ORIGINS AND MAGNITUDE OF WASTE IN THE TURKISH CONSTRUCTION INDUSTRY

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Approval of the Graduate School of Natural and Applied Sciences

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ABSTRACT

ORIGINS AND MAGNITUDE OF WASTE

IN THE TURKISH CONSTRUCTION INDUSTRY

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The aim of this study was to determine the quantity of construction waste for several construction materials and to state the probable origins of this waste, depending on case studies in Turkey.

There is a lack of documented quantitative data in Turkey on how much material waste the construction industry generates and what amount of such materials remain unused due to this waste. Although some amount of waste is accepted as unavoidable, the probable reasons for it are unclear. Therefore, the study focused on determining waste percentage values for certain materials based on several construction projects and assessing the reasons for this as stated by the professionals who were involved in the construction process of these projects. For practical reasons, it was confined to the material amounts in the bill of quantities, progress payment reports and invoices for four different construction materials; namely, ready-mixed concrete, rebar, brick and floor block, which belonged to eight different projects of two construction companies.

Data compiled on these aspects were analyzed statistically via ANOVA and regression analyses. The results showed that waste percentage values displayed differences among materials. Design-related aspects, skill level and attitude of labor, incorrect calculation of material quantities, contractual clauses and material defects were the most effective reasons for waste within the projects analyzed.

Keywords: Construction Waste, Construction Materials, Materials Management,
Turkish Construction Industry.

ÖZ

TÜRK İNŞAAT SEKTÖRÜNDE

ATIK KAYNAKLARI VE MİKTARI

Baytan, Mehmet
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Bu çalışmanın amacı, Türkiye'de bulunan örnek inşaat işleri üzerinden yola çıkarak çeşitli inşaat malzemeleri için inşaat atık miktarlarını belirlemek ve bu atıkların olası kaynaklarını ortaya koymaktır.

Türkiye'de inşaat sektörünün ne kadar malzeme atığı ürettiği ve bu malzemelerinin ne kadarının atık sebebiyle kullanılamadığı konusunda belgelenmiş nicel veri eksikliği bulunmaktadır. Bir miktar atığın önlenemez olduğu kabul edilmekle beraber, bunun olası sebepleri belirsiz durumdadır. Bu nedenle, bu çalışma, örnek inşaat işleri üzerinden yola çıkarak, belli malzemelerin atık yüzde değerlerinin belirlenmesi ve bu işlerde rol almış profesyonellerin belirttiği atık sebeplerinin değerlendirilmesi üzerinde odaklanmıştır. Ugulanabilirlik açısından, bu çalışma, iki inşaat firmasına ait sekiz farklı inşaat işinden alınan ve hazır beton, betonarme demiri, tuğla-briket ve asmolen olmak üzere dört farklı malzemenin ön keşiflerde, hakedişlerde ve faturalarda bulunan miktarları ile sınırlandırılmıştır.

Bu konularla ilgili toplanan bilgiler ANOVA ve regresyon analizleri yoluyla istatistiksel olarak analiz edilmiştir. Sonuçlar, atık yüzde değerlerinin malzemeler arasında farklılık gösterdiğini ortaya koymuştur. Tasarımla ilişkili konular, işçilerin beceri ve tutumları, malzeme miktarlarının yanlış hesaplanması, sözleşmeye dayalı bazı konular ve malzeme kusurları incelenen örnekler içinde en etkili atık sebepleri olarak öne çıkmıştır.

Anahtar Kelimeler: İnşaat Atığı, İnşaat Malzemeleri, Malzeme Yönetimi, Türk İnşaat Sektörü.

to my family…

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BRE	Building Research Establishment
C&D	Construction and Demolition
CO_2	Carbon Dioxide
EU	European Union
GIS	Geographical Information System
GPS	Global Positioning System
IRP	Incentive Reward Program
JIT	Just-in-time
LSD	Least Significance Difference
SEPA	The Scottish Environment Protection Agency
UK	United Kingdom
USA	United States of America

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CHAPTER 1

INTRODUCTION

Each construction project contains dynamics peculiar to itself in terms of time and cost limitations, context, people involved, technology used, *etc*. In the contemporary world, especially time and cost play a major role in most construction activities and constitute a major part of the uncertainties existing in the construction industry. These two aspects usually act contrary to each other; an advantage in one may be a disadvantage in the other; and management practices introduce systems to control these uncertainties of the industry and to keep time and cost in balance as much as possible.

Being a general problem in the developing world, construction and demolition (C&D) waste constitutes a considerably important part of resources spent during the project. Undoubtedly, an excess amount of waste in construction affects the cost of a project. Similarly, managing waste consumes time, too. In other words, waste has significant effects on the uncertain parameters of time and cost in the construction industry.

Especially after the increasing importance of global warming, C&D waste brought together different environmental considerations other than just economy and scheduling. Occupying a large portion of landfills all over the world, it is one of the major problems of the construction industry to be dealt with.

This study focused on material waste during the construction of building projects. In this context, the following sections of this chapter include information on the argument and objective of this study, the methodology followed and the disposition of the following chapters.

1.1. Argument

Information flow associated with inter-organizational communications is generally considered to be the key to construction management. This information flow between different parties involved in a construction job is mainly based on documents including architectural and engineering drawings, specifications and bills of quantities. However, due to the above mentioned uncertain nature of the industry, there is always a gap between the predetermined bill of quantities and actual amounts of construction materials used. Such a difference in any given construction project may arise due to several reasons, such as incorrect calculation, reworks, incorrect recording or measurement, short or excess deliveries, damage during transportation, burglary, defects of workmanship, *etc*. Whatever the reason may be, a large amount of waste is seen as an inevitable by-product of major construction projects all over the world.

When construction waste in different countries is considered, it becomes apparent that the majority of the building sector is aware of the problem. As mentioned in following sections, this awareness is highly related to the management strategies on materials. It is a problem of reducing and preventing waste before it is generated as well as treating generated waste. A holistic strategy covering these issues would probably affect the costs more than expected.

