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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

REINFORCEMENT WASTAGE AND MANAGEMENT SCHEME ON SELECTED APARTMENT BUILDING PROJECTS IN ADDIS ABABA

By

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Advisor

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of materials used for the thesis have been accordingly acknowledged.

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ABSTRACT

Cutting reinforcement bars from only one length of 12 meter to suit construction project requirements result in cutting losses. Major waste is encountered in huge projects such as housing apartments and high rise building projects during cutting of steel from standard lengths. The actual amount of wastage generated on-site exceeds the initial estimated amount which leads to the additional project cost. The loss of rebar can be minimized with proper planning and optimizing the procedure of bar cutting and fixing. To achieve this goal, the accurate and detailed information of rebar is extracted, followed by both a rapid and efficient bar combination. Therefore, reducing steel waste (or minimizing cutting losses) has long been the focus of academic research in one-dimensional stock design and cutting problems.

This thesis determines the amount of rebar wastage generated on-site by classifying potential sources of wastage and waste minimization practice applied on-site. This will be applied for the Army foundation apartment (Kality 1 and Kality 2) project with a total of 28 buildings. Methods used for data collection and analysis are interview, content analysis method, participatory observation and case study. The optimum cutting pattern was assessed using structural design and optimization software such as MaxCut and GoNest 1D. Secondary sources of data were collected from previous studies done on the subject and various works of literature. As the main source of data, direct site observation, and accurate measurement were done.

The findings of this research illustrate the direct sources of rebar wastage are cutting bar waste, un-optimized working procedure, rework, design change, and corrosion. Also, indirect sources of waste are ahead of time material delivery, management waste, and late deliveries. Rebar waste minimization implemented on-site are design modification, on-time deliveries, reusing cutoffs, establishing a kaizen team, and return leftover rebar to the client. Challenges in the site to enforce material management schemes are undefined scope on material waste, lack of communication between parties involved, lack of details in drawings, and improper storage of materials.

The recommendations given based on the obtained results are proper and detailed planning of material usage before beginning project work to reduce the amount of wastage. Planning also should include a map of storage, transportation, and cutting areas within the site. The construction industry is a fast-growing field therefore professionals involved in the industry must update themselves to current practices to avoid misusage of materials and reduce waste. Designers and consultants should develop a design that includes the most optimal dimensions and supervision is mandatory for waste minimization.

Keywords: Rebar optimization, Wastage percentage, Rebar waste reduction.

LIST OF ABBREVIATIONS

BIM - Building information modeling

DCE - Defense construction enterprise

EPA - Environmental protection agency

GFA- gross floor area

IS- Indian standard

KCMPF - Kality construction material production factory

MMC - Modern methods of construction

NACE - National association of corrosion engineers

Rebar - reinforcement bar

RC - reinforced concrete

RMC - ready mix concrete

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CHAPTER 1

INTRODUCTION

The material management system for a specific project includes identifying, acquiring, distributing and disposing of materials. Major expenditure in a concrete structure work consists of concrete, reinforcing steel and formwork. In Ethiopia, constructors often encounter a problem of a large number of lengths of reinforcing steels used in construction but there is only one length of 12-meter reinforcing steel produced in the market. Therefore, cutting steels from one length causes a large number of wastes of reinforcing steels. Hayat (2017) has found that the percentage of rebar waste in the reinforced concrete building located in Addis Ababa is 15-20%. Also, Eskedar (2016) reported the amount of rebar waste generated in Condominium projects to exceed 14%. However, for a construction project that has a very good optimization system, the percentage of waste of reinforcing steel was reduced to 3.9% in UAE building projects (Assem and Karima 2011).

Practical optimization is an art and science of allocating limited resources to the best potential outcome (Amponsah 2006). Optimization is a branch of mathematical programming that has enjoyed enormous appeal after World War II, both in academia and in practice (Wing 2009). Subsequently, these methods can be applied to solve cutting stock problems in certain materials such as reinforcement. For rebar optimization, the technology ranges from developing linear programming for simple problems to the most advanced software that gives results in less than a minute.

This thesis focuses on reinforcement bar wastage and management practice applied for on-site construction. For the case study, the Army foundation apartment project located in Addis Ababa, Kality was selected.

1.1 Rebar optimization

Reinforced concrete is the most commonly used structural material in engineering construction. Although concrete is tough in resisting compressive stress, it is weak in tension. Hence to withstand tensile stresses, steel is needed in concrete. Reinforcement in concrete may be straight or bent bars and tied to stirrups according to the structural drawing. The usual diameters of bars used at the site are Ø8, Ø10, Ø12, Ø14, Ø16 and Ø20 with a length of 12 m. Engineering drawing is a language to communicate with details. Therefore, there is a standard to indicate reinforcement in drawing such as 4Ø12 L=12000 which means 4 number of bars, 12 mm diameter, and length of 12 meters.

Most construction projects assign areas within the site for storing, cutting and bending of rebars. Reinforcement bars are cut into required lengths and bent into required shapes shown on the bar schedule either manually or through machinery. Bar bending detail should be prepared and submitted to bar benders for the cutting and bending procedure of rebar. Therefore, developing and submitting a rebar cutting pattern with the least amount of wastage while reaching demand is called optimization.

The optimization of rebar has a benefit to all stakeholders, since it provides a better estimation of rebar requirements for every structural member which can be used to compute the overall reinforcement requirement for the entire project. Optimizations of rebar cutting pattern results in the most optimal amount of rebar utilization, hence reduce cutoff waste. When the amount of cutoff waste is reduced in the site, it provides a clean workspace and requires less cost of transportation for the removal of those leftovers.

1.2 Background on Defense construction enterprise /DCE/

Defense construction enterprise was established in 2010 by the Ethiopian Ministry of Council regulation NO 185/2010 as a public enterprise and National Defense as supervising authority of the enterprise (Retrieved from http://www.dce-et.com). Before its establishment as an enterprise, it was structured as an engineering department under the Ministry of National

Defense responsible for the construction of the army hospitals, depot, camps, access roads, and other infrastructure activities owned by the Ministry of National Defense.

Defense construction enterprise (DCE) was one of the leading construction companies in Ethiopia. DCE has undertaken projects in remote and difficult areas of the country. The enterprise has been in the business of construction for more than two decades.

DCE has constructed governmental buildings, hotels, apartments, real estates, hospitals, engineering colleges, and other industrial buildings in various parts of the country. DCE has gained working experience for road construction, irrigation and dam construction projects in various parts of the country with different climate conditions.

1.2.1 Background of the site

The project selected for this thesis is the Army foundation apartment project located around Kality, Addis Ababa. The project is intended for army soldiers as a residential living facility. Although the writer has done its research on this selected site, the other 5 projects in different locations with relatively same standards are being constructed. The site farther divides into Kality 1 and Kality 2 with a total number of 28 buildings. The project consists of 1 and 2 bedroom buildings with G+9 floor height, 2 and 3 bedroom buildings with G+9 floor height, and 4 bedroom buildings with G+7 floor height. Data were collected from 15 buildings located in Kality 1 project and 13 buildings in Kality 2 projects. Progress of the buildings varies from ground level to the 5th floor by the beginning of the research. This helps the researcher to quantify the amount of waste produced as construction progresses. The motive for selecting this project site is the willingness of the project team to provide the information required for the research. In addition, since relatively similar projects are being repeated in other sites, information obtained from Kality site can help to improve site practice in other sites.

1.3 Problem Statement

The major endeavor for launching apartment projects is providing a conventional housing facility for residents with minimum acceptable prices. However, a large amount of wastage and improper management of materials result in price escalation of the houses. Most researches are done on material wastage indicate that excess amount of rebar wastage is encountered in sites. Underestimation of material amount leads to dispute between stakeholders regarding material usage and an overall cost overrun. Un-optimized and inefficient working techniques in cutting, bending, and positioning of rebar can lead to large amount rebar wastage. Additional wastage is also encountered due to design changes and rework of structural members.

This thesis identifies the major sources of rebar waste and amount of rebar waste produced in army foundation apartment buildings. It also addresses overall material management practice and challenges that occur while implementing those material management practices in the site.

1.4 Objective of the study

General Objective

The general objective of this study is to identify major sources of rebar waste, quantify the amount of waste generated and recognize potential management schemes for Army foundation apartments.

Specific Objectives of the study are;

- to identify key sources of reinforcement material wastage on the selected project.
- to calculate the percentage of waste in the selected projects and evaluate the amount of waste.
- to assess management and waste minimizing schemes of rebar waste on the selected projects.
- to provide practical suggestions and recommendations to upgrade knowledge of minimizing and management of rebar wastage.

1.5 Brief Methodology

This thesis seeks to quantify the amount of rebar waste generated onsite to discover the potential of reducing such waste using proper optimization and efficient working procedure. The cross-sectional dimension of various sizes and quantities of each type of rebar per design (detailed structural drawing) was obtained from the Defense construction enterprise, the Army foundation apartment project site office engineering department.

Primary data for the study were obtained through direct personal interviews with professionals involved in the project and quantification was done through data analysis and direct measurement. To recognize potential sources of waste and quantification methods implemented, a review of literature such as textbooks, journals, and research papers was done as a secondary source of data. Finally, the findings of the study were analyzed, discussed and conclusions and recommendations were drawn.

1.6 Scope and Limitation of the Research

This research focuses and was limited to the Army foundation apartment projects, particularly Kality 1 and Kality 2 project sites with a total number of 28 buildings. During the time of conducting this research, the project progress varied from the ground floor up to the top tie beam which assists data collection in each phase. The interviews were conducted with direct professionals involved in the project specifically in rebar work. Numerical data were collected based on data obtained from the office engineering team and direct measurements.

1.7 Thesis Organization

Chapter 1 Introduction: This section provides background on the research topic for this study. The main idea of this chapter is to explain the background of the problem, the objectives, brief methodology, and scope of the study.

Chapter 2 Literature Review: This chapter provides information about construction waste and its effect on the construction industry. It discusses causes and sources of reinforcement bar waste, quantification of wastage amount and waste management practice in different countries. The literature review provides information on why this research is important.

Chapter 3 Methodology: describes in detail the methodology adopted in the research.

Chapter 4 Data collection and analysis: summaries the results of the research. It includes the views of the construction industry participants towards rebar wastage and constraints in implementing waste reduction management. Also, the actual amount of waste produced and management practices applied to the site are included in this chapter.

Chapter 5 Conclusions and recommendations: Provide conclusions and recommendations of the research. It summarizes the main issue of this research and it provides an overview of the main findings. It also recommends suggestions based on the findings of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of construction material waste

Different scholars and writers have defined construction material waste in different ways. Formoso et al. (1999) defined waste as any losses produced by activities that generate direct or indirect costs but does not add any value to the product. Another definition by Ajayi (2008) was "construction material waste is the by-product generated and removed from construction, demolition and renovation workplaces or sites of building and engineering structure". Napier (2008) defined construction material wastes as "waste materials generated by construction activities, such as damaged or spoiled materials, temporary and expendable construction materials that are not included in the finished project, packaging material and waste generated by the workforce". Kim et al. (2004) define construction waste "the difference between materials ordered and those placed for fixing on building projects". Construction wastes can also be defined as "any material, apart from earth materials, which needs to be transported elsewhere from the construction site or used within the construction site itself for landfilling, incineration, recycling, reusing or composting, other than the intended specific purpose of the project due to material damage, excess amount, non-use, or non-compliance with specifications or being a by-product of the construction process." (Wing 2009).

On the above-given definitions, researchers explain material wastes as materials meant to be incorporated into a building or engineering construction work but due to mishandling, damage, or excess misapplication it becomes unfit for the intended purpose. Another type of waste from the definitions is waste that is inevitable even after all considerations since it will be required as a temporary structure or remains as a trim loss. Material wastes most times lead to unexpected expenses and additional costs.

2.2 Overview of building material wastage and its implications on the construction industry

The wastage of construction materials in building projects has led to a loss of savings for many building clients and loss of profits for contractors (Ugochukwu et al. 2017). Thus, managing wastes on a construction site is a vital component of a sustainable building project.

Due to its fast increment, construction and demolition waste had become one of the major environmental problems (Kibert 1994; Ferguson et al. 1995; Graham and Smithers 1996; Guthrie et al. 1999; Symonds 1999; Poon et al, 2004). Developed countries such as the USA (Kibert 2008), Australia (Crowther 2000), China (Hao et al. 2008), Norway (Myhre 2000), etc. had launched a waste management system, policies and applied an advanced technologies in construction which reduced construction waste numerously during the last two decades.

According to Ugochukwu et al. (2017), developing countries like Nigeria lack reliable and sufficient data regarding solid waste management system. Cities in developing countries are characterized by inadequate and inaccurate data on their waste situation due to a shortage of skilled personnel, priorities to be solved, lack of interest by the local authorities and alike (Wing 2009; Ugochukwu et al. 2017).

A huge amount of waste generated due to the construction process and its environmental impact attract the attention of many researchers and professionals toward the minimization process. Many researches are done on the field assist to improve the overall construction process in developed countries. Developing countries still fabricate a vast amount of waste, although there is a small amount of improvement (Wing 2009).

Hong Kong Polytechnic and Hong Kong Construction Association Ltd in 1993 researched construction waste aiming to reduce the generation of waste at source and to propose alternative methods for the treatment of construction waste to reduce demand for final disposal areas (Wing 2009).

In 2016, 61% of the total solid waste generated was from the construction, demolition, and excavation industries in the UK (Burton 2019). However, the UK Government stated that from a total of 66.2 million tons of construction and demolition waste produced, it managed to recover 60.2 million tons which is about 91% of recovery rate (Burton 2019). This implies that despite the UK's high output of waste from construction and demolition activities, it was achievable to incorporate reuse and recycling processes.

In 1998, the U.S. Environmental protection agency (EPA) estimated that 136 million tons of building-related waste was generated in the U.S. annually. A 2003 update of the report showed an increase to 164,000 million tons annually of which 9% was construction waste, 38% was renovation waste and 53% is demolition waste (Napier 2008). EPA (2017) reports 569 million tons of construction and demolition waste was generated, which was more than twice of the amount generated in municipal solid waste. The report states that there is an incentive for recycling. However, the actual amount of recycled waste is not stated (EPA 2017).

In Brazil, several studies on construction material waste had been done. Pinto and Agopayan (1994) reported that indirect waste (materials unnecessarily incorporated in a building) can be higher than direct waste (rubbish that should be disposed-off in other areas) based on one site study. The research project on construction waste developed at the Federal University of Rio Grande Sul (UFRGS) started in April 1992 had the main objective of analyzing the main causes of material waste in the building industry to propose guidelines for controlling it in small-sized firms (Formoso et al. 1999).

A much more ambitious research project carried out by Agopyan (1998) for the Brazilian construction industry was a two-year study, coordinated by Brazilian Institute for Technology and Quality in Construction (ITQC), involving 15 universities and more than one hundred building sites. Data of eighteen construction materials were collected to measure wastage amount. Agopyan (1998) reported waste of building materials is far elevated than nominal figures assumed by companies in their cost estimation. Also, the amount of material wastage varies from site to site for the same material. Agopyan (1998) stated some companies were not concerned about material waste since they did not apply relatively simple procedures to avoid waste on-site. None of them had a well-defined material management policy or systematic control of material used which is another important cause of waste. Before the development of this study, most firms were not aware of how much waste was produced. He concludes that the major cause of waste is related to a defect in the management system rather than a lack of qualification and motivation of workers (Agopyan 1998).

