Quantification of Material Waste in Building Construction Industry and its Impact on Cost

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THESIS ACCEPTANCE CERTIFICATE

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Abstract

Construction industry has a significant impact on the economy and environment. It contributes to the provision of infrastructure, buildings, jobs and much more. But it has negative impacts in the form of poor reputation of environmental and economic performance. One significant factor contributing to this dismal state is generation of material waste in construction activities. Globally, various studies have attempted to measure the magnitude of this waste through qualitative and quantitative methods, and developed management strategies to reduce waste and enhance the overall performance. This paper presents a quantitative study of material waste in the construction industry of Pakistan by using primary data collected from 40 completed building projects. It is found that the highest wasteful materials are wood, sand and bricks. Interestingly, they are both the costliest (wood) as well as cheapest (sand) of all. Also, waste generation due to various subcontracting arrangements are investigated to reveal that the labor-only configuration results into maximum waste. Despite a lower appeal on upfront cost, sustainability implications are discussed. Also, the best practices applied by construction organizations generating lower amount of waste are synthesized and discussed in order to provide practicable strategies to industry professionals in the form of a waste management plan. This is the first of its nature study in the context of local construction industry and recommends to continue gathering vast amounts of waste data which can help benchmark the national practices along with implementing best practices to improve the economic and environmental performance of the construction industry.

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Chapter 1

Introduction

1.1 Study background

Construction industry is best known for contributing the economic growth of any country. On average it is accounted for 5-15% towards GDP of a country (DTIE, 2009). But such significant output does not come cheap. Construction industry is one of the largest resource consumer (Saraiva and Borges, 2012; Womack and Jones, 1996). Sharma et al. (2011) state that approximately 40% of the materials are used in building construction. But material waste results into lower efficiency of construction processes (Egan, 1998).Thus construction industry has negative impacts on the environment by generating on site and production material (Poon et al., 2004). According to Holm (1998), a staggering 40% of total global waste is due to the building industry, closely followed by household waste 36.73%, market and commercial waste 21.54% (Hassan et al., 1998). Bossink and Brouwers (1996) determined that about 1-10 % of purchased material by weight are left on sites as a waste in Hong Kong construction industry. According to a report of Eurostat, almost two billion tonnes of waste is generated by construction industry and its contribution to the total waste is 31% (DEFRA, 2007). Some of the major sources of construction waste are design, procurement, material handling, operation, residual and others (Bossink and Brouwers, 1996). The large amounts of waste generated is now becoming a pressing problem in many cities of the world (Begum et al., 2006).

Major causes of construction waste in Egyptian construction industry are late information, unskilled team, poor quality control, incomplete design, unskilled labor, insufficient specifications, etc. (Garas et al., 2001). Different sub-contracting arrangements are considered as one of the major factors causing material waste on sites. Tam et al. (2007) studied the effect of three sub-contracting arrangements Labor only (L-O), Labor and Material (L-M) and Direct Labor (D-L) or main contractor's labor on the generation of material waste. Results show that most of the material wastes are generated with L-O arrangement as compared to D-L and L-M. L-M was found to be the least waste generating arrangement. The main reason is that the Sub-contractor bears cost of material waste in case of L-M while in other two cases it is borne by the main contractor. Similarly, Oko John and Emmanuel Itodo (2013) also studied the amount of material waste with different sub-contracting arrangements and found that L-O was the only arrangement causing the highest material waste, while L-M cause the lowest waste.

Construction waste is not only important because of the perspective of efficiency but also its adverse effects on the environment. After a broad utilization of "*use and throw away*" philosophy, it has been perceived that utilization of resources and resultant contamination levels are unsustainable (Chong et al., 2001). Hendrickson and Horvath (2000) studied the impact of SO_2, Volatile organic compounds, NO_2, toxic releases to the air and harmful waste generated due to the construction activities. Although his findings suggest that construction contribution to harmful waste generation is smaller compared to its share to the GDP in USA.

Not only large quantities of wasteful material reduce the utility of construction operations, they hinder the financial viability as well in the form of cost overruns and excess contingency utilization (Teo et al., 2009). Oko John and Emmanuel Itodo (2013) identified that the material waste contribution to the project cost overrun is between 21-30%. Similarly, material waste contributes 20-30% of project cost overrun (Bossink and Brouwers, 1996). Khanh and Kim (2014) found that the cost overrun due to waste in construction activities is almost 9.36% of total project cost. On the other hand, construction industry can help to conserve the resources by implementing waste management plan. Begum et al. (2006) determined that by implementing waste minimization practices, 73% of total material waste can be recycled and reused. Further, by recycling and reusing the waste generated on site, net benefit of 2.5% of total project budget can be achieved. Thus, the significance of implementing the waste management plan in construction practices cannot be emphasized enough.

Construction industry of Pakistan plays an important role in the development of economy and provides employment opportunities to a large workforce. It shares 2.3% of country's GDP. Khan (2008) states that the construction sector in Pakistan is flourishing as it has grown by 17.2% in 2006-07 against the previous years and the wages have got almost doubled. Azhar et al. (2008) identified top ten cost overrun factors in construction industry of Pakistan. Among them fluctuation in the prices of raw materials, unstable cost of manufactured material and additional work were more significant. These results show the importance of material waste control in construction industry of Pakistan.

The purpose of this research is to quantify the most wasteful building materials during construction operations, investigate the level of wastage in the practice of various subcontracting arrangements, and quantify the contribution of different construction waste materials in project cost overrun. In the end recommendations to control the waste generation will be suggested.

1.2 Problem statement

Most of the building projects suffer from material wastage during construction process due to poor design, improper handling of materials, poor management practices, unskilled labor, etc. (Bossink and Brouwers, 1996). The level of waste varies at different project stages like design, planning, operation and control (Ekanayake and Ofori, 2004). Globally, a lot of studies have been conducted to quantify the material waste in the past few years (Bekr, 2014; Nagapan et al., 2013; Oko John and Emmanuel Itodo, 2013), but a lot more effort is required to quantify the material wastes on sites in Pakistan construction industry. Further, very few studies are present related to the level of material waste with different sub-contracting arrangements and contribution of different material wastes to the project cost overrun. So this research will help quantify the most wasteful materials in the construction industry, their effect on project cost, their relation with different sub-contracting arrangements and strategies reduce them.

1.3 Research objectives

The main objectives of this research are:

- To identify the most wasteful building materials during construction operations
- To investigate the contribution of each material waste in total waste cost and impact of total waste cost as a percent of project cost
- To quantify the level of wastage in the practice of various subcontracting arrangements
- To recommend the solutions to mitigate the waste generation process

1.4 Research significance

This research will focus on identifying the most wasteful materials during building construction process. This is required because of:

- High economic and environmental impacts of material wastage.
- High impact of construction waste on project cost overrun
- Danger of depletion of materials used in construction industry such as sand, timber, gravel, etc.
- These wasteful materials are also harmful for the ground.
- Production of more construction material will be required that will contribute to harmful emissions
- If this material wasting process continues at the same rate in short time there will be no landfill spaces.

Further, research objectives set forth will be helpful determine which materials are most wasteful and contributing to project cost overrun. By implementing proper preventive actions construction waste can be reduced which will ultimately reduce the project cost, improve economy and most importantly reduce the environmental impacts.