A closer examination of the Turkish construction industry reveals the fact that, although there are existing laws and regulations which define C&D waste, stating the environmental dangers and disadvantages, and offer prevention and reduction strategies, there is almost no written documented information on its quantity. The existence of C&D waste and the need for preventing and reducing it are also realized by many people who are involved in the industry. On the other hand, "how much do we waste?" is a question without an answer. Although it is an important problem, even the most organized and well-known construction companies in Turkey do not attempt to develop a database of material waste to use as a reference for their future works. Non-existence of such information hinders the application of prevention and reduction strategies. Furthermore, although construction costs are of prime importance for all contractors, the effect of waste on this cost is neglected.

In such a context, a study on the determination of average amount of waste for certain materials in a construction job, based on the principles and methodologies of materials management, supply chain management and waste management reveals the importance of this issue.

1.2. Objectives

The main objectives of this study were:

- to elicit quantitative data on the amount of construction waste, which would constitute an example on the topic in Turkey and give a hint on the actual amount of waste rather than that predetermined.
- to derive certain percentage levels for several construction materials depending on the information gathered on the case studies.
- to point out possible reasons for this waste.
- to suggest solutions applicable to the Turkish construction industry, considering firstly materials management, then supply chain management and waste management systems.
- to help develop a consciousness among professionals in the construction sector, regarding origins of waste.

In other words, the objective was, in the first place, to reveal the fact that although some residual waste seemed unavoidable, the potential of minimizing waste was considered something to which attention was worth paying attention.

1.3. Methodology

The research was based on case studies comprising eight different construction projects of two different companies operating in Turkey; namely, the Sarılar Construction and Excavation Co. and the Botam Construction Group. This delimitation depended mainly on their timely availability for the study period and the reliability and accessibility of their data sources.

Data on bills of quantities, progress payment reports and invoices were collected for several construction materials. Interviews were conducted with the directors of the company and the site supervisors of the construction projects. Their opinions were referred to on the probable reasons of differences between the above mentioned material quantities. However, considering the subjectivity of the opinions, these reasons were stated merely to shed light on the topic and were not considered as definite reasons generating waste. Data compiled on these material quantities were analyzed using statistical analyses (analysis of variance-ANOVA, and regression analyses).

1.4. Disposition

Results of the study are presented under six chapters. This first chapter includes the argument, the objectives and the methodology of the study, in addition to this section.

The second chapter includes information on the subject domain. It presents how construction waste is perceived in the world, what waste levels in several other countries are, how the Turkish construction industry approaches the problem of waste and how management systems deal with this issue.

The third chapter consists of data on the study material and method.

The fourth chapter presents data collected and derived on material quantities.

The fifth chapter includes the analysis of data together with discussion and interpretation of results.

The last chapter concludes the research by emphasizing the major points learned during the study.

CHAPTER 2

LITERATURE SURVEY

This chapter is comprised of information on construction (and demolition) waste, waste statistics in the world, existing research in Turkey and material and waste management systems taken from 14 published books and theses, 40 published articles and 10 websites/presentations. However, most of these references were found to treat the topic of waste by considering construction and demolition waste together. Thus, in some parts of this chapter, information includes both C&D waste concurrently, although demolition waste was considered outside the scope of this study.

2.1. Construction Waste

Materials have significant effects on the cost and time of any construction job. Ibn-Homaid (2002, p.263) indicates that, according to expert estimates and historical data analysis, 50–60% of project costs depend on materials and 80% of its schedule is controlled by material-related activities. These figures make it clear that, achieving high construction productivity and safety largely depends on managing construction materials and waste.

Together with rapid urban development strategies, the quantity of C&D waste increased highly in the world. This also led to a situation with a lack of control and effective management strategies on waste. Today, many countries are facing problems of diminishing landfill capacities and increasing C&D waste volumes. 500-1000 kg/inhabitant/year of C&D waste is generated even in developed countries (Kartam, Al-Mutairi, Al-Ghusain and Al-Humoud, 2004, p.1051) and this amount constitutes 10-30% of landfill areas in the world (Begum, Siwar, Pereira and Jaafar, July 2006, p. 87).

This excessive amount of C&D waste not only affects the economy of these countries, but also exploits natural resources and gives irreversible harm to the environment. Garvin (2004, p.3) points out certain statistics to draw a picture of the current effects of C&D waste on the environment. According to the author, the generated C&D waste uses 40-50% of the world's produced energy and contributes to CO_2 emissions by 50%; a figure which goes up to 75% if transportation of these waste materials is also included. The same author indicates that 40% of the 7.5 billion tons of raw materials are disposed of each year as waste, which makes 3 billion tons/year. On the other hand, he mentions that the construction industry uses 25% of the world's timber production while 16% of global water withdrawals are due to the C&D waste generated. Although the numbers may not seem very meaningful at first glance, when closer attention is paid and the present threat of global warming is considered, the importance of high amounts of C&D waste can easily be realized.

2.1.1. Definition and Characteristics of Construction Waste

As Tam and Tam (2006, p.210) indicate, when the nature of the construction industry is considered, it becomes evident that construction is not an environment-friendly activity. They point out that, in addition to its unfriendly environmental aspects, there is also a lack of consideration given to waste prevention during design and construction and to minimization of waste generation. In order to understand the nature and importance of waste, a clear definition and specification of its characteristics is first required.

In general, waste is defined as "…a product which is no longer used in its primary role…which the holder then intends to, or is required to, discard"[1] by The Scottish Environment Protection Agency (SEPA). On the other hand, construction waste is

[1] Waste Aware Construction, 2005, "Waste Definitions," http://www.wasteawareconstruction.com/definitions.asp, [Accessed: 3 January 2007].

also defined more specifically by SEPA as "…materials resulting from the construction, remodeling, repair or demolition of buildings, bridges, pavements and other structures" and "…the use of energy, materials and labor which does not add value to the construction process."

Kulatunga, Amaratunga, Haigh and Rameezdeen (2006, p.59) define construction waste similarly, based on several other sources. They thus indicate that:

> "The Building Research Establishment defines construction waste as the difference between the purchased materials and those used in a project. According to Hong Kong Polytechnic, construction waste is the "by-product generated and removed from construction, renovation and demolition work places or sites of building and civil engineering structures". Further, construction waste has been defined as 'building and site improvement materials and other solid waste resulting from construction, re-modeling, renovation, or repair operations'."