Waste is usually the result of a combination of factors, rather than an isolated incident. Many studies done on the field of construction waste highlight the significance of waste minimization and management system adopted on-site. The studies also reported that most sites had difficulties implementing suggested management systems. Wing (2009) reported in most studies, the amount of waste of materials is quantified as a single entity related to the conversion model, in which material losses are considered to be synonymous. This method makes quantification less practical. Also, data collection is usually tedious, expensive, involving a large team of researchers, including people who are deeply involved in observing the work of the site (Wing 2009). Another drawback of such studies is that waste is observed after the production of the waste (Siti and Wan 2013). Therefore, measures and suggestions listed on the study will be less practical for the studied sites. However, for repetitive projects, measures can easily be adapted and can be effective. Another study by Wan (2011) reported that since most waste control systems are external, the company's involvement in data collection and study is relatively small. As a result, the learning process in companies makes suggested measures less effective.

According to Napier (2008), construction wastes and demolition debris (C&D) generates a sequence of adverse effects that are not always obvious to building professionals. These effects include loss of useful property, greenhouse gas generation, and environmental impact associated with the production of new materials instead of using existing materials. From the foregoing, it is obvious that wastes are not to be encouraged in projects in any way. To eliminate this trend from the industry, it is relevant to identify the root causes of waste on sites that are linked to the type or category of waste.

2.3 Waste generation and quantification in different countries

Many research studies have been carried out to quantify waste, identify its source and negative impact on projects, and the environment. Investigations of waste are believed to be started in the United Kingdom in the year 1963 during the highlighting of new forms of tender documentation (Skoyles and Skoyles 1987). A considerable difference between the standard used by contractors and actual waste generated on-site was discovered during the research. In Brazil, the quantity of construction and demolition waste accounts for between 15 to 30% of total solid waste (Bossink et al. 1996) that fairly is similar to outcomes of other studies carried out in other countries- Netherlands, Germany, Australia, UK, China, etc. In Brazil, Pinto and Agopayan (1994) revealed that the total waste generated on-site accounts for 18% of the total weight of all materials purchased, representing an additional cost of 6% overall project cost based on one site study. Hamassaki and Neto (1994) reported that 25% of construction materials were wasted during construction operations and activities in Japan. Some studies done in Hong Kong indicated a waste index for various projects - Private housing: 0.250 m^3 per m^2 GFA; Public housing: 0.175 m^3 per m^2 GFA; Office building: 0.200 m^3 per m^2 GFA (where GFA is gross floor area) (Wing 2009).

Patel (2011) in his research revealed that 1.2-6.5% of the additional project cost is encountered due to material loss in mass housing projects located in Mumbai, India, and 5-10% of the total project material end-up as wastage in construction sites. He shows that 5.8 million m^3 of waste was produced annually in Mumbai, India due to construction waste generated from the demolition of buildings, testing labs, and ready-mix concrete (RMC) plants, and excavation of road footpaths (Patel 2011). Another study in India by Ajayi (2008) reported that the cost of material waste varies between 5-15% of the total construction cost.

Studies carried out in Malaysia by Chen and Chang (2000) showed that a significant portion of wastes in landfills came from activities such as demolition and construction. The breakdown of waste generated in Hong Kong is shown in Figure 2.1. Private housing waste showed the highest rate due to non-standardized elements, variation in the design and changes in the specifications (Neto 1994). This is also similar to many findings of researches that are done in developing countries like Ethiopia (Mulualem et al. 2012; Asmera 2015; Eskedar 2016; Hayat 2017; Garba et al. 2016; Tariku 2018; Ugochukwu et al. 2017).

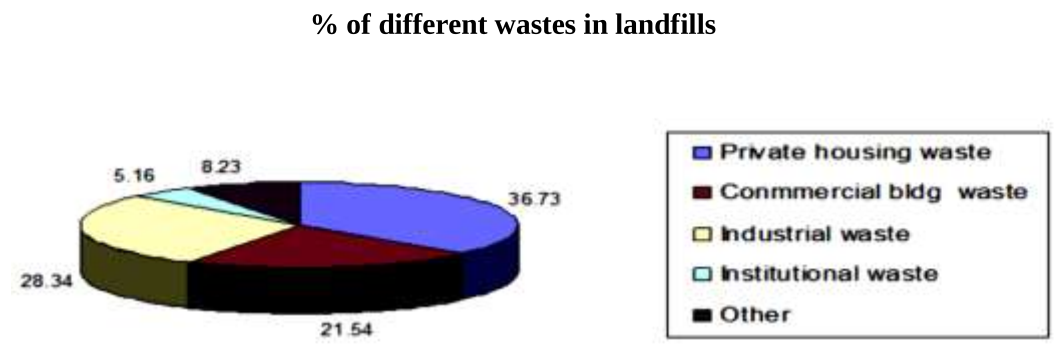

Figure 2.1: Levels of wastage in different types of projects in Hong Kong (Neto, 1994)

The study conducted in Nigeria by Garba et al. (2016) shows that the major source of waste was a last-minute change in client requirements that leads to design variation and construction material change. Also, other factors that contribute to waste are poor workmanship, setting-out, order not meeting specifications, excessive use of materials, and breakage in handling materials, improper storage, and misdemeanor. Such kind of waste typically accounts for 15-30% of urban waste (Garba et al. 2016).

2.4 Classification of reinforcement bar wastage

In addition to the general understanding of waste, further classification will be helpful to have a better clear understanding of how to avoid and manage waste developed in the site. Regarding whatever control measure is taken, some range of waste is inevitable. Therefore, identifying which or how much quantity of waste is preventable can be essential. Formoso et al. (1999) classified waste as unavoidable and avoidable waste. Categorizations of the sources of rebar waste are listed below;

2.4.1 Unavoidable waste

Unavoidable waste is a waste generated even after all measures of avoiding and management practice is implemented. Mulualem et al. (2012) defined unavoidable waste as “material wastage in which the investment necessary to its reduction is higher than the economy produced.” This definition needs a detailed context as it may vary from material to material and particular site conditions associated with its level of technology. Source of unavoidable waste for reinforcement bar is;

A. **Cutting bar waste after optimized cutting:** - once the structural design is set and delivered to the site, cutting will be done according to the design specifications (Chinanuwatwong 2000). Most of the time reinforcement bars are arranged in their structural member and cut accordingly. Optimization is the arrangement of this cutting pattern in a way to produce the least amount of wastage (Garba et al. 2016). Therefore, unavoidable cutting waste is a waste that remains on the site even after optimal cutting pattern is applied.

2.4.2 Avoidable waste

Avoidable waste refers to a waste that is produced due to a lack of management (Mulualem et al. 2012). Researches done in Japan, Nigeria and Ethiopia indicate that most of the construction wastes are a result of such an unorganized working procedure (Eskedar 2016; Garba et al. 2016; Hayat 2017; Wan 2011). Avoidable waste was further classified into direct and indirect waste (Formoso et al. 1999). Direct waste is related to waste produced directly related to the work. Indirect waste is a waste produced not directly related to the work rather other external factors. Sources of direct waste include (Formoso et al. 1999);

A. **Un-optimized working procedure**: - this refers to cutting of bar in a random and manual pattern (Tariku 2018). This refers to the non-optimized cutting of 12 m long bars as supplied. This can lead to a left over pieces that are greater than 1 m which could be un-economical (Tariku 2018).

B. **Rework**: - this term refers to an overdoing of a work after it is completed. For RC construction reasons for rework are failed concrete and formwork. Besides the economic disadvantage, such cases also discourage engineers and workers (Asmera 2015).

C. **Design change**: - such a problem is mostly encountered in public projects due to the information gap between a client and contractor (Asmera 2015). Possibilities of miscommunication between the design consultants cause miss out in design (Eskedar 2016). Changes of the design made by client and the designer while construction period may cause the previous work done have to be aborted and also resulted huge of material wastage. (Wan 2011).

D. **Production of defective materials**: - sample material tests must be conducted before selected materials reach the project site. It has to be done involving all parties that include supplier, purchaser and engineer of the site (Mulualem et al. 2012).

E. **Corrosion**: - is one of the major problems encountered in steel bars. Therefore, it is further explained in section 2.6.

An indirect source of waste include; (Formoso et al. 1999);

A. **Inventories:** - inventories are associated with an excess or shortage of material supply system that will affect the performance of the project. Excess stock of rebar leads to extended idle time which will result in corrosion. It also results in deterioration, inadequate stock conditions on-site, robbery and vandalism. Shortage in supply will lead to waiting for stock that may extend project time.

B. **Transportation**: - transportation source of waste is concerned with the movement of material from the supplying chain to the site and from storage to working space. Depending on the material, proper care must be implemented to avoid damage. Concerns usually arise when there are poor site layouts and a lack of planning for material flows. It additionally results in a waste of energy, unnecessary manpower, and storage space waste.

C. **Management waste: -** incorrect decisions, poor organization, and lack of supervision rest in this category.

D. **Criminal waste: -** robbery, theft, and vandalism.

E. **Learning waste: -** learning waste usually produced when there is unskilled labor for the specific tasks given or when there is new technology implemented.

2.5 Reasons for loss of rebar at different stages of construction

Loss of rebar can occur at different stages or phases of construction. According to Kim et al. (2004) during the pre-construction waste rate can be estimated as high as 3 to 5% in the material ordering phase. The study shows that the highest rate of waste is observed when the purchase order with redundancy is made to steel without an accurate understanding of manufacturing information, such as structural drawings and bar schedules. Wastage of construction materials increases as the construction phase progresses. Therefore, before ordering, analysis of the amount of material required for the project has to be reflected (Kim et al. 2004).

Another important source of material waste is when rebar with a length of 2-3 m is not reused after cutoffs (Kim and Kim 1987). In the design process, using standard dimensions can reduce material waste by 7% (Baldwin et al. 2007). In some cases, the length and location of bar splice in the construction work might not match codes and specifications (Ugochukwu et al. 2017). Such cases mostly occur when there is no satisfactory quality control system. Therefore, it needs to be monitored as it relates to quality reduction rather than waste minimization. Also, it provides an open platform for embezzlement (Ugochukwu et al. 2017).

The inefficiency of inventory management is one of the frequent causes of waste of rebar (Ugochukwu et al. 2017). This type of waste is observed in urgent and large-scale construction projects.

Inappropriate management of rebar shops and layout of cutting and bending machines was another source of waste of rebar for sites that use machines for cutting rebar (Wing 2009). The quality of labor provided by the subcontractor can significantly influence the waste rate (Wan 2011).

Site investigation shows that waste of rebar decreases if optimal rebar combination and systematic inventory management are probably carried out from the ordering phase to the manufacturing phase. The optimum combination of rebar cutting pattern, calculated by computer software, provides very useful information for the manufacturing of rebar as well as systematic inventory management that reduces waste rate (Kim et al. 2004).

2.6 Corrosion

Corrosion has a huge negative impact on the structural integrity of buildings, bridges, and other structures that use reinforcement. Damage caused by corrosion can be expensive for public and private project owners (Lewis 2012). National association of corrosion engineers NACE (2002) reported that the annual cost of corrosion in the United States was 276 billion dollars (NACE 2002). The estimated cost for maintenance of concrete bridges alone was 4 billion dollars. This costs only show direct expenses, indirect costs such as lost productivity, increased time travel, etc were estimated to be ten times as much (NACE 2002).

Corrosion is a process through which metals in manufactured states return to their natural oxidation states. This process is a reduction-oxidation reaction which the metal is being oxidized by its surroundings, often the oxygen in air. Other process of corrosion is by chlorine infiltration in the reinforcement bar which is not common in Ethiopia. To prevent this process two mechanisms are used. The first one relates to before casting of the concrete by providing a physical barrier to prevent rebar from coming in contact with the external environment. This includes materials such as water, salt, or any other damaging ions reaching the surface of the rebar. This is an easy process if the site material management reduces the idle time of the rebar before casting. Once the process starts it gets harder to know the right amount of damage done. The second mechanism includes providing an alkaline environment of the concrete with a PH value of 11 to 12.5. This relates to the material quality of concrete components such as cement, sand, and water. If each item is clean from acidic ions the steel does not corrode actively but rather form a protective passive layer (Lewis 2012).

Understanding the very basic bond between concrete and rebar assists in why preventing corrosion is important. The strength of reinforced concrete is dependent on the bond between concrete and steel reinforcement. Since concrete is weak in tension compared to compression, steel is used as reinforcement. Therefore, this composite action is possible if the bond between concrete and rebar is sealed and corrosion affects this bond strength (Lewis 2012).

2.7 Relationship between material waste and construction cost overrun

Construction waste can also be classified into two, which are physical waste and nonphysical waste depending on the nature of the waste (Nagapan et al. 2012). Physical construction wastes are wastes from construction, renovation activities, including civil and building construction, demolition activities, and roadwork. However, sometimes such waste is referred to as solid waste which is an inert waste which comprises mainly sand, bricks, blocks, steel, concrete debris, tiles, bamboo, plastics, glass, wood, paper, and other organic materials (Salem et al. 2007). Such type of waste consists of a complete loss of materials because it is irreparably damaged or simply lost. Therefore, such wastage is usually removed from the site to landfills and dumping areas (Nagapan et al. 2012).

Non-physical waste normally occurs during the construction process depending on the execution of work. As the name implies non-physical waste relates to time and cost overruns for a construction project (Nagapan et al. 2012). Figure 2.2 shows the general classification of construction waste. It further describes that there is a relationship between material waste originating from physical waste and cost overrun from the non-physical waste. Waste is not only associated with wastage of construction materials. it is also related to other indirect activities such as repair, waiting time and delays. Also, waste can be considered as any activity that results in the use of equipment, materials, labor, and money inefficiently during the construction process. In other words, waste in construction is not only focused on the number of materials on-site, but also overproduction, waiting time, material handling, inventories, and unnecessary movement of workers (Nagapan et al. 2012).

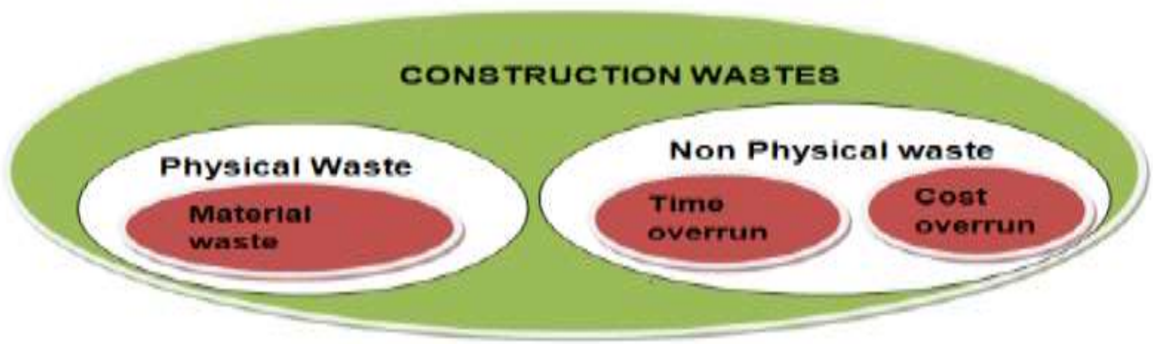

Figure 2.2: source of construction waste (Nagapan et al. 2012)

Non-physical waste includes undesired activities, which can cause physical waste, such as rework, unnecessary material movements, un-optimized working procedures, lack of management, and so forth. In Ethiopia, cost overrun was also noticed in projects such as condominium projects and private real-estates. Research papers were done on 40/60 and 20/80 condominium projects and private buildings illustrates that a high rate of waste is encountered which is one of the major factors for project cost overrun (Mulualem et al. 2012; Asmera 2015; Eskedar 2016; Hayat 2017).

