achieve a realistic vision of waste generation status in a project. However, since there is no predefined baseline for waste performance comparison and due to unavailability of a systematic reporting process for further analysis, the waste analyzing and controlling process is largely neglected by companies. Considering the fact that not all the material damages results in repurchasing, it can be concluded that damage reports prepared in this way are not capturing all physical losses of materials. Therefore, it is required to improve the waste capturing and reporting process originated from material damagaes.

4.1.2.2. Nonconformity Reporting

Any nonconformity to original works, involving construction errors, failures and poor workmanships are reported using nonconformity reports. This type of report is mostly used in large prefabricated companies for project documentation purposes and additional material purchase requests, however, is rarely used in medium size companies. Since this type of report is generally used for nonconformities resulted in direct physical material losses, therefore, indirect material wastes are not subjected to identification by nonconformity reports in most cases. In addition, nonconformity reporting is not identified as a part of waste management process in companies, therefore the collected data are not generally analyzed and recorded as project waste management information.

4.1.2.3. Material Request

As it is mentioned before and is demonstrated in Figure 4-1, most of the direct wastes, resulted from physical damages of materials are identified by "Damage Reports" or "Nonconformity Reports" which are mostly ends up with additional material purchases for compensating material losses at sites. However, indirect wastes are widely occurring in projects and material requests for compensation of wasted materials due to indirect wastes are not properly identified using these types of reports. Material reordering from construction sites, resulted from indirect wastes, are performed directly using material request forms without attaching any material waste reports due to lack of procedures for identifying indirect wastes.

Since the project team cannot identify indirect wastes as easily as direct ones, therefore, they are not recognized as material waste in project records; consequently, the waste cause identification is not properly done for this type of waste. Most of the prefabrication companies are involved in material requests from construction sites, however further analyzing of the root causes of these requests are not performed properly due to the lack of efficient waste management process and tools. Therefore, the considerable amount of wastes in projects are not identified properly for taking on time preventive actions. This gap is also recognized during expert interviews and according to questionnaire survey results explained in section 3.4, about waste management in prefabricated construction companies.

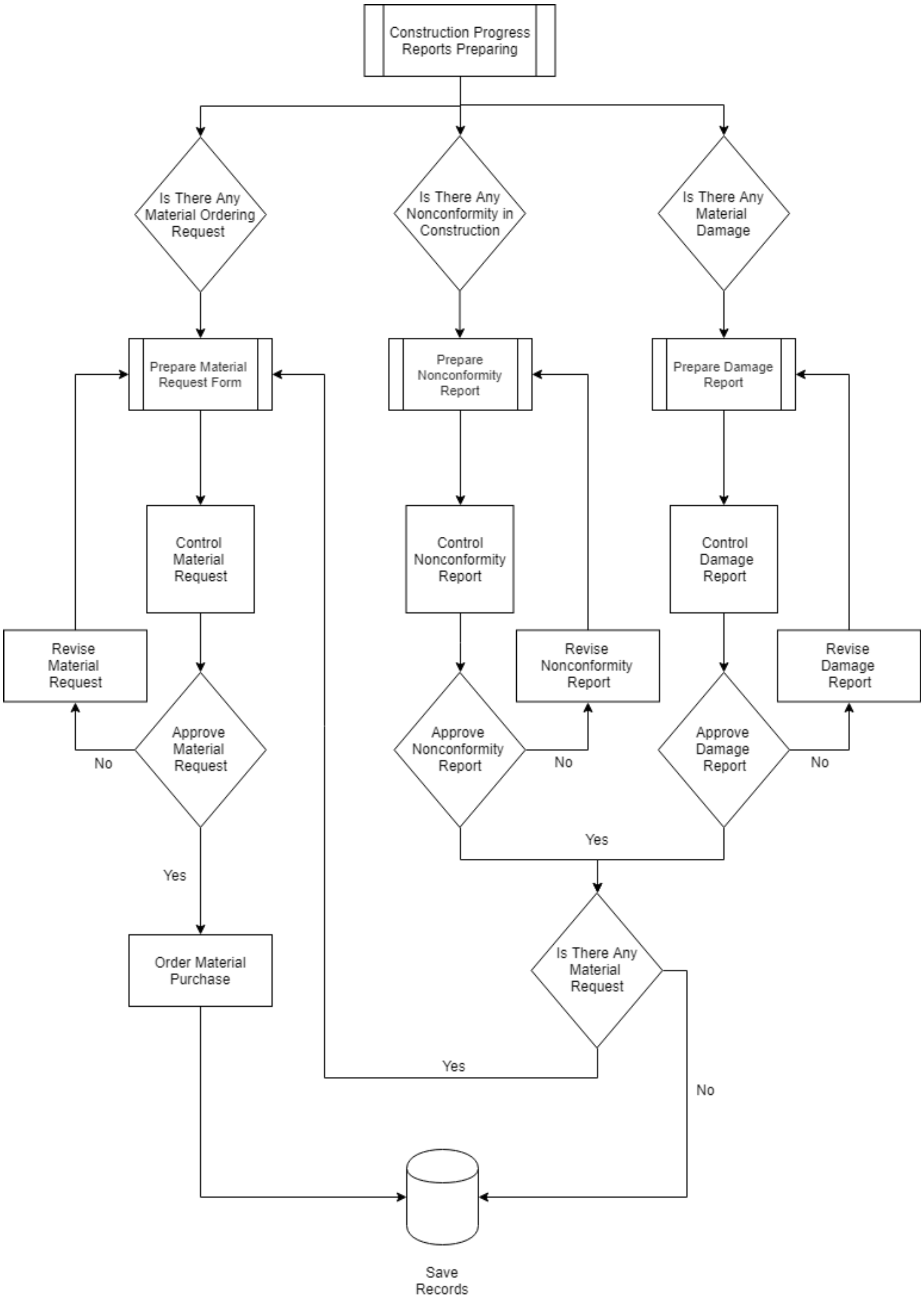


Figure 4-1- Existing "Waste Monitoring and Controlling Process" model in companies

The above-mentioned reporting types are generally used in prefabricated construction companies in Turkey, however some companies partially implement them and some are using whole package as part of their project management reporting system. Meanwhile, the analysis of collected data for producing waste information is rarely conducted by prefabrication companies and almost none of them are using the waste data as a source of corporate knowledge in the form of lessons learned for improving the waste reduction strategies in projects. The main reason behind this deficiency is unavailability of integrated waste management process or poor implementation of existing waste management plans within companies. As it is mentioned in previous chapters, the effect of poor waste management in prefabrication sector has considerable impacts on company performances than in traditional construction. Therefore, it is essential to develop a standard system for waste estimation, waste data capturing, analyzing and sharing within companies to avoid deficient procedures in material waste management.

4.1.3. Existing Obstacles in Efficient Waste Management

Generally speaking, unavailability of integrated and standard waste management process and tool within the companies, leads to poor performance in material waste planning, monitoring and control. Since the existing procedures resulting in identification of a portion of waste generations in projects are not considered as part of a comprehensive waste management system, the collected data are not analyzed and recorded with the purpose of waste reduction and minimization within the projects. The main problems in achieving efficient waste management results, in prefabricated construction companies, can be summarized as non-availability of corporate waste knowledge, unreasonable waste estimation and waste source analysis to maintain an approximate waste baseline; as well as poor monitoring and controlling of waste and consequently not taking timely proper actions while variations are identified. The following sections explain the main barriers in achieving efficient waste management results in prefabricated construction companies.

4.1.3.1. Poor Waste Identification and Data Reporting

Efficient management of waste in construction companies requires comprehensive waste data collection and expedited information flow through the course of the project. Although the literature studies reveal that direct material wastes are generally recognized and reported as debris in most construction projects, however indirect wastes which comprise a considerable portion of total material wastes, are not identified and controlled in a systematic way within companies. On the other hand, waste generation originates widely from sources over the course of project phases, from design to on-site construction, therefore, the contribution of all project participants is required for implementation of extensive waste capturing and reporting. Moreover, the project participants need to have a common understanding of waste concept and must be aware of waste generation sources. It seems that in most of the companies in this study, unavailability of predefined and standard method of waste identification and reporting system, which is an essential requirement of implementation of common understanding and action about waste generation, leads to poor waste reporting performances. On the other hand, the lack of common and accurate waste knowledge of project team members and unavailability of a joint platform for waste reporting, as part of a waste management system, stimulates the waste ignorance or missing in construction projects. These failures, as demonstrated in previous sections, cause to defective waste quantification and documentation; and consequently poor waste management results. Therefore, the proposed system must facilitate the capturing of all types of material wastes throughout the project lifecycle, and develop a common platform with predefined form and structure to establish a comprehensive waste data identification and collection.

4.1.3.2. Poor Waste Estimation

Waste estimation is the basic step of a waste management process, since it defines a benchmark for monitoring waste generation variances during waste monitoring stage. Poor waste estimation or unavailability of waste baseline will result in misleading outcomes during waste monitoring and controlling stage. Therefore, it is essential to establish a realistic and reliable waste estimation process for efficient monitoring and controlling of waste. Moreover, waste reduction requires a proactive management approach, meaning that project team must be able to anticipate the potential sources of waste and take preventive actions accordingly at the right time. This requires a realistic and reasonable estimation of waste quantity and waste generation source identification based on available and reliable corporate knowledge asset, as well as efficient monitoring and controlling of waste generation. Failure to take proactive and on-time preventive actions will lead to poor waste control and unsuccessful results in waste reduction strategies. Moreover, depending on the findings of this study, represented in section 3.4, the majority of waste estimations are conducted based on the individual perceptions of estimators, which are mostly influenced by personal experiences. This method of waste estimation in the absence of using company knowledge database mostly cause to misleading outcomes and unrealistic benchmarking for waste control; and in most cases, may increase the amount of waste. Based on the results of questionnaire survey, described in section 3.3.4, the waste source identification during design and estimation stage is rarely conducted by companies. Therefore, there is not a clear strategy available about managing potential causes of waste generation in most of the projects; consequently, the preventive actions cannot be taken properly. Accordingly, it is a requisite to establish an efficient way for considering the waste source identification in waste estimation documents for each group of materials separately, in order to facilitate the decision making process to minimize the impact of waste generation sources prior to waste event occurrence.

4.1.3.3. Late Prevention to Waste Generation

As it is mentioned previously, waste management process is a proactive function which requires early identification of the waste generation sources. According to the results of company surveys, it is found that the main cause of delayed actions in waste management is mostly related to late identification and poor monitoring of the waste generation within the organizational structure. In most companies the available waste data are extracted after project completion and there is a big lack of real-time data collection and analyzing for ongoing projects. This necessitates the live capturing of waste generation and identifying the root causes of waste to take preventive actions timely and reduce the waste amounts as soon as identified.

4.1.3.4. Lack of Waste Related Information Database

The collected waste data may not be analyzed and preserved properly after project completion and may not be turn into corporate knowledge, which must be available for company members for learning from them. This may be caused by loss of data due to high staff turnover in construction projects and unavailability of an integrated waste management and lessons learned management system within the company. Lack of systematic waste data collection and recording in past projects is one of the main causes of poor and insufficient knowledge transfer in waste estimation and waste management planning process. Therefore, improving the company waste knowledge, based on the information collected from previous projects will encourage more realistic and practical estimations of waste sources and waste quantities in design stage and improves the efficiency of waste management plans in waste minimization. Even though the construction projects are mostly unique and various, learning from previous projects will improve the company performance on waste reduction due to the repetitive nature of construction activities. The waste information collected from past and continuing projects has significant contribution in formation of corporate waste knowledge and if managed properly, will have a considerable effect in achieving high cost and time performances by waste minimization.

4.1.3.5. Unavailability of Classified Waste Information

Waste generation in construction projects is a dynamic event which is significantly varying between projects, due to the uniqueness of waste sources in construction. Although waste can be originated from similar factors in different projects, however the effects of these factors can be extremely dissimilar. On the other hand, the waste generation is varying depending on material type, meaning that the same waste causes with equal intensities will lead to different waste quantities. Therefore, it is essential to investigate and record the waste generation information for every material in each project to achieve more realistic results of waste management. Ignorance of material type and project specification in waste source analysis would be misleading in cumulative assessment of waste management performances and preparing waste related lessons learned documents. Therefore, the proposed tool must be able to classify the waste information according to the material type and project meta data to facilitate data retrieval depending on these specifications.

4.2. Needs and Objectives of Tool Development

Depending on the findings of investigation of existing state of waste management in prefabricated construction companies, the following sections describe the deficiencies of current waste management endeavors and analysis the corporate needs and objectives of waste management tool developments.

4.2.1. Objectives of a Waste Management Tool Development

As it is mentioned in previous sections, unavailability of an integrated waste management system and consequently poor estimation, tracking, analyzing and documentation of material waste is the significant deficiency of existing waste management procedures in construction companies. This leads to poor controlling of waste generation in continuing projects and the lack of corporate knowledge on waste management in previous experiences. Therefore, there is a need for developing a tool with the ability of recovering the current defects and facilitating the efficient waste management in projects and companies.

Considering the above-mentioned issues, the main objectives and features of the proposed tool and process for waste management can be summarized as follow:

1- Establishing an **integrated** waste management system involving waste estimation, reporting, analyzing and recording.
2- Improving the quality of waste estimations and reducing poor estimations due to personal perceptions by developing **material waste database for previous projects** and facilitating the access of project team to database.
3- Facilitating the systematic waste source estimation to improve **proactive** waste management by anticipating of waste generation sources for project team and letting them to plan for proper waste management procedures.
4- Improving the extent of material waste capturing by establishing a predefined procedure and structure for **direct and indirect waste reporting**.
5- Promoting the **common understanding** of project participants about material waste by establishing a standard format of waste reporting and waste sources identification.

6- Establishing the material waste reporting as part of the project progress reporting process to **minimize the amount of waste ignorance** by project participants.
7- Facilitating the **live capturing and monitoring** of waste generation by developing a systematic method for waste identification and reporting by project participants.
8- Developing a waste analysis tool to assist project management team in **tracking** the waste generation and comparing with previous projects performances to **improve** the efficiency of waste monitoring and controlling processes.
9- Developing **a waste data recording system** by establishing a classified waste information database for each project based on the different material groups to facilitate the preparation of waste-related lessons learned documents.

4.2.2. Proposed Structure of Material Waste Management Tool

Considering the above mentioned deficiencies in existing procedures of waste management in companies, and in light of the tool development objectives, the fragmentation of waste estimation, monitoring, analyzing and recording processes must be resolved in proposed tool to overcome the majority of existing failures.
Figure 4-2 demonstrates the general layout of the proposed integrated waste management tool which involves all features of an efficient waste management system including, “Waste Estimation”, “Waste Monitoring”, “Waste Analyzing” and “Recording the Waste Information” for further data retrievals. Based on the proposed structure in Figure 4-2, the waste estimation process is performed considering the previous project records within the company to achieve more realistic and feasible estimations. The estimated values will be saved in the system and the waste generation will be monitored and reported by the authorized persons

in the system during project execution. The reported data in waste monitoring stage comprises of either quantity and sources of wastes. The tool will also be able to analyze the waste generation status based on the estimated and actual waste data as well as in compare with the previous project performances. All entered data, as estimated and actual values, during waste monitoring and waste analyzing process will be saved in the system for further data retrieval by users. Therefore, the proposed scheme in Figure 4-2 is establishing the basis of the waste management tool with an integrated structure which is expected to improve the performance of waste management in companies.

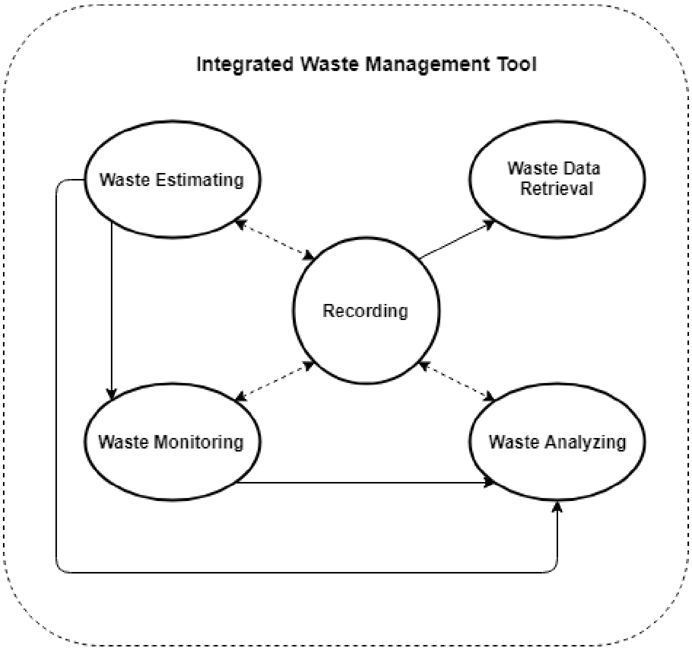


Figure 4-2: General Scheme of Integrated Waste Management Tool

Since waste generation originates from wide sources over the course of the project, from design to on-site construction, the contribution of all project participants is required to implement an extensive and integrated waste management system in the company. For this purpose, a waste management tool demonstrated in

Figure 4-3, based on the proposed structure in Figure 4-2, is developed as a web based program which will be accessible by every project participants from any location. The tool is developed in computer environment using PHP language as the web based programming language and is hosted by a server. The tool is named as "Waste Tracker" and is located in the center of the system in

Figure 4-3 which is accessible through the web using personal computers without need to setup any program. All generated information is stored in a SQL database (Structured Query Language).

Figure 4-3 demonstrates the general structure for material waste data capturing, analyzing, recording and sharing using "Waste Tracker" which must be operated as a part of waste management process within the company organizational structure to facilitate the information flow and recording the material waste data efficiently.

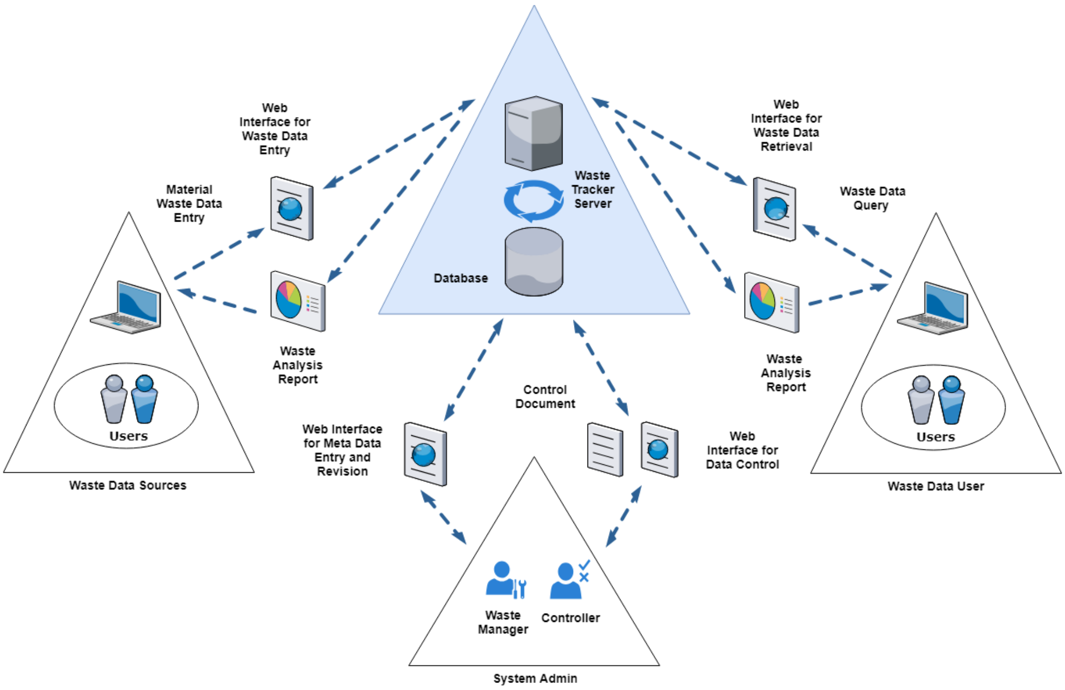


Figure 4-3- Proposed structure of "Waste Tracker"

4.2.3. “Waste Tracker” Process Model

A simple presentation of “Waste Tracker” process model is provided in Figure 4-4. In order to save the material waste data for each project and enable the data retrieval based on the project data, it is required to enter project data in the system. As it is shown in Figure 4-4, in first step of process, the project is created by “System Admin” based on the general project data. The output of this step is used as input in next step which is related to the scope of the project. The “System Admin” adds the project scope data after project information is defined in the system. Project scope data includes the project building types and quantities beside their specifications, which is entered using the related interfaces. The project creation process will be completed after defining all project and scope information and since the key project personnel data have been entered by “System Admin”. At the same time the similarity analysis is performing by system based on the previous project data stored in the system data base. After project is created, the material data, based on the project BOQ (Bill of Quantities), is defined in the system to construct the project waste baseline. The project material list can be created by either “System Admin” and “Data Source” and is prerequisite step for defining the material waste baseline. After the project material list is created in the system, the waste quantity and causes will be estimated for each material group by “System Admin” or “Data Source”. At this point, the material waste baseline is completely created and all actual waste events, reported during project execution, will be compared with this baseline hereafter. During waste estimation process, the system assists the user by suggesting the waste quantity values for each material group based on the results of similarity analysis, performed in system background, considering the previous project data stored in system database. Whenever any waste is arising in project, the waste generation data, including the actual quantity of wasted material and the causes of waste generation, will be reported by “Data Source” or “System Admin”. The actual material waste is associated with project and material in the system, therefore, project, material and user data, are entered as process input data for waste reporting process. The output of waste reporting process in step 6, is a draft waste report which are the process inputs of report controlling process in step 7 together with project material list and waste baseline. Draft report of waste event is reviewed by “System Admin” to ensure that waste identification data are entered accurately by “Data Source”. The draft report can be approved, returned for revision or completely rejected by “System Admin”. In the case of approving, the output of the process will enter as actual waste generation data in project database for related project and material. Therefore, according to the user needs, the recorded data can be retrieved by “Data User” in step 8. This step is providing waste analysis reports according to the needs of the user in two types including: “Waste Quantity Analysis” and “Waste Cause Analysis”. Considering the above-mentioned structure for proposed tool and process, the system capabilities and features can be summarized as follow:

1- Establishing an integrated waste management system involving waste estimation, monitoring and real-time analysis as well as material and project waste data recording features.
2- Improving the quality of waste estimations by developing standard interfaces for estimating of waste quantities and waste causes for each group of materials as well as providing actual waste values from past similar projects in portfolio.
3- Promoting the waste data capturing and retrieval by fostering the accessibility of project participants using a web based tool from any location at any time.
4- Defining the material waste data, based on the project meta data to establish a project-based waste recording system in companies.
5- Developing a comprehensive waste data collection system by promoting the data capturing for direct and indirect wastes using the standard forms of waste report interfaces.