Arnold (1991, p.216) defines construction waste from a more materialistic approach as: "…anything other than the minimum amount of equipment, parts, space, material, and workers' time that is absolutely necessary to add value to the product.". Tersine (1994, p.410) adds even a more materialistic phrase to this definition, saying that: "cost without value is waste".

Gavilan and Bernold (1994, pp.537-540) make a definition of construction waste, depending on another source of information as; "Wastes from the construction, remodeling, and repairing of individual residences, commercial buildings, and other structures are classified as construction wastes." Depending on this definition, they specify that, at the end of a construction process, materials are generally found in four conditions: in the building structure (used), leftover, reused on the same project and wasted, as presented in Figure 2.1. As they indicate, within these four categories leftover materials may also be considered as waste because reselling or storing these materials is very often not considered or is found unfavorable. In other words, this definition puts the leftover or unused materials into the category of waste, too.

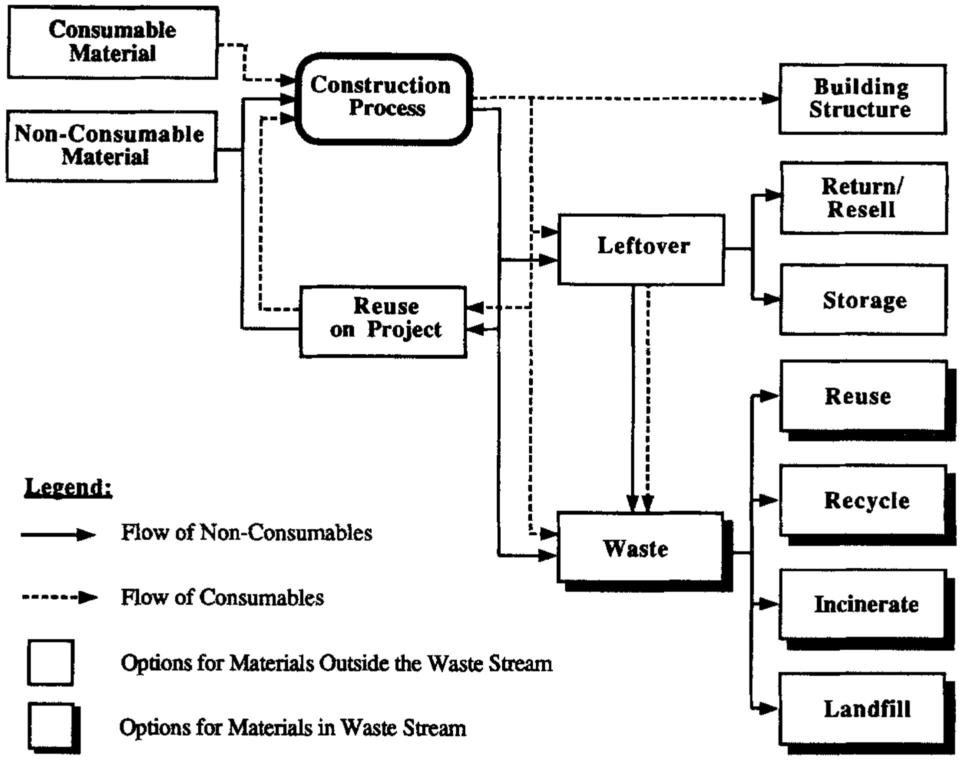

Figure 2.1. The generic flow pattern of construction material on site. (Gavilan and Bernold, p. 540)

Considering the characteristics of construction waste, it is necessary to state that there are many factors that affect its content and quantity. U.S. Environmental Protection Agency Office of Solid Waste (1995, p.2-1) defines three major factors as "structure type", "structure size" and "activity being performed". The Agency also states several additional factors such as geographical location, types of materials used and type of schedule ("rushed" v.s. "paced"). Similarly but with a different classification, Chen, Li and Wong (2002, p.523) divide the sources of construction waste into four as "construction technology, management method, materials and workers." They add that, waste due to construction technology is more difficult to prevent than the others.

All of these statements prove that, the amount of construction waste depends on the economic and cultural conditions in a country. However, its contents may be described in a general sense. Depending on their origin and including demolition waste, some researchers classify it into four as "excavation materials, road planning and maintenance materials, demolition materials–debris and worksite waste materials" (Fatta, Papadopoulos, Avramikos, Sgourou, Moustakas, Kourmoussis, Mentzis and Loizidou, 2003, p.82). Waste generated from "production of building materials" is also included into this definition by others (Kartam et al. 2004, p.1051). On the other hand, in terms of materials, construction waste consists of mainly sand, stone, brick, tile, concrete, timber, glass and metal. Taking into account all these classifications that are based on the origin and the content of C&D waste, statement of its origin will be useful to determine management strategies for coping with this problem.

2.1.2. Construction Waste Generation

It is possible to mention several reasons for the generation of construction waste. However, first of all, it is necessary to state that most of these reasons are due to human errors occurring at different stages of a construction process (Chung and Lo, 2003, p. 125).

Gavilan and Bernold (1994, p.541) identify the reasons of waste as "design, procurement, handling of materials, operation, residual waste and others". On the other hand, Building Research Establishment (BRE) divides it into four as "design, take off/specification, delivery and site waste" (Cooke and Williams, 2004, p.231). Shah (1988, p.409) also classifies these sources under six different headings as: "planning and design, purchasing, transportation and handling, storage, production or repairs and consumption of materials". In this classification, "planning and design" includes errors in the design, "purchasing" includes excessive, incorrect or untimely procurement of materials and "transportation and handling, storage, production or repairs and consumption" all relate to the attitudes and waste awareness of workers'. There are other classifications found in literature. However, there is a great commonality within these descriptions of the reasons of C&D waste generation.

Almost every source considers “design” as the major source or one of the major sources of material waste.