2.8 Reinforcement material management on project sites

Efficient material management ensures productive and cost-efficient work on the site. According to some researches, construction materials and equipment may account for 50% and more of the total project cost (Garba et al. 2016; Wing 2009; Asmera 2015). Therefore, proper management of one of those components such as materials can improve overall productivity, cost efficiency, and timely completion of the project.

Material management refers to the process of planning, executing, evaluate requirements, sourcing, purchasing, transporting, storing, and controlling materials, minimizing the wastage, and optimizing the profitability by reducing the cost of material (Garba et al. 2016). Its main goal is to ensure that construction materials are available at their point of use and removed when no longer needed. It also deals with material quality selection, purchasing, deliveries, and handling on-site in time and reasonable cost. Since material accounts for most of the project expenses, material management plays an important role in overall project management. Poor management of materials results in construction cost overrun and delay in time which is a major dispute among stakeholders in the construction industry (Saidu and Shakantu 2016). Any material that arrives too early before it is needed time has a chance of deterioration, being stolen, and taking up too much storage space. This is especially true for materials such as reinforcement bar and cement that require extra care for storage and require large storage space. Material that arrives late than planned will result in a schedule delay.

Rebar waste has to be recorded and measured compared to users to manage the project overall cost. The processes of material management include (Agyekum 2012);

- **Planning**: - Planning refers to the leveling of work tasks on time. It put tasks to be done in sub sequential manner so that it gives a highlight on what to do next, which material to order, attention to be given and resource allocation.

- **Purchasing**: - depending on the plan, bidding for material vendors proceeds. This has to be done before the planned time of execution of work so that there will not be any waiting time or to return if the delivered material is found to be under standard quality.

- **Receiving:** - material ordered has to be notified to store workers and purchasers before receiving the material. Such a process will assist the workers to prepare proper storage space, arrange appropriate documents, to have an overall knowledge about the material they should receive and the quality should monitor.

- **Inventory control**: - inventory control is simply the process of controlling materials that are used and remaining in the store. This will conclude material management in many projects. However, researches done suggest proper material management should also include recording and counting of materials wasted to understand how it can be minimized for the future (Wan 2011; Garba et al. 2016; Asmera 2015). Rebar is most likely the easiest to count and record wastage amount if proper attention is given.

Some of the challenges faced on material management according to research done by Patel (2011) are;

- Undefined scope (No good definition of what is wanted)
- Lack of communication between parties involved
- Incomplete drawing
- Lack of conformance to requirements (lack of a list of material quality needed)
- Non-standard specifications
- Incomplete/ineffective meetings
- Difference between plans and specifications
- Lack of qualified bidders
- Late deliveries
- Poor storage and lack of storage space
- Theft
- Deliveries of incorrect material type, size, and quality
- Poor inventory management, etc.

For efficient and effective management of materials, a performance measure must be done. Figure 2.3 shows the process of performance measure for effective material management. Performance measure relates to computing competence of material management (Agyekum 2012). For example, during the planning phase if it is assumed that an ordered material will be delivered in three days but if it arrives in five days performance measure has to be done to improve delivery service (Agyekum 2012).

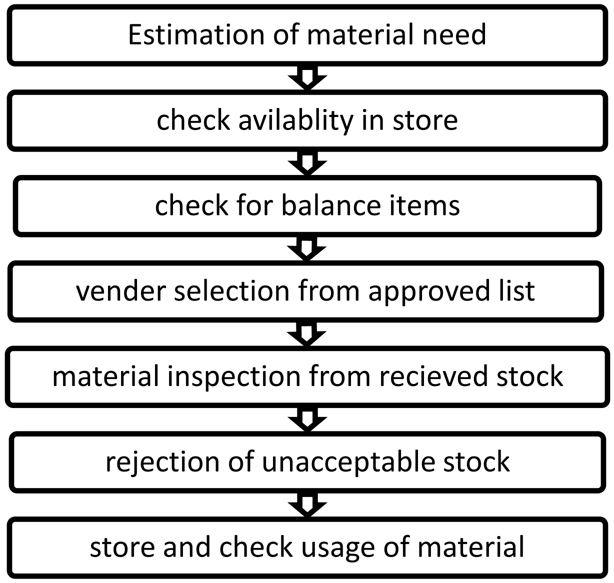

Figure 2.3: The process performance measure of material management (Agyekum 2012)

2.9. Waste minimization at different phases of construction

The economic and environmental benefits to be gained from waste minimization and recycling are enormous (Guthrie at al. 1999). It benefits the construction firms in terms of cost reduction and increased profit. Implementing a construction waste management (CWM) system will reduce production costs increasing the contractor’s competitiveness and a better public image. Completing a project in or before the scheduled time is the topmost priority of all the contractors. Hence their efforts automatically get diverted to time factors rather than the prevention of negative impacts of the project on the surrounding environment (Wan 2011).

Wastage may also lead to delays that cause idle time for other resources leading to loss of productivity (Agyekum 2012). By appreciating the principles of handling and using materials onsite, attitudes to prevent waste can be developed and the construction process can be managed more efficiently (Burton 2019). To be able to reduce the amount of construction waste, it is essential to identify the main causes of its generation. Abdul-Rahman et al. (1993) captured the costs of construction waste during the construction project and suggested that its reduction would improve profit margin, competitiveness, and client satisfaction. A considerable amount of waste that is common on many projects suggests that there are systems, structures, and processes that are leading to the generation of wastes. It shall be understood that the prevention of construction waste is preferable to recycling at the end of the pipeline (Burton 2019).

Waste minimization provides financial benefits in terms of reduced transportation cost, less disposal cost, minimized purchase quantity and price of raw materials, the reduced purchase price of new materials when considering reuse and recycling, increased returns achieved by selling waste materials, etc (Tadesse 2016). The net benefit of reusing and recycling of waste materials is estimated at 2.5% of the total project budget (Begum 2005). Environmental benefits consist of minimized amounts of waste disposed of at landfills, which therefore extend the lifespan of landfills, reduced environmental effects as a result of the disposal, e.g. noise, pollution, and decreasing global warming. Other benefits include increased site safety, enhanced work efficiency, and productivity, and improved image of the company (Agyekum 2012).

Many literatures suggest different types of management mechanisms (Kibert and Chini 2000; Ferguson et al. 1995; Crittenden and Kolaczkowski 1995; Faniran and Caban 1998 cited by wing 2009). This is due to the management system vary from site to site and project to project. Also, the type of material has a great impact on its management system. Therefore, among alternatives in New Zealand Waitakere city council sustainable home guideline defines and recommended means of how to minimize material waste as follows (NZWCC 2002);

“Waste minimization is about commonsense and a change of attitude, rather than new technologies.” (Mulualem et al. 2012)

Most of the rebar waste is avoidable. Although, technology has a huge impact on avoiding waste, stakeholders’ consideration towards preventing waste have a bigger impact. Waste reduction is a process that needs its policy and management system (Mulualem et al. 2012). As the project progresses, it needs proper supervision and removal mechanisms. In other words, for a huge project, it is an investment. Also, depending on the material different mechanisms have to be implemented. The cost of waste is the summation of cost of original raw material, plus labor time wasted on it plus disposal cost (Mulualem et al. 2012). Future reuse of the material, the flexibility of the design and new construction ideas also influence waste production and environmental impact (Agyekum 2012). For the reinforcement bar, waste minimization technique can be implemented in different phases of the project. Considerations for the pre-designing phase, the design, and construction phase are discussed below (Waitakere City Council's Sustainable Home Guidelines, New Zeland);

2.9.1 Pre- designing

Before the actual design process begins proper assessment and feasibility study will be conducted in most projects. Such a feasibility study most times includes serviceability, return value, location of the site, etc. Poon et al. (2007) stated 10% of construction waste in Hong Kong was generated from the cutting of building materials. The alternative for conventional work procedures has to be revised to produce resource-efficient building structures. Also, once the project starts design changes have to be the last alternative due to its cost and redundant waste production (Ajayi 2008). Some components of the pre-design phase are discussed below;

A. The functionality of the building

The functionality of the building refers to a detailed study of the people who will live in the building once it is completed. How many apartments in a single floor, how many rooms in an apartment, what should be included in an apartment, what would be the size of the rooms, is it luxury or standard, etc. each component in the building will assist on what type of cost minimization techniques can be implemented and avoiding unnecessary avoidable wastes.

B. Picture the building in years

Technologies used in the construction industry are in continuous updates. Therefore, buildings become old-fashioned before reaching their actual serviceable age. The idea of using the latest technology in any construction might be a bit expensive compared to using conventional methods especially in developing countries where innovation and technological ideas are not easily accessible (Ofori 2019). However, it might worth it if the building reaches its full intended serviceable life computing with upcoming technologies. In addition, most technologies focus on reducing project money, time and waste (Chinanuwatwong 2000).

C. Discuss with the project team

Involving all project teams before design assists the design process to form a common understanding among owner, architect/designer, contractor and sub-contractors. Such a working procedure also helps to solve the problem encountered by all parties.

D. Research

Research is an important element to determine the latest practice and materials which may reduce waste and increment profit. Talking to professionals, reading books and the internet are the major tools for this section. After a detailed study of options, it is much simpler to make an informed decision.

Source: (Waitakere City Council's Sustainable Home Guidelines, New Zealand)

2.9.2. Design phase

After the pre-design stage is completed, it is followed by the design phase. In the pre-design stage, complete knowledge of the building is assumed to be known. All parties are aware and included their need within the design. Therefore, some components in the design phase are listed below (Baldwin et al. 2007);

A. Design buildings in an optimized manner

In the design phase, rebar can easily be optimized to produce less waste if appropriate consideration is given by the designer. Some issues to consider are (Mulualem et al. 2012): -

- The dimension of structures must correspond with the available market length to reduce cutting loss
- Develop a framing layout to avoid waste and cost
- Include all the clients' interest within the design to avoid redesign work

- Ensure quality of material within the design to avoid failure
- Site layout must also be included in the design phase to reduce unnecessary time and effort wasted to transport materials within the site and remove waste
- If possible include cut pieces to be used for other parts

It is not always easy to avoid waste in design. This is because mechanisms to reduce waste might be expensive than the cost to remove the waste (Garba et al. 2016). It is a designer’s responsibility to present, compare, and select the most optimized procedure to design feasible, efficient, and optimized buildings.

B. Consider standardization for size determination in design

Considering the standard size for room size selection will assist the optimization procedure. Most developed countries including New-Zealand most rooms are aligned with material market length to reduce a cutting loss (waste). In Ethiopia, such standardization is still not available (Eskedar 2016).

C. Use pre-fabricated and pre-cut components

The use of pre-fabricated elements for repetitive structures is much more efficient than onsite production since it reduce the requirement for temporary structures (Wing 2009). Since pre-fabricated elements are produced in factory, onsite waste can be minimized to zero (Wing 2009).

D. Less is more

This concept is true for cost-efficient projects such as condominiums and housing apartments. Design for simplicity, user-friendliness, and low-technology solutions (Mulualem et al. 2012).

E. Plan and consult systematically

This is related to taking time to plan, consulting the design team and finding alternatives for less material usage to reduce waste. A waste estimation has to be done during the design phase to plan for a waste management scheme (Wan 2011). Avoidable waste must be avoided and room for material usage improvement has to be left. This means recycling and reusing have to come as an option. The quality of material to be used has to be stated clearly in a design so as to avoid ambiguity between supplier and purchaser.

F. Documentation of design

The design will be documented and submitted to the contractor. However, additional components have to be included to optimize the working procedures including site layout and waste minimization systems (Siti and Wan 2013).

G. Design for future

Architects and Designer have to think ahead of time in the design procedure. This means the types of materials, amount of materials and the construction procedure has to be done considering ahead of time to reduce redoing of work and demolition activities. A building has to complete its service time with competitive durability and serviceability (Mulualem et al. 2012).

H. Design for green living

This topic relates to the above subchapter design for the future. This stands for constructing eco-friendly options to increase the value of the building and avoiding future complications rising due to emerging of new technologies.

2.9.3. Construction phase

Most of the avoidable waste is developed at construction phase (Foromso 1999). Experience and consideration given towards waste management schemes have an impact on the overall amount of waste production. According to Garba et al. (2016), construction sites in developing countries such as Nigeria are a good example of unorganized, waste-producing, and un-optimized working procedures. Many studies done in Ethiopia indicate there is room for development and lots of work has to be done to minimize cost, time, and waste (Mulualem et al. 2012; Asmera 2015; Eskedar 2016; Hayat 2017). Components of construction phases are further explained in the following sub-topics;

A. Building site layout

Construction site layout includes office location, store, cement store, rebar storage, and cutting space, sand dumping area, and any other material storage units that are vital to construction. This layout has to form a flow that results in the most optimized working procedure. Reduction in transportation time and theft of material can easily be avoided in this simple procedure. Also, material sitting time and transportation costs can be decreased. An organized work environment will create a good image for the contractor and it will also provide a safe work atmosphere for employees (Agyekum 2012).

B. Isolated cutting areas

If possible, isolated cutting areas should be provided on-site. It will make it possible to access and reuse cut pieces. According to Mulualem et al. (2012), such a work procedure reduces waste by 15%.

C. Material order

Material order should be done before starting that phase of material usage. On the other hand, it should not be ordered in an excess manner to avoid sitting time. Such a factor is important especially for rebar since it can easily corrode if it is exposed to the atmosphere after a certain amount of time (NACE 2002). Also, if rebar is ordered after the start of formwork, it may delay schedule since it needs to be cut and bent according to design. Therefore, when to order and how much to purchase has to be a concerning matter. Also, the supply of material depends on suppliers' potential too (Garba et al. 2016).

D. Waste management strategy

For avoidable wastes and reusable items, a contractor should have a plan for a waste management scheme. Also, the actual amount of waste should not exceed the estimated amount of waste plus a tolerable percentage (Wing 2009). Dumping place and waste transportation mechanisms have to be recognized before waste production begins. If the client is responsible for supplying materials, waste amount must be estimated.

E. Documentation

Documentation in the site includes photos before, during, and after a project site. Efficiency reports, payment requests, letters, supervised work formats, a design change in site, and any relevant documents that justify the work of the contractor, consultant, and client. New practices implemented by the site, like additional waste management procedures have to be documented to share experience to other sites as a contractor and to develop a good image to other stakeholders.

F. Learn from previous works

The source of waste reported and minimization techniques implemented in other previous sites could be a good source of information to avoid past mistakes. Each project has its execution procedure. For repetitive projects taking lesson from previous sites provides an insight on how to improve overall efficiency and resource utilization. Also, design changes adopted will assist the next contractor to avoid such issues. Waste produced, amount of waste removal cost and management used has to be studied based on previous experience.