1.5 Advantages

- Provide information about most wasteful construction materials so the contractor can supervise those materials properly
- Reduce the environmental impacts as less waste will be generated
- Improve the country's economy
- Improve the efficiency of project
- Improve the project feasibility as reduction of waste will also reduce the project cost

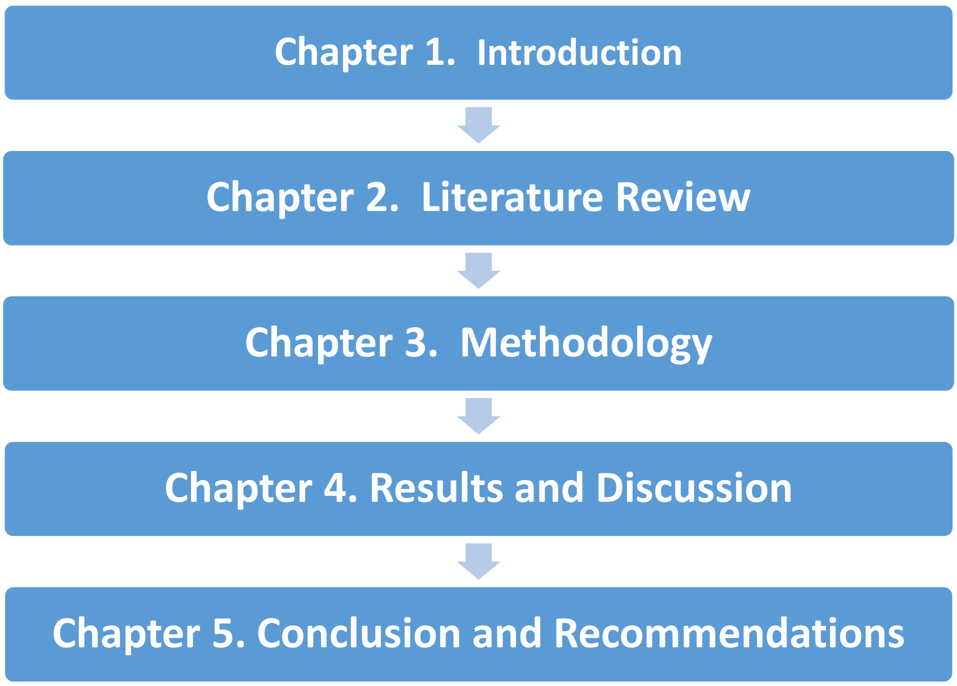
- Reduce the depletion of resources

1.6 Scope of research

This research will mainly focus on semi high-rise buildings used for office commercial and residential purposes. Since facility use does not influence the tendency of waste generation, as many buildings use as available will be considered.

1.7 Thesis organization

This research has been organized into five chapters. An overview of those chapters is given below.



Chapter 1 is “Introduction” includes Background Study, Research Significance, Problem Statement, Research Objectives, Advantages and Scope of Research.

Chapter 2 is “Literature Review” includes Definition of Waste, Types of Construction Waste, Sources of Waste Generation, Wasteful Materials, Effect of Different Sub-Contracting Arrangements on Waste Generation, Effect of Waste on Project Cost Overrun and Environmental Aspects of Construction Waste.

Chapter 3 is “Research Methodology” includes Selection of Materials and Research Method used for this research.

Chapter 4 is “Results and Discussion” describes the detailed findings of this research and comparison with past studies.

Chapter 5 discusses the conclusions of this study and future recommendation are also suggested in the end.

Chapter 2

Literature Review

2.1 Introduction

This chapter presents a detailed review of the research studies already carried out on material wastage, causes of waste, economic befits and impact on project cost overrun in building construction industry.

2.2 Characteristics of construction industry

Construction industry plays a vital role for the economic development of any country. According to DTIE (2009) building construction contributes 5-15% towards GDP of a country. It consumes 40% global energy and provides 5-10% employment opportunities. Construction industry is considered as one of the largest resource consumers (Saraiva and Borges, 2012; Womack and Jones, 1996). Sharma et al. (2011) state that almost 40% of the materials are consumed by building construction activities. Although it is important to complete the projects within time, cost and anticipated quality, cost overrun and material waste are common issues faced by construction work (Teo et al., 2009). Material waste is generated at different stages of the project including design, estimation, planning and construction. Identification of the causes and implementation of proper preventive measures will help to alleviate the consequences (Nagapan et al., 2012; Oladiran, 2009).

2.2.1 Construction industry of Pakistan

Construction industry in Pakistan plays a vital role for the economic growth of the country by decreasing the unemployment. It shares 2.3% of country's GDP. Khan

(2008) stated that it offers jobs to about 5.5% of the total employed labor force or to 2.43 million persons. Construction sector in Pakistan is flourishing as it has grown by 17.2% in 2006-07 against the previous years and the wages have got almost doubled. According to Ali (2006), construction industry of Pakistan is labor intensive. In comparison to other industries, it is considered backward due to the lack of good management practices and modern technologies. Azhar et al. (2008) identified that fluctuation in the prices of raw materials, unstable cost of manufactured material and additional work were significant factors causing cost overrun in the construction industry of Pakistan.

2.3 Definition of waste

Waste has been defined in number of ways. Formoso et al. (1999) defines the waste as any loss resulted by construction activities that causes direct and indirect costs but do not add any value to the product from the customer's point of view. Another simple way to define waste is elimination of activities, roles and resources without reducing the value for the customer (Polat and Ballard, 2004).

2.3.1 Construction waste

Construction waste can be defined as the solid waste coming about exclusively from construction activities while waste generating from demolition, land clearing, earthworks and renovation operations is excluded from the scope (Lau et al., 2008). Begum et al. (2006) define the construction waste as the weight of products and materials generating from construction processes.

2.4 Types of construction waste

Some of the important types of construction waste are discussed briefly in the following paragraphs.

2.4.1 Natural waste

Shen et al. (2000) defined natural waste as the minimum amount of waste that always occurs no matter which type of project it is, called natural waste also known as un-avoidable waste. For example, natural waste for reinforcement is 1.91% in private commercial projects which occurs due to cutting. The waste in which cost of reduction is higher than the cost of its saving is also known as natural or unavoidable waste (Formoso et al., 1999).

2.4.2 Potential waste

The items which have higher differences between maximum and minimum levels of waste and there is large room available to reduce such difference are called potential or avoidable waste item (Shen et al., 2000). For example, formwork waste in private housing projects is 18.21% so there is much opportunity available to reduce it. But Formoso et al. (1999) defined the avoidable waste as the waste in which cost of saving is more than the cost of its reduction.

So, cost effectiveness is the basic criterion to differentiate between avoidable and unavoidable wastes, because if the cost of waste reduction is more than the cost of saving then it is also a waste of money.

2.4.3 Physical waste

It is defined as the loss of construction material that is damaged and cannot be repaired during construction process (Nagapan et al., 2012). Physical waste is further classified into structure and finishing waste.

Structure waste is generated during construction of different structural elements like concrete, steel, bricks, etc. (Poon et al., 2001). Whereas finishing waste is generated in the finishing stage of the building, for example mosaics, mortar, broken tiles, paint, etc. (Poon et al., 2001).

2.4.4 Inert waste

It consists of materials that can be deposited at public filling areas for land reclamation such as concrete, brick, sand, etc. These materials are chemically inactive and less harmful to the ground (Poon et al., 2001).

2.4.5 Non- Inert waste

It consists of materials that are disposed of at landfills as a solid waste like plastics, wood and other organic materials. These materials are chemically active and should be disposed of at landfills (Poon et al., 2001). By sorting waste this way helps to reuse the inert waste at public filling areas while non-inert waste is disposed of at landfills so that less landfill space is used.

2.5 Sources of construction waste

Some of the major sources contributing towards the waste of construction materials are discussed below.

2.5.1 Improper handling of materials

Improper handling of material is found as one of the major sources of construction waste generation (Al-Hajj and Hamani, 2011; Bekr, 2014; Craven et al., 1994; Garas et al., 2001). Improper material handling includes damages during the transportation, unpacked supply and throwaway packaging (Bossink and Brouwers, 1996).