A research conducted in UK construction industry by Saunders and Wynn (2004, p.154) shows that site management quality, poor material handling and storage, poor design, lack of care by operatives and lack of education about waste awareness are the main factors affecting the level of waste in construction. They add that, these results put forward the importance of a worker’s talent and approach in the generation of waste. The workers’ inclination and desire to work collectively together with their awareness highly affect the level of waste.

Rework may be another major reason as accepted by many researchers. It is simply defined by Love and Sohal (2003, p.329) as; “doing something at least one extra time due to non-conformance to requirements”. Researches showed that, 50% of these reworks were due to design and 40% were due to construction errors; and according to Karim, Marosszeky and Davis (2006, p.31), these construction errors were causes of carelessness and negligence of the workers. It is also stated that, cost of rework may vary between 3 and 15% of total construction cost (Love and Edwards, 2004, p.259). These findings prove the effectiveness of design in waste generation.

Packaging is also included in construction waste and considered as a big problem by some researchers and writers (Gavilan and Bernold, 1994, p. 542). However, taking into account that packaging of construction materials is an indirect waste of construction process, it will not be taken into consideration within the scope of this study.

2.1.3. Construction Waste Minimization Strategies

Tam and Tam (2006, p.210) call three basic waste minimization strategies, “reduce, recycle and reuse” as “3Rs”. Within these three, reduction of waste is seen as the most desired strategy by many authorities. For example, Gavilan and Bernold (1994, p.551) denote it as the best and most economical option that required “cause-and-effect relationship" understanding. Begum, Siwar, Pereira and Jaafar et al. (October 2006, p.2) also call reduction as the most efficient solution that minimizes most problems related to waste.

Reduction option includes strategies existing in the supply chain management and materials management practices. Within these strategies, just-in-time (JIT) delivery, controlling storage levels to stay away from excessive ordering, managing design to avoid over specification, increasing off-site prefabrication usage, providing supplier flexibility in procuring smaller amounts of materials, educating workers and developing waste consciousness among them can be counted (Dainty and Brooke, 2004, pp.20-24). Being a recent concept, JIT delivery is one of the most attractive measures among these.

JIT is a synonym of "stockless production" (Tersine, 1994, pp.409-412). It aims to improve productivity and minimize waste. The main idea is procuring just the right quantity at the time of production. Thus, according to Tersine this strategy considers stocked materials as the amount that is planned for waste; and as the quantity of material on site decreases, there will be less for waste. However, it has some disadvantages. For example, in order to modify JIT concept according to the uncertain nature of the construction industry, a buffer level of time should be included, which can only be achieved by effective management (Pheng and Chuan, 2001, p.423). In addition, applying this concept only to a single project will cause problems due to the temporary nature of the construction industry; thus it should be adopted as an organizational philosophy (McGeorge and Palmer, 2002, p.201).

Recycling and reusing, considered as the other waste minimization strategies, are highly effective in developed countries. Researches and reality show that it is possible to recycle 90% of C&D waste (Begum et al. July 2006, p.96). In other words, reusing and recycling may give an advantage of 2.5% of total construction cost as Begum et al. indicate. Needless to say, these strategies play an important role environmentally, too.

There are several other strategies such as bar-code system applications, "Global Positioning System (GPS)" and "Geographical Information System (GIS)" technologies. As Chen et al. (2002, p. 532) indicate, the bar-code system not only tracks the flow of materials to and within the site, but also measures the workers' performance in terms of the amount of materials they wasted. The system helps in quantifying the materials taken and returned by each working group. On the other hand, Li, Chen, Yong and Kong (2005, p. 331) point out another technology that combines this bar-code system with GPS and GIS to let the personnel on site and in the headquarters track the materials during their transportation and get concurrent information about its arrival time. As they indicate, both bar-code system and GPS-GIS technologies are based on "incentive reward program (IRP)", which encourages the workers to reduce material waste and prizes them according to the quantity of the materials they saved

2.2. Magnitude of Construction Waste in the World

When construction waste is considered, many researchers complain about the difficulty in finding reliable data on the amounts; because, it is hard to determine the exact quantity and composition of this type of waste. However, studies reveal certain figures and facts such that; C&D waste occupies 20-30% or even more than 50% of the landfill areas in the developed cities (Chung and Lo, 2003, p.124). When waste quantities in these cities are taken into consideration, one can easily understand the amount of construction materials that leave the site as waste.

2.2.1. Construction Waste Allowances

Many contractors have certain standards for waste percentages to be applied in making estimations for the bill of quantities. These percentages are largely based on their experience with their own labor force (Haris and McCaffer, 2001, p.118). However, there is the probability that the contractor will work with different sub-contractors in different works, and the sub-contractors' labor will have a desire to finish the work as soon as possible. Thus, waste levels will probably be different than the estimated, as Haris and McCaffer point out.

Cooke and Williams (2004, p.230) have published the results of a study which prove the above mentioned statement. According to these results, there is a great gap between the estimated waste levels and the actual ones as presented in Table 2.1.

Table 2.1. Estimated and actual % wastes. (Cooke and Williams, 2004, p.230)

	Normal estimator's % allowances	Typical % loss in practice
Ready- mixed concrete		
in foundations	2.5	10
in formwork	2.5	6-10
Bricks and blocks		
commons	4	8
facings	5	12
engineering	2.5	10
lightweight blocks	5	10
concrete blocks	5	7
Roofing		
tiles	2.5	10
felt	2.5	8
lead flashings	2.5	7

Another research in UK shows that waste percentage by volume of certain materials is as follows; drywall 16.6%, timber 14.8%, bricks 7.5%, ferrous metal (steel) 6.4%, concrete 6.0%, tiles 3.8% and ceramics 3.0%.[2] Although most of the materials show the same trend with the values in Table 2.1, there is a great difference in terms of tiles. On the other hand, Wang, Touran, Christoforou and Fadlalla (2004, p.991) mention that, the industry uses a waste percentage of 10 for wood and 5 for drywalls. When compared to the above mentioned results, the diversification within the

[2] Waste Aware Construction, 2005, "Waste Aware Facts," http://www.wasteawareconstruction.com/why.asp, [Accessed: 3 January 2007].

industry becomes apparent. Because of this, Chen et al. (2002, p.523) give a wider range of 10-30% which may be assumed as the most correct estimation.