6- Establishing a corporate waste knowledge database by recording the waste causes and quantities and analyzing the collected data for each project in portfolio.
7- Providing the access of project participants to real-time waste generation information and take effective actions for waste minimization, based on the deviations from baseline.
8- Developing a waste data retrieval mechanism for facilitating the information querying and waste knowledge producing and sharing.

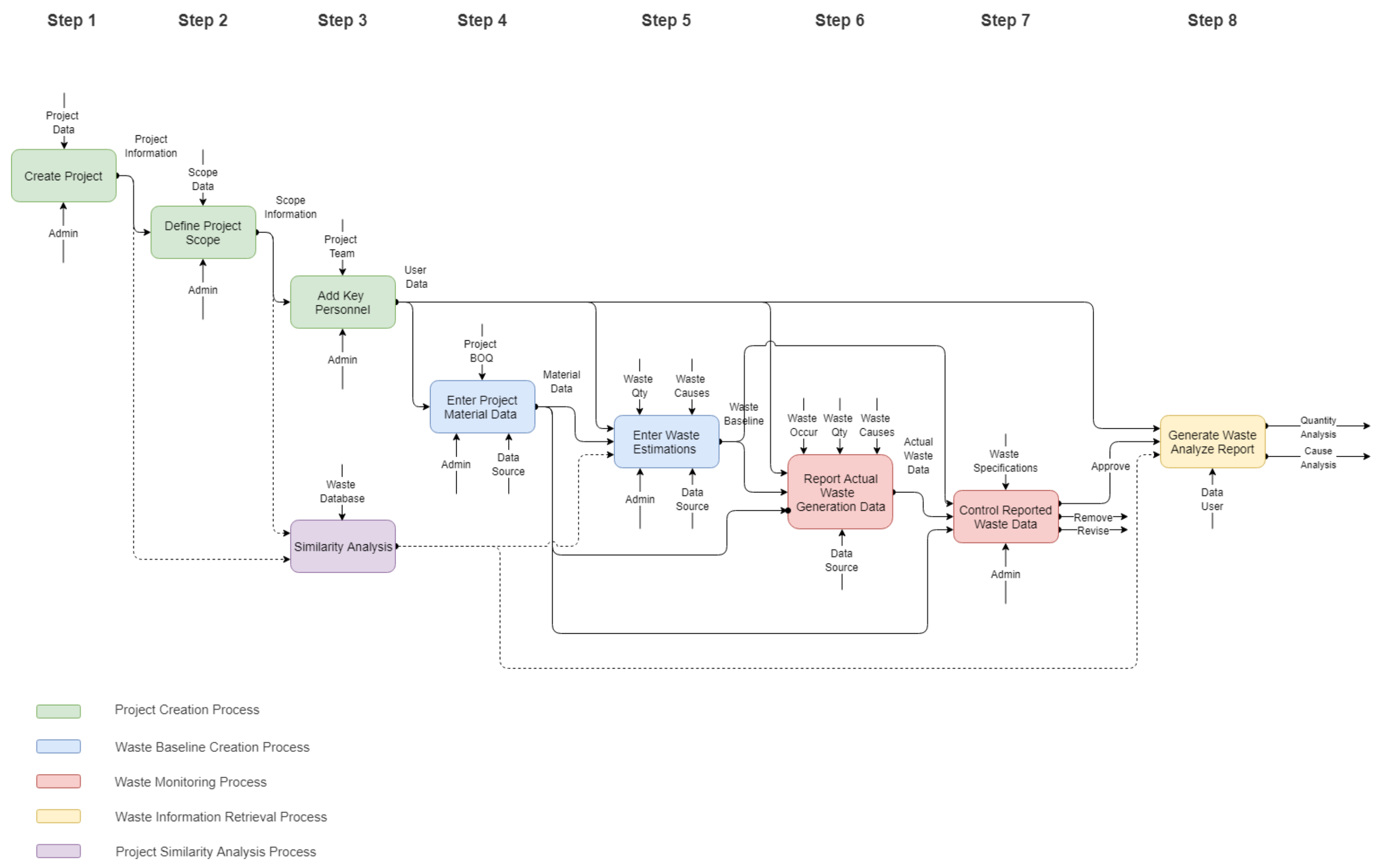


Figure 4-4: General waste management process model using "Waste Tracker"

According to the proposed structure provided in
Figure 4-3, and process model demonstrated in Figure 4-4, the model contains three types of user groups with different roles and accessibilities in the system as follow:

1- System Admin
2- Waste Data Source
3- Waste Data User

Waste data capturing and reporting through the system in the course of the project is one of the objectives of "Waste Tracker" which is implemented by "Waste Data Sources". All project team members from construction site and project offices who are eligible for reporting waste generations are authorized as "Waste Data Sources". Entering waste data in the system is performed by "Waste Data Sources" using standard waste reporting forms provided in the system for direct and indirect wastes. Moreover, all company and project team members that need to access corporate or project waste data are considered as "Waste Data User". The analyzed waste data and comparison results with waste benchmarks are available in the waste analyze reports and are accessible for "Waste Data User". Since the access level of "Waste Data Sources" and "Waste Data Users" are limited, the system needs to have a user category in addition to these basic categories, with administrative access to the system. "System Admin" is responsible for system maintenance, defining project, waste baseline creation and documents reviewing and controlling in the system. Waste mangers, project managers and document controllers depending on their responsibilities, can be assigned for this role. "Waste Tracker" consists of different menus which are arranged in system preferences to be accessible by different roles according to their access level. Any user in the system can be authorized for one or more user categories according to his/her role in the project.
Figure 4-5 demonstrates the use case diagram for "Waste Tracker" which explains the user roles and privileges.

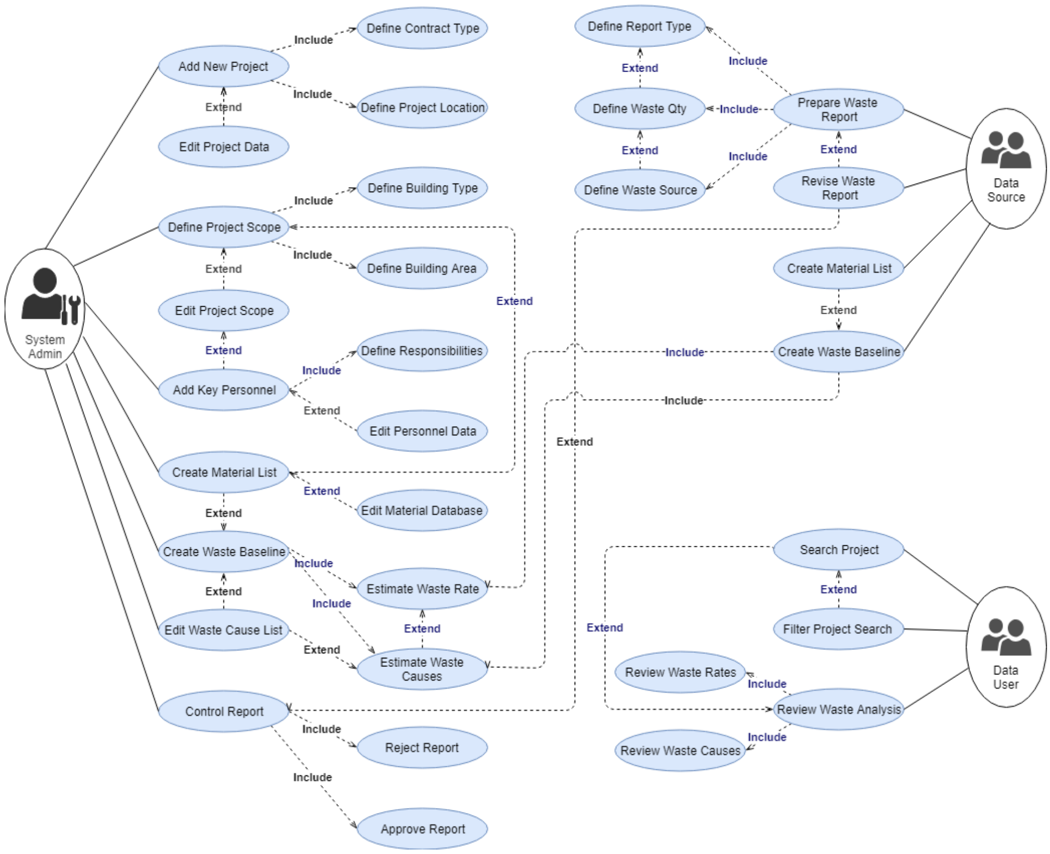


Figure 4-5: Use Case Diagram for "Waste Tracker"

4.2.4. A Generic Process Model of Waste Management Tool

The proposed material waste management process using waste management tool named as "Waste Tracker" requires the involvement of all project and company participants to establish a comprehensive waste estimation, reporting, analyzing and recording system to enhance the corporate waste management performance and develop corporate waste knowledge database. Therefore, it must be operated as an integrated part of company organizational structure and should be supported by company team members, especially by top organizational managers, to enhance the level of participation, usage and recognition within the company. For this purpose, it is essential to define the operational process of proposed tool within the existing corporate organizational structure to avoid additional and parallel procedures and establish a predefined process for organizational operations. This will reduce non-procedural operations and parallel processes within the company which can negatively affect the dedication and eagerness of project participants in waste management processes. As it is mentioned previously, the main procedural barriers to promote the efficiency of waste management in companies, participated in this study, can be summarized as follow:

1- Poor waste estimation due to the lack of analyzed waste data from past projects and unavailability of a waste benchmark for evaluation of variations.
2- Poor waste capturing and analyzing process due to unavailability of standardized tool and predefined process for waste identification and reporting.
3- Unavailability of corporate waste knowledge for improving the waste management processes due to the lack of systematic data collection, analyzing and recording.
4- Poor controlling of material waste generation due to the lack of real-time waste data monitoring and analyzing process and unavailability of a tool for assisting decision makers in appropriate waste management.

To overcome the above-mentioned barriers, and facilitate the operation of waste management tool within the company organizational structure, a process model for each module of the system including: Project Creation, Waste Baseline Assignment, Waste Reporting and Waste Analyzing are developed. These modules with their components and operating processes are being described in following sections.

4.3. The Modules and Components of the "Waste Tracker"

"Waste Tracker" comprises of four general interrelated modules, which collectively constitutes an integrated material waste management tool. The modules are as follow:

1- Project Creation
2- Waste Baseline Creation
3- Waste Monitoring
4- Data Analyzing and Retrieval

Details of the tool components and the processes of each module are described in the following sections. Besides, a summarized explanation of the application from logging to project creation and analyzing processes in "Waste Tracker" are provided.

4.3.1. Logging to the System

As it is mentioned previously the "Waste Tracker" is a web based application and is accessible via the address of http://www.wastetracker.online/ . In order to use the application and defining a project, or access to the waste data of an existing project in waste database, it is required to login to the system. Any user can login to the application, using the unique username and password assigned for each user by system administration. The tool functions and stored data will be accessible after logging to the system using the login interface as shown in Figure 4-6. Since logging to the application, the "Home Page" screen will be appeared as shown in Figure 4-7. Any existing project data in the system database is accessible from "Home Page" screen by direct selecting of desired project from "Project Selecting" segment or by searching a project using the project search function based on the projects attributes. Material searching option is also available in this page. If the desired project is not existing in the system database, it must be created using the "Home Page" interface. A new project in the system can be created using the "Add New Project" tab provided in "Home Page" screen. The complete processes of creating a new project in the system and defining the waste baseline and the method of waste reporting and analyzing using "Waste Tracker" is explained in following sections.

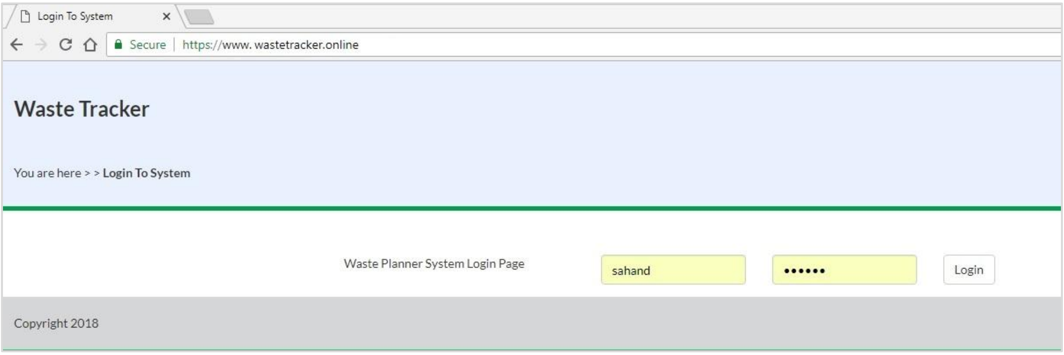


Figure 4-6: Login page of "Waste Tracker"

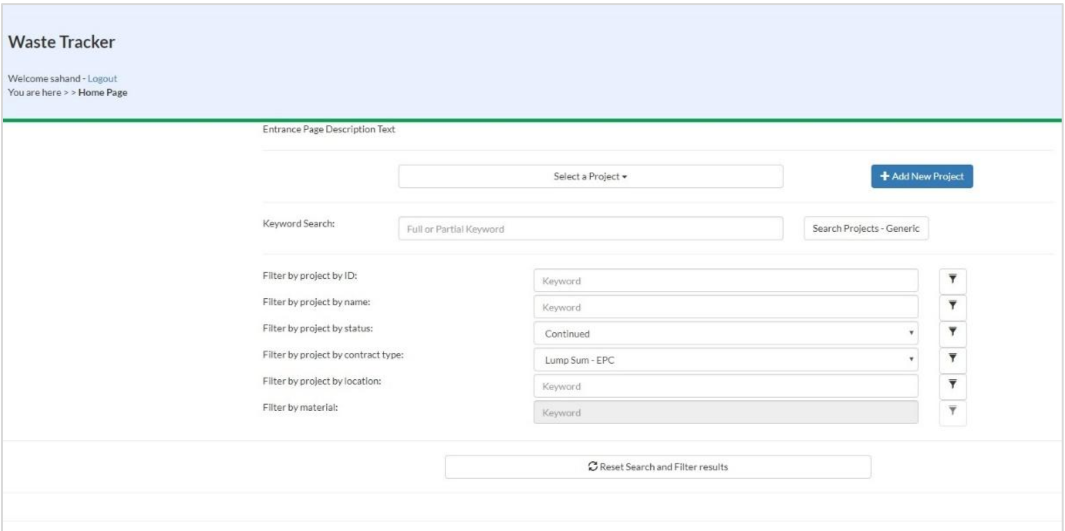


Figure 4-7: Home Page interface

4.3.2. Project Creation

Although the construction sector is a project based industry and each project carries mostly different properties than the others, however, the construction operations, as the main sources of waste generations, consist of common procedures with similar events. On the other hand, there are significant similarities between projects due to the common attributes. Therefore, comparing the waste quantities and investigating the common waste sources in similar past projects is an effective way for waste quantity and source estimations and preparing efficient planning for waste reduction or avoidance in projects. Monitoring, analyzing and storing of waste information based on the project data and comparing the waste management performance results in similar projects is the main idea behind the proposed material waste management process using "Waste Tracker". For this purpose, it is required to define the waste related information under project data for each type of material.

4.3.3. The Process of Project Creation

Using "Project Creation" module, the project and scope meta data as well as user's information can be defined in the system using the related interfaces. These data are the basic project attributes in waste and similarity analysis and can be used for searching a project in database or enquiring waste analysis results. Figure 4-8 demonstrates the flowchart and process of "Project Creation" module within the "Waste Tracker". "Project Creation" module consists of three main components as demonstrated in the process flowchart in Figure 4-8, including:

1- Defining general project data
2- Defining project scope data
3- Defining key personnel data

Therefore, the process requires three separated steps as it is shown in Figure 4-4.

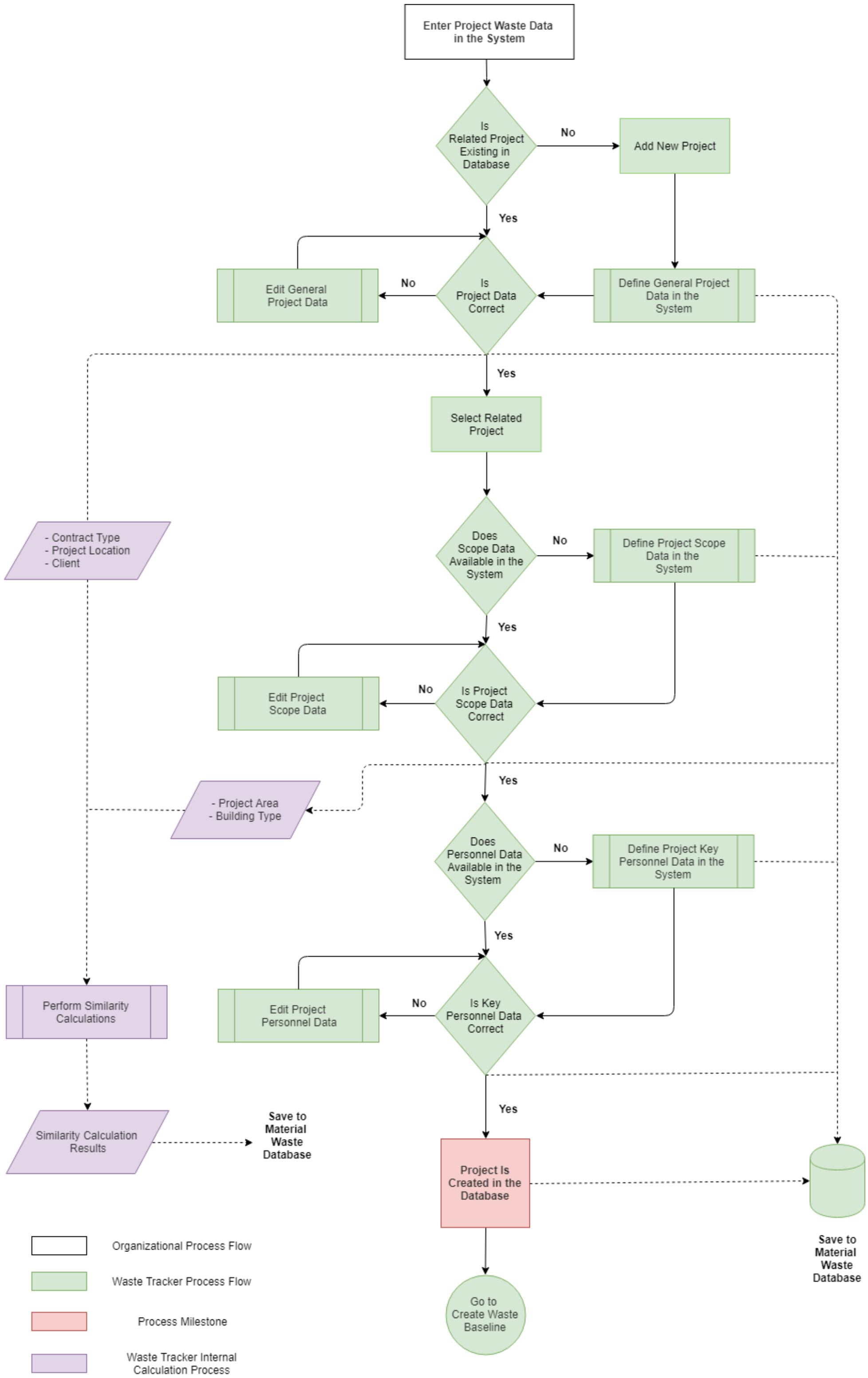


Figure 4-8: Flowchart of "Project Creation" process

4.3.3.1. Defining Project Data

General project data including: “Project Name”, “Client Name”, “Project location”, “Contract type” and “Start and Finish Dates” must be entered to the system using the related interfaces shown in Figure 4-9. These attributes are generally used for project similarity analyzing and searching a project waste information in system database. As it is explained in section 3.3.2, “Client”, “Contract Type” and “Project Location”, are the most important project attributes in similarity analysis. As shown in Table 4-1, four types of contract are defined in the system as a drop-down list demonstrated in Figure 4-9.