2.5.2 Procurement problems

Craven et al. (1994) have found that procurement methods contribute to waste of construction materials. Major causes involved are ordering errors, and over- and under-ordering (Al-Hajj and Hamani, 2011; Garas et al., 2001). Other causes related to the procurement methods are use of products that are not according to the specifications and lack of chances to order smaller quantities of materials (Bossink and Brouwers, 1996).

2.5.3 Change in design

Bekr (2014) has identified that change in design is a major source of waste generation. If the contractor has already purchased the materials based on the original design, there will be waste if that material is not taken back by the supplier in case of design change. Further, if the structure has already been constructed, design change will definitely generate waste as the applied materials have to be removed due to rework (Love and Li, 2000).

Similar kind of results have been found in other studies that design change and design errors are the major sources of waste generation (Al-Hajj and Hamani, 2011; Bossink and Brouwers, 1996). Al-Hajj and Hamani (2011) identify that design related problems are outside the control of contractors. Important reason can be lack of awareness of construction workforce.

2.5.4 Workforce

Chen et al. (2002) have suggested that behavior of the workforce towards the waste generation is a significant factor. There are some wastes which are avoidable if workers perform their duty carefully. Workers become careless in the absence of proper control and reward system. Three major factors identified are their behavior, enthusiasm and collectivism towards the waste reduction. Results show that group based Incentive Reward Program (IRP) has significant influence in reduction of waste.

Similarly, Kulatunga et al. (2006) have identified that the attitudes of the workforce towards waste reduction are negative in Sri Lankan construction industry. Major factors causing obstruction in the implementation of waste management practices are lack of trainings and negative attitudes of higher management towards the subordinates.

2.5.5 Wrong material storage

Wrong storage of construction material is also an important factor of material waste (Bekr, 2014; Bossink and Brouwers, 1996; Garas et al., 2001). Enshassi (1996) identified that the inadequate stacking of material waste contributes to the material waste. Other possible reasons can be storing the material in wrong place like storing cement in open area where dampness or rain can damage it.

2.5.6 Theft and vandalism

Construction material is also lost due to the lack of proper security. Theft and vandalism are also considered as the sources of waste (Bekr, 2014; Garas et al., 2001).

Major sources of construction material waste identified after thorough literature review are presented in Table 2.1.

Table 2.1: Sources of construction material waste

Sources	Bossink and Brouwers (1996)	Bekr (2014)	Al-Hajj and Hamani (2011)	Garas et al. (2001)	Kulatunga et al. (2006)	Chen et al. (2002)	Saidu and Shakantu (2015)
Design	✓	✓	✓				
Procurement	✓	✓	✓	✓			
Material Handling	✓	✓	✓	✓		✓	
Workforce	✓	✓	✓		✓	✓	
Contract Documents	✓						✓
Theft and Vandalism	✓	✓		✓			

Wrong Storage		✓	✓	✓			
Weather Conditions	✓	✓	✓				
Poor Estimates		✓					✓
Poor site conditions		✓					

2.6 Material specific causes of waste generation

2.6.1 Concrete

Lu et al. (2011) identify the major causes of concrete waste. Most of the time concrete is wasted due to improper formwork, if the formwork is not installed correctly then there will be some leakages. Further, pre-fabricated piles are of standard sizes, usually they are longer than the unknown depth of the foundation, due to which extra part of pile is cut as a concrete waste. Shen et al. (2000) determine that over-ordering due to poor planning is a common cause of concrete waste. It is also generated because of improper handling (Foo et al., 2013). Most of the time, site managers also order extra concrete so that concrete pouring process is not interrupted (Formoso et al., 2002).

2.6.2 Steel reinforcement

Foo et al. (2013) identify that poor design is a significant cause of steel waste. Due to poor design in terms of standardization, steel bars have to cut at non-optimized lengths and unusable pieces of steel bars are produced. Improper handling is also found major reason of waste generation. Lu et al. (2011) find that metal cutters used by the inexperienced labors are main cause of steel waste on site. Prefabricated pile is also causing reinforcement waste because when pile is installed, some of its part is left out above the ground level which is cut off later as a waste of concrete and steel. Shen et al. (2000) describe that the damages during the handling of steel bars and rusting due to improper storage are major causes of steel waste.

2.6.3 Timber

The main reason of timber waste is the formwork. It is said that formwork can be re-used almost 8-12 times before it is discarded (Poon et al., 2004). But in actual it is discarded after re-use of 5-6 times (Lu et al., 2011). Second main reason of timber waste is cutting (Lu et al., 2011; Poon et al., 2004; Shen et al., 2000). Third main reason can be improper storage of timber without any protection from climatic deterioration (Lu et al., 2011).

2.6.4 Cement

It is difficult to quantify the cement waste because it is used as a component of mortar, concrete, etc. Formoso et al. (2002) describe some of the major causes of cement waste. They have identified that improper handling and transportation of mortar and concrete are major causes of its waste. Excessive use of mortar in joints is also responsible for cement waste in construction industry.

2.6.5 Bricks

There are multiple causes of brick waste in our construction industry. Lu et al. (2011) have found that rework due to design change is an important cause of brick waste. Cutting of bricks due lack of modular coordinated design is the most important cause of waste generation (Formoso et al., 2002; Forsythe and Máté, 2007; Lu et al., 2011). Improper handling and transportation also contribute towards the brick waste (Formoso et al., 2002).

Forsythe and Máté (2007) have performed a detailed study on the causes and remedies for brick waste. Some of the major causes they found were ordering mistakes, control issues, delivery waste, cut bricks, stacking breakages, use of bricks for false work, bricks contaminated by dirt and theft. They identified that 75% of brick waste was generated due to the cutting of bricks. But brick waste can be reduced by making some changes in brick design.

2.6.6 Mortar

Lu et al. (2011) have found that mortar waste is caused by plastering and masonry work. But its waste is reduced as mortar that is dropped on the floor during its application, can be reused. In the absence of proper management waste generation rate of mortar is increased. Most of the mortar is lost during its transportation (Formoso et al., 2002; Poon et al., 2004). Now a days, due to the use of "*ready to use mortar mix*", generation of mortar waste has been reduced (Formoso et al., 2002).

2.6.7 Tiles

Major causes of tile waste are poor handling, transportation, loading, unloading and storage problems (Poon et al., 2004). Formoso et al. (2002) have identified that lack of planning and coordination in the supply of materials are causing waste generation. Most of the waste is generated due to the negligence of workforce as they do not try to re-use the cut off piece. Modular coordinated design is also an important cause of waste due to which tiles have to cut into pieces to meet the requirements.

2.6.8 Packaging waste

Packaging waste is generated when materials are delivered in proper packing like tiles, cement, etc. Packaging waste is found as a minor contributor towards waste generation in construction industry (Begum et al., 2006; Nagapan et al., 2013). When a material is used, its packing is left on site as a waste (Foo et al., 2013).

2.6.9 Paint

Paint is one of the most important building material, used during finishing works. Babatunde (2012) found that paint was not among the highest waste materials in construction industry of Nigeria. It was found the second lowest waste generation material. The major reason of waste he found, was the loss of paint during its application. It is mainly due to the negligence of the workers.

2.7 Effect of different sub-contracting arrangements

A quantitative research was conducted by Tam et al. (2007) in Hong Kong construction industry, who found the level of wastage with different sub-contracting arrangements. Results showed that L-M sub-contracting arrangements had generated least waste as compare to D-L and L-O. Results are shown on a Table 2.2.

Table 2.2: Material waste with different sub-contracting arrangements

Trade	Sub-Contracting Arrangements		
	L-M	D-L	L-O
Tile	6.62%	6.67%	15.58%
Brick	5.87%	6.02%	8.90%
Formwork	4.97%	_____	20.00%
Reinforcement	4.11%	5.00%	7.70%
Concrete	4.48%	4.86%	8.99%

Similarly, Oko John and Emmanuel Itodo (2013) have also conducted a research on material waste with different sub-contracting arrangements in Nigerian construction industry. Data was collected from 56 building project sites. Results show that plaster, timber, sandcrete blocks, concrete and ceramic tiles are wasteful materials. Further, L-O is the most waste generating sub-contracting arrangement as compare L-M and D-L.