Saunders and Wynn (2004, p.150) conducted another study in UK. Similar to Chen et al., they consider a waste level of around 10% as acceptable. They also state that, depending on another research done via questionnaire, 31% of the respondents consider a level between 11-20% as normal. However, Harper (1978, p.348) indicates that; “the usual allowance for waste is of the order of 5% over the nett measurements.” This estimate was published around 30 years ago. Therefore, when it is compared with the results by Saunders and Wynn, it is possible that the acceptable waste rates have changed or the quantity of construction waste has increased in time.

2.2.2. C&D Waste Statistics in the World

In order to have a general picture of the waste levels in the world, several examples from other countries will be presented in this section. Because of the more specific examples existing in literature on Hong Kong, Brazil, USA and European countries, these countries will be handled in separate sections.

As it is denoted in the previous sections, waste is a cause of population growth and rapid urban development. From this point of view, it is certain that developing or underdeveloped countries will have a higher degree of waste compared to developed ones and published figures also prove this fact. However, it is also mentioned before that, a general understanding of management and attitude towards waste prevention and minimization is also another determining factor in waste levels.

In Canada, C&D waste occupies 35% and in Australia 20-30% of landfill areas (Esin and Coşgun, 2007, p.1667); this amount is 60% in Sydney according to Öztürk (2005, p.5). Within this quantity, recycling rates reach as high as 80% for residential construction and 69% for commercial construction (Crowther, 2003, p. 6). On the other hand, Singapore generates 105 kg/inhabitant/year of C&D waste, which is below many European countries (Chung and Lo, 2003, p.125). Despite this fact, 70% of this amount is recycled or reused in this country.

There are significant differences between waste allowances and actual waste levels of certain materials in Sri Lanka as shown in Figure 2.2. This example shows that, the difference between the estimated and the actual waste is a major problem in construction all over the world. Appendix A also proves that construction waste levels show great differences all over the world in terms of material types.

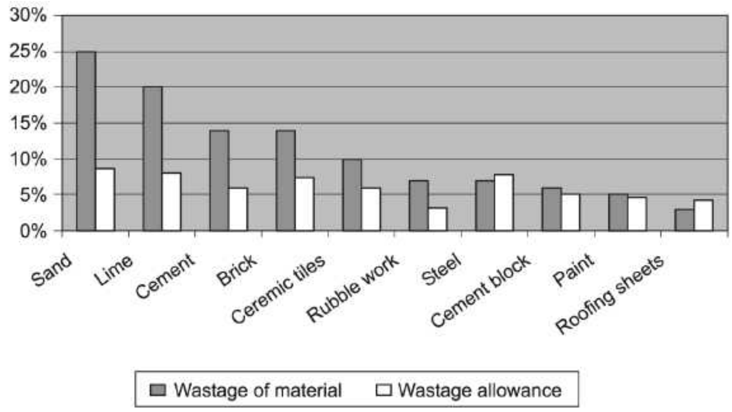

Figure 2.2. The difference between waste allowances and actual waste levels in Sri-Lanka. (Kulatunga et al. 2006, p.65)

In the Middle East, Kuwait also produces very high levels of C&D waste but very low levels of recycling rates; 15-30% of total generated waste belongs to C&D and 90% of this quantity is disposed of in landfills (Kartam et al. 2004, p.1049-1054). Based on the statistical data obtained between 1990 and 2005, the estimated amount of C&D waste was between 2.2 and 3.6 million tons/year, which equal 3.01-4.93 kg/inhabitant/day. The composition of this amount is shown in Figure 2.3.

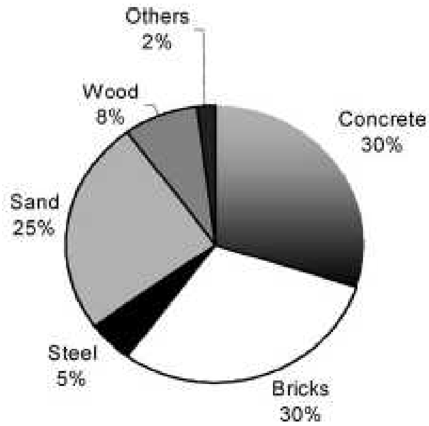

Figure 2.3. Composition of C&D waste in Kuwait. (Kartam et al. 2004, p.1053)

a. Hong Kong

When Hong Kong is analyzed in terms of its C&D waste generation, it is seen that it was 7030 tons/day in 1998, which makes around 2.5 million tons/year (Table 2.2). However, in 2002, the amount of C&D waste and its percentage within the total amount of waste reached its peak with 10.202 tons/day and 48% respectively. Then, in 2003 the figures showed a sharp decrease and the generated waste decreased to 38% of the total waste. The average of years 1998-2003 was 7621 tons/day or around 2.8 tons/year as it is seen in the table; and this was 42% of the total waste generation.

Table 2.2. Analysis of C&D waste quantities in Hong Kong between 1998 and 2003. (Chen, Li, Kong, Hong and Xu, 2006, p.707)

Year	Amount of waste disposal at landfills (ton/day)		Percentage of C&D waste (%)
	C&D waste	Total waste	
1998	7030	16.738	42
1999	7890	17.932	44
2000	7470	17.786	42
2001	6410	16.686	38
2002	10.202	21.158	48
2003	6728	17.757	38
Average	7621	18.010	42

Appendix A presents the waste figures for certain materials in Hong Kong construction industry. Within the construction materials, 45% of wood used is recorded as waste. This is a very high level compared to other materials and levels in other countries. However, as wood is not frequently used in Hong Kong, it constitutes only 7.5% of C&D waste and the rest of C&D waste is composed of reinforced concrete (34%), concrete (20%), brick (7%), metal (4%) and other materials (27.5%) (Öztürk, 2005, p.6).

b. Brazil

According to John, Angulo, Miranda, Agopyan and Vasconcellos (?, p.2), it is estimated that C&D waste generation is around 1.37 kg/inhabitant/day in Brazil, which makes a total of 68.5 million tons/year. On the other hand, Nunes, Mahler, Valle and Neves (2006, p.1) state that, in certain developed cities like Sao Paulo, Rio de Janeiro and Salvador, the estimated quantity decreases to 0.49 kg/inhabitant/day. Table 2.3 shows the major components of C&D waste in some Brazilian cities.