Source: (Waitakere City Council's Sustainable Home Guidelines, New Zealand)

2.10. Reduction of bar wastage in the design phase

Rebar waste can be generated at any phase of construction. It can even start before the beginning of construction due to storage and transportation (Salem et al. 2007). Generally, most of the rebar cutoff is produced at the cutting phase which is dependent mostly on the structural design. It accounts for more than 60% of the total scrap production in Korea (Kim et al. 2004). Therefore, the sustainable design of construction in the design phase presents an opportunity to significantly reduce cutting waste (Salem et al. 2007). If a suitable assessment is done in the design phase, it is possible to identify and quantify the amount and sort of rebar waste in the most optimized working procedure (Baldwin 2007).

The design phase also presents a prospect to approach a continuous effort within the industry to achieve objectives of sustainable construction to reduce the environmental impacts of construction in each working phase (Cochran et al. 2007). This directly relates to the reduction of waste using technology or alternatives within the work. One way used to develop the sustainable design of construction is through building information modeling (BIM). BIM is a tool that allows modeling by multi-disciplinary superimposed information within one model (Begum 2005). Such modeling systems are not implemented widely in developing countries such as Nigeria (Garba et al. 2016).

Modern methods of construction (MMC) mainly involve the fabrication of construction elements in factories. It has advantages of faster construction, fewer defects, saving energy and waste reduction. MMC has shown a dramatic waste reduction in the site and most common in European building construction (Bossink 1996). Although prefabrication elements are on a blooming phase, some building projects are implemented in Ethiopia (Hayat 2017). MMC includes the use of pre-cast (pre-fabricated) components passed through the manufacturing process, in various materials that are joined to form a part of a final installation (Chen and Chang 2000). A study done by Tam et al. (2007), suggested that modern methods of construction reduce 92% of the total rebar fixing waste of conventional methods of construction.

2.11. Options for reusing of reinforcement bar

In Ethiopia, reinforcing steel in many sites are collected and sent to scrap collecting factories where it is melted down and turned back into a new reinforcement bar or other steel materials (Asmera 2015). Also, some bars that are higher in lengths are collected and straightened manually and sold for lower prices for people with smaller projects. Reusing of rebar needs to be further studied to gain more benefits such as saving energy required for prefabricating steel bars as well as reducing CO_2 to save the environment (Agyekum 2012).

Steel is one of the construction materials that can easily be reused and recycled depending on the effectiveness of waste collection and storage (Wing 2009). Recycling of steel requires energy and it has a negative environmental impact (Wing 2009). Therefore, it is preferable if rebar is reused rather than recycled.

2.12. The economic effect of Rebar wastage

Managing and controlling of building construction material waste has a significant economic and environmental profit. Waste management practice has a benefit for all parties that involve in construction. Contractors can increase competitiveness by lowering production costs and imprinting a better public image (Agyekum 2012). Clients can adopt eco-friendly projects that both reduce overall project cost and sustainable building that is ecological and economical. Such moderations can be applied to reduce rebar wastage. By adopting optimal cutting patterns and avoiding misuse of reinforcement bar more than 5% of the total waste can be minimized (Poon et al. 2004). Despite those facts, many studies conducted including Lam (1997) cited in (Tam et al., 2007) has shown that only few construction parties spend effort in considering the environmental and economic implication of waste to developing new concepts of controlling waste generation. An overall advantage of waste reduction can appreciate over a short and long term practice throughout the whole building process by carrying out an analysis of project life cycle costs. According to poon et al. (2004), financial benefits associated with material wastage minimization include;

- reduction of the purchase quantity and price of raw materials
- reduction of transportation cost for wasted materials from site to site and disposal area
- reduction of disposal costs of waste materials
- reduction of the purchase price of new materials when reusing and recycling came as an option

- long term benefits through optimizing building life concept

Rebar wastage is one of the major construction waste generated in the site that can easily be avoided. For many reasons, construction industry participants require to have an insight into the financial consequences of construction waste. Significant savings could be generated by reducing the amount of construction waste. Financial profit can be a motivation for stakeholders in construction projects to put more effort into avoiding construction waste. According to Bossink et al. (1996), the costs of construction waste consist of purchase losses, collection expenses, transportation outlay, recycling costs, and dumping expenses. Therefore, if an approximate amount of waste is determined, it will defiantly drive attention towards stakeholders' to make an effort toward minimizing at least avoidable wastages.

The total expense of construction material waste for a project consists of the sum of purchase collection costs, transportation costs, recycling costs, dumping costs and any cost associated with the removal of waste per building. Bossink et al. (1996) studied cost incurred through waste generation in the construction industry and found that purchase losses constitute about two-third of the ultimate total costs in Amsterdam.

Damping fills and storage areas are difficult to find in city areas. Considering this, developed countries come up with different waste reduction approaches with almost zero waste. One of those methods includes the fabrication of rebar in factories that include bar listing fed to the machine and it will produce the exact amount of length and specified diameter (Tam et al. 2007). Such productions reduce waste amount, improve the quality of production and save time. However, such technologies are not adopted in Ethiopia; optimization of cutting patterns has a great implication. All rebar wastes are not inevitable; however, it can be reduced to an acceptable rate so that it can be added to the pricing level. By incorporating waste reduction techniques, achievable cost reduction can build interest among stakeholders. Plus, overall waste reduction mechanisms open ideas for innovations and technologies. Therefore, rebar waste management should be an important issue in developing countries where resources do not come easily (Siti and Wan 2013).

2.13. Review on reinforcement waste quantification

The amount of rebar waste should be estimated before the beginning of the construction project. If the source of the rebar waste being generated on construction sites are not recognized, the waste reduction management systems will be unable to accurately track, monitor, and quantify the total amount of wastes generated (Mulualem et al. 2012). Accurate waste quantification gives information about the effectiveness of production system performance. Quantity of rebar waste acts as an indicator to level rebar waste management practices as to whether poor, standard good, or best practices. It shows a room for improvement by identifying major sources of waste (Formoso et al. 1999).

Diverse methods have been implemented by researchers to quantify construction material waste. Different methodologies and systems have been employed in the estimation and assessment process of waste quantification. Among the first approaches implemented was the source of a waste framework which was based on the general flow pattern of construction material on site (Poon et al. 2004). It includes quantification of waste by sorting and weighing waste at the construction site. However, such a method has a drawback since partial records of waste were covered in inventory and static evaluation (Poon et al. 2004). Another method for waste quantification was conducted through site audits where regular site visits, checklist, and estimation on the disposal record were conducted to produce a construction waste index (Poon et al. 2004).

Different countries adopt different types of construction methods, work procedures, and construction practices which make it difficult to compare results of different sites (Poon et al. 2004). For example, some countries like Kuwait produced excess amounts of waste compared to other countries due to the Gulf war and lack of construction material management in the industry (Navon 2005). Most construction waste generated depends on the type of construction materials used and the method implemented to execute the work. Such conditions result in different amounts of waste in diverse site conditions since it involves different construction methods and technology, workers experience (skill) and building designs. Quantification of data is dependent on the type of structure, specific practice by the contractors, uniform standards used for disposal and storage of waste samples (Ugochukwu et al. 2013).

According to poon et al. (2004), there are two methods for tackling rebar waste by either quantification from its generation quantity or its disposed quantity. Generation quantity refers to quantity of waste generated at a construction site (Salem et al. 2007*)*. Disposed quantity refers to quantification of rebar waste based on records at the disposal site and waste flow system used by contractors. Nevertheless, Lack of readily available data on construction waste limits the quantification of rebar waste methods (poon et al. 2004).

Another method includes quantifying the amount of waste based on the floor area which is limited to the building structure and inapplicable for other structures such as bridges and roads (Hayat 2017). This technique of measurement needs modification according to the availability of data as the construction progress (Cochran et al. 2007). Such a method is valid for smaller-scale projects. The alternative for this method is the volume of construction waste generated for every $100m^2$ floor area and density of waste generated (ton/m^3) (Cochran et al. 2007). Quantification of waste in this method is estimated by measuring building area and building demolition works and converting construction and demolition waste computable data from cubic meters to tones.

The system dynamic approach is another method that was first introduced in 1958 by Forester found to be a well-accepted approach for evaluation of waste. Although this method was old (over 60 years) it is still applied by researchers such as Amponsan (2006) to quantify waste. A system dynamic approach focuses on creating models or representations of real-world methods and studying their dynamics. The system dynamic model assists to deal with the complexity of interrelationships and dynamics of any social, economic and managerial system. It integrates the main variables that affect construction and demolition waste reduction elements. Amponsan (2006) used this approach in a framework model for Newark urban region in the U.S.A and running a forecast simulation. He incorporates the complexity of waste generation and management processes in the dynamic system. As the construction progresses prediction of waste flow can be modeled through building elements at each construction stage (Amponsan, 2006). Since construction activities are dynamic, quantification of waste at every building element is necessary. Referencing the European waste list, the researcher employed a systematic structure on the construction process, waste classification system and analytical expression based on factors before waste sorting and weighing based on the list at every building element (Amponsan 2006). However, this approach is valid if there is a standard list of waste.

In Ethiopia, many research papers are done on amount of construction waste and ways to avoid it. Eskedar (2016) reported more than 25% of waste was produced on the site using stock balance in condominium projects. Also, Hayat (2017) reported more than 10% rebar waste generated in the site using Cochran et al. (2007) method of waste quantification which is kg/m^2 using floor area in three private buildings located in Addis Ababa.

2.14 Rebar Optimization

Rebar cutting problem is one of the typical one-dimensional cutting optimization problems which most manufacturing industries face (Salem et al. 2007). An algorism to reduce steel waste becomes an important factor since the price of steel is escalating and waste products on the site are directly related to cost overrun in projects (Kim et al. 2004). Reinforced bars are cut in different lengths based on structural drawings. Therefore, the algorithm should be able to select the best rebar cutting patterns with less cutoff waste to minimize cost and wastage. Since optimization is a combinatorial problem under many practical constraints, selecting an optimized cutting pattern is not an easy task. Applying optimization algorithms on computers is one of the most effective ways to solve those problems and has attracted the attention of scholars since World War II (Wing 2009).

Gilmore and Gomory (1993) introduced an ingenious column generation technique to generate the cutting patterns and solve for a 1D cutting stock optimization problem. Such method applies to small elements. Another method adopted to solve such a problem is linear programming which involves the process of setting equations and constraints. However, using linear programming to obtain relaxed non-integer solutions would normally depart from optimality, giving rise to unnecessary waste (Poonkodi 2016). Navon et al. (1995) introduced the benefits of computer-aided design and computer-aided manufacturing (CAD/CAM) systems for concrete reinforcement; they developed a model for rebar constructability diagnosis and correction in an object-oriented programming environment. Such methods are applicable when elements to be cut are small in number. Most of the time rebar structure involves a large number of elements that could not easily be solved using the above methods. Therefore, technology-based programs are being developed.

Currently, different software such as '1DcutX', 'cutting optimization pro', etc. are implemented by design engineers and project managers to optimize cutting operations for manufactures that cut a lot of linear materials. 'Cutting optimization pro' software reads data directly from Excel spreadsheets and instantly generates both a graphical layout and detailed cutting reports within the Excel workbook. The 'cutting optimization pro' software can reduce the usage of linear material by 20-40%, compared to manual cutting (Adapted from Optimization Software Ltd. Official website). In addition to minimizing raw material waste, it saves time, minimizes production cost, improves productivity, and provides engineers with accurate quotations in just a few seconds. Advanced software function with high performance, generate cost estimating reports, graphical layout (plan) of length cutting, waste/leftover stock order worksheet, and other features (Copied from Optimization Software Ltd. Official website).

2.15 Standard for permissible reinforcement wastage

The permissible amount of wastage varies from standard to standard. Even most projects set their permissible wastage amount to be included in the cost breakdown. As per IS 1786 code, the tolerance for rebar wastage due to bar cutting and bending is 3%. Allowable steel wastage according to IS 1200 Code is 1.5-3% and if reinforcement steel is provided by the client is 3-5%.

2.16 Construction waste in Ethiopia

The construction industry has a great undeniable contribution to the overall growth rate of Ethiopia. Within the last decade, Ethiopia has launched mega projects such as the Renaissance dam, light rail project, condominium housings, industry villages, highway projects, etc. Addis Ababa alone has gone through tremendous demolition activities and construction projects. Places that were once small villages are now blooming into large apartment areas and luxury hotels.

According to a study conducted by Eskedar (2016), the level of material waste in 40/60 condominium construction projects is fairly high in all the assessed construction materials. The additional cost of construction material waste leveled up to 10% of the original contract amount. Client material supplying in the construction of 40/60 condominiums has increased the generation of material waste. According to the majority of stakeholders, poor quality constriction materials are being provided by the client leading up to the excess amounts of waste (Eskedar 2016).

Another research done by Hayat (2017) reported more than 12.7% reinforcement bar wastage in 3 building projects. Major causes of waste according to the research are poor quality raw materials, rework, poor construction methodology, and unskilled manpower (Hayat 2017). Also, Mulualem et al. (2015) stated 15% rebar waste in Addis Ababa public projects with major sources of material wastage found to be design, material handling, and procurements. Other research by Asmera (2014) stated major causes of rebar wastage in construction sites are cutting, damages during storage and design change.

2.17 Literature summary

Due to fast increment in the industry, construction and demolition waste have become major problems in many countries considering environmental issues and shortage of waste dumping land areas. The amount of waste produced in the construction industry attracts the attention of many scholars to identify the source of waste, quantify the amount of waste, possible reduction mechanisms and to modernize the industry by technological innovations.

Many researches are done on the field indicates that the amount of waste produced in construction exceeds the nominal amount that is included in standards and contracts. The actual amount of waste had consequences of project cost overrun and delay in the schedule.

Currently, most developed countries can reduce rebar waste by using standard dimensions in the design phase and using a factory cutting system during production. However, many developing countries still produce large amount of rebar waste.

In Ethiopia, researches are done regarding construction waste and factors influencing waste production. Most researches are focused on identifying the perspective of professionals in the field using organized questionnaires. Some researches further studied the amount of waste produced, showing that it exceeds the amount assumed by professionals and included in standards.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter specifies the research methodology implemented. It covers the research methods, advantages and disadvantages of the research tools chosen for this study. The selected method will be checked for its ability to produce valid results, meeting aims and objectives set by this research. The sample size and sampling strategy applied by the author and the data analysis used will also be elaborated. Finally, it concludes with a brief clarification on ethical considerations and limitations set by research methodology, as well as problems encountered during the study.

3.2 Research methods

For this research, it was decided to use interviews, site investigation and case studies as research tools. The interview was conducted with main stakeholders to further explore knowledge on the subject. Then case study was conducted on the selected site. The advantage and disadvantages of each method are discussed below.

3.2.1 Interview

To cover more aspects of the research, structured interviews consisting of several questions were conducted among professionals directly involved in the rebar work. The interviews are often used as complementary research methods in applied science studies. Interviewing gives more in-depth open discussion and more informal free interaction between the interviewer and interviewee (Sarantakos 2002). Despite its disadvantage of producing subjective results, the flexible format of the interviews was a major advantage for this study, as some factors could not be found in literature review and previous researches are done on the subject. Because of the subjectivity of the data obtained, results from the interviews were not generalized.