Table 4-1: Contract type classification in "Waste Tracker"

Contract Types	
Lump Sum Contract - EPC	Lump Sum Contract - PC
Unit Price Contract - PC	Cost Plus Contract

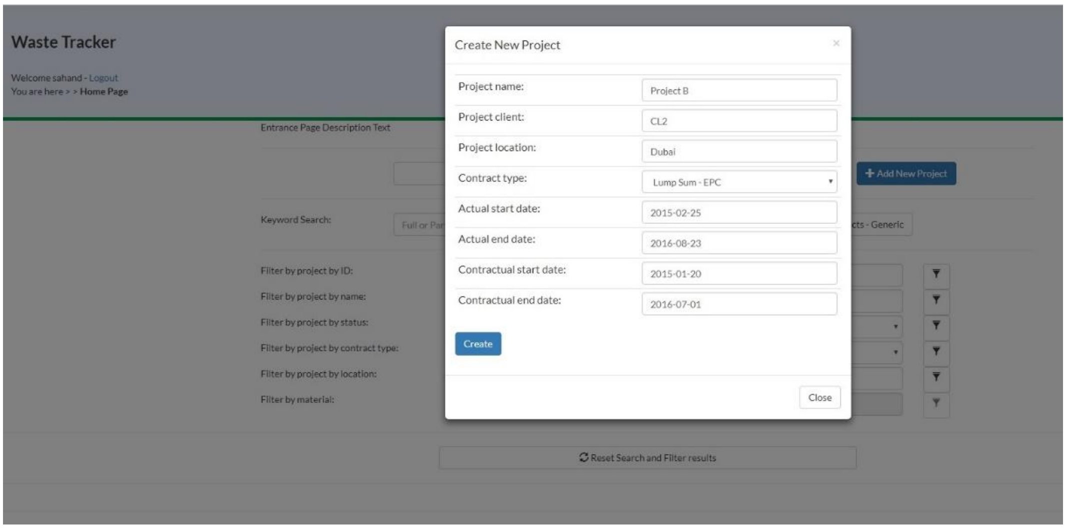


Figure 4-9: Project Creation interface for defining project data

4.3.3.2. Scope Meta Data

Scope of work in prefabricated projects is generally comprises of two general fields including building and infrastructure packages. Some projects consist of both, and some contains only superstructure package. Therefore, any material waste management process and application should cover the waste generation in both fields. Details of superstructure and infrastructure works must be defined in this step. Building field of information consists of data related to “Building Name”, “Building Type”, “Building Category”, “Building Quantity”, “Number of Stories”, and “Unit Area”. According to the results of similarity attributes investigation presented in section 3.3.2, “Building Type” and “Total Building Area” are identified as most important waste influencing factors in waste and similarity analysis and are mandatory to fill out in system. Figure 4-10 and Figure 4-11, demonstrate the project scope screen and adding new building data interface. As it is indicated in Table 4-2, “Building Type” is categorized in three general groups and is presented in the form of drop down list in “Waste Tracker” scope defining interface as it is demonstrated in Figure 4-11:

Table 4-2: Building type classification in "Waste Tracker"

Building Types		
Heavy structural steel	Light steel panelized	Containerized

“Building category” classifies the buildings according to their usage purposes. This factor in some cases can be considered as similarity factor in waste analysis; however, it is not identified as project similarity attribute in questionnaire survey. “Building category” should also be defined by user from provided list as follow:

Table 4-3: Building categories classification in "Waste Tracker"

Building Categories			
Office	Administrative	Hospital	School
Accommodation	WC/Shower	Mosque	Sport facilities
Recreation	Store	Service building	Classroom
Kitchen	Laboratory	Workshop	Library
Dining hall	Clinic	Hangar	Guardhouse

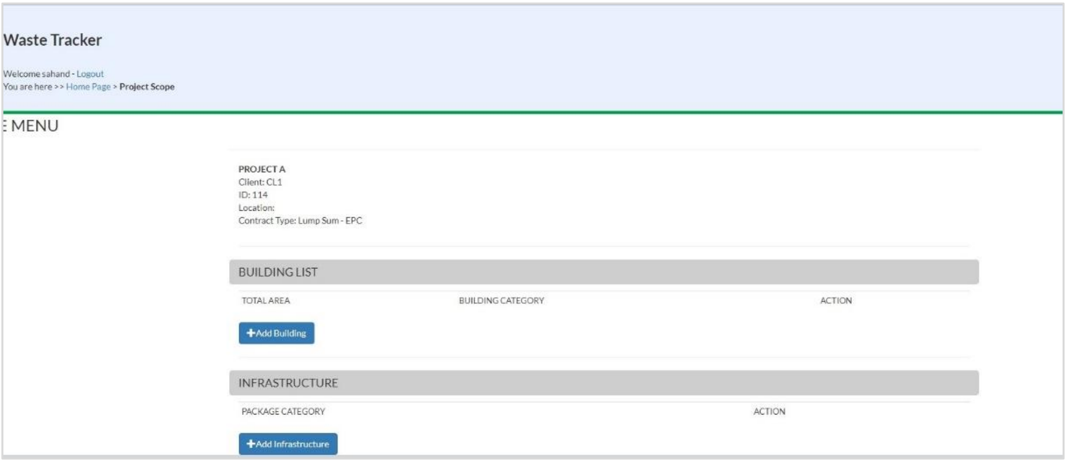


Figure 4-10: Project scope data defining interface

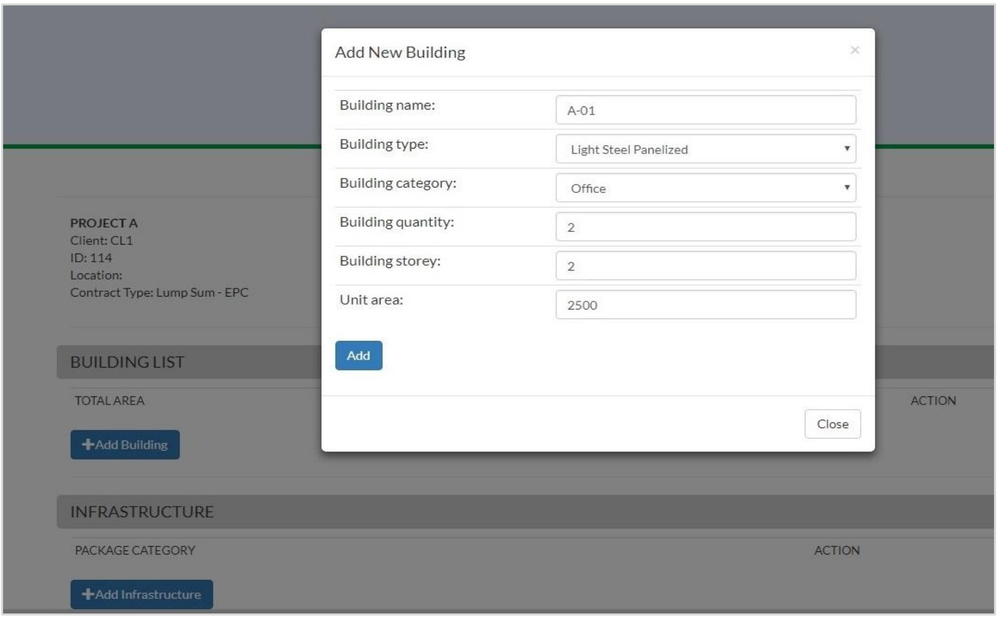


Figure 4-11: Defining new building data in project scope interface

Infrastructure scope of work should also be defined to the system using infrastructure scope interface. This interface includes data related to "Package Name", "Package Category", "Quantity" and "Measurement Unit". These data are all mandatory fields to be filled out. Infrastructure packages are divided into ten categories as indicated in Table 4-4, and user should select one of them from provided drop down list as shown in

Table 4-4: Infrastructure packages classification in "Waste Tracker"

Infrastructure Packages	
Potable water	Waste water
Hot water	Firefighting system
Gas line system	Electrical power system
Lighting system	Emergency system
Telephone and data	CCTV and TV systems

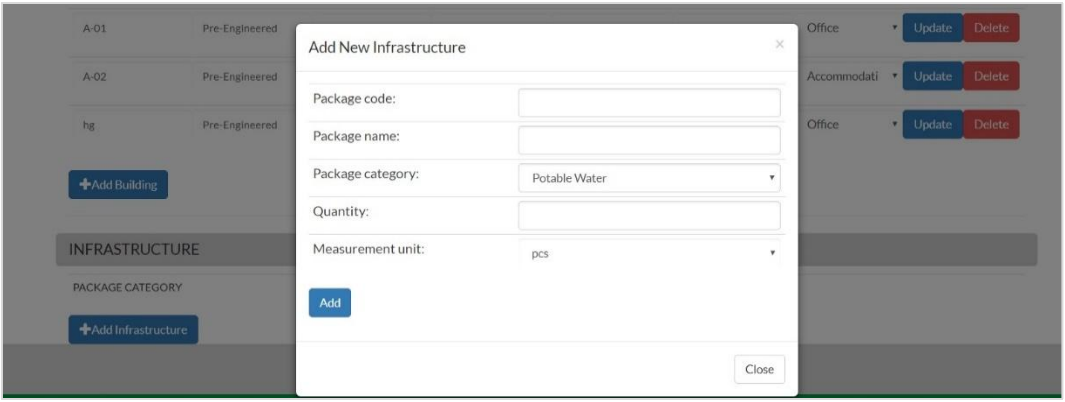


Figure 4-12: Defining Infrastructure data in project scope interface

4.3.3.3. Key Personnel Data

After defining the project and scope data in "Waste Tracker", the next step is to enter project key personnel information to ensure the system security and identify the user's accessibility level to application as it is explained previously in section 4.2.3. In this field, along with general identities and contact details of users, their job titles in project or company organizational structure should also be identified. The Job titles are divided in six categories and related user groups are assigned for each job according to Table 4-5. These assignments are default settings in the system and can be changed for each person according to their positions and authorities by admin.

Table 4-5: The user group assignment for each job title

	User Group		
Job Title	System Admin	Waste Data Source	Waste Data User
Manager	X	X	X
Deputy manager		X	X
Technical personnel		X	X
Designer/ Estimator		X	X
Document Controller	X		
Non-technical personnel			X

Since key personnel data are defined, the project creation process is completed in the system and each user can access to system according to their accessibility level.

4.3.4. The Process of Waste Baseline Creation

As mentioned previously, project creation in database is the prerequisite for defining waste baseline and entering actual waste data into the system. According to the "Waste Tracker" process model demonstrated in Figure 4-4, the next step following to the project creation process, is creating the material waste baseline, which consists of three main components as shown in process flowchart in Figure 4-13. First of all, the project material list must be added to the system and then going through the estimating waste quantity and waste causes. The estimated waste quantities establish a benchmark for analyzing the performance of waste management by comparing the actual waste quantities versus estimated waste values. The process flowchart represented in Figure 4-13 illustrates the three main steps in assigning waste baseline in “Waste Tracker” as follow:

1- Defining project material data
2- Estimating material waste quantities
3- Estimating waste causes

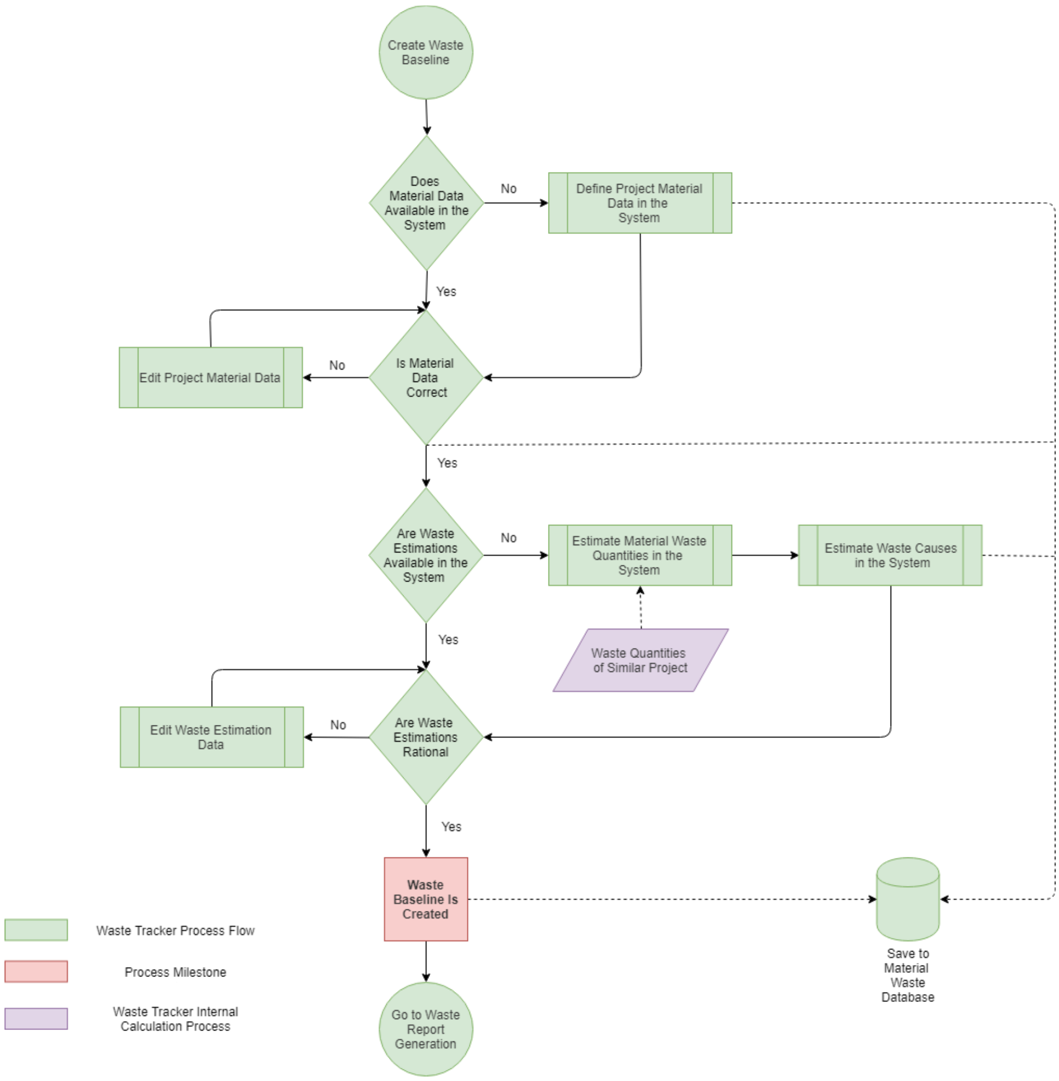


Figure 4-13: Flowchart of "Waste Baseline Creation" process

4.3.4.1. Defining Project Material Data

According to “Waste Baseline Creation” process presented in Figure 4-13, the first step is defining material data for an active project and entering the material quantities using material data interface shown in Figure 4-14. The material data will be defined based on the estimated BOQ values.

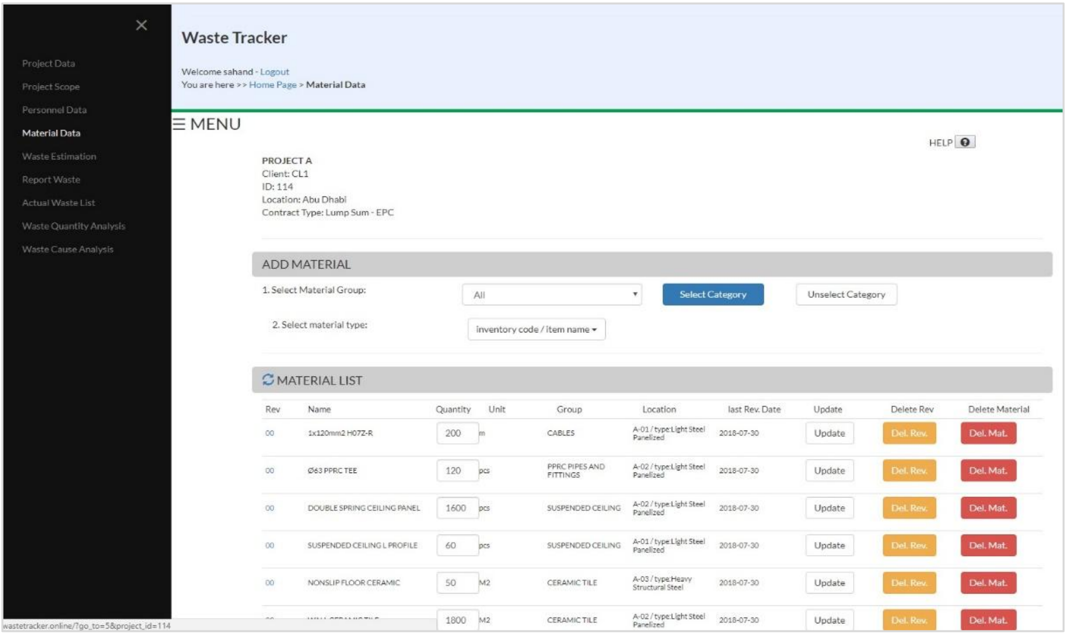


Figure 4-14: Material data interface

Wide range of materials are used in construction projects and considering their inventory identification system, which depending on technical and physical specifications, the diversity of material is considerably detailed and limitless. On the other hand, managing the extensive range of materials based on their inventory coding system will be extremely complicated and inefficient. Therefore, in order to simplify the material entering and tracing within the system, the prevalent materials in prefabricated projects were investigated in four prefabricated projects and categorized under definite groups of materials as demonstrated in Table 4-6 .

Table 4-6: Building material categories used in "Waste Tracker"

Category	Material Group
Building materials	
	Aluminum Board/Tiles
	Aluminum Window
	Carpet Flooring
	Cast/Cut Stone
	Ceramic Tile
	Door handles and Accessories
	Fasteners/ Connection Elements
	Fiber Cement Board
	Gypsum Board
	Heat Insulation (Glass Wool - XPS - Rockwool)
	Laminated Parquets
	Laminated Separation Panels
	Paint
	Plaster (Gypsum & others)
	Premixed Structural Concrete
	PVC Flooring
	PVC Window
	Sandwich Panels
	Sealing Materials (Silicons and etc.)
	Steel Profiles/ Structural Elements
	Steel Reinforcement
	Unstructural Concrete (Screed & others)
	Vapor Barrier
	Waterproofing Material
	Window handles and Accesories
	Wood (OSB - Timber & Plywood)
	Wooden Doors
Electrical materials	
	Cables (LV - LC - MV)
	Cable Trays
	Electrical Equipments
	Lighting units
	PVC Cable Conduits & Pipes
	Switch, Sockets and Electrical Installations

Table 4-7: Building material categories used in "Waste Tracker" (continued)

Category	Material Group
Mechanical materials	
	Air ducts and fittings
	HDPE pipes and fittings
	Mechanical Equipments
	Pipe Heat Insulations
	PPRC pipes and fittings
	PVC pipes and fittings
	Sanitary/ Bathroom Accessories
	Sanitary Wares
	Steel pipes and fittings

This classification will simplify the process of waste estimation, monitoring and analysis in "Waste Tracker". As it is shown in Table 4-6, materials are classified under three general categories including:

1- Building materials,
2- Electrical materials and
3- Mechanical materials.

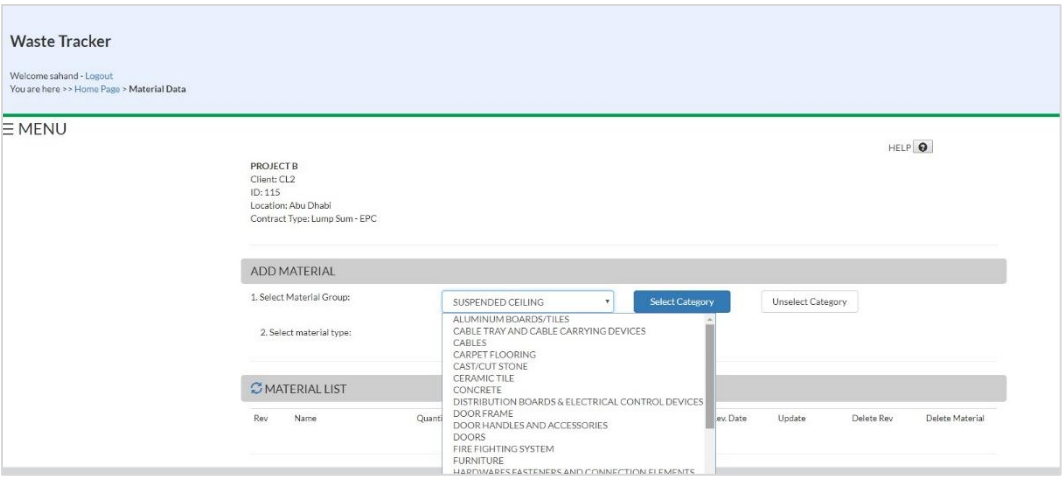


Figure 4-15: Material data entering interface - Selecting material group

Each category consists of several material groups and each group includes various types of material represented by a unique inventory code. In this study 525 material types categorized under 42 groups have been entered into the system as a default material database. To define the project material data in the system, at first, the corresponding group of material must be selected as it is shown in Figure 4-15. Since the material group is selected, the related type of material should be identified from the material database, as illustrated in Figure 4-16.

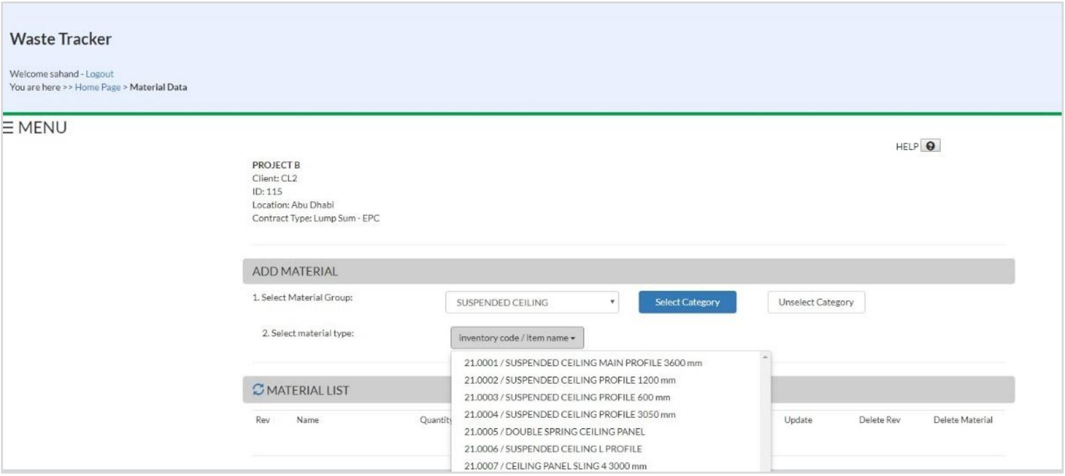


Figure 4-16: Material data entering interface - Selecting material type

Material quantity, the revision number of BOQ and the location where the material will going to be used and derived from project scope data, must be defined as shown in Figure 4-17.

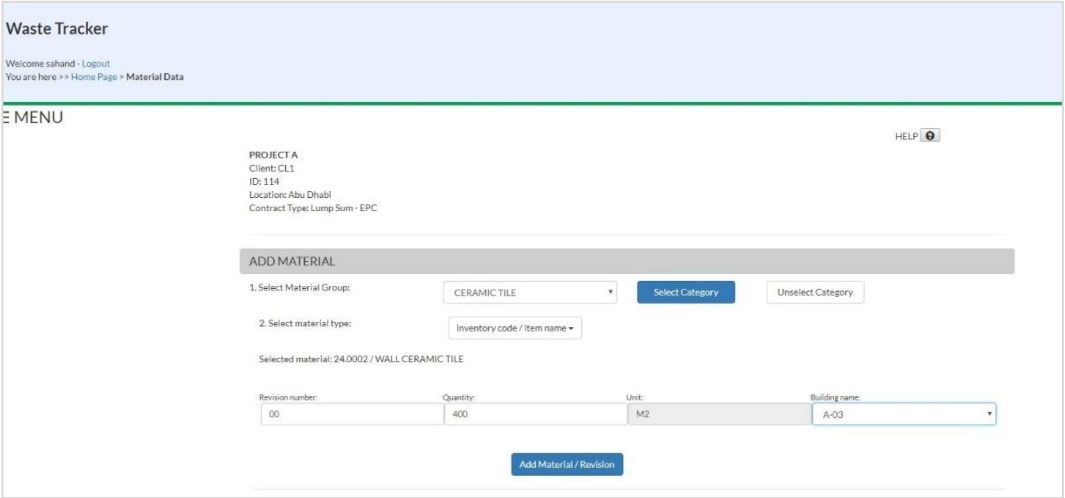


Figure 4-17: Material data entering interface - Defining quantity and location

Figure 4-18 demonstrates the collective list of materials entered to the system. This list is editable and can be updated or removed from the database by user.