Table 2.3. The major components of C&D waste in certain cities of Brazil (by % weight). (Wooley, Goumans and Wainwright, 2000, p.832)

	Salvador	Sao Paulo	Sao Carlos	Ribeirao Preto
Concrete and Mortar	53	63	69	89
Soil and Sand	21	-	-	18
Ceramic	15	29	30	23
Stones	4	-	1	-
Others	7	8	-	-

It is very clear in the table that C&D waste characteristics and quantities may vary even within a country, from city to city. However, to give a general idea of Brazil, Appendix A will be helpful. It is seen that, similar to Hong Kong, wood has a very high level of waste; but mortar has the highest level with 46%. This is also a striking fact when compared to the waste levels of mortar in the other countries. Similarly, rebar and brick/block have also very significant waste percentages with 21%, compared to the other countries. Moreover, Bossink and Brouwers (1996, p.56) specify that, in general C&D wastes constitute 20-30% of the total weight of the materials on site in Brazil.

c. USA

Being one of the largest and populated countries of the world, USA presents high levels of waste. Depending on data from US Environmental Protection Agency (EPA), Nunes et al. (2006, p.1) indicate that 136 million tons of C&D waste was generated in USA in 1996; and waste from road and bridge constructions was not included in this amount. They add that, when population of USA was considered, this made 1.27 kg/inhabitant/day and around 465 tons/inhabitant/year. On the other hand, Chung and Lo (2003, p.125) state the yearly waste generation of USA as 123 million tons in 1998; and Chini and Bruening (2003, p. 1) indicate it as 143 million tons in 2000, 90% of which were due to demolitions. Depending on another study done in 2001, EPA reports that 53% by weight of waste materials in metropolitan areas and 45% in non-metropolitan areas were generated by construction.[3] This constitutes 29% of the landfills by volume (Kulatunga et al. 2006, p.58). Within this amount, 43% belongs to housing and 57% belongs to other constructions, as presented in Appendix B. In addition, 8% is due to new constructions, 44% due to modifications and 48% due to demolitions, as shown in Figure 2.4.

As the figures in Appendix A indicate, within C&D debris of USA, wood has the highest percentage of waste with 16.5%; because the type of construction is mostly timber frame and drywall in USA. On the other hand, brick and mortar have the lowest with 3.5%. Generating such a large quantity of waste, USA recycles only 20-30% of this amount (Nunes et al. 2006, p.1). However, it is much higher in some states. For instance, in Massachusetts, only 20% of the generated C&D waste was disposed of in landfills in 1999, as Nunes et al. point out. On the other hand, the facts

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[3] Government of South Australia, Department for Environment and Heritage, 31 January 2005, "Annual Amount and Composition of Waste Consigned to Landfill," http://www.environment.sa.gov.au/reporting/human/waste/landfill.html [Accessed: 2 January 2007].

are different for steel. As Kartam et al. (2004, p.1051) state, according to an estimation by The Steel Recycling Institute, the recycling rate of C&D steel is around 85%.

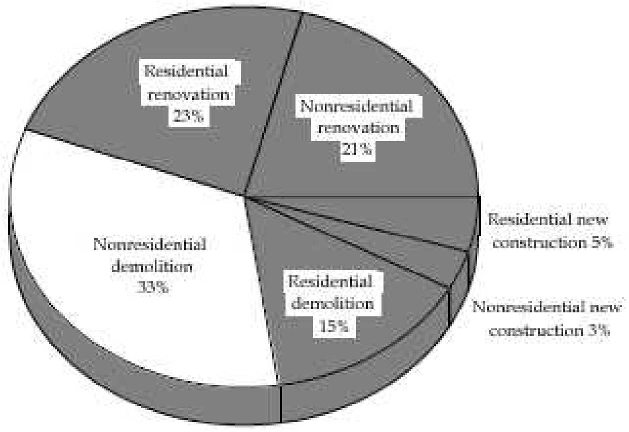

Figure 2.4. Generation of C&D waste in USA. (Franklin Associates, 1998, p.2-11)

d. Europe

Statistics in European countries show that, recycling rates reach up to 80-90% in some countries, although it is below 5% in the others; and as Te Dorsthorst and Kowalczyk (2003, p. 2, 10) indicate, there are several reasons for this diversity. These reasons can be stated as the economical and technological conditions, the quality of natural resources, the population growths and the carriage ranges. They also specify that, the diversity of laws within each country makes the different attitudes against waste obvious. Most of the countries do not have definite measures against the problem of waste in construction.

As Fatta et al. state, the European Union (EU) Waste Strategy Report, which was prepared in 2001 as part of the Sixth Environment Action Program, considers C&D waste as one of the "priority" aspects that should be dealt with. However, when the quantity of the generated waste is considered, EU countries exceed USA with an average of 180 million tons of C&D waste and 495 kg/inhabitant/year which makes a daily generation of around 1.36 kg/inhabitant according to the data from 1995 (Öztürk, 2005, p.8).

In order to understand the situation in Europe, more detailed examples from several countries will be helpful. Based on data from 1999, it is estimated that UK generates a waste of 70-80 million tons yearly, 6-7 million tons of which is generated by Scotland and 72.5 million tons by England and Wales (Garvin, 2004, p.11). On the other hand, Hurley and Hobbs (2003, p. 1) specify it as 94 million tons, based on 2000 data. They also add that, data on C&D waste is difficult to access and the waste levels are mostly presumed. This is why the figures are not constant among different sources.