The main reason is that the Sub-contractor bears cost of material waste in case of L-M while in other two cases it is borne by the main contractor. Therefore, they work carefully in case of L-M arrangement so that less material is wasted, even they try to re-use the material that is wasted at first place like reinforcement pieces.

Saunders and Wynn (2004) have studied the awareness and understanding level of labor only subcontractors about waste, its causes and financial responsibility of its control in UK construction industry. Results have shown that there is general awareness of waste as an issue among subcontractors. They consider that major causes of waste generation are poor design, storage problems, loading and unloading of materials but they consider their workmanship to be the least cause of waste. Further, subcontractors are willing to take financial responsibility of waste generation but at the same time they want some share as a reward in case of saving due to less waste generation. It is also found that sub-contractors want to be educated to reduce the wastes on site.

2.8 Quantitative assessment of waste generation

According to a report by Hendriks and Pietersen (2000), construction and demolition waste comprises up to 35% of total solid waste in the world and most of it, is dumped in landfills and inappropriate places. Construction waste also constitutes almost 29% of total solid waste in United States of America (Rogoff and Williams, 2012). According to the US Environmental Protection Agency USEPA (2003), 170 million tons of construction and demolition waste was generated in the USA in 2003. Similarly, two billion tons of construction waste is generated in European Union every year (DEFRA, 2007).

Lu et al. (2011) identify that there have been many studies which measure construction waste generation rates by adopting one of the following measurement methods:

- As a percent of purchased material
- As a percent of material required by designed
- Weight of material per unit area (kg/m^2)
- Volume of material wasted per unit area (m^3/m^2)

Table 2.3: Different waste measurement methods used in previous studies

Reference	Country	Measurement Method	Overall Methodology
Bossink and Brouwers (1996)	Netherlands	As a percent of purchased/used material	Materials were sorted and weighed. Wastage was quantified as a percent of total waste as well as percent of purchased materials.
Tam et al. (2007)	Hong Kong		Data was collected through direct observation and interviews. Wastage was calculated by a formula: Wastage (%) = [(Mp--Mu]/Mu * 100
Formoso et al. (2002)	Brazil	As a percent of designed/estimated material	Data was collected through direct observation and contractor's record. Wastage was calculated by a formula: Wastage= [(M_p-Inv)-M_d]/M_d, where M_p is amount of purchased material, M_d is amount of design material and Inv is final inventory of material.
Chen et al. (2002)	Hong Kong		Data was collected through bar-coding system which keeps the record of each group. Material waste is calculated using formula: dQ= Q (estimated) - Q (delivered) - Q (returned).
Lau et al. (2008)	Malaysia	Weight/Area	Waste was quantified as tons per hectare.
Lu et al. (2011)	China		Materials are sorted then weighed separately. Waste was measured as w/A where w= weight and A=Gross floor area.
Foo et al. (2013)	Malaysia	Volume /Area	Rectangular and pyramidal shapes are used to measure volume (m3) of wasteful materials. Then wastage of each material is measured as a percent of total waste.

2.8.1 Quantification of material waste

A recent quantitative study has been conducted by Nagapan et al. (2013) in the Malaysian construction industry. They found that timber (50%) was the most wasteful material followed by bricks (22%), packaging (16%), concrete (9%), mortar (2%) and metals (1%). Bekr (2014) has conducted a qualitative study in Jorden construction industry and found the most wasteful materials are sand (20.98%), timber (19.49%), cement (18.34%), concrete blocks (17.05%), steel reinforcement (16.91%), concrete (16.76%) and ceramic tiles (15.57). Results of different quantitative studies are presented in Table 2.4 and Table 2.5 while results of Qualitative studies are presented in Table 2.6.

Table 2.4: Material waste as a percentage of purchased or designed materials

Materials	Bossink and Brouwers (1996)	PINTO (1989)	Soibelman et al. (1994)	Pinto and Agopayan (1994)	Formoso et al. (2002)
Stone Tablets	9.00%	-	-	-	-
Piles	5.00%	-	-	-	-
Concrete	3.00%	1.00%	12.00%	2.00%	-
Sand	1.00%	28.00%	31.00%	28.00%	45.80%
Tiles	10.00%	-	-	9.00%	-
Mortar	10.00%	50.00%	48.00%	46.00%	91.20%
Bricks	6.00%	11.00%	23.00%	12.00%	30.00%
Reinforcement	-	21.00%	16.00%	26.00%	19.10%
Cement	-	25.00%	46.00%	33.00%	84.10%
Pre-mixed Concrete	-	-	-	-	13.20%
Blocks	-	-	21.00%	-	26.70%

Table 2.5: Material wastes as percent of total waste generated on site

Material	Foo et al. (2013)	Asaari et al. (2004)	Lau et al. (2008)	Nagapan et al. (2013)	Lu et al. (2011)	Kofoworola and Gheewala (2009)	Begum et al. (2006)
Concrete	7.50%	25.74%	13.8%	9.00%	22.7%	23.00%	33.00%
Sand	-	-	-	-	-	-	13.50%
Tiles	-	2.94%	-	-	-	-	-
Mortar	-	-	-	2.00%	6.10%	-	-
Packaging Material	20.00%	-	-	16.00%	-	5.00%	0.05%
Bricks	21.00%	12.91%	13.70 %	22.00%	7.10%	23.00%	1.16%

Metal	-	10.16%	3.0%	1.00%	0.73%	1.00%	1.00%
Wood	49.00%	46.67%	69.5%	50.00%	29.7%	14.00%	5.00%
Reinforcement	2.50%	-	-	-	-	-	-
Plastics	-	1.58%	-	-	-	-	-
PVC Pipes	-	-	-	-	0.58%	-	-
Miscellaneous (mix of brick, concrete, metal that it cannot be sorted separately)	-	-	-	-	33.0%	26.00%	-
Aggregate	-	-	-	-	-	-	33.00%
Gypsum	-	-	-	-	-	6.00%	-
Insulation	-	-	-	-	-	2.00%	-
Paper	-	-	-	-	-	-	-
Soil	-	-	-	-	-	-	13.50%
Roofing Materials	-	-	-	-	-	-	0.20%

Table 2.6: Material waste (Qualitative studies)

Material	Bekr (2014)	Poon et al. (2004)	Tam et al. (2007)	Al-Hajj and Hamani (2011)	Babatunde (2012)	Kulatunga et al. (2006)
Stone Tablets	15.14%	-	-	-	-	-
Concrete	16.76%	5.00%	8.99%	4.10%	14.13%	-
Sand	20.98%	-	-	-	-	7.00%
Tiles	15.57%	8.00%	15.58%	7.40%	21.38%	6.00%
Mortar	-	3.00%	-	-	14.91%	7.00%
Packaging	-	-	-	16.30%	-	-
Bricks	-	3.00%	8.90%	11.30%	14.15%	8.00%
Metal	-	-	-	3.90%	-	-
Wood	19.49%	-	20.00%	13.90%	-	-
Reinforcement	16.91%	5.00%	7.70%	-	19.03%	8.00%
Cement	18.34%	-	-	7.80%	-	6.00%

Blocks	17.05%	-	-	-	-	-
Paint	-	-	-	-	12.95%	5.00%
Plastic pipes	-	-	-	-	15.70%	-
Ceiling Boards	20.70%	-	-	-	15.70%	-
Insulation	-	-	-	3.80%	-	-

2.9 Material waste impact on project cost overrun

Material waste in building construction industry is a major contributor towards project cost overrun (Teo et al., 2009). Oko John and Emmanuel Itodo (2013) have identified that concrete, mortar, sandcrete blocks and timber are the most contributing materials towards the project cost overrun. Contribution of different material waste to project cost overrun is 21-30% in Nigerian construction industry. There is not a single material identified, contribution of which is less than 20% in project cost overrun.