The main purpose of the interview was to find additional factors and onsite cases resulting in wastes such as rework, design changes and their perspective on the subject. Seven interviews were conducted. Interviewees were a site engineer, construction engineer, rebar work sub-contractor, office engineer, bar bender, resident engineer and finally client representative. Each of the interviews lasted for approximately twenty minutes - one hour via face to face conversations. The interview was conducted in Amharic and English since those languages are the primary languages in the construction site. After each interview, the contents were summarized into text for further analysis.

3.2.2 Case study

A case study is an in-depth study of a specific research problem rather than a sweeping statistical analysis. A case study has been used with a view of providing a detailed account of events, relationships, experiences or processes occurring in that particular instance (Denscombe 1998). The disadvantage of a case study is a single or small number of cases offers little basis for establishing generalized findings. Also, a deep study of the case may bias a researcher's interpretation of the findings.

An analytical case study was conducted on two different sites located in Kality, Addis Ababa. Both sites have three types of residential buildings with a total number of 28 buildings. A field survey was conducted from November 2019 to March 2020. The case studies focused on rebar waste generation source, amount of waste generated, motivations and barriers behind the reduction of waste and management practices in the targeted construction site. It was used to illustrate the key issues and reasons on why so much rebar waste in the site is produced. The study recognized where further research is required and what future actions should be in place to promote waste minimization and improve waste management practice of construction firms so far.

3.2.3 Other methods

Both qualitative and quantitative data could be collected from primary and secondary sources. Some details might be overlooked or variables due to lack of evidence or unstructured manner of the data. Therefore, information was collected based on observations to learn facts. Thus, data were collected and certified either before or after physical observation and measurement was taken if possible. Photo images were also taken to evidence findings.

3.3 Sample strategy

The interviews were conducted to gather data that can be used to determine the perspectives of professionals within the construction industry towards reinforcement waste and management systems. Information gathered from interviews was analyzed to establish how further to investigate in the case study. It was decided a face to face interview was conducted with seven people who have a direct relationship to the subject. The interview questions were directed to the individual responsible for answering the questions. The interview took place over for two weeks.

Another sampling strategy for this study was an analytical case study that was similar to the concept of analytical survey (i.e. counting, association, and relationship) which is applicable in detailed cases. The writer had to examine two separate construction sites that have three types of housing apartments and a total number of 28 buildings.

The actual waste generated between each phase of rebar installation was estimated from the data collected. Basic data such as design and bar schedules were collected from the office engineering department. Further data were collected during the detailed site investigation during the case study. Other data and information required were further issued by the site construction department. Each site was directly observed for a total of 5 months. Actual material consumption starting from the design up to the placement of rebar to the top floor was studied.

The full transcripts of the interviews as well as data collected are attached in the appendices.

3.4 Data collection

The interview scripts for all participants consist of a brief and open questions. The questions for construction, office, site engineer, resident engineer and client representative were designed to discuss their knowledge regarding rebar waste generated and reduction management schemes followed. The questions for the bar bender and the sub-contractor was designed to reflect their experience as a performer and understanding in the field.

For the field study the following procedure was devised for systematic data collection;

- General description of the site: gross floor area, location, method of construction and relevant list of documents were provided by the company;
- Site analysis was done to identify potential sources of reinforcement waste and the amount of reinforcement waste generated due to each source of waste was measured until the end of structural work;
- Weighing of reinforcement waste was done after potential sources are identified. Waste was calculated from design, cutting phase, rework, design change and the amount estimated was summed up to give the total amount.
- The quantification used weight (kg). Also using a gross floor area (m^2) waste generation rate (kg/m^2) was calculated.

3.5 Data analysis

The first phase of analyzing data was data preparation, to convert raw data into something expressive and readable. Therefore, data collected was validated so that it will not raise any bias. Typically, large data sets include errors. To avoid such errors, basic data checks and raw research data edits were done to identify and clear out any data points that may affect the accuracy of results. Then, all data measured in meters (m) were converted to kilograms (kg) to set standard measuring units.

Most of the data for this study was delivered from direct field examination. Therefore, Calculation of waste generated according to each stage of construction will be performed by using the following equation (1),

$$W = Ms - Mu \quad \text{[Eq. 3.1]}$$

$$\% Ws = W/Ms*100 \quad \text{[Eq. 3.2]}$$

$$\%Wu = W/Mu*100 \quad \text{[Eq. 3.3]}$$

Where:

W = Waste generated

Ms = Material supplied

Mu = material used

Ws = percentage of waste over material supplied

Wu = percentage of waste over material used

Other calculation of generated waste is using gross floor area given in Equation [3.4];

$$C = \frac{W}{GFA} \quad \text{[Eq. 3.4]}$$

Where:

W = total waste generated given in kg

GFA = gross floor area

C = waste generation rate

i.e. construction of 1 m^2 gross floor area generates C kg of waste.

The actual waste generated on the selected project will be compared to the estimated amount of waste and the standard amount given in codes.

3.6 Ethical consideration

There are some types of ethical issues to take into consideration for such types of projects. The most important one was the informed consent of the participants. All of the participants were informed in advance about the purpose of this project and gave their informed consent to participate in giving information and data.

3.7 Problems and limitations

Major problems and challenges which were encountered while studying this project were;

1. The first challenge was selecting sites. During the beginning of this project, a 40/60 condominium project was selected. However, by the time data collection began most of the construction projects exceeded the structural construction level which made it difficult to obtain reliable data. Therefore, selecting a site that can fulfill the minimum requirement set by the writer was challenging. Also, the requests of the researcher were turned down by some contractors because most of the contractors rarely allow the opportunity for external research due to the misconception of data being used for other purposes.
2. The outbreak of coronavirus in the country restricted the research time limiting the final days of site visitation.
3. The software used for rebar cutting optimization is not easily accessible in Ethiopia. Even if available the pro versions cost around $147 which was unaffordable for the writer to obtain the official version. So, trial versions with limited time offers were used.

3.8 Conclusions

This chapter has outlined and justified the research methodology implemented in this research and its validity. The key research tools were case study and interview. And another tool used was site observation. The participants were carefully targeted by their direct relation to the selected case. The major results and findings of the thesis are discussed in the following chapter.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 Introduction

This chapter aims to discuss data collected and analyzed to achieve a result. As described in the Research methodology, two sites with three different types of residential buildings and a total number of 28 buildings are studied. By the time of finalizing this paper most of the buildings were near to completion of structural work. The rebar wastage amount at each phase was computed which includes the design phase (after optimizing the cutting pattern using a bar schedule for each building), un-optimized cutting procedure waste, re-work and design change. The optimal pattern of rebar cutting was developed using software such as 'GoNest 1D' and '1D cutting optimizer'.

4.2 Analysis of data gathered from interview

The main intention of this interview was to find the perspective of professionals who participate in rebar work that may contribute to rebar waste generation and management systems. The respondents of the interview were construction engineer, site engineer, resident engineer, client representative, office engineer, bar bender and rebar sub-contractor. All respondents have a minimum of four years of experience in the field.

Rebar waste on the site

All respondents agree that there was a rebar waste generated on-site.

Source of rebar wastage and avoidable/ non-avoidable waste

Most of the respondents agree that the major source of wastage was cutting waste that was developed in the cutting phase of the rebar. However, the client representative stated that the main source of rebar wastage might be the non-optimized working procedure implemented by the contractor. The construction engineer and site engineer specified that since structural design governs how rebar is cut and bend from standard length, cutting waste was an unavoidable waste. However, the resident engineer stated there was an attempt to follow the optimal cutting pattern developed manually. The optimal pattern was manually developed by office engineers by the initiation of the resident engineer. According to office engineer, since there were large sets of lengths in the structural design, developing optimal pattern manually was a tedious procedure and dependent on personal performance. Therefore, the manually developed optimal pattern was not implemented on site. According to bar bender and rebar work sub-contractor, the rebar detail required for cutting work was submitted by the site engineer and foreman that do not include optimized cutting patterns. So, cutting patterns were randomly selected by bar-benders.

Avoidable waste according to respondents was rework and design change. Respondents agree that if proper quality control was done in the concrete production batching plant, rework could have been avoided. Also, a design change has to be done before the beginning of the project to avoid time and cost losses. The site engineer indicated that rework was done for a few floor beams, slabs and columns due to the failure of concrete. At the beginning of the project, the proposed buildings were G+5. After six months of excavation, it was decided to be changed to G+7 buildings. Although many buildings were in the excavation phase, rebar required for the footing pad and column was cut and bent for installation. The sub-contractor and bar bender stated in addition to rebar waste, working space and storage areas were occupied by unused cut and bend rebar pieces due to the design change.

Rebar supplying system

The client is responsible for supplying materials required for the project such as rebar, concrete, cement, HCB, electrical and sanitary materials, finishing and roofing materials. According to the client representative, rebar was supplied by the client to reduce costs using duty-free tax permitted for military projects when importing materials from other countries. Since the Army housing project is being done for many sites, the client supplying rebar reduced costs tremendously. Client supplied rebar by the request of the contractor with the approval of the consultant. In special circumstances, rebar may be supplied to the contractor without a request, to reduce large stocks and to free up the storage area in client stores. And a delay in requested material delivery occurred when there was no stock and delay in delivery from other countries happened due to lack of foreign currency and unstable conditions in transporting roads.

According to office engineers, any material required for the project was requested three months earlier. This time frame allows enough time for the client to deliver materials without delaying project schedule.

The site and construction engineer stated some of the rebar required for the projects was delivered at the beginning of structure work which increased the idle time of the reinforcement bars. This made site management difficult also the delivered rebar corroded after a few months which means it had to be wire-brushed to be used.

Material supplied by the client and material used by the contractor will be checked by the consultant. Therefore, if the contractor fails to use materials supplied properly, payment will not be issued until justification was done according to the resident engineer.

Effectiveness of client material supplying system

Regarding quality, all parties agree that materials supplied by the client are up to standard and the required tests are done before materials reach the construction site. According to the client representative, the material requested by the contractor was only supplied if the consultant approved. The resident engineer agrees that approval for material requisition was done when materials supplied previously are used for structural elements it was planned for.

Management of rebar wastage

Every month the client, consultant and contractor representatives sit for a meeting regarding material management and to address necessary issues. According to the site engineer, such meetings improved site conditions such as storage area, waste material storage sites, material supply and delivery systems.

Rebar waste on-site will be returned to the client according to the resident and construction engineer. Nonetheless it was not collected on time of the request. The client representative stated the reason for that was the lack of storage area. And selling cutoff waste takes a longer time than planned. Mechanisms to get rid of waste pieces are transfer usable pieces to other sites and selling unusable small pieces.

The construction engineer stated that to manage material storage areas and waste materials, the management team established a Kaizen team. This Kaizen team was responsible for checking storage areas, material usage and reporting any misuse and damaged materials on the site. The Kaizen team was effective in improving the overall site conditions and making site personnel accountable for any misuse. The client representative also stated since the establishment of this kaizen team in the last seven months, there was a noticeable change in material handling.

Waste quantification method

All parties used the same method of quantification of waste which is reducing the utilized and stocked amount to delivered amount.

Optimization of rebar

The reinforcement bar list which was submitted to bar-benders was developed by the site engineer and checked by the construction engineer. However, it does not include optimal rebar cutting patterns. Also, both the site engineers and construction engineers are not aware of optimization software that can assist in rebar cutting procedures.

The resident engineer stated that cutting patterns were developed using the bar list from structural drawing and arranging it in a way to produce the lowest waste manually by hand to optimize the cutting procedure. However, since there was large number of bar sets, patterns developed manually was not accurate and was not implemented on site. He mentioned they do not use software for optimization due to a lack of resources and knowledge on the field.

Corrosion

Both the construction and resident engineer agreed that there was some degree of corrosion on the rebar stocked before the requested time. According to them, the degree of corrosion was not severe. Therefore, it was wire-brushed and used for the structural members. It was stated by the site engineer that no test was conducted to the corroded rebar to check if the strength was altered.

Contract Vs actual amount of waste

The office engineer and site engineer stated that the client does not consider cutoff pieces while estimating rebar amount. Therefore, a shortage of rebar occurs due to underestimation, especially in the Ø20 bar. It should be noted that the client assumed 5% rebar waste. The actual amount of waste was greater than the contract amount, according to the client representative which was justified by the contractor.

Design for waste reduction

All of the participants agree that design can be used to reduce waste. The construction engineer stated that if we had standard dimensions, construction materials can be optimized. On this structural design, every column has a rebar length of 4.10 m Ø20 with an overlap 0.8 meter (80 centimeter). Since only a 12-meter length available in the market it will result in 12 m - (4.10+4.10) = 3.8 m of leftover length. Even though some of it will be used for other members and can be used in other sites it still will result in a huge amount of leftovers. Therefore, the construction and office engineering department consulted with the designer and client to reduce the length of the bar to 4 meters which reduced overlap length to 70 centimeters. To increase anchorage, ‘C’ bar was added for additional support which saved cutting loss in columns. A ‘C’ bar is a c shaped rebar that was used to increase the bond between rebars when overlap length was reduced.

Summary

All interviewees agree that most of the rebar waste was produced due to cut-off from the standard market length. Also, design change and rework result in avoidable rebar wastes. Rebar was supplied by the client to reduce costs. It was stated that design can be used to reduce material waste. Finally, all parties agree that establishing a kaizen team designated for material management has improved site conditions and material waste handling procedures.

4.3 Case study

This case study intended to identify the source of rebar waste in a site, the amount of rebar waste, challenges faced to implement a material management system and waste minimization techniques implemented in the site. Two sites (Kality 1 and Kality 2) with a total of 28 buildings were chosen for the case study. The basic information about the projects is presented in Table 4.1,

Table 4.1 project site description

Project Description		
Project name	Army foundation Kality 1 apartment project	Army foundation Kality 2 apartment project
Client	Army foundation	
Location	Addis Ababa	
Contractor	Defense construction enterprise	
Consultant	Defense construction design and supervision	
Contract amount	192,329,017.38	168,786,105.77
Total site area	35903m^2	38723m^2
Original contract time	1411 calendar days	1370 calendar days
Original completion date	26-Dec-2021	12-Aug-2021
Extra time from the time claim	136 calendar days	95 calendar days
Revised completion date	30-Dec-2021	15-Nov-2021

Figure 4.1 and Figure 4.2 shows a 3D model of a G+9 and G+7 buildings that was used for this case study. (Adapted from an architectural drawing of the project)

Figure 4.1: 3D model for the G+9 apartment buildings

Figure 4.2: 3D model for the G+7 apartment buildings

4.3.1 General description of the site

The case study was conducted in two sites with three types of typology of the blocks. It should be noted that since the main source of knowledge for this thesis is site investigation, the study was detail and descriptive. Table 4.2 shows the number of buildings that were used for this case study in each typology.