C&D waste constitute 25% of all waste generated in UK and 13 million tons within this 25% is composed of unused materials.[4] Sealey, Phillips and Hill (2001, p.323) give a very dramatic example of the effect of these unused materials on economy, stating that; because of improper ordering of ready-mixed concrete, £400 million of it is wasted annually in UK. Moreover, within total C&D waste, residential C&D waste constitutes 40% and others 60% (Lawson, Douglas, Garvin, McGrath, Manning and Vetterlein, 2001, p.148). On the other hand, similar to USA, wood is the most wasted material in UK, too. It is followed by tile and drywall (Appendix A). UK also recycles around 40.3 million tons (57%) of its C&D waste.[5]

It is seen in Appendix C that, Germany, with 59 million tons of total and 750 kg/inhabitant/year, had the highest waste generation level in 1995. Schultmann (2003, p. 3, 19) makes an assumption and declares that 45 million tons of this amount was generated via demolitions. On the other hand, he states that Germany also has a low level of recycling and high level of landfill with respect to many other European countries. In such a context, the first law on waste was put into force in 1972; and after 1986 the importance was given to management of waste instead of

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[4] Waste Aware Construction, "Waste Aware Facts."
http://www.wasteawareconstruction.com/why.asp, [Accessed: 3 January 2007].

[5] Waste Aware Construction, "Waste Aware Facts."
http://www.wasteawareconstruction.com/why.asp, [Accessed: 3 January 2007].

disposing it (Te Dorsthorst and Kowalczyk, 2003, p.11). Finally, with an agreement signed in 1996, it was decided to decrease the amount of C&D waste disposed to landfills by 50% between 1995 and 2005.

Bossink and Brouwers (1996, p.56) state the results of a study carried out in Netherlands in 1993 as; C&D waste constituted 26% of the total amount of waste produced, which was 14 million tons. On the other hand, today Netherlands and Denmark have the highest rate of recycling with 80-90%. As they indicate, the main reason is that, 80-85% of C&D waste in these countries is composed of concrete and wall blocks, which are highly convenient for recycling. There is also another case for Netherlands. In 1990, a plan was made to recycle or reuse 90% of the total C&D waste by 2000 (Te Dorsthorst and Kowalczyk, 2003, p.1). Similarly, together with the studies done between 1993 and 2000, it was forbidden to landfill recyclable wastes (Öztürk, 2005, pp.9-12). As a result, Netherlands achieved a very high level of recycling and a significantly low level of generated C&D waste.

The estimated C&D waste in Ireland in 1995 was just 1 million ton with a recycling rate of 5% (Duran, Lenihan and O'Regan, 2006, p.304). There is no current data regarding the waste generation of this country today; however in 2001 Ireland recycled 65.4% of its C&D waste as Duran et al. indicate. On the other hand, total C&D waste generation of Spain was around 13 million tons in 1995 (Rodriguez, Alegre and Martinez, 2006, p.4). However, in 2003 it reached 39 million tons with a very rapid increase. 10.3% of this quantity was recycled, 25.6% was consigned to landfills and 64.1% was disposed of in uncontrolled areas, as Rodriguez et al. state.

Greece has one of the lowest levels of C&D waste per inhabitant compared to the other European countries. Although the generated C&D waste was around 1.6 million tons in 1996, excluding the infrastructure works, it became about 2.1 million tons in 2000 with a slight increase (Fatta et al., 2003, p.86). Considering the population of Greece, which was around 11 million in 2000, this waste level was about 191 kg/inhabitant. Although this value is far below the average of EU countries, when infrastructure works are included, the results are expected to be more or less equal, as Fatta et al. point out.

Some southern European countries like Italy, Portugal and Spain recycle very few of their generated C&D waste (Te Dorsthorst and Kowalczyk, 2003, p.11). That is due to the underdeveloped market conditions for recycled materials and the available natural resources in these countries. Similarly, Norway also has low levels of recycling and reusing with 1.5 million tons total annual and 340 kg/inhabitant/year C&D waste generation (Myhre, 2003, p.4). However, in this country, the reason for such a low level of waste with respect to many other European countries is described as the low density of C&D waste; because most of the constructions in Norway use lightweight wooden elements and very few use brick and concrete.

No up-to-date data available about the other countries in Europe could be reached during the literature survey. However, certain values for 1995 regarding countries such as Belgium, Austria, Denmark, *etc*. are presented in Appendix C.

2.2.3. C&D Waste Statistics in Turkey

The first regulation on C&D waste in Turkey, called "Regulation on the Control of Excavation Soil and C&D Waste", dated 18 March 2004.[6] Until that time, there were regulations on the control of solid waste and hazardous waste that were put into effect in 1990s; however C&D waste was not taken into consideration separately. Thus, as Istanbul Metropolitan Municipality declares, the generated C&D waste all over large cities was disposed of in illegal landfills located on private and public lands with the lack of permission and control.

When the above mentioned regulation is analyzed, it can be seen that reduction of C&D waste and recycling to reuse in infrastructure works are considered as the

[6] İstanbul Büyükşehir Belediyesi Çevre Koruma ve Kontrol Daire Başkanlığı, 2006, "Hafriyat Toprağı ve İnşaat/Yıkıntı Atıklarının Kontrolü," http://www.ibb.gov.tr/tr-TR/CevreKoruma/Hafriyat/ [Accessed: 20 January 2007].

primary principles. The advantages of recycling are also stated as preservation of natural resources, sustainable production, decreasing the amount of waste to be landfilled and creating economic value.[7] However, when literature is surveyed, it becomes so obvious that reality is very different or ambiguous for Turkey.

According to Elias-Özkan (2003, p.2), data regarding the quantity of C&D waste generated in Turkey is not collected by governmental or non-governmental organizations and there are no statistics to be found on how much waste the construction industry produces in Turkey. On the other hand, a limited study on the amount of demolition waste in Ankara has been conducted by this author (Elias-Özkan, 2001, 499-495). In this study, Elias-Özkan mentions the uncontrolled condition of demolition waste in Turkey, indicating that none of the state organizations had exact statistical data on the demolition of existing buildings. She adds that, based on the obtained data, 46,738 m^3/year of debris was landfilled just in Çankaya Municipality, Ankara, excluding the illegally dumped debris.