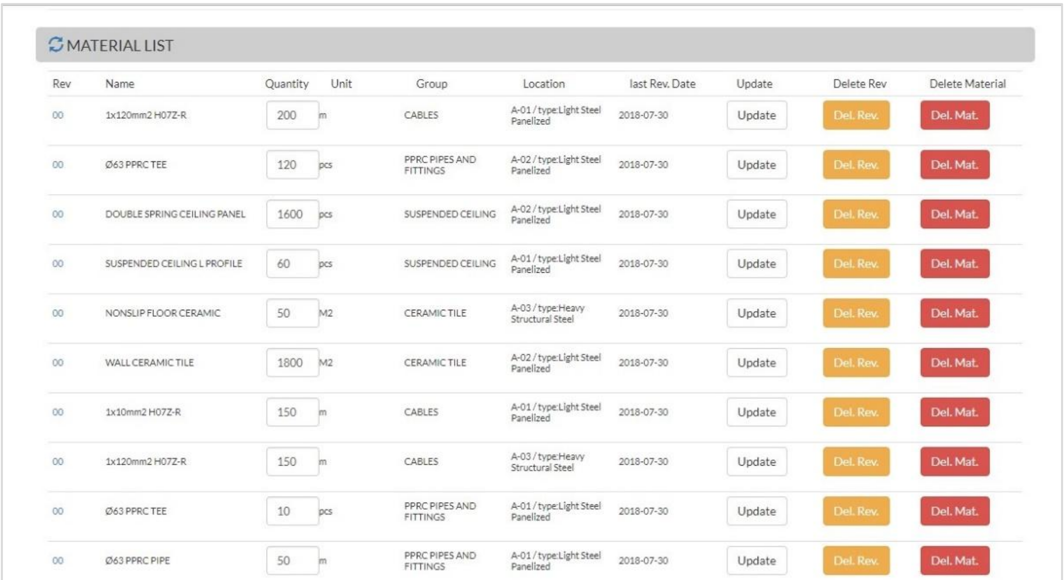


Figure 4-18: Project material data list

4.3.4.2. Waste Estimating

While the project material list is generated, the waste baseline creation process will be completed by estimating the waste quantities and causes using the "Waste Estimation" interface shown in Figure 4-19. The complete list of material in a project can be more extensive and waste estimation for all types of material listed in project BOQ would be extremely complicated and time consuming. Therefore, the process of waste estimation may be found exhausting for users and may lead to less cooperation and unrealistic results. Accordingly, it would be more efficient to perform the estimations and analysis in material group level to simplify the processes and results. So that, any material type in project material list will take the values assigned to the corresponding material group as shown in Figure 4-19.

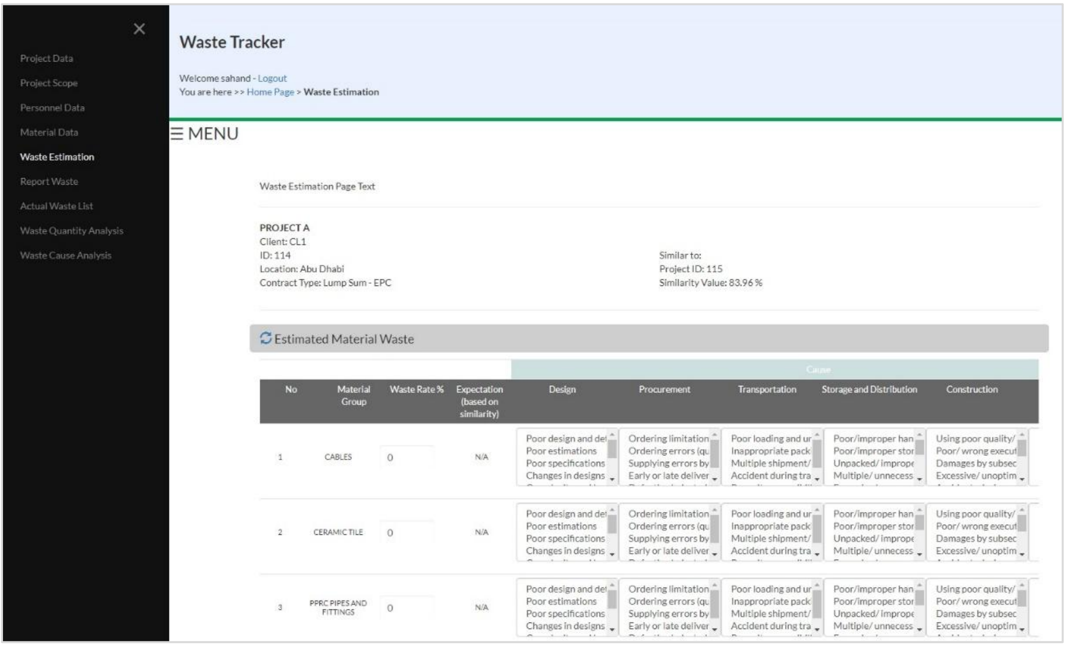


Figure 4-19: Waste estimation interface

A cumulative list of material groups, retrieval from entered project material list, is appearing in waste estimation interface as shown in Figure 4-19. The user must identify the waste quantities and waste generation causes for each group separately. While estimating the waste rate quantity, the average rate of actual waste in the most similar projects in database, is calculated by "Waste Tracker" for each group of material. This will assist estimators to define the most realistic values, considering the actual waste rates in similar past projects. The details of similarity analysis and calculation of expected waste rate in most similar project is explained in section 4.3.6.1.1.

The expected waste causes for each material group must be additionally identified in this stage to complete the waste estimation process. To avoid scattered estimations leading to uncategorized reports, a classified list of waste causes in six different categories are defined in the system as shown in Table 4-8. The given classification is proposed based on the study findings demonstrated in section 3.3.3. While estimating the expected causes of waste, this classification facilitates the waste source identification for each material group and encourages efficient and more realistic estimations.

By completing the waste estimation stage for existing material groups in project material list, the waste baseline creation process is completed. This baseline provides a benchmark for comparing the actual waste data, captured by waste reports during project lifecycle, and planned waste rates and causes defined in waste estimation stage. The measuring waste data with the previous waste performances in completed projects in company portfolio enables live monitoring of waste management performance in current project. Therefore, real-time analyzing of waste performance will assist decision makers on taking on-time and efficient preventive actions for waste control.

According to Figure 4-4, the next step following to the “Waste Baseline Creation” process is “Waste Reporting Process” in which the actual waste data will be captured in the course of the project. The next section is explaining the waste reporting process in detail.

Table 4-8: Waste sources and waste causes

Waste Category	Waste Cause
Design	
	Poor Design and Details
	Poor Estimations
	Poor Specifications
	Changes in Designs and Specifications
	Complexity and low constructability of Design
	Poor interdiciplinary design integration
	Improper/ Wrong material selection or substitution
	Ignorance of material specifications in designs
Procurement	
	Ordering errors (Quality or Quantity errors, wrong selection or substitution)
	Supplying errors by suppliers (Quality or Quantity errors)
	Early or late delivery
	Defective/Rejected Products
	Ordering limitations applied by suppliers (Quantity and Quality limitations)
Transportation	
	Poor Loading and unloading
	Inappropriate packing for transportation
	Multiple shipment/ transportation points
	Accident during transportation
	Poor site accessability/ Road condition
Storage & Distribution	
	Poor/Improper handling and distribution on site
	Poor/Improper storage and protection
	Unpacked/ Improper packaging of materials
	Multiple/ Unnecessary relocating or Handling
	Excessive/Unnecessary inventories
	Poor site storage capacity
	Accidents during storage and distribution
	Handling Equipment failure (Breakdown or malfunctioning)
	Untraceable/Left-over Materials on site
	Poor stock management

Table 4-9: Waste sources and waste causes (continued)

Waste Category	Waste Cause
Construction	
	Using poor quality/ wrong material
	Poor/ wrong execution of work
	Damages by subsequent trades
	Excessive/Unoptimized cutting (Conversion waste)
	Accidents during construction
	Excessive use of material
	Overproduction
	Ignorance of designs/method statements during construction
	Unavoidable process waste
External Affecting Factors	
	Poor planning an scheduling
	Poor waste management
	Poor supervision and control
	Poor project contracting/ subcontracting
	Unfavorable weather conditions
	Natural/Manmade disasters (e.g. Earthquake, Floods, War, etc.)
	Unknown site conditions
	Theft and Vandalism
	Unskilled/ Unexperienced labour

4.3.5. The Process of Waste Monitoring

Waste monitoring is the basic part of the integrated waste management system in "Waste Tracker" and aims to capture the most of the waste generations in the course of the project. Waste monitoring consists of two major steps as shown in process flowchart represented in Figure 4-20; including "Waste Reporting" and "Controlling". According to the proposed process model, waste reporting is defined as a part of project progress reporting process. In any event of material waste generation, the user should follow the proposed process in
Figure 4-20 to report the waste generation using the "Waste Tracker".

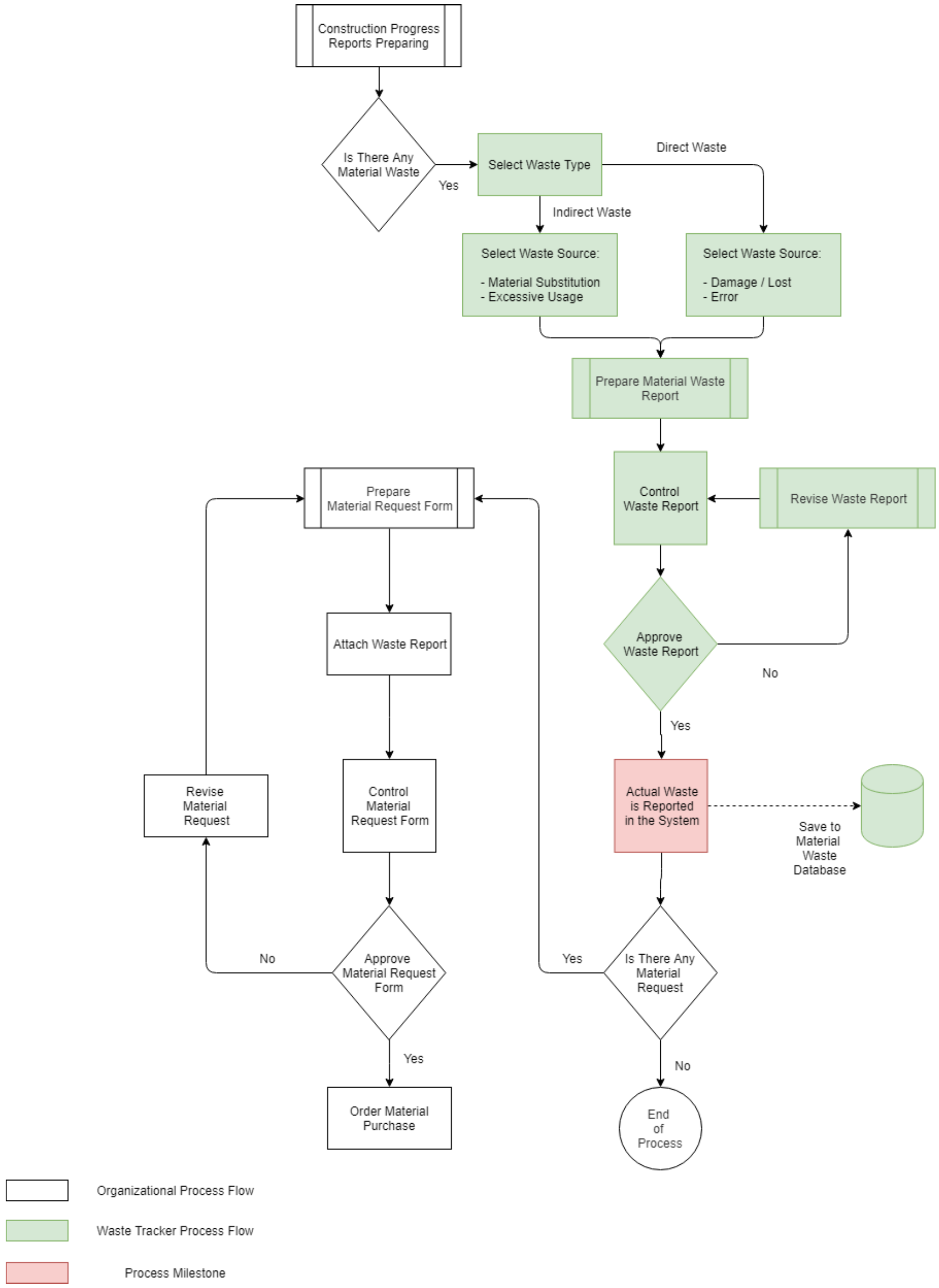


Figure 4-20- Flowchart of "Waste Monitoring" process

The main objective of considering the waste reporting process as part of the existing project progress reporting system, is to avoid lateral processes and extra works within the organization. This combination will increase the efficiency of reporting procedures without applying significant changes on the existing organizational structure. Since the project progress reports are generally prepared in daily intervals, therefore merging the waste reporting process with daily progress report system will enhance the timely reporting of waste generation and enables the early identification of waste generation.

4.3.5.1. Waste Reporting

The accuracy and timing of waste data capturing, directly affect the quality of waste analyzing and controlling results. Therefore, the main objective of waste reporting module in "Waste Tracker", is to capture the more accurate data at the earliest time during the project lifecycle. The waste reporting module enables the users to identify the most real quantities and causes of any types of waste, to ensure taking more effective and timely actions in waste management efforts. Waste monitoring is performed using the predefined waste reporting system, to enhance the categorized data gathering and recording. In order to achieve the maximum efficiency in waste capturing and analyzing, it is essential to develop a standard form of reporting and recording system in waste management process. This will cause to minimize the scattered data inputs and will enhance directed information flow in the system. For this purpose, the main sources of waste generation in construction projects are investigated through the literature review and expert interviews as explained previously. According to the findings of literature review, the waste events mostly originates from five different sources as follow:

1- Physical damages of material
2- Getting lost
3- Substitution of original material with another material
4- Excessive usage of material according to design
5- Construction and workmanship errors

Considering the above-mentioned waste sources and waste types, it can be concluded that direct material wastes are originated from two sources as “damage or lost” and “construction errors”. On the other hand, indirect wastes are the result of “material substitution” and “excessive use of material” in construction projects. Therefore, the following classification for reporting direct and indirect wastes using the “Waste Tracker” is developed:

1- Damage/Lost report
2- Material substitution report
3- Excessive material usage report
4- Error report

This classification of waste reports will provide a standard data collection platform for direct and indirect wastes and will enhance the quality and quantity of waste data capturing. Moreover, standard and categorized reporting module will encourage the formation of common perception about waste sources within the company. According to the process model presented in Figure 4-20, in order to report a waste case using the “Waste Tracker”, it is required to identify the type of waste according to the above-mentioned classification considering the direct and indirect wastes in waste reporting interface demonstrated in Figure 4-21. As it mentioned before, “Damage/lost report” and “Error report” refer to direct material wastes; whereas, “Material substitution report” and “Excessive material usage report” point out indirect wastes. This method of waste capturing using predefined form of waste reports facilitates the waste type and waste source identification and recording in a uniform model and minimize inconsistence data capturing and analysis.

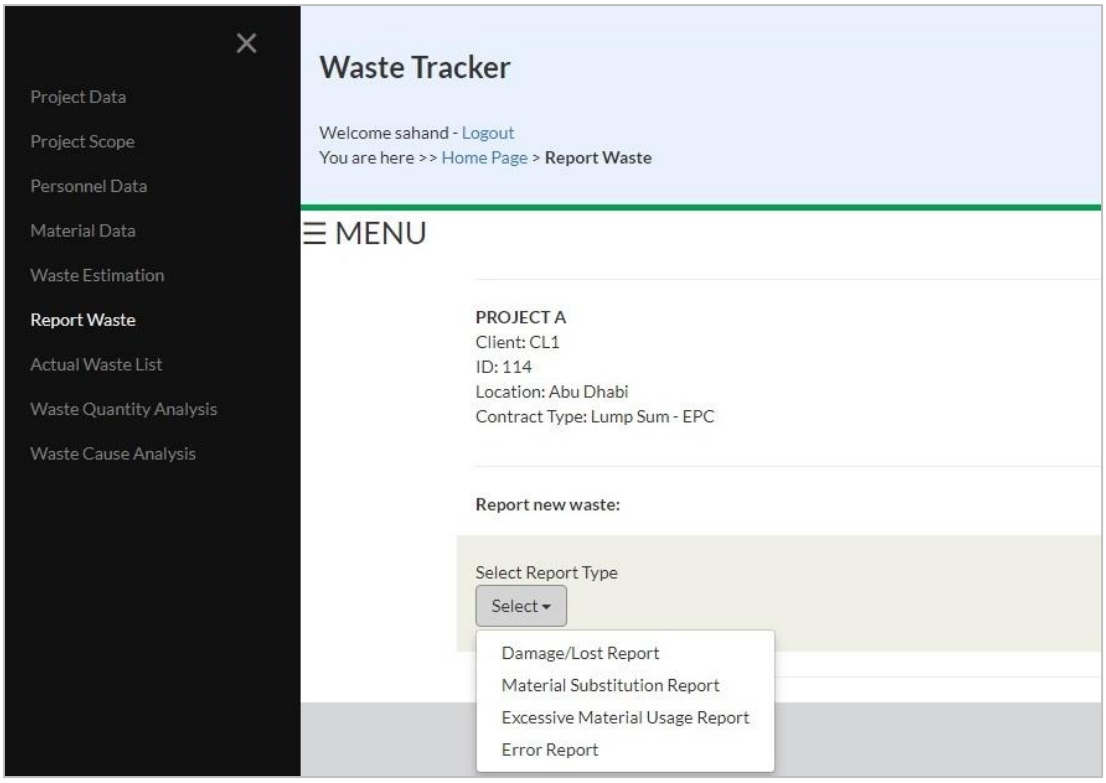


Figure 4-21: Waste reporting interface – Selecting report type

After selecting the report type, it is required to locate the waste generation according to the project scope data, as it is shown in Figure 4-22. Identifying the location factor of waste case will assist project management team in exact identification of waste generation causes. The locational factor for prefabricated building projects in "Waste Tracker" is considered as the building number and for infrastructure packages is considered as package name.

Since the report type and building number where the waste is occurred were identified by the user, the type of material must be defined by the user. As it is shown in Figure 4-23, the complete list of material for related location appears as drop down list in waste reporting interface.

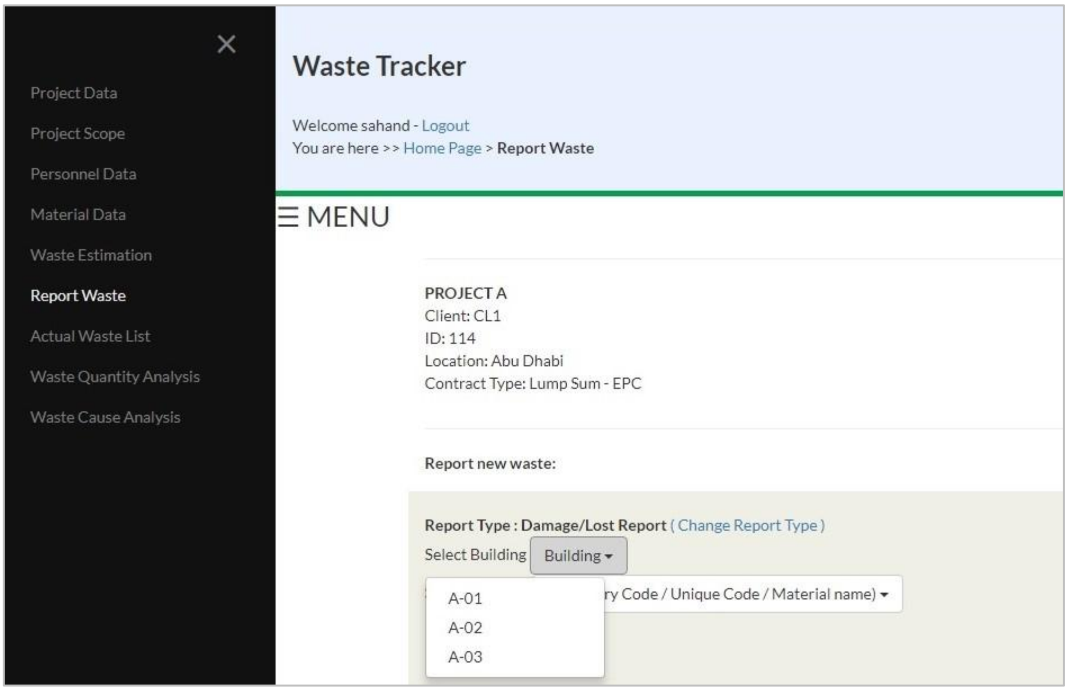


Figure 4-22: Waste reporting interface – Identifying the location of waste

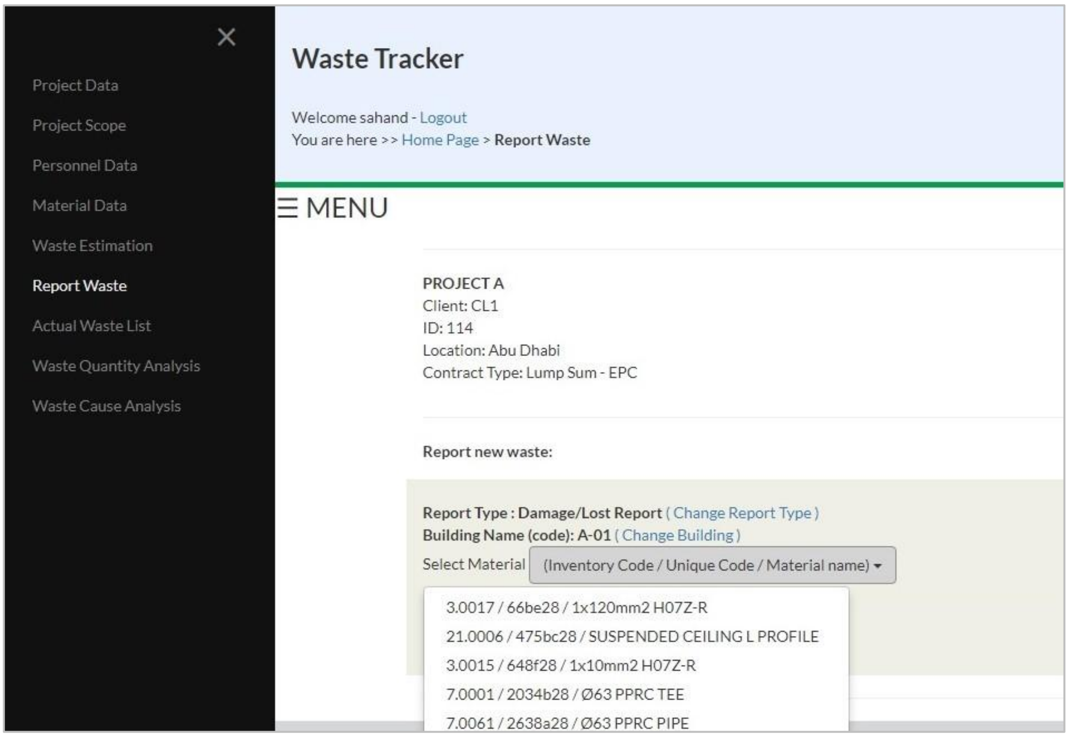


Figure 4-23: Waste reporting interface – Selecting the wasted material type

As it is demonstrated in Figure 4-24, the waste quantities and waste causes should be identified by the user, to complete the waste reporting process. Each report is assigned by a unique number; the user can decide to assign a new number to the report or attach the current report to an existing report as a supplementary document. The prepared report of waste, includes the project, and material data as well as the quantity of wasted material and main causes that resulted in the waste generation.