A study was conducted by Bossink and Brouwers (1996), who determined the contribution of different material waste as a percent of total waste costs. Stone tablets, with a contribution of 26%, were found major element contributing towards the project cost overrun followed by piles (13%), roof tiles (13%), sand-lime elements (8%), concrete (7%), mortar (5%) and bricks (3%).

One of the most significant source of construction waste generation is rework. Major causes of rework are design change, design error and construction change (Love and Li, 2000). Rework cost varies from 2 to 6 % of the contract amount in commercial, industrial and residential projects (Josephson and Hammarlund, 1999). Love and Li (2000) have identified that rework costs are 3.15 % and 2.40% of the contract values in residential and industrial projects respectively. Similarly, Hwang et al. (2009) have identified that rework costs of light industrial, infrastructure, buildings and heavy industrial are 9.3%, 5.7%, 4.6% and 4.4% of the contract value respectively. On average rework cost is almost 5% of the total project cost.

But construction industry can help to conserve the resources by implementing waste minimization practices. Chen et al. (2002) have studied the effect of group based incentive reward program (IRP) by comparing two similar projects. Both residential projects have 34 storeys and involved same number of workers. Team A has not adopted IRP technique during its operation while Team B did. At the end of project completion, it was found that Team A has wasted extra amounts of materials valued at US $ 95,890 while Team B has saved US $ 90,429.

Similarly, Begum et al. (2006) have identified that construction industry can save up to 73% of materials through implementing proper waste minimization techniques like reusing and recycling. Overall construction industry can achieve net benefit of 2.5% of total budgeted cost. Thus, the significance of implementing the waste management plan in construction practices cannot be emphasized enough.

Research Methodology

To achieve the set objectives, this research is carried out in three stages, as shown in Figure 3.1.

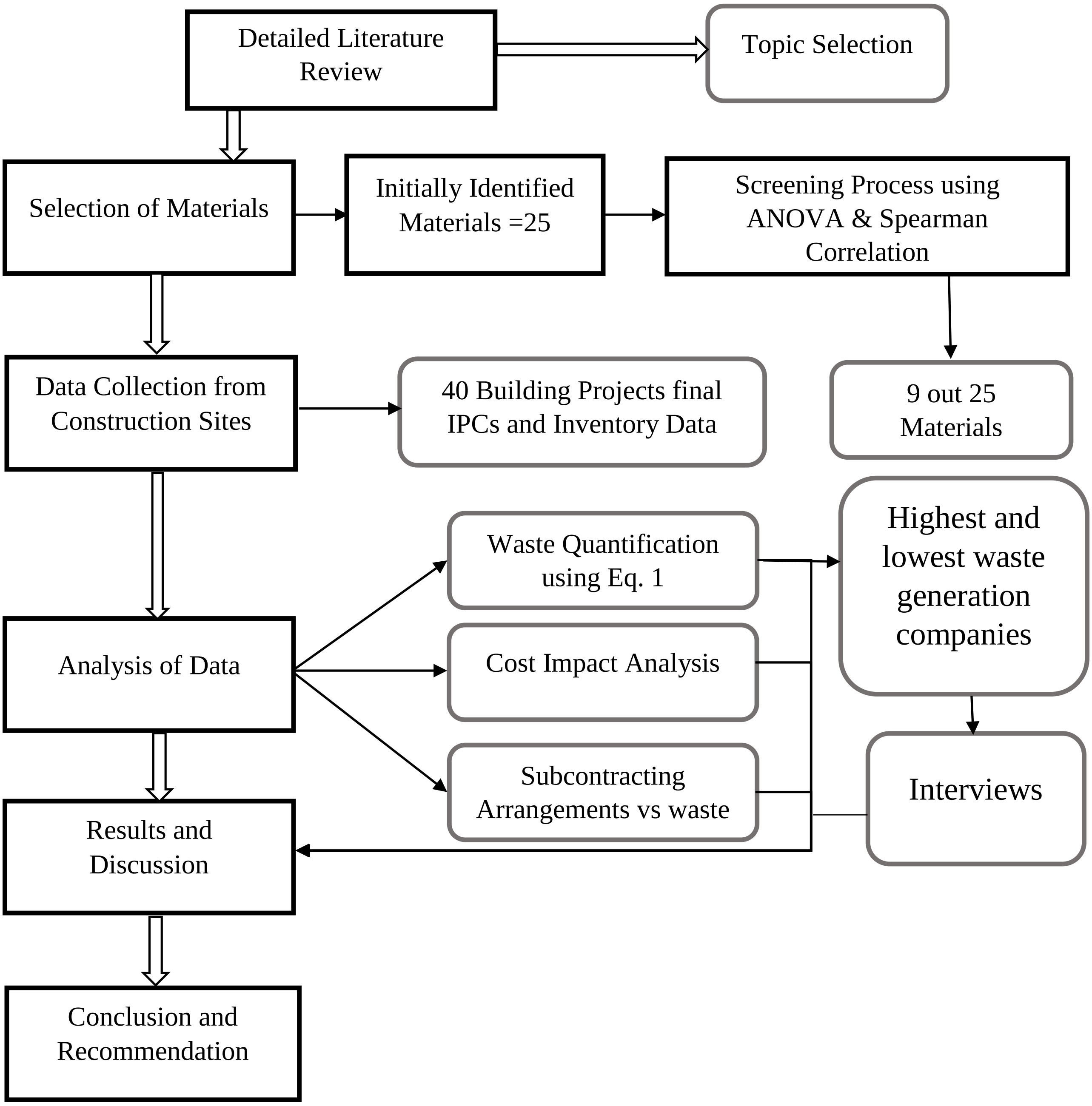


Figure 3.1: Flowchart of research process

3.1 Selection of materials

The first stage focused on selecting the materials for which wastage data should be collected. The materials were to be selected from a total of 25 materials identified from literature. This screening was necessary because otherwise it is difficult to monitor the waste of each material on site and a proper methodology had to be adopted to shortlist the most wasteful materials. Also, all the materials do not necessarily warrant such detailed assessment owing to their lower impact.

For material selection, a criterion was established which includes frequency of material appearing in different studies (Φ), waste percent (ι) and cost impact (κ) of each material. To avoid any bias, an equal weight of 33% was given to all three criteria and their values were normalized. The mathematical synthesis of this criteria given in Equation 1 where σ represents the total score, $\Phi\omega$ is the weight of frequency, $\iota\omega$ weight of impact, $\kappa\omega$ is the weight of cost, Φn is the normalized frequency count, ιn normalized impact count and κn is the normalized cost count.

$$\sigma = \Phi\omega * \Phi n + \iota\omega * \iota n + \kappa\omega * \kappa n \qquad \text{Equation 1}$$

To account for the cost, two schedules of rates were used including Military Engineer Services Pakistan, (MES, 2014) and Architectural Services Department Hong Kong (ASD, 2013). Then score of each material was determined by substituting their values in Equation 1.

It is important to note that literature containing both quantitative and qualitative studies was used and the total score was separately calculated for both categories. So, to check the consistency of results obtained through quantitative and qualitative studies, ANOVA was applied. It was found that there is no statistically significant difference among the ranking of top nine out of 25 waste materials appeared in both quantitative and qualitative studies and correlation between the rankings through both studies was 60%, which is moderate.