Table 4.2 total number of apartment buildings in the site

Project detail	**Kality 1**	**Kality 2**	
Type of building	**Housing Apartment**	**Housing Apartment**	**Total**
1&2 bed room (G+9)	6	5	**11**
2&3 bed room (G+9)	7	6	**13**
4 bed room (G+7)	2	2	**4**
Total	**15**	**13**	**28**

4.3.2 Direct source of rebar waste in the site

During site investigation, the main sources of rebar wastage were identified. Direct wastes include cutting bar waste, un-optimized working procedures, rework and design change. For the selected project, the client was responsible for supplying the reinforcement bar. Therefore, the client set allowable rebar wastage of 5%. Rebar waste generated in each category is listed below;

4.3.2.1 Cutting waste

This category refers to a bar waste generated due to design. This waste was computed using optimization software. This means using the structural drawing, the bar schedule was developed. This bar schedule was further used to describe possible patterns of cutting. In this particular site, optimization software was used neither by office nor by the construction engineers. And proper cutting patterns were not supplied to the bar benders. Table 4.3 and Figure 4.3 shows the amount of bar used and cutting bar waste. According to IS 1786 code, permissible wastage is 3% (1% accountable wastage/scrap + 2% rod length not over 1.0 m). Some standards further classify allowable wastage if the material is supplied by the client or if it is supplied by the contractor. In this project, the client is responsible for supplying material. For this project, the client set allowable rebar wastage of 5%.

Table 4.3 Rebar cutting wastage amount for 28 buildings

Diameter	Quantity supplied in kg	Quantity used in kg	Wastage amount in kg	% C to B	% C to A
	A	B	C		
Ø 8	889,551.06	853,168.60	36,382.46	4.26%	4.09%
Ø 10	577,008.53	549,978.29	27,030.24	4.91%	4.68%
Ø 12	204,669.79	189,384.48	15,285.31	8.07%	7.47%
Ø 14	687,940.34	650,483.14	37,457.21	5.76%	5.44%
Ø 16	496,077.59	460,502.80	35,574.78	7.73%	7.17%
Ø 20	1,032,595.06	975,083.28	57,511.77	5.90%	5.57%
TOTAL	**3,887,842.37**	**3,678,600.59**	**209,241.78**	**5.69%**	**5.38%**

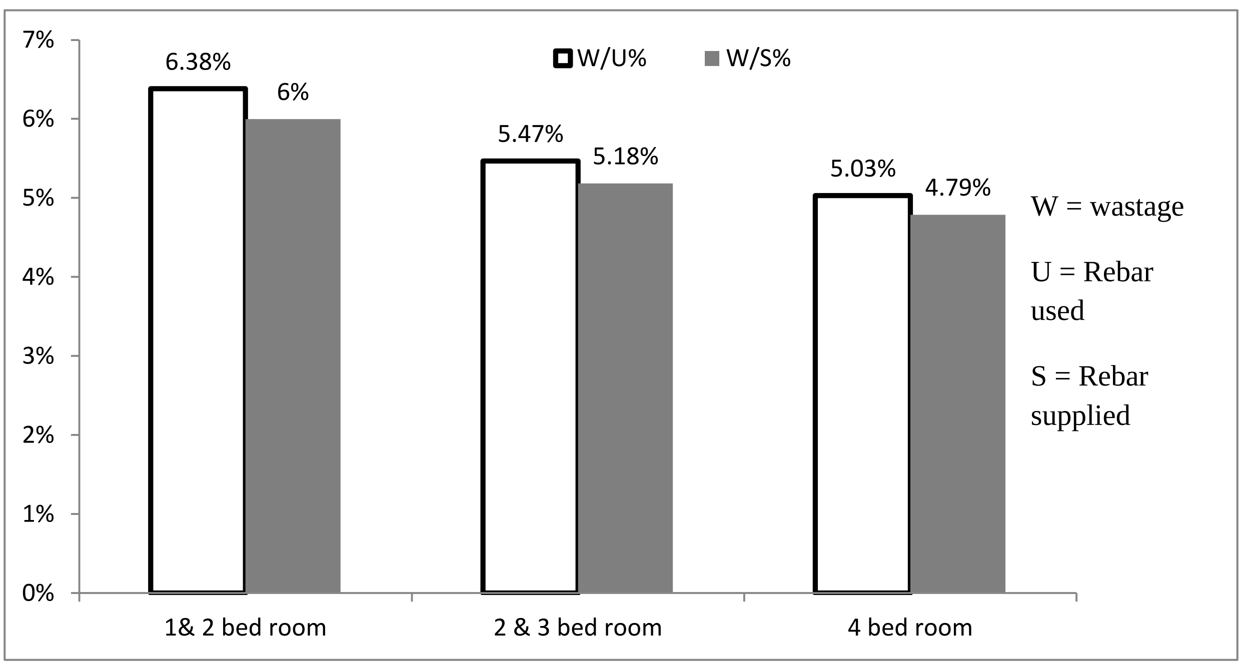

Figure 4.3: Cutting waste in each type of apartment building

Actual cut-off waste encountered exceeds the maximum allowable amount of 5% waste which was set by the client. Table 4.3 shows that Ø16 has the largest amount of waste percentage about 8%. This is due to Ø16 was included only in few structural parts that produced cutoff pieces that are long (greater than 1 meter). Most of the Ø20 waste is developed in 2&3 bed room apartment buildings. This is due to footing column used a length of 4.47 meter which produced a 3.06 meter cutoff pieces and other structural elements required a Ø20 with 4 meter length. Ø12 most waste is recorded for 2&3 bed room since the cutoff was developed in roof beam; it could not be used in other structural element. Ø8, Ø10 and Ø14 produced a rebar waste in each structural part that was too small to be further used. Rebar usage in each building is attached to the appendices.

Figure 4.3 shows that 1&2 bed room apartment buildings produce a large amount of waste compare to the other typologies. The maximum amount of rebar waste is 6.38% and the lowest rate is 4.79% which shows an estimated amount of 5% waste is not enough compared to the actual amount of rebar waste.

Kim et al. (2004) in his study reported that an optimum combination of rebar, calculated by computer, provides very useful information for the manufacturing of rebar as well as systematic inventory management that reduces the waste rate. Also, another study conducted on 17 building projects in Hawassa by Tariku (2018) indicated that waste of rebar is mainly influenced by the cutting of rebar from actual market length leaving unwanted cutting pieces.

Figure 4.4 shows how rebar is stored after being cut and bend in the site. After rebar cut and bent it was laid on the wooden bed. The wooden bed prevented the rebar contacting the ground. Also, each rebar was categorized according to its diameter. The neatness and accessibility of the storage area made transporting of cut and bent rebar pieces to fixing area easier.

Figure 4.4: Appropriate rebar bed used for arrangement of rebar after cutting

4.3.2.2 Un-optimized working procedure

Un-optimized bar cutting refers to cutting of bar in a random manner rather than an optimized cutting pattern. Since the work was executed in an unsystematic manner it was hard to compute the exact amount of waste generated since it varies from bar bender to bar bender.

The procedure used to estimate bar loss due to un-optimized cutting was measuring the actual amount of material used minus the executed work. The results are presented in Table 4.4;

Table 4.4 Rebar waste due to un-optimized working procedure

Diameter	Material supplied (Ms)	Material used (Mu)	Wastage (W)	W/Ms%	W/Mu%
Ø 8	889,551.06	853,168.60	8,642.71	0.97%	1.01%
Ø 10	577,008.53	549,978.29	14,033.52	2.43%	2.55%
Ø 12	204,669.79	189,384.48	1,020.21	0.50%	0.54%
Ø 14	687,940.34	650,483.14	6,324.29	0.92%	0.97%
Ø 16	496,077.59	460,502.80	3,802.73	0.77%	0.83%
Ø 20	1,032,595.06	975,083.28	452.22	0.04%	0.05%
TOTAL	**3,887,842.37**	**3,678,600.59**	**34,275.68**	**0.88%**	**0.93%**

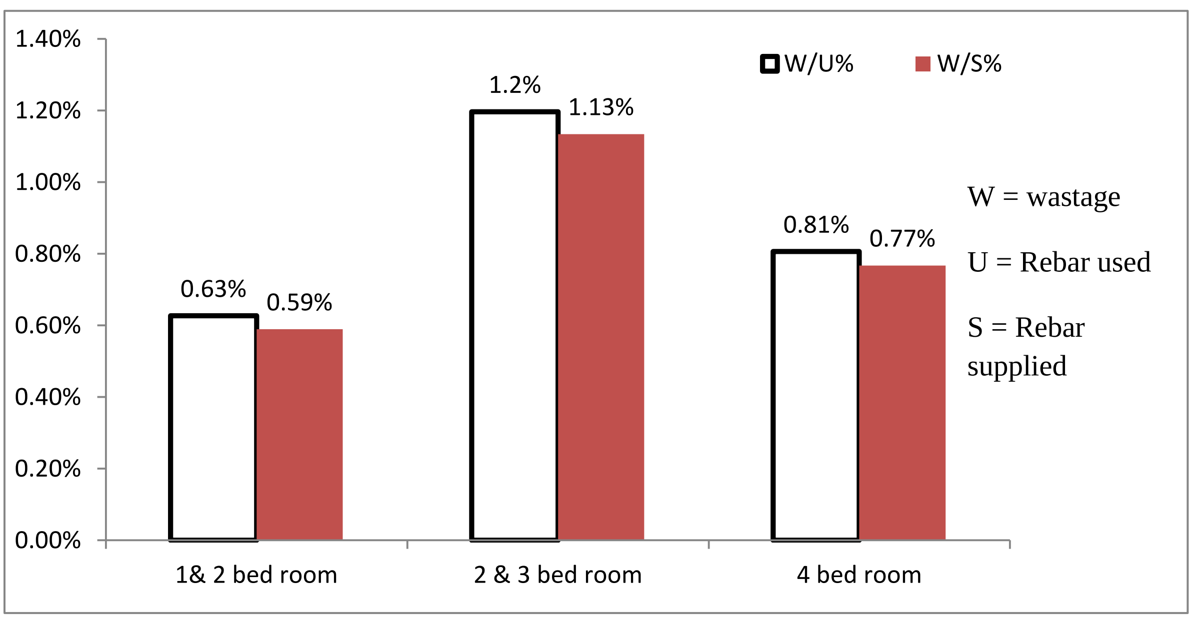

Figure 4.5: Rebar waste due to an un-optimized working procedure in each type of building

Table 4.4 shows that rebar waste due to un-optimized cutting procedure ranges from 0.05-2.55%. The maximum amount of rebar waste was recorded for Ø10. Ø10 is also the largest sets of rebar with different lengths. The minimum amount of rebar waste was Ø20 which was also the smallest set of different lengths. From the findings, the sets of different lengths affect amount of waste produced.

Figure 4.5 show that 2&3 bedroom apartment buildings record the maximum amount of wastage which is about 1.2%. The rebar list in structural drawing for each building affects the amount of waste produced. As the number of bar to be cut increases, so does the waste produced.

As seen on the results additional 0.05-2.55% of waste was generated due to un-optimized working procedures (See Table 4.4). The above data was collected by comparing the results of bar benders assigned to each building. During sampling, the author noticed that the amount of rebar used varied from bar bender to bar bender. This was due to the variation in cutting pattern selection. By submitting a cutting pattern for bar benders, such waste could have easily been avoided.

Figure 4.6: Before and after an arrangement of Rebar cutoffs

Figure 4.6 shows how cut-off bars were stored in the site. After rebar cutting, the bar bender will take time to arrange it properly. Arrangement of pieces of rebar prevented damage of rebar. It also improves the conditions of the working space area. Materials can easily be accessed and transported to fixing areas.

Research by Kim et al. (2004) in Hong Kong projects showed that an amount of 1% waste had occurred due to an un-optimized cutting pattern. A study done by Tariku (2018) on 17 buildings in Hawassa stated that one of the factors causing cost overrun due to rebar wastage was an un-optimized cutting procedure.

4.3.2.3 Rework

Rework for concrete structures refers to the redoing of structure members after demolishing an already constructed floor or column due to concrete failure. For this site, ready-mix concrete was supplied by KCMPF (Kality construction material production factory). Therefore, the contractor was only responsible for molding, casting and testing of the concrete. The main reason behind using ready-mix concrete rather than cast-in-situ was to avoid concrete failures, reduce material waste and improving the quality of production. Although this assumption proofed to be right in most projects, some failures had occurred. The reason listed by the resident engineer and client representative for concrete failure was, during the travel of the concrete from the batching plant to the site, the drivers were allowed to use chemicals that can retard setting time. Over-using of this chemical has the potential to reduce the strength of concrete. Such rework is done for;

1. Footing pad and footing column for a 4 bedroom apartment
2. 2nd floor column and lift for a 1&2 bedroom apartment
3. 1st and 2nd floor column and lift for a 2&3 bedroom apartment
4. 1st floor beam and slab for a 2&3 bedroom apartment

Table 4.5 shows rebar wasted due to rework;

Table 4.5.Rebar wasted due to rework

	Initally estimated total amount of rebar		Additional rebar due to rework			
Diameter	for the project kg	for four buildings kg	Actual Quantity in kg	Theortical Quantity in kg	% waste from total project	% waste for the four buildings
Ø 8	853,168.60	128,438.52	4,901.16	4,753.69	0.57%	3.82%
Ø 10	549,978.29	88,047.82	2,820.92	2,661.37	0.51%	3.20%
Ø 12	189,384.48	32,564.45	660.67	622.27	0.35%	2.03%
Ø 14	650,483.14	95,977.93	11,084.11	10,559.60	1.70%	11.55%
Ø 16	460,502.80	72,791.16	5,892.83	5,508.53	1.28%	8.10%
Ø 20	975,083.28	138,598.80	41,893.99	40,083.38	4.30%	30.23%
TOTAL	**3,678,600.59**	**556,418.67**	**67,253.69**	**64,188.85**	**1.83%**	**12.09%**

Table 4.5 shows rebar wasted due to rework caused an additional 12% of waste was encountered in those four buildings and almost 2% waste from the complete project estimated amount of rebar. When the client replaces rebar for the rework, the actual quantity used was not considered. Cutting loss again was not considered. This means the actual quantity lost exceeds the amount assumed or estimated by the client. The lost quantity exceeds the requested quantity by 5%. Rework is an expensive and time-consuming work. Rebar collected from the demolition process is a complete waste for the site since it cannot be reused within the project.

4.3.2.4. Design change

At the beginning of this project, the design was for G+ 5 building apartments. Six months after the beginning of the excavation work, a design change was requested by the client. Therefore, by the time of the design change request, the footing pad and column rebar that were cut and bent and were ready for installation are listed below;

1. Footing pad and column for 6 blocks (1&2 bedroom apartments)
2. Footing pad and column for 7 blocks (2&3 bedroom apartments)
3. Footing pad for 2 blocks (4 bedroom apartments)

Thus, rebar wasted due to design change for all buildings are listed in Table 4.6;

Table 4.6 Rebar waste due to design change

	Initally estimated total amount of rebar		Additional rebar due to design change			
Diameter	for the project kg	for fifteen buildings kg	Actual Quantity in kg	Theortical Quantity in kg	% waste from total project	% waste for the fifteen buildings
	A	B	C	D	C/A	C/B
Ø 8	853,168.60	455,196.22	5,190.30	4,869.17	0.61%	1.14%
Ø 10	549,978.29	292,118.78	-	-	0.00%	0.00%
Ø 12	189,384.48	99,891.45	8,258.40	7,876.20	4.36%	8.27%
Ø 14	650,483.14	347,527.57	51,314.80	49,190.15	7.89%	14.77%
Ø 16	460,502.80	244,979.96	4,206.46	3,556.73	0.91%	1.72%
Ø 20	975,083.28	522,576.76	-	-	0.00%	0.00%
TOTAL	**3,678,600.59**	**1,962,290.74**	**68,969.95**	**65,492.25**	**1.87%**	**3.51%**

Table 4.6 shows an additional 3.5% of waste is encountered in those 15 buildings and almost an additional 2% waste from the estimated amount of rebar for the complete project. Rebar wasted due to this design change was reported and requested to be collected by the client over a year ago. Nevertheless, so far the client has not collected the items and it is buried on the grasses as seen on the bottom picture. The reason stated by the client is the lack of storage area and the committee established to complete this work was busy with other tasks.