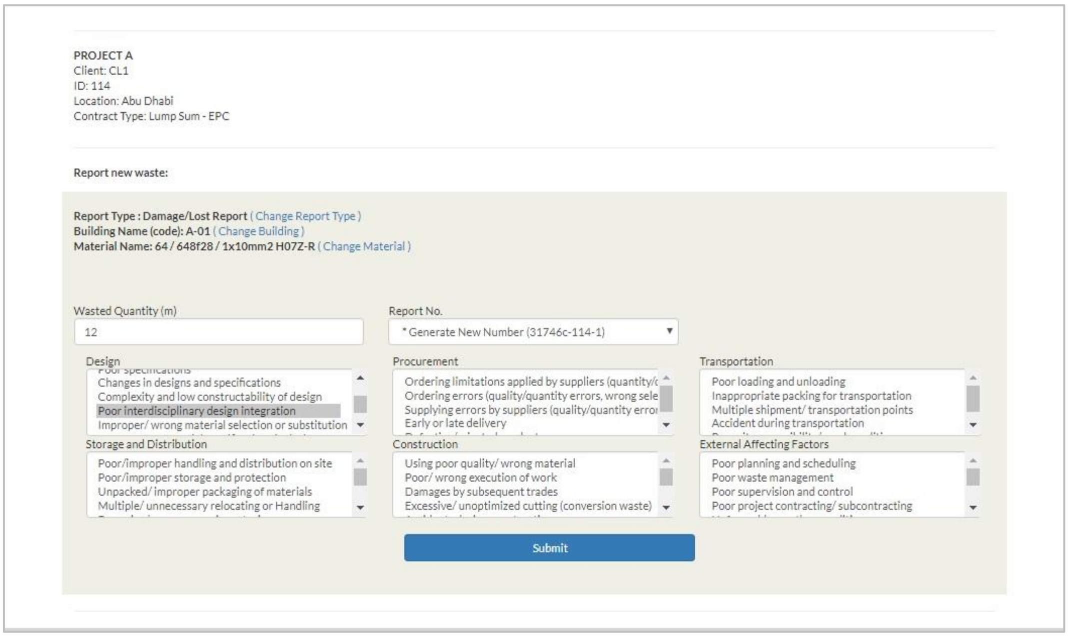


Figure 4-24: Waste reporting interface – Defining waste quantity and causes

4.3.5.2. Waste Data Controlling

Since the report is created, a draft version will be sent to “System Admin” for checking and controlling of the prepared report in accordance with the actual waste case specifications. By admin authorization, the approved copy of the waste report, is will be saved in “Waste Tracker” database as actual waste data.

According to the process flowchart demonstrated in Figure 4-20, after approving of waste report, the process will continue through the regular organizational process depending on whether the additional material purchase for waste compensation is required or not.

The proposed system is expected to compensate the deficiencies of current waste management procedures and facilitate waste data collection, analysis and sharing to maintain a joint platform for waste monitoring and waste data sharing. This will promote the quality of waste management by:

1- Enhancing the quality and quantity of waste data capturing by providing a standard data collection platform for direct and indirect wastes.
2- Enabling the storing of collected data in a waste database for further analysis and data enquiry for waste estimations and lessons learned documentation.
3- Establishing more accurate and real-time comparison of actual and expected waste generation (waste baseline) as well as previous projects performance to enable the users in taking timely proper actions in waste controlling process.

4.3.6. The Process of Waste Data Analyzing and Retrieval

Using this module, the waste management performance is analyzed and published based on the estimated and actual waste data and in comparison with the actual waste indicators in similar past projects. Two types of waste analysis can be generated using this module in "Waste Tracker" as follow:

- Waste quantity analysis
- Waste cause analysis

The results of analyses are generated automatically by the application and can be retrieved by the user according to their needs using the process flowchart given in Figure 4-25.

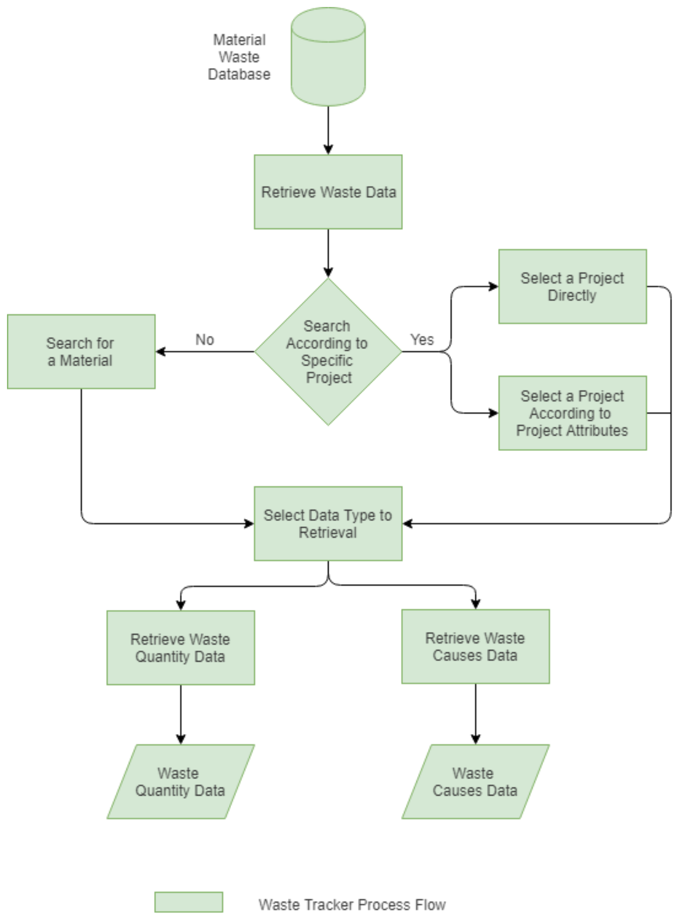


Figure 4-25: Flowchart of "Waste Data Retrieval" process

Two options are available for accessing the waste analysis results in "Waste Tracker" home page, represented in Figure 4-26. The user can search for a specific project by selecting the project from drop down list of projects; or by filtering the projects according to project attributes. The waste analysis results are also accessible based on material groups using the search box as shown in Figure 4-26.

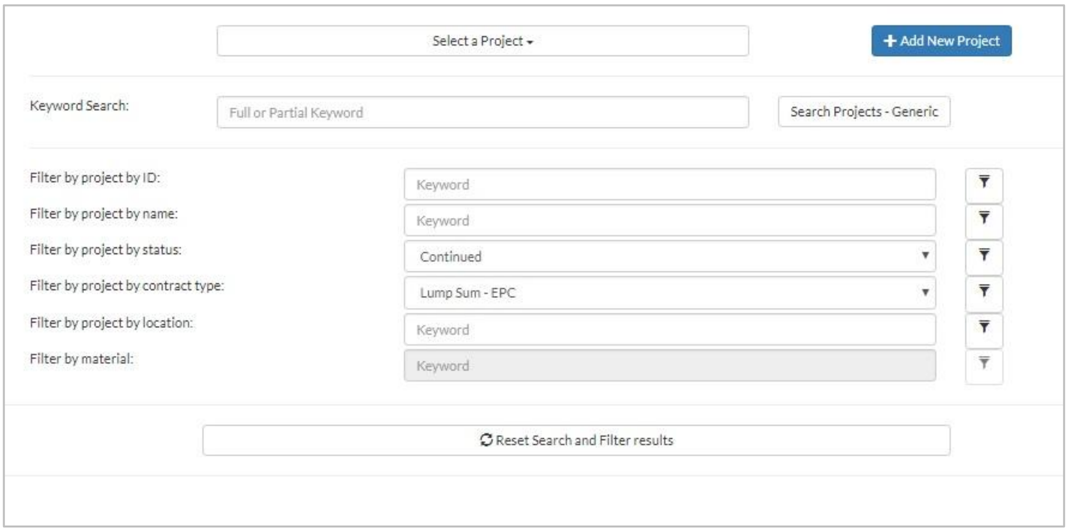


Figure 4-26: Data retrieval page - Project or material based search

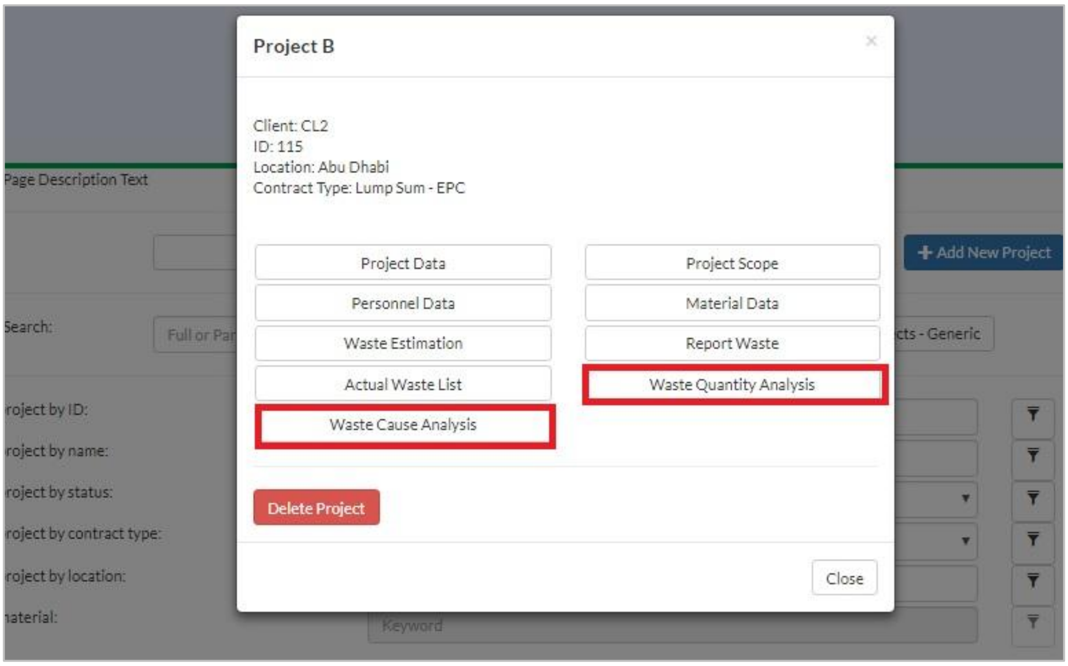
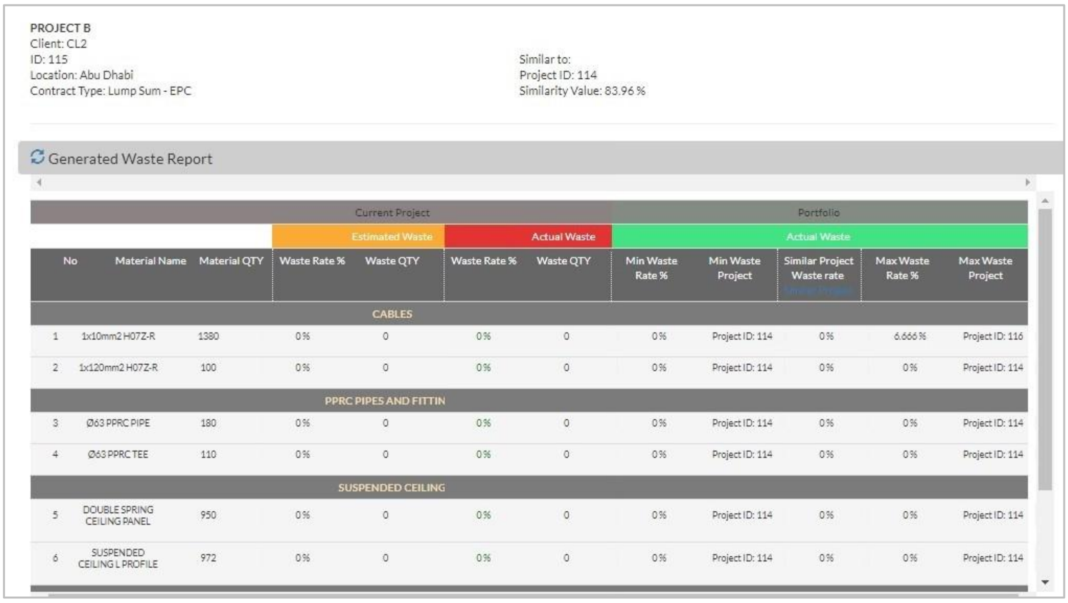


Figure 4-27: Data retrieval page – Quantity/ Cause analysis

After defining the project for reviewing the waste analysis results, a dialogue box as shown in Figure 4-27, will appear to select the analysis type. The following sections explain the two types of analyzing modules in detail.

4.3.6.1. Waste Quantity Analysis

By selecting the “Waste Quantity Analysis” option from dialogue box given in Figure 4-27, the “Waste Quantity Analysis” page will be displayed as shown in Figure 4-28. As it is demonstrated in Figure 4-28, “Waste Quantity Analysis” page comprises of quantitative information of estimated and actual waste in current and portfolio projects. The quantity data of portfolio projects consists of minimum and maximum waste rates in projects and also the average rate of waste in most similar project. The given information assists the user to evaluate the project waste management performance in controlling the quantity of waste in compare with previous projects in portfolio and according to the expected values defined in “Waste Estimation” stage as a project waste benchmark.



			Current Project				Portfolio				
			Estimated Waste		Actual Waste		Actual Waste				
No	Material Name	Material QTY	Waste Rate %	Waste QTY	Waste Rate %	Waste QTY	Min Waste Rate %	Min Waste Project	Similar Project Waste rate	Max Waste Rate %	Max Waste Project
CABLES											
1	1x10mm2 H07Z-R	1380	0 %	0	0 %	0	0 %	Project ID: 114	0 %	6.666 %	Project ID: 116
2	1x120mm2 H07Z-R	100	0 %	0	0 %	0	0 %	Project ID: 114	0 %	0 %	Project ID: 114
PPRC PIPES AND FITTIN											
3	Ø63 PPRC PIPE	180	0 %	0	0 %	0	0 %	Project ID: 114	0 %	0 %	Project ID: 114
4	Ø63 PPRC TEE	110	0 %	0	0 %	0	0 %	Project ID: 114	0 %	0 %	Project ID: 114
SUSPENDED CEILING											
5	DOUBLE SPRING CEILING PANEL	950	0 %	0	0 %	0	0 %	Project ID: 114	0 %	0 %	Project ID: 114
6	SUSPENDED CEILING L PROFILE	972	0 %	0	0 %	0	0 %	Project ID: 114	0 %	0 %	Project ID: 114

Figure 4-28: Quantity analysis page

Based on the estimated quantities entered in “Waste Estimation” stage and actual waste data, captured during “Waste Monitoring” process, the following equations are used to calculate the “waste rate” in current project and portfolio:

$$EWRi\ c.p\ (\%) = EWRj\ c.p\ (\%)$$

or (4.1)

$$EWRi\ c.p\ (\%) = \frac{\sum EWQi\ c.p}{\sum EQi\ c.p}$$

(4.2)

$$AWRi\ c.p\ (\%) = \frac{\sum AWQi\ c.p}{\sum EQi\ c.p}$$

(4.3)

$$WRi\ p.min\ (\%) = \min_{p}\left(\bigcup AWRi\right)$$

(4.4)

$$WRi\ p.max\ (\%) = \max_{p}\left(\bigcup AWRi\right)$$

(4.5)

$$EWCi\ c.p = EWQi\ c.p\ \times UCi\ c.p$$

(4.6)

$$WRAi\ s.p\ (\%) = \frac{\sum AWQi\ s.p}{\sum EQi\ s.p}$$

Where:

- $EWRi_{c.p}(\%)$: Est. waste rate of material (i) in current project
- $EWRj_{c.p}(\%)$: Est. waste rate of material group (j) in current project
- $EWQi\ c.p$: Est. waste quantity of material (i) in current project
- $EQi_{c.p}$: Est. quantity of material (i) in current project
- $EQi_{s.p}$: Est. quantity of material (i) in similar project
- $AWRi_{c.p}(\%)$: Act. waste rate of material (i) in current project
- $AWQi_{c.p}$: Act. waste quantity of material (i) in current project

- $AWQi_{s.p}$: Act. waste quantity of material (i) in similar project
- $WRAi_{s.p}$ (%) : Average Waste rate of material (i) in similar project
- $WRi_{p.min}$ (%) : Min. waste rate of material (i) in portfolio
- $WRi_{p.max}$ (%) : Max. waste rate of material (i) in portfolio

The above-mentioned calculations provide a brief overview about the performance of waste management in active project based on the quantities of generated wastes. Comparing the values of estimated and actual waste rates demonstrates the variation between planned and actual waste quantities in project; if actual waste rate for any material is above the estimated (planned) value, the project team will be aware of deviation from waste baseline for that type of material and by investigating the causes of waste generation will be able to take preventive actions accordingly as earlier as possible. Another feature of quantitative analysis is similarity based calculations which demonstrate the average waste rates in most similar project and assist users to compare the waste rates in current project with the waste values in similar project. Details of similarity calculation and identifying the average waste rate in most similar project is explaining in following sections.

4.3.6.1.1 Similarity Analysis

As previously discussed, similar projects may result in equivalent waste rates originating from identical sources, thus similar procedures can be applied for avoiding these wastes. To assist users in estimating more realistic waste rates, based on the values in similar past projects in company portfolio, the similarity analysis is needed to be developed. The projects similarity is calculated according to the method proposed by Boriah et al. (Boriah, Chandola, & Kumar, 2008), which is based on matching ratios of project attributes between selected project and existing projects in company database by identification of the categorical data similarities using the project attributes. Each attribute is represented by a relative weighting in calculations; when the project attributes are matched the project similarity value is increased. A simple procedure for calculating total similarity value is presented in Figure 4-29.

Project similarity attributes and related weights are defined through a questionnaire survey represented in section 3.2.1.2. According to the survey results, 5 project attributes were identified to calculate similarity value in “Waste Tracker”. The project attributes and corresponding similarity weights are presented in Table 4-10. While estimating the waste rates for material groups in “Waste Estimation” stage, and during the “Waste Quantity Analysis” in “Waste Tracker”, the similarity calculation is performed based on the following project attribute weights.

Table 4-10: Similarity attributes and relative weights

Ranking	Project Attribute	RII	RII %
1	Contract type	0,80	22,26%
2	Project area	0,79	22,09%
3	Project location	0,72	19,97%
4	Building type	0,71	19,64%
5	Client	0,58	16,04%
	Total	**3,59**	**100,00%**

Considering two projects named “Project A” and “Project B”, the total similarity value (TSV) is calculated according to the following equations:

$$S(A,B) = \sum_{k=1}^{n} w_k \times s_k(A_k, B_k) \tag{4.7}$$

$$s_k(A_k, B_k) = \begin{cases} 100\% & if\ A_k = B_k \\ 0 & otherwise \end{cases} \quad k = 1, \dots, n \tag{4.8}$$

where;

- $S(A, B)$: Total similarity value (TSV)
- w_k : Attribute weight for attribute *k*
- $s_k(A_k, B_k)$: Similarity for attribute *k*
- n_k : Maximum number of attributes

Project attribute data automatically comes from entered information for active project and existing portfolio saved in database and depending on the matching condition of these attributes and predefined weights, total similarity value (TSV) is calculated. After (TSV) is determined between active project and each project in data base, the waste information of a project with maximum (TSV) will be selected as similar project values.

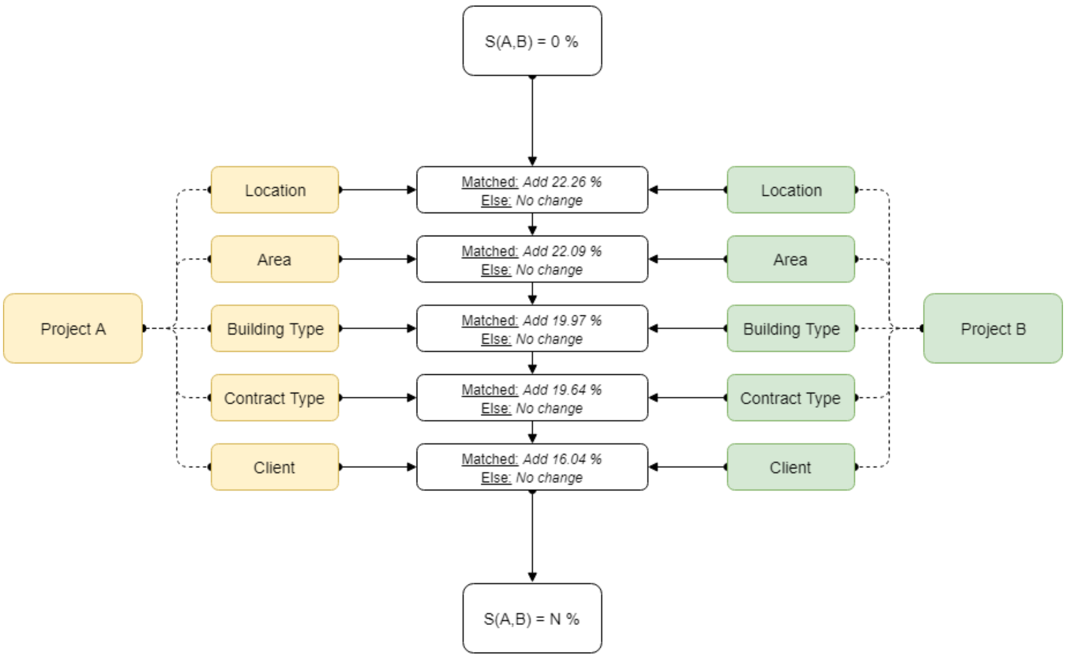


Figure 4-29: Total similarity value calculation process

Extra data input is allowed in the form of "additional project attributes", to provide flexibility in similarity calculations. Whenever a user identified that there can be similarity between active project and an existing project with un-matching attribute, the "additional project attribute" can be considered as similar to attributes of the interested project. The matching conditions for each attribute is considered as exact matching with the same value or content. However, considering the project area the value is a continuous range of numbers which in most cases will not match exactly. To solve this issue the project size scaling shown in Table 4-11 is developed for categorizing the project area attribute. Each project is fall into the corresponding category according the given project size scale. In this case, the projects in same range of area will be exactly matched based on the project size value.