3.2 Sample size

To enhance the reliability and generalizability of findings, it is important to collect data from a representative number of projects. For this purpose, past studies were reviewed to identify their sample size, as synthesized in Table 3.1. It can be seen that for quantitative studies based on primary data, a maximum of 40 projects have been considered as studied by Forcada et al. (2017). Otherwise, the number of projects range between 1 and 30. In order to ensure reliable findings, the current study has gathered data from a total of 40 building projects. Other than being representative in number, the nature of these projects had also to be representative of building sector. Thus, the selected projects are of mid-rise commercial and residential building, with number of floors ranging between 2 and 8. The selected projects were relatively recent; they were started and completed between the years 2011-2017.

Table 3.1 Sample size of past studies

Reference	No. of Projects	Study Type	Data Type
Gavilan and Bernold (1994)	05 and 69	Quantitative	Secondary data
Bossink and Brouwers (1996)	05	Quantitative	Secondary data
Mcdonald and Smithers (1998)	01	Quantitative	Primary data
Asaari et al. (2004)	30	Semi Quantitative	Primary data
Tam et al. (2007)	19	Quantitative	Primary data
Lau et al. (2008)	05	Semi Quantitative	Primary data
Lu et al. (2011)	04	Quantitative	Primary data

Foo et al. (2013)	02	Quantitative	Primary data
Forcada et al. (2017)	40	Quantitative	Primary data

The waste data was extracted from Interim Payment Certificates (IPCs) and inventory (purchased material) data of each of these projects. These IPCs and inventory data was collected from quantity surveyors and materials engineers. The data was mainly in raw form, therefore multiple operations were performed to make it useful for any analysis.

3.3 Method for quantitative assessment of material waste

After shortlisting the most wasteful materials, the quantification methodology was selected. Reviewing and screening various already established quantification systems, a research methodology similar to Tam et al. (2007) has been adopted for this research. Interim Payment Certificates (IPCs) and inventory (purchased material) data of each of these projects was collected then material waste was quantified by using Equation 2 which quantifies percent waste as a function of purchased and used materials.

$$Material\ Waste\ (\%) = \frac{[(M\ purchased - INV) - M field\ measurements]}{M\ field\ measurements}\ x\ 100 \quad \text{Equation (2)}$$

For a reliable cost related assessment, two different schedules of rates, namely MES (2011) and MES (2014), were used to minimize the effect of inflation with time in the unit cost of selected materials. Using these schedules, waste cost of each material was estimated by multiplying its waste quantity with corresponding unit cost. Afterward, contribution of each material in total waste cost was calculated. Then total waste cost impact of selected materials was determined as a percent of project cost. Along with the IPCs and inventory data, information regarding the subcontracting arrangement for each selected material was also gathered as Annexure-II in order to analyze the effect of different subcontracting arrangements on waste generation.

3.4 Structured interviews

After waste quantification of all 40 building projects, the lowest and highest waste generating companies were identified where maximum number of materials are used. Project managers of these companies were interviewed to find out the major reasons of this difference in performance. A structured interview as Annexure-I was conducted to collect information on waste generation and its control. A two-part interview form was developed for this purpose; the first part consisted of general information regarding project, company and the respondent while the second part contained multiple questions regarding the reasons of waste generation and their organizational practices to control its amount. Also, the project managers were requested to provide suggestions for further improvement.

Chapter 4

Results and Discussion

4.1 Quantification of material waste

Based on waste data of 40 projects, Table 4.1 synthesizes the findings of material wastage on site. It is found that wood (36.2%) and sand (28.8%) are the most wasteful items while concrete blocks (14.5%), bricks (13.7%), ceiling boards (13.6%), tiles (13.5%) and aggregate (12%) are the medium ones. Apart from them, cement (5.4%) and steel (4.5%) are found as the least wasteful materials but despite that they cannot be ignored due to use of various resources for their production from cradle to gate. Moreover, cement has been found a major source of CO_2 emission during its production which is an important concern in efforts to address the climate change (Gregg et al., 2008).

Table 4.1 Material waste as a percent of used material

Sr. No	Material	Average Waste	Ranking
1	Wood	36.2%	High
2	Sand	28.8%	
3	Concrete Blocks	14.5%	Medium
4	Bricks	13.7%	
5	Ceiling Boards	13.6%	
6	Tiles	13.5%	
7	Aggregate	12%	
8	Cement	5.4%	Low
9	Steel	4.5%	

These findings tend to support earlier studies; wastage of sand (28.81%) is very close to the findings of a qualitative study by Bekr (2014) where major reasons of such waste were described as change in design causing rework and wrong storage causing material abandoning on site as a waste. Sand was also found having a waste of 28% in previous quantitative studies (Pinto and Agopayan, 1994; PINTO, 1989) where it was measured as a percent of purchased material. Similarly, Chen et al. (2002) and Pinto and Agopayan (1994) found waste of wood at 45% and 32% respectively which is very close to the finding of this study. But the findings of Al-Hajj and Hamani (2011), who quantified waste in UAE construction industry, rate wood as low as 13.9%, which is different from the results of current study mainly due to the difference of methodology. Their study was based on qualitative data in contrast to quantitative method followed in the current study. Also, other major reasons for this difference can be change of practices and operations in various construction industries. In that, a major cause is the skills and behavior of labor as labor in the Pakistani industry is predominantly unskilled as well as seasonal (Shah, 2010) and in the absence of proper management of resources, efficient waste control is not possible (Arshad et al., 2017). Further, Kulatunga et al. (2006) found that labor's attitude towards waste control is vital. It was determined when labor did not get incentives for their efforts to control waste, ultimately its quantity increases (Chen et al., 2002). Pakistan's construction labor is one of the lowest paid human resources in the country and a major portion of the construction industry operates less formally (Riaz et al., 2015). Therefore, waste control and optimization practices are quite unheard of in the local context.

A recent qualitative study by Arshad et al. (2017) in the local context, where data was collected through questionnaires and interviews from field experts, found the waste of bricks (6.82%), tiles (6.68%) , wood (6.41%) and ceiling boards (4.32%) as quite low and completely different from the findings of this research. The difference between opinion of filed experts and findings of this research is more than double in case of bricks, tiles and ceiling boards but in case of wood this difference is almost 6 times. As in this research, data was collected from recently completed building projects, the findings are more reliable to assess the actual condition of waste on sites. Not only this, it also underlines the fact that perception of industry experts and practitioners regarding waste is significantly different from the actual conditions. It is quite alarming because, based on their lower waste perception, practitioners tend to make lesser efforts to control it. This perception needs to change in the light of quantitative data so that they may be able to make significant efforts to control material waste because there is a significant potential to do so.

In terms of overall waste, it is important to note that though sand is not the costliest construction material, its sustainability implications are too high to be ignored it due to its lowest financial appeal. Excessive use of sand due to its higher waste leads to its extraction in large quantities. As a result, process of sand mining causes destructive impacts on public assets and increases the stress on commercial and noncommercial natural resources (Ashraf et al., 2011). Acid mine drainage is one of the techniques used for sand extraction which has serious threats for water bodies. It may have destructive impacts on streams and aquatic life where water may runoff into the ground and affect human life as well when used for drinking purpose (Saviour, 2012).

Further, the data was analyzed to identify the most waste generating (Company A) and least waste generating (Company B) organizations. Interestingly, both these companies are categorized into C-A by Pakistan Engineering Council (PEC), which a professional and statutory federal institution for accreditation and regulation of engineers in the country. The category C-A refers to no financial limit on the size of project these organization can bid for (PEC, 1976), which is a measure of the size and financial strength of a construction company. Overall, it is found that material was used as high as 154% in case of Company A and as low as 104% by Company B with respect to the quantities derived from IPCs. The interview findings show that there are four major reasons behind this significant difference as presented in Table 4.2.