Figure 4.7 (a) and (b) show some of the rebar that were buried. Footing pad and column rebar was bent and cut for the above buildings. It was a total loss for the project and could not be used for this project. It was requested by the contractor to be removed from the site. The client could not remove it from the site due to lack of storage area. Care was not taken to store the rebar. There is no wooden bed below the rebars; therefore it was buried under the grasses.

Figure 4.7: Buried Rebar due to delay in client collecting remaining pieces

4.3.2.5 Corrosion

Batcoda (technical specification and method of measurement) (2007) recommends reinforcement shall be delivered in sufficient quantities before the start of concrete work, to ensure that no constructed formwork lies idle and exposed to the weather due to reinforcement not being placed in position. Reinforcement shall be stored in an off the ground position to prevent rust by contact with soil, dampness and other objectionable materials.

Most of the rebar supplied for the project was delivered to the site according to the request of the contractor. However, Figure 4.8 (a) and (b) shows rebar sizes Ø12 and Ø16 were supplied excessively at the beginning of the project due to excess stock by the client and shortage of storage area. The bottom layer of this reinforcement bar stock was buried and exposed to open air and moisture that lead to corrosion. Corrosion decreases rebar-concrete bond strength if it exceeds certain limit. Therefore, the bottom layers of rebar were used by brushing the top surface using a wire brush. Nevertheless further test must have be done to check if brushing action reduced tensile strength which was not done assuming it will not affect strength greater than the tolerable rate.

(a)

Figure 4.8: Unused Rebar that corrodes due to excess stock

4.3.3 Total amount of rebar waste due to direct sources

After computing waste generated in each source, it was important to utilize the total amount of waste generated to understand how much the client lost due to avoidable and unavoidable sources of rebar waste. Table 4.7 and Figure 4.9 show the total rebar waste amount.

Table 4.7 Total amount of rebar waste

Description	Wastage amount (kg)	Wastage %
Cutting bar waste	23,317.13	14.28%
Un-optimizated cutting procedure	3,726.08	2.28%
Rework	67,253.69	41.19%
Design change	68,969.95	42.24%
Total	**163,266.85**	

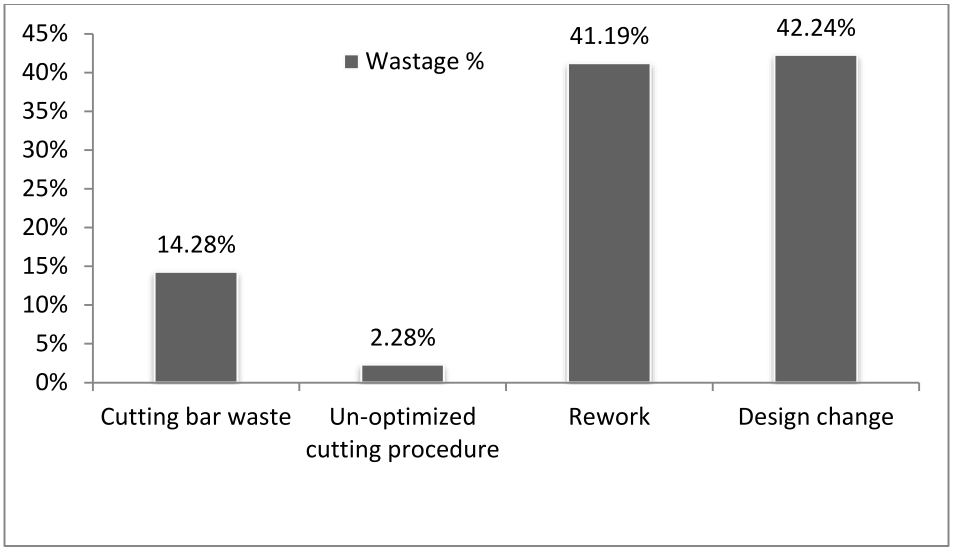

Figure 4.9: Total wastage amount

Table 4.7 and Figure 4.9 shows that most rebar waste occur due to design change. Design change was initiated by the client. Therefore, the client was aware of the wastage and costs associated with changing the design. The other major source of waste was rework. Rework was done when the concrete fail strength test after casting. It accounts for 41.19% of the total waste. The least amount of wastage was recorded for un-optimized cutting procedure. This was a preventable waste in simple optimization procedures. The numerical figure shows that waste due to avoidable sources was greater than unavoidable sources for this site.

When the project starts the estimated amount of rebar to be used is 421,948.51 kg plus 5% wastage. However, the actual amount consumed 581,489.28 Kg which is an estimated 31.25% increase from the planned estimate. Even in considering client return loss of rebar due to design change and rework general waste still additional 6.1% of waste was encountered.

Other researchers also reported that actual quantity exceeds the theoretical amount such as Mulualem et al. (2012) reporting 15% waste of rebar in the Addis Ababa project. Also, another study was done in Brazil by Pinto and Agopayan (1994) reported a 20% waste developed in 15 projects in Brazil. Hayat (2017) in her study of three projects in Addis Ababa showed that rebar waste produced exceed 10%. Therefore, the amount of waste produced varies from site to site.

4.3.4 Total waste per built-up area

One method that is used to quantify waste was based on the floor area. Such a method was used by Cochran et al. (2007) for quantifying the rate of kg/m^2 that can be used in estimating the quantity of waste generated per floor area in building projects. Also, Hayat (2017) in her study of construction waste in Addis Ababa used this method to quantify waste. Therefore, for the selected projects mean waste kg/m^2 is shown in Table 4.8;

Table 4.8 Relationship between total waste generated per floor area

	Single Floor area (m^2)	**No of buildings**	**Total waste (kg)**	**Total waste per floor area (kg/m^2)**	**Mean waste per floor area (kg/m^2)**
1&2 bed room	378.4	11	43,083.15	113.86	**108.64**
2&3 bed room	533.6	13	64,212.53	120.34	
4 bed room	995	4	55,971.19	56.25	

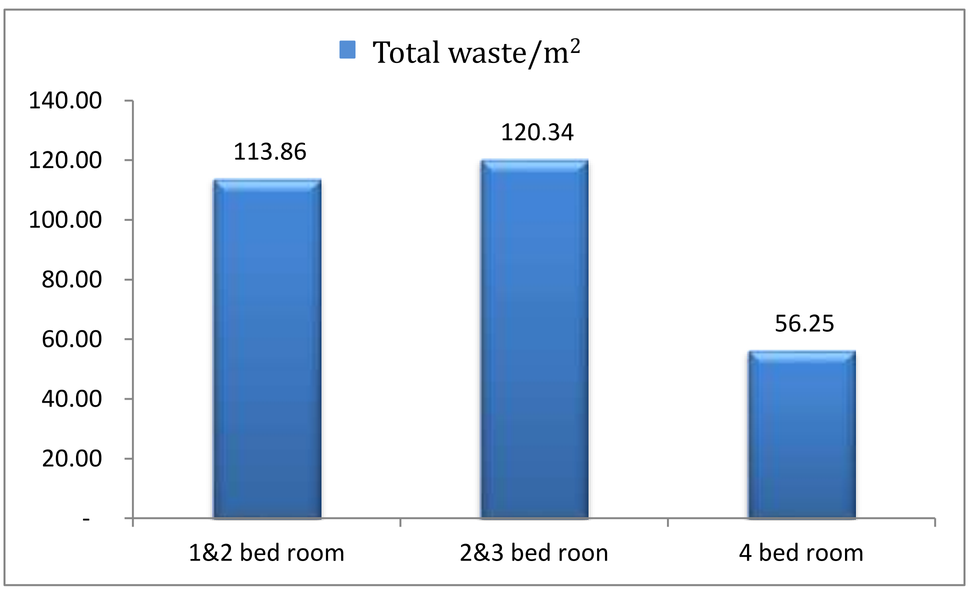

Figure 4.10: Relationship between total waste generated per floor area

Table 4.8 shows that rebar wastage (kg) per floor area (m^2) has a mean waste generation rate of 108.64 kg/m^2. Both Table 4.8 and Figure 4.10 show that the least amount of total waste per floor area (kg/m^2) was reported for 4 bed room apartment buildings with the largest floor area. Large amount of total waste (kg) was recorded for 2&3 bed room apartment building which also had the maximum amount of total waste/m^2.

4.3.5 Indirect source of rebar waste in the site

An indirect source of waste refers to waste generated from external sources. It was difficult to quantify the amount of waste generated by this source of waste. Few factors contribute to such waste in the site;

4.3.5.1 Ahead of time delivery

This specifically refers to bar diameter Ø12 and Ø16 which were delivered ahead of schedule. All of the quantity needed for the project was delivered 1 year and a half ahead of schedule. Therefore, its idle time was extended and exposure to atmosphere and moisture resulted in corrosion in the bottom layers of reinforcement bars. Figure 4.8 illustrates the effect of ahead of time delivery.

4.3.5.2 Management waste

Management waste refers to the handling of waste inadequately. The client could not collect rebar pieces in time resulting in occupied storage areas and working places. This made the site an unpleasant and unsafe working environment. The client stated lack of storage space and the committee established to complete this work was too busy on other tasks as a reason for not picking wastage pieces in time.

4.3.5.3 Late delivery

Office engineering team plans schedule and request materials 3 months ahead of time. This was a very good system to generate just in time delivery. Nevertheless occasionally the client delayed deliveries because of different reasons. For the reinforcement bar Ø8 was delayed for over 2 months which was enough to slow down the project activity and causes delay in schedule time. Such cases cause an indirect impact on other materials not to be used in time which extends the operational time. Sometimes, to some degree, such late deliveries motivate engineers and workers to collect and reuse leftover cutoff pieces.

4.3.6 Challenges faced with rebar material management

Some challenges the contractor faced to manage reinforcement material is described as follows;

4.3.6.1 Undefined scope

Undefined scope refers to no good definition of what is expected. The contractor and client have no agreement or written numerical figures to show how much waste was expected and which type of waste was unacceptable. This is mainly due to a lack of attention and knowledge towards minimizing and managing material waste.

4.3.6.2 Lack of communication between parties

Lack of communication between parties occurred during rebar estimation phase and after completion of rebar work. The first one was an underestimation of the reinforcement bar which was seen in the direct waste topic of this chapter. Such cases raise issues such as the client assuming to deliver all rebar materials needed for the project while the contractor faces shortage of reinforcement bar before completing the structure. They had to sit and talk about their material estimation, consumption and wastage generation process. The other was negligence to collect cutoffs from the site at the time of the request.

4.3.6.3 Incomplete drawing

Structural drawings have to be checked along with other drawings before the beginning of the project to clear out any missed elements. In this case, lintels were not included in structural drawing while in architectural drawing it requests mono-construction to some of the columns. However since architectural drawing was not checked in the structural construction phase, it raises a question on how to complete the work whether to redo columns by chiseling or any other option. The design team and construction team decide to go with no chisel options which are to extend the door length to reach the beam so that lintels will not be needed. Also, another option used was to reduce door width to construct the HCB wall to support lintels. However, for door and windows where such an option was not applicable, chiseling was done on columns to install the lintels with the columns.

4.3.6.4 Improper storage of materials

This was seen in most researches are done around material wastage. Most construction sites are full of materials that are stored in an unorganized manner and result in more wastage than intended. The same mistakes were seen on this site and it was improved through time using the kaizen system initiated by the kaizen team.

4.3.7 Waste minimization techniques implemented in the site

Different materials are wasted on the site during its project life cycle. Although waste is inevitable it can tremendously be minimized with proper planning and management schemes. Some techniques used to minimize rebar waste in the site are mentioned below;

4.3.7.1 Design modifications

This refers to a change in structural drawing specifications regarding rebar Ø20. Most of the rebar length for columns in the structural drawing is 4.1 m. Since the only standard market length of rebar is 12 m it will result in 3.8 m leftover pieces. Therefore, the project team and design team sit down to come with a solution to reduce the length to 4 m without affecting the strength of the structure. It was decided to add C-bar in each section after reducing the rebar length to 4 m. This simple change in design length avoids about 43,735 kg of leftover in the project even after some pieces are used for other structural members.

4.3.7.2 Kaizen team

Kaizen team was established by the management team to reduce wastage on the site and improve material storage conditions. By the time of completing this research, it has been 7 months of the establishment. This team visits the site every week and report findings to the management making the construction team accountable for any site conditions. This dramatically improves material handling procedures and storage conditions. Also, waste was properly handled which improved working place safety and comfort.

4.3.7.3 Advance material request

Materials required for construction are requested three months before the construction schedule. This system works and it gives the client enough time to supply materials requested without causing any delays in schedule. The office team and construction teamwork on requests to make sure the amount and type of material are correct. It also improves storage time and operation period for materials.

4.3.7.4 Reusing cutoffs for small structural parts

As mentioned in the above sub chapters some of the cutoffs developed in structural parts are greater than 2 meters. Such pieces were used for other structural parts that are compatible. A lintel is a structural horizontal support used to span an opening in a wall or between two vertical supports. It is frequently used over windows and doors, both of which represent vulnerable points in a building’s structure. Therefore, rebar cutoff Ø12 and Ø8 are used to form these lintels. The exact amount of rebar used for this purpose was not computed because most of the work began after the completion of the case study for this paper. Also, small concrete ditches and pipes for the access roads within the site used these cutoff pieces.

4.3.7.5 Return to the client

Another management system was to remove the scraps from the site. Since rebar was supplied by the client any remaining pieces should be delivered to the client. Again the exact amount of rebar returned was not measured since this has not begun by the completion of this paper. So for returned scraps of other completed projects are stored in the client’s store. The client established a committee to handle such wastes; however, the committee stated they were too busy with other tasks and plans to sell it to factories using bidding procedures.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The general objectives of this study are to identify major sources of rebar wastes, to quantify the amount of waste generated and to identify potential management schemes for Defense construction enterprises on the Army foundation apartment project. Therefore, depending on the results obtained the following conclusions have been made;

1. In the selected site, the main sources of direct rebar wastage are cutting waste, un-optimized cutting procedure, design change, rework and corrosion. Indirect sources of wastes are ahead of time deliveries, management waste and late delivery.
2. Challenges faced on rebar material management are undefined scope, lack of communication between parties, incomplete drawing and improper storage of materials.
3. Management of rebar waste implemented in a site was the establishment of a kaizen team, advance material request, reusing cutoffs and return to the client.
4. The results of the research indicate that design change and rework have the greatest impact on overall waste production.
5. Most of the rebar wastage reported was avoidable by implementing a waste reduction plan before the beginning of rebar cutting and bending and avoiding design change after the beginning of a project.
6. Concrete failure was another major cause of rebar wastage as it leads to the rework of structural members. The main cause of such failure reported for this site was the overuse of retarding chemicals during transportation.
7. The Kaizen team established on the site by the management team has been an effective method to improve material storage conditions and reducing material damages. Also, it improved the working environment safety and comfort.