Table 4-11: Project Size Category

Area Range (sq.m)	Project Size
A ≤ 3,000	Very Small
3,000 < A ≤ 10,000	Small
10,000 < A ≤ 30,000	Medium
30,000 < A ≤ 80,000	Large
80,000 < A	Extra Large

In order to clarify the similarity calculations performed by "Waste Tracker", the following example is presented. The information of four sample projects were entered to the system as given in Table 4 12. "Project A" is selected as active project in system and similarity calculations are performed in two ways as they are shown in Table 4 13 and Table 4 14. The results of first example calculations, represented in Table 4 13, are performed without considering additional attributes. As it is shown in Table 4 14, "Project B" represents the maximum value of similarity, equal to 83.96%. Therefore, "Project B" is identified as the most similar project to "Project A" between all projects in database; and waste information of "Project B" will be displayed as similar project values in system.

Table 4-12: Example project data

ID	Project Name	Location	Area	Building Type	Contract Type	Client
114	Project A	Abu Dhabi	46,700	Light steel panelized	LS - EPC	CL1
115	Project B	Abu Dhabi	43,500	Light steel panelized	LS - EPC	CL2
116	Project C	Azerbaijan	18,150	Containerized	LS - PC	CL1
117	Project D	Georgia	15,000	Light steel panelized	LS - EPC	CL3

Table 4-13: Example similarity calculation for Project A

Active project: Project A						
	w_k					
	19,97%	**22,09%**	**19,64%**	**22,26%**	**16,04%**	
Project Name	Location	Area	Building Type	Contract Type	Client	Total
Project B	19,97%	22,09%	19,64%	22,26%	0	**83,96%**
Project C	0	0	0	0	16,04%	**16,04%**
Project D	0	0	19,64%	22,26%	0	**41,90%**

In second similarity calculations, demonstrated in Table 4-14, it is considered that, the locational attribute in “Project A” is 90% similar to “Georgia” as the locational attribute of “Project D. Besides, it is assumed that “building type” factor in “Project A” is 60% similar with “containerized” buildings. Considering these additional attributes, the calculations are performed as given in Table 4-14.

Table 4-14: Example similarity calculation with additional attributes for Project A

Active project: Project A						
Additional Attribute	**Georgia** **90%**		**Containerized** **60%**			
	w_k					
	19,97%	**22,09%**	**19,64%**	**22,26%**	**16,04%**	
Project Name	Location	Area	Building Type	Contract Type	Client	**Total**
Project B	19,97%	22,09%	19,64%	22,26%	0	**83,96%**
Project C	0	0	0	0	16,04%	**16,04%**
Project D	0,9 X 19,97%	0	0,6 X 19,64%	22,26%	0	**52,02%**

In this case the results reveal that similarity value of “Project D” varies from 41.90% to the value of 52,02 %.

After identifying the most similar project in portfolio based on the above-mentioned calculations, the average waste rate ($WRAi_{s.p}$) of each material will be calculated according to equation (5-6).

4.3.6.2. Waste Cause Analysis

“Waste cause analysis” comprises of information related to the waste generation sources which have been estimated in “Waste Estimation” process and have been reported in “Waste Monitoring” stage as realized waste causes. A set of waste causes, which are the elements of the union set of estimated and actual sources of waste, is listed for each group of material, as shown in Figure 4-30. The frequency of occurrence for each cause is calculated for each material group, based on the iteration of that cause within the project waste reports for each group of material.

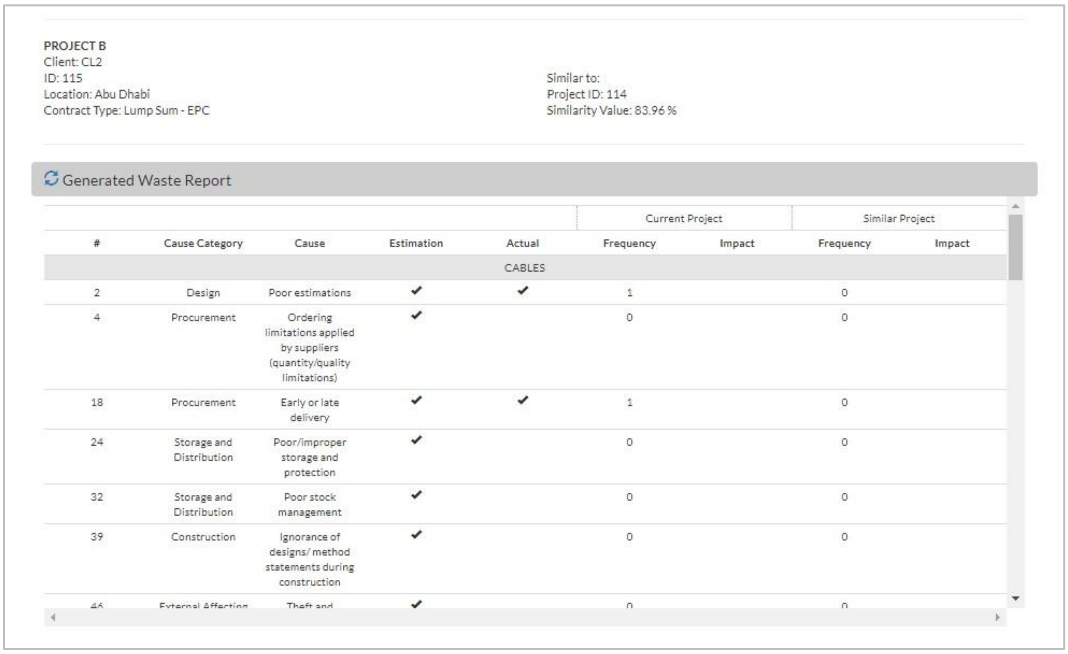


Figure 4-30: Waste cause analysis page

Using this report, the users will be able to investigate the root causes of waste generation for each material group and find out whether the actual causes were having been estimated in "Waste Estimation" stage or not; and take adequate preventive actions to overcome the waste generation. If a waste cause has been realized despite being predicted previously, the reasons of iteration must be investigated to identify if the preventive actions were effective or not. The frequency of each waste cause is also demonstrated in waste cause analysis page as shown in Figure 4-30. The frequency of each cause lets the user to identify the most frequent causes for each group of material. The frequency of waste cause reveals efficiency of waste source management efforts and demonstrates the needs to make proper improvements in applied measures to resolve existing deficiencies. The impact of each cause in the form of waste rate is also demonstrated in waste cause analysis page. The rate of waste associated with each cause helps user to identify the most impactful sources of waste generation and lets them to decide about the priorities of waste management actions that must be taken by project management team. In order to compare the performance of active project with the most similar project the frequency and impact values for similar project are also demonstrated in this page.

The frequency and impact values reveal the critical sources of waste generation for each material group in a project or company. The most critical waste sources with high value of frequency or impact needs to be investigated and waste management efforts must be concentrated on these sources to achieve more effective results in waste reduction plans. The results of waste quality and quantity analysis can be exported to excel for further analysis and visualization of results.

CHAPTER 5

TESTING AND VERIFICATION

The testing and verification process of "Waste Tracker" were carried out in two steps as follow:

1- Functional test using black-box testing method
2- Interview with sector professionals

5.1. The process of testing and verification

The below-mentioned processes were followed:

1- Five sector professionals from three prefabricated construction companies were selected. The company and participant's data are provided in Table 5-1, and Table 5-2. The testing and verification meetings were conducted individually with all participants.
2- A general description of the proposed waste management system and "Waste Tracker" was given to each participant separately to provide them the initial information about the system functionality and purposes.
3- A portfolio scenario, consisting of 4 projects as given in Table 5-3, Table 5-4, Table 5-5, and Table 5-6 has been defined, and related project data were entered to the system by each participant separately with accompaniment of the tester. The data entering process gives the participants the chance of

evaluating the functionality and applicability of data entering process according to the company procedures.

4- After entering the sample projects data, the data analyzing results and system outputs were examined for each project in portfolio according to the given information.

5- At the end, discussions were carried out with five sector professionals from three prefabricated construction companies, based on the questions provided in Table 5-9 and the participants were asked to evaluate the given expressions according to the rating scale as shown in Table 5-8. The results of the interview are explained in upcoming sections.

Table 5-1: Testing and validation participant's company profile

Company ID	Company Size	Company Experience
A	Large (> 250 employees)	36 years
B	Large (> 250 employees)	29 years
C	Medium (50 < employee < 250)	24 years

Table 5-2: Testing and validation participant's profile

Participant ID	Company ID	Experien ce	Job Designation
1	B	9	Project Monitoring and Reporting Responsible
2	B	14	Manager of Construction and Project Management Department
3	A	12	Lead Planning and Project Control Professional
4	A	18	Director of Project Management Office
5	C	21	Senior Project Manager

The following sections explain the details of above-mentioned process.

5.2. Functional Testing and Verification by Black-Box

The "Black-Box" method was selected to test the functions of the "Waste Tracker". This method of software testing, examines the functionality of an application without considering the coding details and internal structure of the software. Therefore, the outputs of the system for specific inputs must be known by the tester. For this purpose, a sample portfolio, consisting of four projects were defined in the system to test the application outputs. The details of the sample projects are represented in Table 5-3, Table 5-4, Table 5-5 and Table 5-6.

Table 5-3: Sample portfolio - General meta data

	Project A	**Project B**	**Project C**	**Project D**
Project ID	114	115	116	117
Client Name	CL1	CL2	CL1	CL3
Project Location	Abu Dhabi	Abu Dhabi	Azerbaijan	Georgia
Contract Type	Lump Sum - EPC	Lump Sum - EPC	Lump Sum - PC	Lump Sum - EPC
Actual Start Date	5/12/2017	2/25/2015	6/12/2015	1/15/2014
Actual Finish Date		8/23/2016	10/18/2017	5/28/2015
Contractual Start Date	3/10/2017	1/20/2015	6/1/2015	1/10/2014
Contractual Finish Date	12/20/2018	7/1/2016	6/1/2017	12/28/2014

Table 5-4: Sample portfolio - Scope data

	Bld. Name	**Bld. Type**	**Bld. Category**	**Qty**	**Story**	**Unit Area (m^2)**	**Total Area (m^2)**	
Project A	***A-01***	Light Steel Panl.	Office	3	2	2,500	**7,500**	
	A-02	Light Steel Panl.	Accomm.	8	2	4,500	**36,000**	**46,700**
	A-03	Heavy Str. Steel	Workshop	1	1	3,200	**3,200**	
Project B	***B-01***	Light Steel Panl.	Accomm.	45	1	500	**22,500**	
	B-02	Light Steel Panl.	Office	5	1	3,500	**17,500**	**43,500**
	B-03	Containerized	Kitchen	1	1	3,500	**3,500**	
Project C	***C-01***	Containerized	Accomm.	55	1	250	**13,750**	
	C-02	Containerized	Office	2	1	700	**1,400**	**18,150**
	C-03	Heavy Str. Steel	Workshop	2	1	1,500	**3,000**	
Project D	***D-01***	Light Steel Panl.	Accomm.	12	1	750	**9,000**	
	D-02	Light Steel Panl.	Recreation	3	1	1,500	**4,500**	**15,000**
	D-03	Containerized	Kitchen	1	1	1,500	**1,500**	

In order to examine the data entry process in the system and assess the applicability of the system in data entry within the organizations, the project data were entered by participants. After portfolio creation in the application, the system outputs were monitored and compared with the expected results.

Table 5-5: Estimated material quantity and estimated waste rates for each building in sample projects

Material List for Each Building in Sample Projects														
Material Group	**Material Type**	**Unit**	**A-01**	**A-02**	**A-03**	**B-01**	**B-02**	**B-03**	**C-01**	**C-02**	**C-03**	**D-01**	**D-02**	**D-03**
Cables	1x10mm2 H07Z-R	m	150	850		1200	180			200	250	200	280	
	1x120mm2 H07Z-R	m	200		150			100	250					200
Ceramic Tile	Nonslip Floor Ceramic	m^2	200	500	50	650	240	50	300	60	250	250	360	300
	Wall Ceramic Tile	m^2	400	1800	400	2600	480	400	400	120	300	450	580	350
PPRC Pipes and Fittings	Ø63 PPRC Pipe	m	50	350		120		60	120			150		
	Ø63 PPRC Tee	Pcs	10	120		90		20	30			30		
Suspended Ceiling	L Profile	Pcs	60	450		900	72			90	250	250	150	
	Double Spring Ceiling Panel	Pcs	250	1600		650	300			250	500	600	350	
Estimated Waste Rates (%) for Each Building in Sample Projects														
Material Group	**Material Type**	**Unit**	**A-01**	**A-02**	**A-03**	**B-01**	**B-02**	**B-03**	**C-01**	**C-02**	**C-03**	**D-01**	**D-02**	**D-03**
Cables	1x10mm2 H07Z-R	m	2.0%	2.0%		1.0%	1.0%			2.0%	2.0%	1.0%	1.0%	
	1x120mm2 H07Z-R	m	2.0%		2.0%			1.0%	2.0%					1.0%
Ceramic Tile	Nonslip Floor Ceramic	m^2	4.0%	4.0%	4.0%	5.0%	5.0%	5.0%	4.0%	4.0%	4.0%	6.0%	6.0%	6.0%
	Wall Ceramic Tile	m^2	4.0%	4.0%	4.0%	5.0%	5.0%	5.0%	4.0%	4.0%	4.0%	6.0%	6.0%	6.0%
PPRC Pipes and Fittings	Ø63 PPRC Pipe	m	3.0%	3.0%		2.0%		2.0%	1.0%			4.0%		
	Ø63 PPRC Tee	Pcs	3.0%	3.0%		2.0%		2.0%	1.0%			4.0%		
Suspended Ceiling	L Profile	Pcs	4.0%	4.0%		3.0%	3.0%			5.0%	5.0%	7.0%	7.0%	
	Double Spring Ceiling Panel	Pcs	4.0%	4.0%		3.0%	3.0%			5.0%	5.0%	7.0%	7.0%	

Table 5-6: Actual waste quantities and waste rates

Actual Material Waste Quantities for Each Building in Sample Projects														
Material Group	**Material Type**	**Unit**	**A-01**	**A-02**	**A-03**	**B-01**	**B-02**	**B-03**	**C-01**	**C-02**	**C-03**	**D-01**	**D-02**	**D-03**
Cables	1x10mm2 H07Z-R	m	12	20		23					30		5	
	1x120mm2 H07Z-R	m			2			2	14					4
Ceramic Tile	Nonslip Floor Ceramic	m^2	10	25				2	12		23	17		5
	Wall Ceramic Tile	m^2	20	36		26	8			12	16	21	15	
PPRC Pipes and Fittings	Ø63 PPRC Pipe	m		5		20			5			7		
	Ø63 PPRC Tee	Pcs		3				1						
Suspended Ceiling	L Profile	Pcs		6		15	3			6	17	14		
	Double Spring Ceiling Panel	Pcs	6	9		6					3	28	14	

Actual Waste Rates (%) for Each Building in Sample Projects														
Material Group	**Material Type**	**Unit**	**A-01**	**A-02**	**A-03**	**B-01**	**B-02**	**B-03**	**C-01**	**C-02**	**C-03**	**D-01**	**D-02**	**D-03**
Cables	1x10mm2 H07Z-R	m		3.20%			1.67%			6.67%			1.04%	
	1x120mm2 H07Z-R	m		0.57%			2.00%			5.60%			2.00%	
Ceramic Tile	Nonslip Floor Ceramic	m^2		4.67%			0.21%			5.74%			2.42%	
	Wall Ceramic Tile	m^2		2.15%			0.98%			3.41%			2.61%	
PPRC Pipes and Fittings	Ø63 PPRC Pipe	m		1.25%			11.11%			4.17%			4.67%	
	Ø63 PPRC Tee	Pcs		2.31%			0.91%			0.00%			0.00%	
Suspended Ceiling	L Profile	Pcs		1.18%			1.85%			6.76%			3.50%	
	Double Spring Ceiling Panel	Pcs		0.81%			0.63%			0.40%			4.42%	

Table 5-7: Average waste rate for each material group

			Average Actual Waste Rates (%) for Each Building in Sample Projects											
Material Group	**Material Type**	**Unit**	**A-01**	**A-02**	**A-03**	**B-01**	**B-02**	**B-03**	**C-01**	**C-02**	**C-03**	**D-01**	**D-02**	**D-03**
Cables	1x10mm2 H07Z-R	m		2.5%			1.69%			6.3%			1.3%	
	1x120mm2 H07Z-R	m												
Ceramic Tile	Nonslip Floor Ceramic	m^2		2.7%			0.81%			4.4%			2.5%	
	Wall Ceramic Tile	m^2												
PPRC Pipes and Fittings	Ø63 PPRC Pipe	m		1.5%			7.24%			3.3%			3.9%	
	Ø63 PPRC Tee	Pcs												
Suspended Ceiling	L Profile	Pcs		0.9%			1.25%			2.4%			4.1%	
	Double Spring Ceiling Panel	Pcs												

Comparing the output results, the average waste rates were calculated as shown in Table 5-7, also the similarity calculations were examined with the expected results as described in section 4.3.6.1.1 and observed that all the values are matching with expected outcomes. Moreover, the results of waste cause analysis process were examined and compared with the application outcomes. Minor bugs were identified due to some codding problems in waste cause frequency calculations and all were resolved. Also some miscalculations were found in similarity analysis due to wrong categorization of project size according to classification given in Table 4-11. All bugs of the system were identified and resolved. Besides, the tool functions were examined by entering various data for sample portfolio and it was observed that all system functions are working. Considering the “Project A” as active project in the system, Figure 5-1, Figure 5-2, and Figure 5-3, demonstrate the application outputs for waste estimation based on similarity calculations, waste quantity and waste cause analysis results respectively.

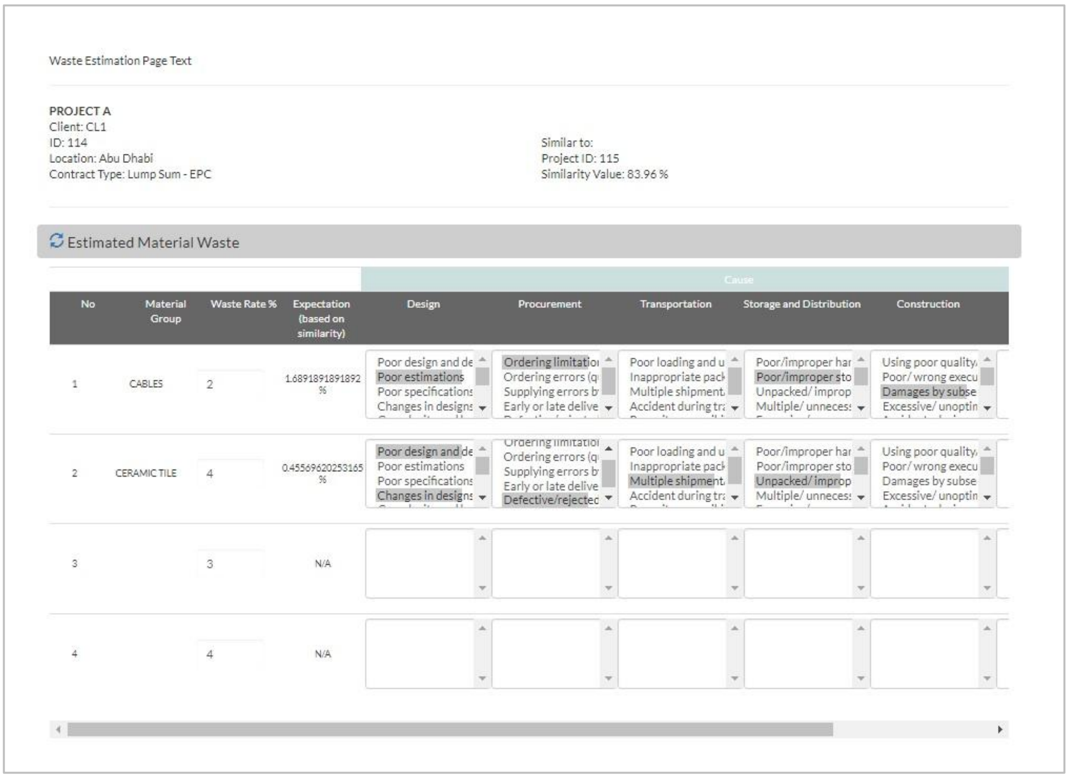
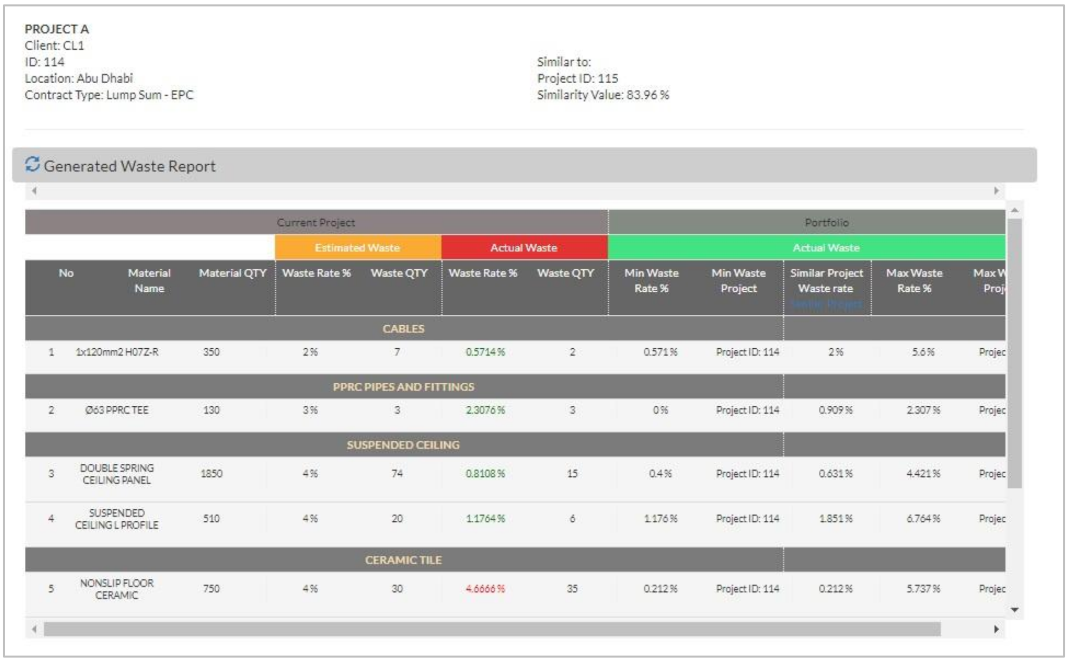