Table 4.2 Reasons for difference in waste generation rate

Sr. No	Strategies	Company A	Company B
1	Procurement panning	Properly planned	No planned
2	Reuse of waste	On a large scale	On a small scale
3	Labor incentive	On a smaller scale	No labor incentive
4	Perception of waste control	Present practices should be improved	Efforts will not make a big difference

It can be observed that Company A adopted proper planning for procurement of materials to avoid their under- and over-ordering while Company B was lacking in this area. To make matters worse, Company B resorted to under-ordering of materials as the idea was to minimize waste by avoiding any kind of over-ordering. However, past studies have proved that both under- and over-ordering cause material wastages (Al-Hajj and Hamani, 2011; Garas et al., 2001). In case of under-ordering, multiple procurement cycles have to be run, hence unnecessary movement due to loading and unloading will cause waste. The second major reason identified was reuse of waste materials; Company A reported to reuse waste materials on a much larger scale in comparison to Company B. According to EU construction and demolition waste management protocol 2020, the proposed strategies will be helpful to achieve target of 70% of C&D waste being recycled by 2020, closing the loop of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy (Commission, 2016). It is reported that the construction industry can save up to 73% of materials by implementing proper waste minimization techniques like reusing and recycling (Begum et al., 2006). Thus, material reuse definitely has a significant effect in waste control. The third reason was labor incentive; it is already established that a positive reinforcement in the form of incentive has a noticeable impact in waste control. The same was observed in case of Company A. Another important difference of strategy was the flexibility and urge to improve in behavior of Company A. Despite its lower waste rate in comparison to others, respondents belonging to Company A were still of the opinion that the waste they generate must be controlled by improving the current practices. On the contrary, Company B showed a resistant approach and were complacent of their performance. Resistance to change is a significant barrier to improvement.

In terms of overall result, 123% more material was used on average than the actual work achieved on site, which is an alarming number from sustainability point of view. Due to the non-availability of larger number of resources, long term adverse effects of these wastes not only on the economy of country but also on the environment and shortage of landfilling areas, it becomes necessity of time to reduce these waste to their minimum level (Yeheyis et al., 2013).

4.2 Comparison of waste quantity and its impact on cost

To evaluate if there is a difference in ranking of selected materials based on their quantity and cost, and how much contribution each material has towards total waste cost, the gathered data has been further analyzed based on the market rate system. As given in Table 4.3, the findings determine that the trend of waste of materials and their impact on cost is not necessarily the same. Such that only wood is found as both most wasteful material (25.44%) and the highest contributor (21.02%) to waste cost. This finding emphasizes the significance of this material and effective management of its use and waste generation. Not only wood has implications on the immediate cost and efficiency of a construction project, the source of this material and its harvesting pose severe sustainability concerns. According to report by Morris (2008), major impacts of construction and demolition wood wastes include climate change, acidification, human health damage from toxics and carcinogens and damage of ecosystems from toxics. Therefore, not only reducing wood waste is necessary but also reuse is inevitable for the sustainable environment as wood reuse is found to have the highest environmental benefit of $100 per ton. One of the major causes of wood waste is cutting (Lu et al., 2011; Poon et al., 2004; Shen et al., 2000) as most of the wood is wasted during manufacturing of its products like doors, kitchen cabinets, beading, etc. Another main reason can be improper storage of wood without any protection from climatic deterioration (Lu et al., 2011).

However, the trend of high contribution to total waste and its cost does not continue for other materials. Such as, sand has the 2nd highest waste rate but its contribution to cost is the lowest (3.79%). But, as previously discussed, despite its low cost, its sustainability implications warrant a smart and effective use of this rapidly depleting natural material. Further, concrete blocks are also found in the top three most wasteful materials but have low impact on cost. However, the constituent materials of concrete blocks, including cement, aggregate and sand pose notable concern. Such that cement, though being one of the lowest wasteful materials, has a significant cost impact. Not only its cost is of concern, the production method adopted in cement manufacturing relies upon use of natural resources including mainly calcium carbonate, silica, alumina and iron oxide. Mehta (2001) determined that one-ton production of cement accounts for 4 GJ energy. Further, for production of 1.6 billion tons of cement, 7% of global CO_2 goes into the atmosphere which definitely has severe impact on environment. Therefore, control of cement waste on sites cannot be emphasized enough.

Similarly, steel, which is the lowest wasteful material, is found at 3rd place in terms of its contribution in total waste cost. Once again, other than cost, the sustainability concerns of steel production warrant an effective waste management. Also, brick is placed in the top materials with the highest waste rate as well as impact on cost. Rework due to design change is an important factor of brick waste (Lu et al., 2011). Cutting of bricks because of lack of modular coordinated design is the most important source of its waste generation (Formoso et al., 2002; Forsythe and Máté, 2007; Lu et al., 2011). Further improper handling and transportation also contribute towards its waste (Formoso et al., 2002). Remaining materials like tiles, ceiling boards and aggregate are found in the middle of the list, their contribution in waste and cost is medium.

Table 4.3 Comparison of waste quantity and cost

Material	Contribution to total waste		Contribution to waste cost	
	Rank	Percentage	Rank	Percentage
Wood	1	25.44%	1	21.02%
Sand	2	20.24%	9	3.79%
Concrete Blocks	3	10.22%	6	8.18%
Bricks	4	9.64%	2	19.34%
Ceiling Boards	5	9.55%	7	4.84%
Tiles	6	9.5%	5	8.88%
Aggregate	7	8.43%	8	4.03%
Cement	8	3.8%	4	12.53%
Steel	9	3.18%	3	17.39%

Similar kind of research was conducted by Bossink and Brouwers (1996) for Dutch construction industry where it was found that against a percent waste of 10% and 6% for tiles and bricks, the percent contribution was 13% and 3% respectively in total waste cost. On the contrary, this study found, against a percent waste of 9.50% and 9.64%, tiles and brick contribute 8.88% and 19.34% respectively in overall waste cost. It is interesting to note that though bricks are wasted 60% more in the local construction industry, but their percent contribution to total waste cost is more than 6 times that of

Dutch construction industry. It is due to a fairly larger unit cost of brick in the local context when compared to The Netherlands. In addition, other reasons are change of construction practices, methodology to collect waste data and behavior of labor as already established. Other materials of that research were not the same as in this study, so results cannot be compared.

So, wood and bricks are ranked at top in the order in terms of waste rate and their impact on cost. Although these material wastes and cost impact are high but others cannot be ignored because we have to control wastage each of these materials either it is costly or its waste rate is high as the purpose here is to make our industry sustainable not only economy wise but also environmental perspective as well.

Further, to check the impact of material wastage on cost, it is found that total waste cost varies from 1.34% to 3.32% of total project cost. On average, this amount is 2.37% of total project cost, which is a significant number. This waste cost was found as millions of currency units for larger projects. In another study, Begum et al. (2006) found that the construction industry can save up to 2.5% of total budgeted cost as a net benefit. Thus, the average cost of waste generation can be entirely rescued through effective waste management. Therefore, contractors must practice waste minimization methods to enhance their profits and overall economic performance of the construction industry. Ultimately, it will increase project feasibility and reduce utilization of resources on sites.

4.3 Effect of sub-contracting arrangements on waste

It is a common practice to sublet parts of work in the construction industry. The idea is to award the specific tasks to the specialized contractors with expertise to perform those works more efficiently. Such improved efficiency allows the subcontractors to complete project activities in time. But on the other hand studies have shown that different subcontracting arrangements significantly affect the waste generation. Tam et al. (2007) identified that L-M is the least waste generating arrangement while D-L is the medium one and L-O is the most waste generating arrangement. For example, concrete waste with L-M is 4.48%, D-L is 4.86% and L-O is 8.99% as shown in Table 2.2. Similar kind of results were also found by Oko John and Emmanuel Itodo (2013) in a qualitative research that L-O was the most wasteful subcontracting arrangement while L-M the least one. Like other construction industries, it is a common practice in Pakistani industry where contractors prefer to hire subcontractors to execute most of the project parts. Therefore, it was deemed necessary to examine the effect of subcontracting arrangements on waste generation. In doing so, the respondents were asked to reveal the subcontracting type opted for particular materials. Results of this study are shown in Figure 2 where it can be seen that D-L generated minimum waste in comparison to L-O subcontracting arrangements. This is in line with past studies. It can be seen that cement, sand and aggregates are the materials where its effect is significant with a difference of 3.5%, 6.2% and 3.8% respectively.