5.2 RECOMMENDATIONS

The findings in the research show that the amount of wastage produced exceed what is assumed by contractors, consultants, and clients. The reinforcement bar is one of construction materials that could easily be optimized and utilized efficiently if proper attention is given. Therefore, measures have to be implemented to reduce the amount of wastage produced which is given in this recommendation section.

1. Planning before the actual construction begins can prevent the amount of waste produced to an acceptable rate. The storage area for rebar has to be included in the site area layout so that it can easily be accessible for loading unloading and transporting to the cutting site. The cutting sites also must be prepared close to the rebar storage area to reduce transporting time. the storage area must be marked in each diameter with an off the ground position to prevent rust by contact with soil, dampness and other objectionable materials. the same procedure has to be used for the leftover pieces to make it reachable for reusing and removal from the site.

2. Planning also must include the amount of rebar needed to complete the project. The actual amount of rebar includes the rebar amount that will be used plus cutting waste. For proper quantification, optimization software has to be employed to develop the actual amount of bar needed plus waste due to cutting. Therefore, educating and training of professionals must be done to use the software and reduce waste. And an optimized cutting pattern developed by using software, has to be submitted to bar-benders so that optimal utilization can be achieved.

3. Most of the waste recorded was due to design change. Therefore, the designer (consultant), client, and the contractor should form a meeting before handing-over of the site to identify if the design can fulfill the request of the client. Design change after a handing-over of the site has to be the last option.

4. Another recommendation that can be given to the designer is ‘standardization’ can go a long way. Small adjustments in the design phase can save a lot of wastage due to cutting.

With only one market length available in the county, designs have to be implemented in a way that cutting waste can be minimized to an acceptable rate.

5. During concrete production, care has to be taken to avoid the rework of structural members. Excess use of chemicals and poor quality materials has to be avoided to improve concrete quality and avoid failure of structural elements.

6. Establishing a team that follows the material storage and wastage activities seems to be a successful method implemented on the site that reduces rebar wastage due to damage and misuse. In addition, safety and comfort of the working environment were achieved. Therefore, such teams have to be developed in all sites to improve material storage conditions and reduce the amount of wastage developed due to damages and misuse.

7. Material management needs to be updated as construction work progresses. It also varies from site to site. Therefore, special training sessions should be arranged for office and site staffs that include updated software and site management techniques. And progress in site material management has to be closely mentored especially in repetitive projects. For reinforcement bar documents from the previous sites have to be studied and information has to be updated to avoid material loss and overall project management.

8. If material is supplied by the client, the consultant can play a major role of monitoring amount of wastage produced in the site. Consultant must make the contractor or any responsible body accountable for any material misuse or excess amount of wastage.

Further studies

Further studies could focus on how to use recycled rebar in construction, a minimum percentage of waste materials could be recycled and/or recovered in different kinds of construction, and ways in helping the development of the recycling and refurbishing industries in Addis Ababa, Ethiopia.

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APPENDIX

Appendix A Interview questions

I. Question for Construction and site engineers

Part one: General Information

1. Classification of your organization___________________________________
2. Your position on this site____
3. Educational background____
4. Years of experience in the construction industry

____

5. Years of experience in Defense construction enterprise?

____

Part two: Perception of waste generation sources

6. Do you believe there is rebar wastage on the site?

____

7. What are the main sources of rebar wastage in this site?

____

8. Which of those is avoidable?

____

9. What did you do to avoid avoidable waste on your site?

____

10. How does the waste generated affect your day to day activity?

____

11. When does rebar supply to the site?

____

12. Who is responsible for requesting the amount of rebar to be supplied on the site?

____

13. Does the Client supply rebar affect the amount of waste generated?

____

14. Did you ever have a conversation or meeting with other parties on how to reduce or manage construction material wastage in the site?

____

15. How do you dispose of rebar wastage?

____

Part three: Estimating rebar waste

16. Is the amount of rebar waste generated on-site known?

____

17. What kind of computational method used to derive the amount of wastage?

____

18. Do you think your method is effective for quantifying all amounts of waste generated?

____

Part four: About cutting patterns

19. Do you supply a rebar list for bar-benders?

____

20. Do you provide cutting patterns with the rebar cutting list? Why?

____

Part four: additional cause of rebar wastage

21. Is there any design change after the beginning of the project? If any why?

____

22. Is there any rework? If any why?

____

23. Did you lose any rebar due to corrosion? If any what measures were taken?

____

24. Any final thoughts on the subject?

II. Question for office engineer

Part one: General Information

1. Classification of your organization_________________________________
2. Your position on this site____
3. Educational background____
4. Years of experience in the construction industry

____

5. Years of experience in Defense construction enterprise?

____

Part two: Perception of waste generation sources

6. Do you believe there is rebar wastage on the site?

____

7. What are the main sources of rebar wastage in this site?

____

8. When do you request rebar to be supplied to the site?

   ____

9. Is the material supplied at the time of your request?

____

10. Did you ever have a conversation or meeting with other parties on how to reduce or manage construction material wastage in the site?

____

Part three: Estimating re-bar waste

11. Is the amount of rebar waste generated on-site known?

____

12. What kind of computational method used to derive the amount of wastage?

____

13. Do you think your method is effective for quantifying all amounts of waste generated?

____

Part four: Optimization

14. Do you know optimization software?

____

15. Did you use software to compute the amount of rebar needed for the project?

____

16. Do you think there would be any difference if we use optimization software rather than a random manner of cutting patterns?

____

Part five: Additional loss of bar

17. How do you calculate rebar loss due to design change and rework?

____

18. How much wastage is permissible in the contract? And is it practical?

____

19. Any final thoughts on the subject?

III. Questions for sub-contractor and bar bender

Part one: General Information

1. Classification of your organization__________________________________
2. Your position on this site____
3. Educational background____
4. Years of experience in the construction industry

____

5. Years of experience in Defense construction enterprise?

____

Part two: Perception of waste generation sources

6. Do you believe there is rebar wastage on the site?

____

7. How does the waste generated affect your day to day activity?

____

8. Who gives you a rebar cutting list?

____

9. How do you choose cutting patterns?

____

10. Do you think is there is a difference between person to person?

____

11. How do you stock the leftover pieces?

____

12. Is the road from the storage area to the cutting area accessible?

____

13. is the storage area suitable for rebar?

____

14. Any final thoughts on the subject?

IV. Question for Consultant representative (resident engineer)

Part one: General Information

1. Classification of your organization________________________________
2. Your position on this site____
3. Educational background____
4. Years of experience in the construction industry

____

5. Years of experience in Defense construction enterprise?

____

Part two: Perception of waste generation sources

6. Do you believe there is rebar wastage on the site?

____

7. As a consultant what is your role to reduce rebar wastage?

____

8. What do you think the main source of rebar wastage is?

____

9. Can design be used to reduce rebar wastage?

____

10. Is the client supplying rebar increase wastage amount according to your perception?

____

11. Do consultants closely monitor wastage rate?

____

12. Do you have a standard to check the amount of wastage produced?

____

13. As a consultant what is the measure taken if an excess amount of rebar is produced?

____

14. Did you ever have a conversation or meeting with other parties on how to reduce or manage construction material wastage in the site?

____

15. How do you dispose of rebar wastage?

____

16. Do you inspect construction material storage areas?

____

17. How do you address the misuse of materials on the site?

____

18. Is corrosion an issue in this site? If it is how do you check to corrode rebar quality?

____

19. How do you check the quality of rebar?

____

20. Do you quantify wastage amount using requested and used amount?

____

21. Any final thoughts on the subject?

V. Question for Client representative

Part one: General Information

1. Classification of your organization__________________________________
2. Your position on this site____
3. Educational background____
4. Years of experience in the construction industry

____

5. Years of experience in Defense construction enterprise?

____

Part two: Perception of waste generation sources

6. As a client and rebar material supplier do you think there is a rebar wastage?

____

7. As a client what is your role to reduce rebar wastage?

____

8. What do you think the main source of rebar wastage is?

____

9. Can design be used to reduce rebar wastage?

____

10. Do you think the client supplying material increase wastage?

____

11. Do you know what amount of rebar wastage to be produced?

____

12. Do you collect cut pieces in time of the request? If not why?

____

13. Where do you dispose of the collected pieces?

____

14. Do you have a system to calculate the expected amount of wastage and the actual amount of wastage?

____

15. How much waste are you expecting and how much rebar waste have you collected in other previous projects?

____

16. Why did you choose to supply rebar for the project?

____

17. When did you deliver rebar on-site?

____

18. Do you examine the quality of rebar before delivering it? Which tests are conducted?

____

19. Any final thoughts on the subject?

APPENDIX

Appendix B: Formats and Table used for case study

Part 1: Bar schedule

No	Location	Shape	Dimension	Length	Number of Bars	Number of Member (pcs)	Number of FLOOR	Total Length	6	8	10	12	14	16	20
Total Length															
Weight (Kg/m)									0.222	0.395	0.617	0.888	*1.209*	1.580	2.469
Total Weight															

Part 2: onsite material usage record

Description of work	No	Dimensions	Actual Quantity (m)	Crew & Equipment Usage			Material request		Material Usage		Difference length (m)
		Length(m)		Composition	No	work executed /day	Type	Unit	Type	Unit	

Appendix C

Assessment of reinforcement wastage on selected apartment building projects which is used for this research

Part 1: off-cut waste for a single building

- **For 1&2 bedroom apartment buildings single building quantity**

				C	D	E		
Dia.	Quantity supplied (m)	Quantity used (m)	meter to kg factor	Quantity supplied in kg	Quantity used in kg	Wastage	% E to D	% E to C
Ø 8	70,368.00	67,462.41	0.395	27,795.36	26,647.65	1,147.71	4%	4%
Ø 10	23,184.00	21,467.34	0.617	14,304.53	13,245.35	1,059.18	8%	7%
Ø 12	4,620.00	4,017.20	0.888	4,102.56	3,567.27	535.29	15%	13%
Ø 14	19,164.00	18,077.51	1.209	23,169.28	21,855.70	1,313.57	6%	6%
Ø 16	7,776.00	6,983.11	1.579	12,278.30	11,026.32	1,251.98	11%	10%
Ø 20	14,976.00	14,244.00	2.469	36,975.74	35,168.44	1,807.31	5%	5%
TOTAL				**118,625.77**	**111,510.74**	**7,115.03**	**6%**	**6%**

- **For 2&3 bedroom apartment buildings single building quantity**

				C	D	E		
Dia.	Quantity supplied (m)	Quantity used (m)	meter to kg factor	Quantity supplied in kg	Quantity used in kg	Wastage	% E to D	% E to C
Ø 8	80,460.00	77,408.08	0.40	31,781.70	30,576.19	1,205.51	4%	4%
Ø 10	35,760.00	34,058.21	0.62	22,063.92	21,013.92	1,050.00	5%	5%
Ø 12	8,256.00	7,692.74	0.89	7,331.33	6,831.15	500.17	7%	7%
Ø 14	19,860.00	18,789.33	1.21	24,010.74	22,716.30	1,294.44	6%	5%
Ø 16	12,300.00	11,672.44	1.58	19,421.70	18,430.78	990.92	5%	5%
Ø 20	15,072.00	14,136.01	2.47	37,212.77	34,901.81	2,310.96	7%	6%
TOTAL				**141,822.16**	**134,470.15**	**7,352.00**	5%	5%

- **For 4 bedroom apartment buildings single building quantity**

				C	D	E		
Dia.	Quantity supplied (m)	Quantity used (m)	meter to kg factor	Quantity supplied in kg	Quantity used in kg	Wastage	% E to D	% E to C
Ø 8	108,000.00	102,882.23	0.40	42,660.00	40,638.48	2,021.52	5%	5%
Ø 10	53,820.00	53,119.35	0.62	33,206.94	32,774.64	432.30	1%	1%
Ø 12	18,084.00	17,269.00	0.89	16,058.59	15,334.87	723.72	5%	5%
Ø 14	25,008.00	23,730.05	1.21	30,234.67	28,689.62	1,545.05	5%	5%
Ø 16	17,184.00	15,771.55	1.58	27,133.54	24,903.27	2,230.27	9%	8%
Ø 20	14,388.00	13,619.58	2.47	35,523.97	33,626.74	1,897.23	6%	5%
TOTAL				**184,817.71**	**175,967.62**	**8,850.09**	**5%**	**5%**

Part 2: un-optimized cutting waste for a single building

- **For 1&2 bedroom apartment buildings single building quantity**

Diameter	Quantity Supplied	Quantity used	un-optimized wastage	% C to B	% C to A
	A	B	C		
Ø 8	27,795.36	26,647.65	215.02	0.81%	0.77%
Ø 10	14,304.53	13,245.35	257.66	1.95%	1.80%
Ø 12	4,102.56	3,567.27	39.66	1.11%	0.97%
Ø 14	23,169.28	21,855.70	138.14	0.63%	0.60%
Ø 16	12,278.30	11,026.32	48.40	0.44%	0.39%
Ø 20	36,975.74	35,168.44	-	0.00%	0.00%
TOTAL	**118,625.77**	**111,510.74**	**698.89**	**0.63%**	**0.59%**

- **For 2&3 bedroom apartment buildings single building quantity**

Diameter	Quantity Supplied	Quantity used	un-optimized wastage	% C to B	% C to A
	A	B	C		
Ø 8	31,781.70	30,576.19	272.42	0.89%	0.86%
Ø 10	22,063.92	21,013.92	817.73	3.89%	3.71%
Ø 12	7,331.33	6,831.15	9.24	0.14%	0.13%
Ø 14	24,010.74	22,716.30	326.85	1.44%	1.36%
Ø 16	19,421.70	18,430.78	182.55	0.99%	0.94%
Ø 20	37,212.77	34,901.81	-	0.00%	0.00%
TOTAL	**141,822.16**	**134,470.15**	**1,608.79**	**1.20%**	**1.13%**

- **For 4 bedroom apartment buildings single building quantity**

Diameter	Quantity Supplied	Quantity used	un-optimized wastage	% C to B	% C to A
	A	B	C		
Ø 8	42,660.00	40,638.48	684.00	1.68%	1.60%
Ø 10	33,206.94	32,774.64	142.17	0.43%	0.43%
Ø 12	16,058.59	15,334.87	115.98	0.76%	0.72%
Ø 14	30,234.67	28,689.62	138.91	0.48%	0.46%
Ø 16	27,133.54	24,903.27	224.29	0.90%	0.83%
Ø 20	35,523.97	33,626.74	113.06	0.34%	0.32%
TOTAL	**184,817.71**	**175,967.62**	**1,418.40**	**0.81%**	**0.77%**

Part 3: Amount of wastage developed for a single building

Waste at blocks	Optimization (kg)	Un-optmized cutting (kg)	Rework (kg)	Design change (kg)	Total waste (kg)
1&2 bed room	7,115.04	698.89	9,928.75	25,340.47	**43,083.15**
2&3 bed roon	7,352.01	1,608.79	28,293.44	26,958.29	**64,212.53**
4 bed room	8,850.11	1,418.40	29,031.49	16,671.19	**55,971.19**