Figure 5-1: Waste estimation based on similarity calculations for project A



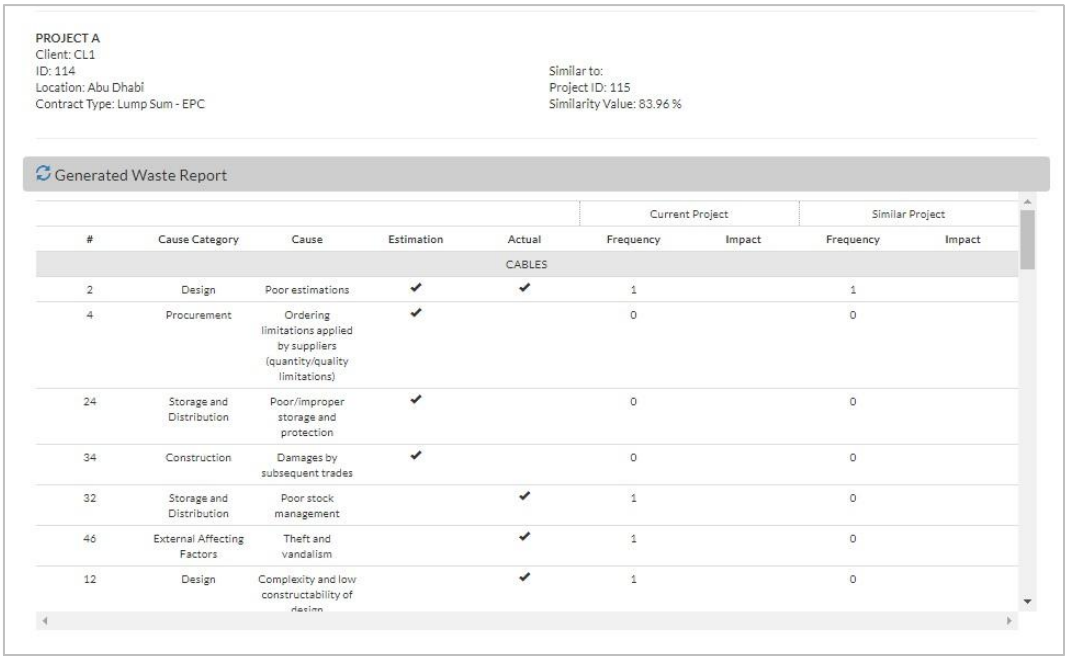
PROJECT A
Client: CL1
ID: 114
Location: Abu Dhabi
Contract Type: Lump Sum - EPC

Similar to:
Project ID: 115
Similarity Value: 83.96 %

Generated Waste Report

Current Project							Portfolio				
			Estimated Waste		Actual Waste		Actual Waste				
No	Material Name	Material QTY	Waste Rate %	Waste QTY	Waste Rate %	Waste QTY	Min Waste Rate %	Min Waste Project	Similar Project Waste rate	Max Waste Rate %	Max W Proj
CABLES											
1	1x120mm2 H07Z-R	350	2 %	7	0.5714 %	2	0.571 %	Project ID: 114	2 %	5.6 %	Projec
PPRC PIPES AND FITTINGS											
2	Ø63 PPRC TEE	130	3 %	3	2.3076 %	3	0 %	Project ID: 114	0.909 %	2.307 %	Projec
SUSPENDED CEILING											
3	DOUBLE SPRING CEILING PANEL	1850	4 %	74	0.8108 %	15	0.4 %	Project ID: 114	0.631 %	4.421 %	Projec
4	SUSPENDED CEILING L PROFILE	510	4 %	20	1.1764 %	6	1.176 %	Project ID: 114	1.851 %	6.764 %	Projec
CERAMIC TILE											
5	NONSLIP FLOOR CERAMIC	750	4 %	30	4.6666 %	35	0.212 %	Project ID: 114	0.212 %	5.737 %	Projec

Figure 5-2: Waste quantity analysis results for project A



PROJECT A
Client: CL1
ID: 114
Location: Abu Dhabi
Contract Type: Lump Sum - EPC

Similar to:
Project ID: 115
Similarity Value: 83.96 %

Generated Waste Report

					Current Project		Similar Project	
#	Cause Category	Cause	Estimation	Actual	Frequency	Impact	Frequency	Impact
CABLES								
2	Design	Poor estimations	✔	✔	1		1	
4	Procurement	Ordering limitations applied by suppliers (quantity/quality limitations)	✔		0		0	
24	Storage and Distribution	Poor/improper storage and protection	✔		0		0	
34	Construction	Damages by subsequent trades	✔		0		0	
32	Storage and Distribution	Poor stock management		✔	1		0	
46	External Affecting Factors	Theft and vandalism		✔	1		0	
12	Design	Complexity and low constructability of design		✔	1		0	

Figure 5-3: Waste cause analysis for project A

5.3. Interviews with Sector Professionals

As described previously, the data entering process were performed by interviewees to let them attain more realistic perceptions about the system functionality by using the application for data entering and retrieval. The participants were selected from three large prefabricated construction companies and all were familiar with the waste management processes in their companies. Before starting to use of the system, the participants were given an introduction to the proposed process of waste management using “Waste Tracker”. Also the functions and processes of the “Waste Tracker” were explained. Each participant was asked to enter one project data and create a predefined project scenario in the system. After completing the project creation for all portfolio projects the system applicability and usefulness were discussed with each participant separately. Finally, a set of expressions have been prepared and asked from each participant to evaluate the functionality and applicability of “Waste Tracker” according to their experiences. The results of interview discussions are explained in detail in following sections.

5.3.1. Participant 1 and 2

Participant 1 and 2 are working in the same company and have 9 years and 14 years of experience in prefabricated construction industry respectively. Participant 1 is project monitoring and reporting responsible and participant 2 is construction and project management department manager. Both are directly involving with waste management procedures in their company.

Participant 1 stated that there is not any waste performance measurement procedure in their company due to the lack of systematic data gathering. And explained his experiences in several projects with significant amount of waste generation and lack of data analyzing and reporting for those projects, which led to considerable delay and cost impacts. He believes that the main problem in project waste monitoring is information flow from construction sites, and states that generally project management team is not eager to share actual waste data with head office to keep their poor performances from upper managers. According to participant 1 the lack of systematic waste data gathering and analyzing mostly leads to late problem recognition and avoidance. He believes that proposed process and tool will enhance data capturing from construction sites by enforcing them to report the material waste data as part of project progress report. Moreover, he declares that project team members are mostly hating from extra reporting works and this may also trigger the poor waste data gathering and sharing. However, considering the implementation of "Waste Tracker" in projects, this problem can be considerably solved. Participant 1 also declared that the responsibility of waste tracking must be clearly defined in companies to avoid discrepancies in responsibilities. He emphasizes that implementation of new applications like "Waste Tracker" in an organization requires comprehensive changes in organizational structure and responsibilities in companies to overcome the potential inefficiencies and responsibility clashes within the organization. For example, project system maintenance and project creation and monitoring responsibilities must be clearly identified by organizational procedures. According to participant 1 material data entering process must be simplified to reduce the work load of users in creating material database for a project. He found the material data entering process comprehensive enough but he declares that it is more time consuming for a project participant especially in large and complicated projects.

According to participant 2 the "Waste Tracker" and proposed process model for material waste management can help project management team in timely and systematic waste data gathering and analyzing and also enables them to have a real-time control on waste generation. He declares that one of the inefficiencies in current project performance measurement is ignorance of waste management factor as a project success factor. He believes that, the successful management of waste will considerably affect timely completion of project within the budget. Like participant 1 he emphasizes the importance of efficient waste management in reducing project conflicts arising from late completion and cost overrun. According to participant 2, the impact of poor waste management on project delay and cost in prefabricated projects is considerably higher than in traditional projects. This is because of the construction method in prefabrication which generally involves high share of plant production; as well as the locational distance of prefabricated projects which are mostly far from residential areas. Participant 2 believes that although implementation of "Waste Tracker" may require higher man-hour in projects, however the company will highly benefit from waste database development and efficient controlling of waste generation in projects. He offers the merging of "Waste Tracker" with existing ERP applications to simplify and enhance the accuracy of data entering process. He also believes that data entering, especially in material data, may be found more time-consuming by system users; and this may lead to increasing complaints and poor data sharing from construction sites.

5.3.2. Participant 3 and 4

Participant 3 is a senior civil engineer with more than 12 years of experience in construction industry and is working as planning and project control department lead in a prefabricated construction company for last 7 years. Participant 4 is a senior architecture with 18 years of experience in construction and is working in the same company from past 14 years as project management office director. The company is a world ranked company in ENR list and have been carried out multiple international EPC projects worldwide. According to participant 3, the material waste management in construction industry in Turkey, is extremely ignored by companies and there are not any predefined and systematic waste management procedures in most of the projects. He believes that the existing waste management plans and procedures are focusing on waste disposal rather than the efficient waste management and reduction. Therefore, the industry encounters with high level of waste generation in construction projects, in the lack of predefined and systematic waste monitoring and controlling plan. He declares that, developing a waste management process with concentration on waste monitoring and control using a web based application like “Waste Tracker” is a requisite for most of the companies. It is expected to be more useful in waste management and reduction in construction projects. According to participant 3, unavailability of waste estimation records and actual waste rates from past projects is the major deficiency in waste management in construction companies and this problem seems to be solved by proposed model in “Waste Tracker”. Participant 3 emphasizes that the existing system must be developed considering the simplicity of the overall structure and more automated data entering processes in the system. He declares that, although the existing data structure in the system is seems to be adequate for establishing a waste management system in a company, however, it needs to be more comprehensive and flexible for any company culture. He proposes to integrate the project data entering process with existing document control applications in the market to eliminate the extra workload of project creation in the system. He also suggests to develop a spreadsheet input option for material data entering, since the existing BOQ documents are prepared in the form of spreadsheets and data transfer using this format will be more simple and efficient. According to participant 3 the existing material categorization system seems useful and applicable in most of the prefabricated companies and simplifies the material tracking process. However, he suggests the development of material categorization structure in a more flexible format. He proposed that the material database in “Waste Tracker” must be synchronized with ERP systems in each company to establish an integrated material database.

Participant 4 strongly believes that, efficient waste reduction is a strategic advantage for a construction company in existing competitive markets; and Turkish construction companies are mostly losing in global markets by ignoring the application of effective waste management system to reduce the extra cost impacts associated with material waste. He states that, waste must be managed in all aspects of resources including manpower, equipment, energy and material and suggests to develop the "Waste Tracker" as an overall waste management application. Considering the "Waste Tracker" and proposed waste management system, participant 4 is accepting the proposals of participant 3 in synchronizing the databases and improving the integrity of the application with existing systems in each companies because un integrated tools will be quitted in one point and will not be sustainable in the system. According to participant 4, the upper management's perception about waste management and their awareness about the negative impacts of waste generation rates in projects is a critical factor to enforce the project team members in application of efficient waste management strategies. He declares that, due to the lack of material waste data and unavailability of material waste reduction performance indexes in most of the companies, the company managers are not aware of the importance of waste in projects. He suggests to improve the reporting modules of the application to be more visualized and understandable by every project participants and especially by upper managers. This will give them a comprehensive vision about the importance of waste management. He also discussed about the integrating the waste estimation and waste controlling processes in "Waste Tracker" and suggests to simplify the waste estimation stage for designers to encourage them in using the system for waste estimation. He declares that this tool can be developed as an Add-on application for excel to simplifying the waste estimation process for design groups.

Both participants state that considering the waste reporting process as a part of project progress reporting is extremely useful in monitoring the waste generation status in projects and believe that this model will encourage the project team in monitoring and controlling the waste generation more effectively. They also declare that, daily reporting of waste generation will increase the quality of information flow to head offices and may need extra indirect personnel in projects, however the advantages of implementation of system will absolutely recovers the imposed costs.

5.3.3. Participant 5

Participant 5 is a senior project manager having more than 21 years of experience in construction industry and holds Master's Degree in civil engineering. He has been spending about 11 years of his career in prefabricated construction industry in several positions in international projects. He states that he rarely experienced projects without material wastages; and emphasizes that the lack of experience transaction from past projects, in the form of lessons learned, is one of the major causes of failures in successful waste management. He declares that, improving processes requires a predefined and systematic data capturing and analyzing with the aim of knowledge production and sharing. According to participant 5, "Waste Tracker" can assist project management team in real-time data gathering and analyzing and will increase the knowledge flow within the company. He also declares that, "Waste Tracker" must be improved in terms of reporting capabilities to be able to produce knowledge from past projects for each material group. He finds the proposed structure of the process and outputs of the system innovative in waste management, which exactly focuses on waste control and reduction at real-time manner. This method of waste monitoring and controlling, in his opinion, will result in more apparent outcomes in waste reduction in construction projects. He also notifies that, the waste management progresses and team performances can be monitored using the outcomes of this system. According to the use of "Waste Tracker" in construction projects he suggests to facilitate the data entering process and enable the online synchronization of database with existing document management applications in companies. Considering the high workloads in construction sites he expresses that it is mostly possible to not be used by project reporting team if the current data entering system would not be improved. He also notified that in some cases, using web based applications in construction sites may be troubling due to unavailability of proper internet infrastructures, specifically in prefabricated projects which are generally located in remote locations. Therefore, he offers to develop an installable version of "Waste Tracker" for standalone uses in personal computers with ability of synchronizing while connecting to the web.

5.3.4. Interview Questionnaire Results

At the end of interview, the participants were asked to answer a set of predefined questions and rate each expression according to a 7 point rating scale as shown in Table 5-8.

Table 5-8: Rating scale for interviewees evaluations

Rating Scale for Expressions						
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6	7

The result of interview questionnaire is demonstrated in Table 5-9. Considering the average score of each expression, the highest scores belong to "suitability of project data entering process" and "the sufficiency of waste estimation data". On the other hand, the lowest score is assigned to "material data entering process" which has been notified several in discussions. This illustrates that data entering process needs to be improved and this is emphasized by all participants. Briefly, according to the overall result, the total assessment of participants about "Waste Tracker" is scored as 5.9, which reflects the positive impression of sector experts about efficiency and functionality of the application in general. Considering the general opinion of the participants about "Waste Tracker", they totally evaluated the application as a useful tool for establishing an efficient waste management in construction companies.

Table 5-9: Responses of interviewees to interview questions

	Please evaluate the following expressions	Participant					Average
		1	**2**	**3**	**4**	**5**	
1	Searching and filtering mechanism is properly developed and is useful enough	5	4	6	6	5	**5.2**
2	Project data entering process is suitable and user friendly	7	6	6	7	7	**6.6**
3	Project data are adequate and comprehensive for project analyzing and data retrieval	6	6	6	5	6	**5.8**
4	Scope data entering process is suitable and user friendly	7	6	5	6	6	**6**
5	Scope data are adequate and comprehensive for project analyzing and data retrieval	6	7	5	7	6	**6.2**
6	Material data entering process is suitable and user friendly	4	4	5	5	5	**4.6**
7	Material groups and data are comprehensive and flexible for waste management	5	6	7	6	7	**6.2**
8	Waste estimation process is suitable and user friendly	4	5	5	6	6	**5.2**
9	Waste estimation data are adequate and flexible for waste management	6	7	6	7	7	**6.6**
10	Similarity calculation attributes are logical and useful	6	6	5	6	6	**5.8**
11	The produced waste quantity information is adequate and useful for efficient waste management	6	7	6	5	6	**6**
12	The produced waste cause analyzing information is adequate and useful for efficient waste management	6	6	7	5	6	**6**
13	Generally speaking, the "Waste Tracker" is useful and will have positive effects in waste management in companies	6	7	6	6	6	**6.2**
	Overall	**5.7**	**5.9**	**5.8**	**5.9**	**6.1**	**5.9**

5.4. The Pros and Cons of the "Waste Tracker"

With reference to oral discussions with sector professionals and results of the questionnaire assessment, the advantages of the "Waste Tracker" can be summarized as follow:

- Establishes a systematic waste data gathering and analyzing process within the companies, which is expected to result in waste reduction in construction projects.
- Low waste generation would lead to lower delay and cost overruns in projects and consequently minimizes the contractual conflicts between project stakeholders.
- Encourages well-structured and regular waste data capturing and documentation.
- Improves the abilities of project management team in implementation of real-time controlling of waste generation in projects.
- Concentrates the waste management procedures on waste reduction rather than waste disposal methods.
- Develops a waste estimation record for future uses and establishes a waste database from past experiences.
- Provides strategic advantage by cost reduction for construction companies, if implemented properly.
- Raises the awareness of project participants and upper managers about the importance of material waste control by facilitating the waste management performance measurement.
- Facilitates the waste information flow within the company by implementation of waste reporting as part of the project progress monitoring process.
- Encourages a continuous process improvement by establishing a real-time waste monitoring and controlling.

On the other hand, bottlenecks of the “Waste Tracker” can be summarized as follows:

- Manual data entering procedures must be improved and automated data transferring from existing ERP or document management applications must be developed.
- Reporting module of the application must be improved and the visual demonstration of outputs must be developed.
- Searching and filtering modules must be developed.
- Standalone version with auto-synchronization capability for the application must be developed.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1. Summary

Construction industry is inherently a devastating combination of environmentally-unfriendly activities, including: material extraction from natural resources, processing of raw materials in manufacturing plants, transportation of materials to construction sites, on-site construction works, dramatically destroying of lands, natural resources depletion and several direct and indirect impacts on the nature. On the other hand, the most majority of construction project's costs involves material related costs. Traditional construction methods are mostly involving waste-prone activities with wet trade methods and less productive practices. In recent years the prefabrication is mostly trending and encouraged by industry professionals and governments with the aim of reducing the negative impacts of material and process wastes, existing in traditional construction methods. however, the prefabrication itself, involves considerable waste generation both in material and process aspects. Therefore, it is essential to improve the waste management practices in parallel with shifting the traditional construction to industrial manufacturing. Several studies have been carried out in different regions all around the world investigating the waste generation and management in construction industry. The majority of existing studies are focusing on traditional construction methods and limited studies are available in prefabricated construction sector. Polat et al. (Polat et al., 2017), categorize existing studies in waste management into three main groups, including:

1- Studies that investigate the root causes of waste generation in specific regions and limited projects;
2- Studies dealing with the estimation and management of C&D wastes;
3- Studies that concentrate on prevention and reduction of waste generation in certain projects and regions.

Due to the limited range of existing studies and flexibility of construction projects depending on regional and project-specific conditions, the results of these studies cannot be generalized in all countries and projects. Therefore, it is required to carry out studies in Turkish construction industry to investigate the existing situation of waste management in Turkey. On the other hand, there are limited studies in this field in Turkey. Accordingly, this study attempted to fill the gap of studies on waste management in prefabricated construction industry in Turkey. The findings of this study, explained in following sections, confirms the needs for further investigations and improvements in this field.

6.2. Findings of Questionnaire Survey and Interviews

6.2.1. Investigating the Most Waste-Prone Materials

The construction processes in prefabrication are mostly industrialized, meaning that, depending on the level of prefabrication, the whole or a portion of building elements are fabricated in production plants which are generally apart from construction sites. Therefore, proper packaging, transportation and storage of manufactured elements are significantly important in this sector. The most common prefabricated elements are wall and roof panels, structural elements, suspended ceilings, doors and windows and the major construction activities on site focus on assembly and installation of these elements. Considering this method of construction, the results of the ranking of most waste-prone materials and critical waste causes can be discussed accordingly. The study confirms that sealing materials are the most wasteful material in prefabrication; indicating that water leakage is a common problem of this industry as it is mentioned by Poon et al. (C. Poon et al., 2001) and Tam et al. (C. M. Tam, Tam, Chan, & Ng, 2005). Due to the problems that arise from poor integration of non-standardized designs with production and on-site assembly, sealing of assembled elements seems to be one of the most challenging obstacles in prefabrication which leads to excessive use of sealing materials. Gypsum and fiber cement boards are ranked as second and third most waste-prone materials respectively in Table 3-17 in Chapter 3. These are the major covering materials in prefabricated wall and roof elements; therefore, as it is mentioned in Table 3-22 in Chapter 3, multiple relocating and poor storage and protection at construction sites may lead to increasing damages on them.

Cables are identified as the most waste-prone material in electrical material group, which are affected by damages from other trades, rout changes by ignoring design during construction and theft or damage due to improper storage and protection on site. Accordingly, cable conduits and cable trays are identified on second and third row respectively as shown in Table 3-18 in Chapter 3.

In mechanical group of materials, PVC pipes and fittings are evaluated as the most waste-prone materials that improper packing, left-over on site and poor interdisciplinary design integration are the most important causes for their waste generation. Pipe heat insulation and PPRC pipes and fittings are evaluated as the second and third waste-prone materials in mechanical materials group as shown in Table 3-19 in Chapter 3.

The results of the study confirm that, the most waste-prone materials in prefabrication industry are totally different than those in traditional construction. Considering the chemical composition of these materials, it is observed that in contrast to traditional construction with inert combination of wastes, the wasted materials in prefabrication are mostly made from synthetic materials. The recycling cost and environmental effect of improper disposal of these materials are extremely high. Therefore, efficient management of material waste in prefabrication is considerably important than traditional construction methods. The existing studies rarely investigate the mechanical and electrical materials in their studies, due to the great portion of building material wastes in total project waste generation. Thus, despite the high share of mechanical and electrical works in a construction project cost, there is a great gap of data about these materials in literature. This study attempts to cover this gap by widening the range of investigated materials. The results of material investigation also illustrate that the participant's evaluation about most waste-prone materials are extremely varying depending on their personal experiences and perceptions; this fact can be concluded from the RII values calculated in Table 3-17, Table 3-18, and Table 3-19 in Chapter 3.

6.2.2. Investigating the Material Waste Causes

The results of investigating material waste causes in prefabrication industry shown in Table 3-22 in Chapter 3, demonstrate that "poor site storage capacity", "poor stock management", and "poor/ improper storage and protection" are the evaluated as the most three important waste causes in in this sector. This ranking is independent from the type of material and confirms that due to the high share of off-site production in prefabricated construction method, the storage and stock management is the most critical factor in waste reduction. This result is different from the previous investigations of waste causes in traditional construction methods; and confirms that dealing with waste causes in prefabrication requires different strategies and methods.

Based on the waste causes ranking, indicated in Table 3-22 in Chapter 3, the most 10 important waste causes belong to three waste categories. Accordingly, 50% of waste causes are originated from "storage and distribution", 30% from "design" and 20% of waste sources are related to "external affecting factors" such as unskilled labor and weather conditions. Therefore, proper packing of materials for long-distance transportation and appropriate storage and protection against diverse weather conditions on construction sites are the major actions should be taken for waste reduction in prefabrication. Besides, standardization of designs and integration of design, production and on-site assembly works, with exact consideration of site conditions will improve the quality of design and details. Moreover, the amount of revisions after design phase must be reduced to overcome the waste generation, arising from on-site variations, for this purpose the customer needs and requirements must be exactly identified and incorporated in designs, also the interdisciplinary integration should be improved in designs by using Building Information Modeling (BIM). Application of BIM in design process, not only reduces the clashes by improving the accuracy of design and details, but also increases the validity of quantity estimations which is found as one of the substantial waste causes.