Mostly these basic materials are frequently used in composite materials like mortar, concrete and plaster. So, there is a high potential to reduce waste of these material when L-O arrangement is adopted for such kind of work items. Major reason for more waste generation with L-O in comparison to D-L is due to the fact that cost is borne by main contractor. Labor are only concerned to complete their work as soon as possible because they do not have any kind of incentive to reduce these wastes.

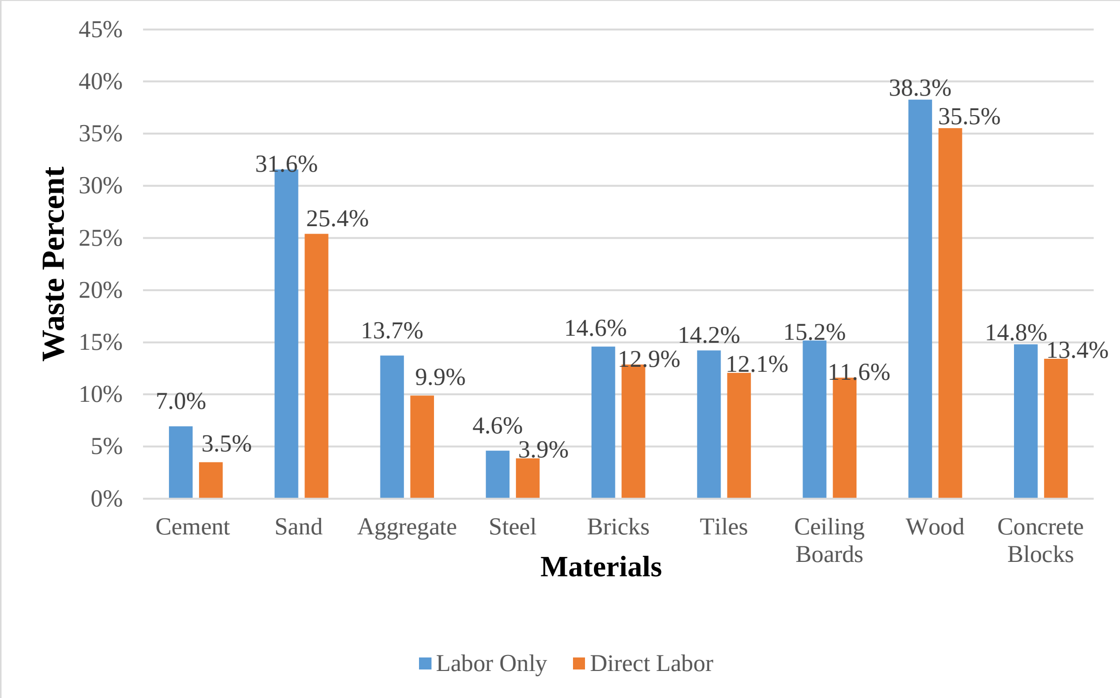


Figure 4.1 Effect of subcontracting arrangement on waste generation

On the other hand, main contractor's labor keeps in mind the profit of their company and perform their duty in a professional way by reducing waste. Another finding of this research is that most of the time wood, ceiling board and tile work is performed through L-M subcontracting arrangement. While for other items like steel, bricks, concrete, mortar and plaster, either L-O or D-L is preferred. This may be due to the fact that wood, tiles and ceiling boards are more wasteful materials and special expertise are required to perform these tasks.

Chapter 5

Conclusions and Recommendations

5.1 Introduction

This chapter closes the study with final remarks. It describes conclusion, recommendations, limitations and areas for future research in detail.

5.2 Conclusions

Based on the need to control the material waste during construction activities, this paper identified wood, sand, concrete blocks and bricks as the most wasteful materials while the least wasteful materials are cement and steel. But this trend changes when the cost impact of selected materials is examined where wood, bricks, steel and cement have the highest contribution in total waste cost while sand impacts has the lowest impact due to its low unit cost. Overall, wood is the only material which has the highest waste rate and impact on project cost. Moreover, in terms of subcontracting arrangements, L-O is found to generate more waste in comparison to D-L. Since this effect was significant in case of cement, sand and aggregate, special care must be taken while selecting subcontracting arrangements for execution of different items of work.

5.3 Recommendations

All these material wastes must be controlled regardless of their impact on cost. These wastes should be stopped by implementing waste management plans. There is always some natural waste, due to which reuse and recycling must be encouraged. Construction industry can save net benefit of almost 2.5% of total budgeted cost by reusing and recycling the waste materials (Begum et al., 2006). Governments should also take actions to control construction waste by introducing national policies. Some of the guidelines identified through interviews from field experts and literature to control waste on sites are given below

- One way to achieve better waste management is through enforcement on contractors to submit a waste management plan along with other documents during procurement stage.
- Construction companies having trained labor should be preferred and such clauses must be incorporated into the procurement regimes. This will encourage companies to develop reduce, reuse and recycle culture in their organizations.
- Incentive reward programs can also be introduced; there is enough evidence to their effectiveness in not only reducing waste generation on sites but also net cost savings (Chen et al., 2002).
- Adopt adequate subcontracting arrangement to execute specific task in a project.
- Arranging proper storage place.
- Creating awareness of material waste impact on environment.
- Arrangement of proper security at site.
- Proper handling of material on site.

5.4 Limitations

Waste is quantified by collecting data only from midrise residential and commercial building projects.

5.5 Future research recommendation

- Waste quantification of high rise buildings and its comparison with midrise building projects.
- Waste management plan must be developed and implemented on construction projects (An action research)

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Annexure-I

Interview Performa

Section-I

1. Name: ____

2. Email: ____

3. Contact Number: _______________________________________

4. Name of Project: ____

5. Name of Contractor: _______________________________________

6. Contractor is working since (Years): _____________________________

7. PEC Category of Contractor: ____________________________________

8. Type of Building Project: ____

9. Your Designation: ____

10. Qualification ____

Section-II

According to your opinion:

What are the sources waste generation?

What are the measures your company adopt to control material waste on site? (Operation Methods or Company Culture)

Who is the most responsible for waste generation?

To what extent client and consultant behavior effect wastage?

What measures you suggest your company should adopt to reduce waste?

Annexure-II

<u>Data Collection Form for MS Research Purpose</u>

Quantification of Material Wastage in Building Construction and its Impacts on Project Cost Overrun

Project Name:

Building Type (Commercial, Residential, etc.):

Number of Stories: Covered Area:

Location of Project:

Start Date: Completion Date:

Budget at Start of Project: Budget at Completion:

Client: Consultant:

Contractor & Category:

Contracting Arrangement like Design Bid Build etc.:

Material	Properties of Material (Type, Ratio, Size, Strength etc.)	Unit	BOQ Quantity	Material Received on Site	Material used as per IPC	Material sent back to Inventory	Sub-contracting Arrangement
Bricks							
Concrete Blocks							
Tiles							
Ceiling Boards							
Sand (used in plaster)							
Sand (used for Masonry, concrete or any other purpose)							
Cement (Used in any BoQ item)							
Aggregate (Used for concrete or any other purpose)							
Steel Reinforcement							
Wood							
Concrete							
Plaster							