The study also confirms that the waste can be originated from different sources for various materials. The results of waste causes ranking in general and specifically for three different materials shown in Table 3-23 in Chapter 3, indicates the variability and flexibility of waste causes in each case. Therefore, since the waste is not completely avoidable and whole sources of waste may not be managed properly, it would be more efficient to focus on the most waste-prone materials and significant waste causes to achieve more effective waste management results.

6.2.3. Waste Management Performance

The results of investigating the performance of companies in waste management, shown in Table 3-24 in Chapter 3, confirms that the following deficiencies are associated with the waste management in prefabricated construction companies in Turkey:

1- Unavailability of adequate training programs for project and company personnel on waste management is the poorest performance of companies according to respondents. This is mostly originated from the unawareness of company managers about the efficiency of training in efficient waste management.
2- Poor performance of companies in implementation and development of integrated design systems based on BIM technologies which causes to poor interdisciplinary integration of designs and increasing the amount of construction errors and reworks.
3- Poor analyzing of direct and indirect impacts of material waste in project performance due to the lack of efficient waste management system and waste data collection processes.
4- Ignoring the waste management personnel designation in organizational charts and existence of vague areas of responsibilities in waste management processes.
5- Poor lessons learned processes regarding material waste management based on the personal experiences of project management team from past projects.
6- Despite the impact of efficient waste management in project cost and time performance, ignoring the involvement of waste management in total project performance measurements pales the importance of waste management in comparison with other factors.
7- Poor consideration of environmental and waste management issues in design stage due to the unawareness of design team about the significant impact of material waste on project.
8- Indetermination of estimated waste rates for project team and in accuracy of waste estimation methods utilized by designers which in return, cause to less accurate estimations and misleading actions in the course of project execution.

9- Poor controlling of material usage on sites due to unavailability of systematic waste monitoring and measuring procedures and consequently inefficiencies in waste management plans.
10- Despite the partial availability of waste data and documents, the lack of waste quantity and causes data analysis results in poor waste monitoring and controlling outcomes and therefore, leads to corporate waste knowledge absence.

The average evaluation of the waste management performance in prefabricated construction companies according to the results of Table 3-24 in Chapter 3, is moderate and near to poor, therefore it is required to explore the major weaknesses of the existing systems and attempt to improve the deficiencies. Based on the above-mentioned deficiencies, lack of systematic waste estimation according to the past performances of companies in similar projects, incomplete reporting and documentation of waste generation, poor waste source and quantity analysis and poor waste knowledge generation in companies in parallel with disintegration of waste estimation, monitoring, analyzing and documentation processes are the root causes of poor waste management performances in this sector. Since effective waste management depends on the early identification of waste sources for each type of material and prior development of dynamic waste scenarios and planning for waste minimization at source, it is necessary to proactively identify the waste sources and real-time monitoring and analyzing of waste generation. This will enable the project management team to plan for the waste avoidance measures proactively and take effective actions in the earliest time of waste occurrence.

6.3. Discussion on "Waste Tracker"

As mentioned before, the project management team must be able to deal with the waste sources prior to their occurrence, or at the earliest time they are recognized during project life cycle. On the other hand, the most important deficiency of existing systems is unavailability of integrated waste management system in their organization. For this purpose, an integrated waste management tool has been developed for facilitating the estimation, tracking and analyzing of the waste generation during the project lifecycle, by controlling the related waste sources and recording the data while the project is going on. This will provide a corporate knowledge from previous projects for efficient prediction of possible waste generation sources prior to project commence and facilitates an effective waste prediction and management during project execution. Since late preventive actions would be more costly, or in some cases impossible, this tool is expected to be useful for timely management of waste in prefabricated construction projects; and will lead to increase in the efficiency of projects by enhancing the time, cost and environmental performances.

The "Waste Tracker" is a web-based application that facilitates the analyzing and recording of the actual and estimated waste data in database. These data will be used in waste estimation and waste performance analyzing processes during the project execution. Since the waste causes and quantity data are mostly project and company-specific and other projects data cannot be generalized in a typical project, therefore, the development of waste benchmark based on the information in literature, will not be applicable. For this purpose, it is reasonable to develop the waste benchmark based on the actual data from the corporate's past projects. One of the existing deficiencies in current waste management processes is unavailability of classified data of previous projects, which in return causes to the unavailability of waste benchmark for waste data analysis. This application provides a systematic platform for waste estimation based on the actual waste data from previous similar projects within the company and enhances the accuracy of waste estimation processes by reducing the amount of defective estimations based on personal perceptions and experiences. Accurate waste estimation data assist the development of more dependable waste baseline and facilitates the waste monitoring procedures in comparison with the existing waste benchmark. "Waste Tracker" also provides a systematic and predefined process of waste capturing and reporting and enables the users to simply identify the root causes of waste generation and record the actual waste data within the system for further analyzing. The developed system also enables the users to identify the all types of direct and indirect wastes in projects. Live capturing of waste generation for each type of material and real-time analyzing of waste data helps the project management team to take efficient measures, based on the waste sources information, in earliest time and more efficient way. The users are also capable to compare the actual waste generation with performance of most similar projects in the database portfolio. This will help the project team to improve their performances in comparison with previous projects. The integrated structure of “Waste Tracker” is expected to enhance the efficiency of the waste management processes and improve the data transformation to corporate knowledge.

6.4. Limitations of the Study

6.4.1. Lack of Classified Material Waste Data

The main obstacle in this study was lack of classified material waste data in companies and long term of data collection from the professionals. Since data collection and investigating the existing state of waste management in companies were the initial step of the study, the time extension had prolonged the subsequent steps of the study. However, although this issue created a major challenge for the study, the collected information in this thesis about waste is believed to be one of the contributions of this study.

6.4.2. Limited Number of Companies Involved in the Study

Although the prefabrication is trending in recent years, however the number of prefabricated projects and the companies with professional experiences in this field is extremely restricted. Therefore, there are limited number of qualified companies and participants who are willing to cooperate with the study. The restricted number of reference population extends the data collection process and in most cases requires to multiple follow up mailings, individual meetings and conversations.

6.4.3. Restrictions in Cost Data Access

Although one of the main impacts of material waste in construction projects is the cost impact, the cost data of purchased materials have not been shared by companies to be investigated in the study. Therefore, the actual cost impact of wasted materials could not be identified in this study.

6.5. Recommendations for Further Work

Although the data collected by interviews and questionnaires is limited to the Turkish prefabricated construction industry, the process model and the tool, Waste Tracker, are generic to be applied in different contexts after some modifications.

Considering the testing and validation process of the application, the following specific developments can be recommended for further improvements of "Waste Tracker" improvement and also about possible alternative tools that would be developed to support the waste management process in construction companies:

1- Simplifying the data entering processes in the system by synchronizing the tool by existing ERP applications in the market will enhance the accuracy and integrity of the system.
2- Developing the material data entering process by enabling the data transfer between BIM based design applications can improve the accuracy and integrity of the material database.

3- Improving the user-friendliness of the application by developing the user interfaces and enhancing the flexibility of the application settings can increase usability.
4- Improving the similarity analysis by incorporating the fuzzy logic to reflect vagueness can improve the similarity assessment process. Similarly, different artificial intelligence methods (such as case-based reasoning and expert systems) can be used to identify similar cases and adapt previous data to new cases. Waste estimation could also be carried out by using artificial intelligence (such as neural networks) or regression analysis if there were statistical data about waste in previous projects. Waste estimation part of Waste Tracker can be modified considering the availability of data in different companies.
5- Developing the graphical representation of data analysis results based on the user's needs may improve the presentation of results and aid better decision-making.
6- Developing stand-alone and synchronized version of the application to be used in remote construction sites with poor web access can be considered.
7- Integrating the "Waste Tracker" with cost control applications of companies may enable the analyzing of cost impact of the material waste in projects.
8- In parallel with analyzing the cost impact of the waste, time impact on project schedule and environmental effects of the generated wastes could be analyzed using the current structure of the application.

This study proposes and establishes a new waste management process model using an integrated waste management tool which is expected to positively affect the project cost, time and environmental performances. This application has a potential to be commercialized if the above mentioned developments would be realized.

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APPENDIX

This chapter presents the questionnaire used for data collection and distributed between sector professionals.

Middle East Technical University
Civil Engineering Department
Construction Management and Engineering Division

An Investigation of Waste Management and Waste Causes in Building Projects in Turkey

This questionnaire survey is part of an ongoing research on improving the waste management in construction companies in Turkey and aims to study the sources of waste generation and the state of waste management in the sector. The final purpose is to develop a process for improving the efficient waste management by considering the current state of waste generation and management in the sector.

You are kindly invited to be a part of this research and request you to assist us in completing the current questionnaire. Your responses are completely confidential and will not be identified by any individual. The information provided here will be combined together and analyzed as a group and will only be used for academic purposes on academic platforms.

Estimated Response Time: 10-12 min.

Yours Sincerely,

Babak Rahmani
Ph.D. Candidate
Middle East Technical University
Email: bbk.rahmani@gmail.com
Advisor: Prof. Dr. İrem Dikmen Toker

Q1: What is your company size:

- Micro (employee < 10)
- Small (10< employee < 50)
- Medium (50 < employee < 250)
- Large (employee > 250)

Q2: Please identify your company's experience in Prefabricated Construction Industry (Years):

- 0-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25+

Q3: What is your job designation in your company/project:

- Project/Construction Manager
- Technical Manager
- Engineer
- Technician
- Tech. Supervisor and Inspector
- Other (Please Specify)

Q4: What is your major field of experience:

- Civil/Architectural

- Mechanical Engineering
- Electrical Engineering
- Other (Please Specify)

Q5: Your Experience in Construction Industry (Years):

- 0-3
- 4-6
- 7-10
- 11-13
- 14-16
- 17-20
- 20-25
- 25+

Q6: Which of the following methods are generally used for waste estimation in your projects (multiple answers can be selected):

- Specific quantitative methods
- Previous project records
- Experimental estimations
- National / International standards
- I do not have any Information regarding this issue

Q7: Please identify the average percentage of cost overrun due to material wastage in your projects:

- Less than 1% of total project cost
- 1% - 5% of total project cost

- 5% - 10% of total project cost
- 10% - 15% of total project cost
- 15% - 20% of total project cost
- 20% - 25% of total project cost
- 25% - 30% of total project cost
- 30% - 35% of total project cost
- 35% - 40% of total project cost
- More than 40% of total project cost

Q8: Please evaluate the performance of your company regarding the following subjects using the given rating scale below:

	Very Poor	Poor	Average	Good	Excellent
Using integrated design and estimation software (e.g. BIM software)					
Considering environmental and waste management issues in design stage					
The accuracy of methods used for waste estimation in projects					
The material traceability at construction sites					
The awareness of project team about estimated waste rates of each material					
The evaluation of waste management performance in projects					
The availability of actual waste data during project construction					
The analysis of actual and nominal waste data in projects					
Documentation of material wastes and waste sources					
Company knowledge about the actual amount of waste and waste causes					
The analysis of cost impact of material waste in projects					
The quality of systematic control of material usage at site					
The lessons learned process regarding waste management in projects					
Training and education about waste management and control in projects					

Personnel designation for implementation of waste management plan					
The company policies in material waste avoidance or reduction					
The awareness of company/project stakeholders about waste management					

Q9: Please rank the degree of contribution of following Material Waste Causes in waste generation in Prefabricated Steel Structure Projects according to your past experiences:

	Very Little	Little	Moderate	Great	Extreme
Poor Design and Details					
Poor Estimations					
Poor Specifications					
Changes in Designs and Specifications					
Complexity and low constructability of Design					
Poor interdisciplinary design integration					
Improper/ Wrong material selection or substitution					
Ignorance of material specifications in designs					
Ordering errors (Quality or Quantity errors, wrong selection or substitution)					
Supplying errors by suppliers (Quality or Quantity errors)					
Early or late delivery					
Defective/Rejected Products					
Ordering limitations applied by suppliers (Quantity and Quality limitations)					
Poor Loading and unloading					
Inappropriate packing for transportation					
Multiple shipment/ transportation points					
Accident during transportation					
Poor site accessibility/ Road condition					
Poor/Improper handling and distribution on site					
Poor/Improper storage and protection					

Unpacked/ Improper packaging of materials					
Multiple/ Unnecessary relocating at site					
Excessive/Unnecessary inventories					
Poor site storage capacity					
Accidents during storage and distribution					
Handling Equipment failure (Breakdown or malfunctioning)					
Untraceable/Left-over Materials on site					
Poor stock management					
Using poor quality/ wrong material					
Poor/ wrong execution of work					
Damages by subsequent trades					
Excessive/Unoptimized cutting (Conversion waste)					
Accidents during construction					
Excessive use of material					
Overproduction					
Ignorance of designs/method statements during construction					
Unavoidable process waste					
Poor Planning and scheduling					
Poor waste management					
Poor supervision and control					
Poor project contracting/ subcontracting					
Unfavorable weather conditions					
Natural/Manmade disasters (e.g. Earthquake, Floods, War, etc.)					
Theft and Vandalism					
Unknown site conditions					
Unskilled/ Unexperienced labor					

Q10: Please evaluate the degree of effectiveness of the following waste factors on the waste generation in Wall and Roof Boards:

	Very Little	Little	Moderate	Great	Extreme
Poor Design and Details					
Changes in Designs and Specifications					
Poor interdisciplinary design integration					
Ordering errors (Quality or Quantity errors, wrong selection or substitution)					

Defective/Rejected Products					
Ordering limitations applied by suppliers (Quantity and Quality limitations)					
Poor Loading and unloading					
Inappropriate packing for transportation					
Multiple shipment/ transportation points					
Accident during transportation					
Poor/Improper storage and protection					
Multiple/ Unnecessary relocating or Handling					
Excessive/Unnecessary inventories					
Poor site storage capacity					
Untraceable/Left-over Materials on site					
Poor stock management					
Poor/ wrong execution of work					
Damages by subsequent trades					
Excessive/Unoptimized cutting (Conversion waste)					
Poor supervision and control					
Unfavorable weather conditions (e.g. Precipitation, Degree, Humidity etc.)					
Unskilled/ Unexperienced labor					

Q11: Please evaluate the degree of effectiveness of the following waste factors on the waste generation in Pipes and Fittings?

	Very Little	Little	Moderate	Great	Extreme
Poor Estimations					
Changes in Designs and Specifications					
Poor interdisciplinary design integration					
Ignorance of material specifications in designs					
Ordering errors (Quality or Quantity errors, wrong selection or substitution)					
Defective/Rejected Products					
Inappropriate packing for transportation					
Poor/Improper storage and protection					
Unpacked/ Improper packaging of materials					

Excessive/Unnecessary inventories					
Untraceable/Left-over Materials on site					
Poor stock management					
Poor/ wrong execution of work					
Excessive/Unoptimized cutting (Conversion waste)					
Ignorance of designs/method statements during construction					
Poor planning and scheduling					
Poor supervision and control					
Poor project contracting/ subcontracting					
Theft and Vandalism					
Unskilled/ Unexperienced labor					

Q12: Please evaluate the degree of effectiveness of the following waste factors on the waste generation in Cables?

	Very Little	Little	Moderate	Great	Extreme
Poor Estimations					
Poor Specifications					
Changes in Designs and Specifications					
Poor interdisciplinary design integration					
Ignorance of material specifications in designs					
Ordering errors (Quality or Quantity errors, wrong selection or substitution)					
Supplying errors by suppliers (Quality or Quantity errors)					
Early or late delivery					
Ordering limitations applied by suppliers (Quantity and Quality limitations)					
Poor/Improper storage and protection					
Excessive/Unnecessary inventories					
Untraceable/Left-over Materials on site					
Poor stock management					
Damages by subsequent trades					
Excessive/Unoptimized cutting (Conversion waste)					
Ignorance of designs/method statements during construction					
Poor planning and scheduling					
Theft and Vandalism					

CURRICULUM VITAE

SUMMARY OF QUALIFICATIONS

- Over 14 years of progressive experience in international construction industry involving 6+ years of planning and scheduling and 5+ years of project management background in building projects.
- PMP certified (PMP Number: 2170651).
- Master's degree in Civil Engineering (Construction Engineering and Management).
- Extensive experience in scheduling and management of multimillion dollar building and infrastructure projects including, Residential, Commercial, Institutional, Sports facilities, Prefabricated and Modular buildings as well as Highway and Wastewater Treatment Projects.
- Experienced in scheduling and resource planning for more than 100 international tenders.
- Advanced knowledge and experience of construction logic and technics and project management processes from planning, design and procurement to construction, controlling and closeout.
- Proven track record of planning and coordinating of complex construction projects with Iranian, Turkish and International clients.
- Excellent knowledge and experience of Project Planning and Scheduling, Progress Monitoring, Earned Value Analysis, Process Improvement, Resource Estimating and Control, Risk and Change Management.
- Advanced knowledge and experience of scheduling based on international standards and metrics (e.g. PMI Practice Standard for Scheduling, U.S. GAO Scheduling Assessment Guide, DCMA 14 Point Assessments).
- Professional user and instructor of Primavera P6, MS Project and @RISK.
- Proficient in Microsoft Office Packages (Word, Excel and PowerPoint).

- Familiar with, Tilos, Risky Project and Aconex.
- Solid understanding of FIDIC Conditions of Contracts and Negotiation techniques.
- Strong interpersonal skills with ability to work independently or as a team member.
- Highly capable in dealing with cross-functional teams such as sub-contractors, suppliers, architects, and engineers.
- Strong data analysis and presentation skills.
- Proactive and well organized with strong management and problem-solving skills.

PROFESSIONAL EXPERIENCE

Senior Planning and Cost Control Engineer | Risk Management Professional

Jun 2015 – Jun 2018
Dorce Prefabricated Building and Construction Industry Trade Inc. | TURKEY

Key Responsibilities:

- Defining project WBS (Work Breakdown Structure) based on scope of the work and develop the list of activities and their logical relations.
- Develop and maintain detailed and integrated project schedule from design to closeout with collaboration of project management team and project stakeholders.
- Assigning and optimizing project resources and costs, and updating resource usages and reviewing according to budgeted values.
- Reviewing subcontractors and supplier’s schedules and integrating with master project schedule.
- Preparing and reviewing updated work schedules and preparing consolidated operational and management level progress reports.
- Preparing execution plans, manpower and equipment schedules.

- Monitoring project changes/delays and analyzing impacts on schedule/cost and provide recommendations for corrective actions.
- Revising work schedules according to scope changes during project lifecycle and preparing recovery plans and acceleration schedules based on delay analysis results and schedule risk assessments.
- Supporting project management teams to achieve daily, weekly, and monthly deliverables according to the baseline schedule.
- Liaise with clients and other project stakeholders during project lifecycle to ensure the client's satisfaction.
- Earned value analysis using project performance indicators derived from actual and planned progresses.
- Critical path analysis to identify critical activities and schedule risks.
- Preparing planning documents for biddings and assisting marketing and proposal teams in reviewing and preparing planning related tender documents.
- Attending kick-off and project progress meetings with project teams and subcontractors.
- Taking a leading role in developing corporate risk management plan and performing project and portfolio level risk assessment.
- Quantitative analyzing of identified risks and preparing mitigation plans and reviewing the progresses regularly.
- Preparing management level project risk assessment reports.

Main Projects:

- Harmancik Camp Construction for Trans Anatolian Natural Gas Pipeline (TANAP) LOT 4 | TURKEY
- PSG 1 Acc. Camp Construction for Trans Anatolian Natural Gas Pipeline (TANAP) LOT 4 | GEORGIA
- Integrated Workers Accommodations (IWAC) Construction in Umm Slal Plot 5 | QATAR
- Prefabricated Buildings, Civil and Infrastructure Works of ÖKSUT Gold Mine Project | TURKEY

- Jazan Refinery and Terminal Camp Construction | S. ARABIA
- Karaorman Camp Construction for Trans Anatolian Natural Gas Pipeline (TANAP) LOT 4 | TURKEY
- Adana Temporary Accommodation Camp Construction | TURKEY
- Camp Construction for South Caucasus Pipeline Exp. (SCPX) CSG1, CSG2 and Area 81| GEORGIA

Senior Planning and Project Control Engineer

May 2014 – Jun 2015

Prone Proje Kontrol ve BIM | TURKEY
Key Responsibilities:

- Develop and maintain baseline schedule for building and highway projects in P6 and TILOS.
- Preparing project progress reports for client and consultant and analyzing project performance.
- Preparing recovery plans and revising work schedules.
- Reviewing and revising subcontractors work schedule.

Main Projects:

- Mavi Bahce Shopping Mall, Izmir | TURKEY
- Gebze-Orhangazi-İzmir Highway Project | TURKEY
- Samsun - Kalin Railway Modernization Project | TURKEY

Project Manager / Client Representative

Jul 2006 – Sep 2011

Urmia University | IRAN

Key Responsibilities:

- Leading and managing of client's technical office team.
- Preparing technical and financial tender documents and reviewing proposals of tenderers.
- Preparing contractual documents and reviewing contract clauses.
- Supervising activities of contractors and consultants according to contractual scopes and clauses.
- Develop and maintain cost and work schedule and preparing projects progress reports for client.
- Analyzing project performance.
- Leading consultants and contractors to ensure client's needs and satisfaction.
- Controlling and approving of variation orders and managing claims in behalf of the client.
- Managing and controlling of payments to contractors and consultants.
- Preparing technical reports to assist client's decision-making process.
- Reviewing recovery plans and work schedules.

Main Building and Infrastructure Projects:

- Faculty of Engineering
- Faculty of Environmental and Natural Resources
- Faculty of Art
- Faculty of Economics and Business Administration
- Faculty of Literature and Human Sciences
- Faculty of Agriculture
- Central Cafeteria
- Dormitories
- Presidency Central Building

- Waste Water network and Treatment Plant
- In-site Roads and Walkways
- Science and Technology Park
- Gymnasiums and Open Sport Courts
- Indoor Olympic Swimming Pool and Facilities

Technical Office Engineer

Jun 2005 – Jul 2006

Urmia University | IRAN

CEO / Technical Director

Nov 2001 – May 2005

Haftsang Construction Co. | IRAN

EDUCATIONAL BACKGROUND

Master's degree in Construction Engineering and Management

2010 – 2012

Middle East Technical University | TURKEY

Bachelor's degree in Mechanical Engineering

1997 – 2002

Urmia University | IRAN

PROFESSIONAL MEMBERSHIPS

- Member of Project Management Institute, Turkey Chapter.
- Member of Iran Project Management Association (IPMA).
- Member of Iran Construction Engineering Organization.

HONORS AND AWARDS

- Project Management Excellence | Urmia University | IRAN 2009
- Excellent Engineering Performance of the year | Urmia University | IRAN 2008