Another study was carried out by Esin and Coşgun (2007, p.1670) in Istanbul in terms of demolition/modification waste generation. They found out that, yearly waste generation due to demolition and modification was about 39 kg/year/residence. Within the modified materials, ceramic tiles constituted 41% by weight of the total waste. Wood, natural rocks and glass followed it.

Though not quantitative, another research was carried out by Ergün (1999, pp.20-45) based on a questionnaire. It brings up some qualitative information about how the Turkish construction industry approaches the problem of waste. The study shows that every member involved in a construction activity is aware of the existence of waste in very large quantities. Its effect on cost is also accepted and it is believed that waste can be prevented; however no attempts are being made to cope with this obvious problem, as Ergün mentions.

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[7] T.C. Çevre ve Orman Bakanlığı Atık Yönetimi Dairesi Başkanlığı, 18 March 2004, "Hafriyat Toprağı, İnşaat ve Yıkıntı Atıklarının Kontrolü Yönetmeliği," http://www.atikyonetimi.cevreorman.gov.tr/yonetmelikler/hafriyat/ [Accessed: 20 January 2007].

Ergün's study reveals some other facts, too. For instance, the most important reasons of C&D waste generation appear to be inefficient materials flow, inefficient storage conditions and excessive transfer of materials within the site. On the other hand, the materials with the highest level of waste come out to be as brick and concrete. There are also three apparent waste reduction and prevention ways stated as; well-arranged storage facilities and conditions, decreasing over-flow of materials within the site and proper work organization and scheduling to prevent untimely materials flow. It was also declared by most of the participants that waste occurred during the construction phase, rather than before the construction phase, i.e. during transportation.

2.3. Management Issues on Construction Materials and Waste

Material waste or material excess at the end of a construction process due to reasons such as design, procurement, transportation, storage, handling, workmanship, *etc*. is a major problem in the industry and this waste constitutes an important portion of project cost, as mentioned before. The current situation and examples show that management has a major role in minimization and disposing of waste.

2.3.1. Materials Management in the Construction Industry

As Cavinato, Flynn and Kauffman (2006, p.855) mention, the real world involves some degree of probability. There are no definite numbers and values due to the high level of uncertainty. They add that, in order to overcome the negative effects of this uncertain environment, a systematic approach is necessary and materials management is one of the branches of this system

There are different definitions existing in literature about materials management. Cooke and Williams (2004, p.225) state the objective of this management system very basically as producing schedules for materials that the site manager will take advantage of in planning the construction process. On the other hand, Leenders and Fearon (1997, p.7) describe it as a system of material flows that foresees the requirements, acquires materials, incorporates them into the organization and tracks their conditions. Kini (1999, p.30) also defines it as a system that "integrates the traditional areas of purchasing, expediting and controlling the progress of the vendor."

Zenz (1988, p.76), taking into account the economical aspects, defines materials management in a wider sense as: "an organizational approach that brings under one organizational component the responsibility for determining the production requirements, scheduling the production process and procuring, storing and dispersing materials at a minimum cost." Similarly, Ballot (1971, p.6) states that it is a "coordinated function responsible to plan for, acquire, store, move, and control materials and final products to optimize usage of facilities, personnel, capital funds, and to provide customer service in line with corporate goals."

It is important to mention the emergence of materials management system and how it stepped into the construction industry. Although it wholly fits into construction, the roots of this concept were in another manufacturing industry; it emerged because of the problems of airframe industry faced during World War II; because, aircraft production was, and it still is, a very complex process that involved huge number of sophisticated items procured from many different suppliers from all over the world (Leenders and Fearon, 1997, p.7). In other words, the concept was part of an interdisciplinary systems approach in 1950s. However, it came into act in the business environment in 1960s (Zenz, 1988, p.76). During 1670s with the emergence of logistics concept, the system was applied to military forces. Finally, as Zenz declares, in the 1990s, materials management started to act in close relation to supply chain management.

The emergence of materials management concept highly relates to the emergence of the problem of waste, when the chronological orders are analyzed. (Woolley et al. 2000, p.836). Until 1950s, waste in general was not an important problem in the world. In 1960s, environmental aspects became more important and problems were tried to be solved. After a time, different concepts such as efficiency, quality and productivity came into being. From 1980s on, waste prevention and minimization started to attract more attention. Today, with rapidly increasing effects of global warming, there are attempts for attaining “Zero Pollution”. When the construction industry is considered, it is seen that today some countries, like Netherlands, are reducing their landfilled C&D waste levels by almost 90%, as mentioned in the previous sections.

2.3.2. Materials Management Strategies

Materials management is an indispensable part of construction, which constitute a major portion of time and cost related activities. The construction industry has its dynamics that need to be systematized for the sake of environment and success, as mentioned before. In this respect, it will be worthwile to determine the functions of materials management system in more detail to understand how this system operates in construction. It will also be beneficial to relate materials management system to supply chain management and waste management systems.

In general, it is possible to specify the following clauses as the major functions of materials management (Zenz, 1988, pp.78-80):

1. Choosing different material types and their qualities needed in order to execute the project.
2. Planning the amounts of materials to be procured and checking their stock levels.
3. Supplying the needed materials and components.
4. Investigating materials, suppliers and methods.
5. Arranging the contracts for ordering materials.
6. Controlling the transportation services.
7. Controlling the amounts of the materials delivered.
8. Checking their conformity to the standards specified with the contracts.
9. Checking and preserving the proper physical storage conditions of the materials.

10. Making schedules for the productions and material quantities and determining when and how much new material will be required.
11. Transportation of the materials within the boundaries of the site, from the storage area to the point of production.
12. Disposing of waste and excess materials.

Having specified the functions of materials management, it is also necessary to state that cost-overruns due to excess and waste materials are much higher than those due to labor and plant (Haris and McCaffer, 2001, p.161). On the other hand, the amount of C&D waste also constitutes a problem in terms of environment, as mentioned before.

2.3.3. Interrelationship between Supply Chain Management, Materials Management and Waste Management Systems

Supply chain management system emerged as a distinct research area in 1980s (McGeorge and Palmer, 2002, p.193). It consisted of two different management flows of "distribution" and "production", leading to logistics; and as McGeorge and Palmer mention, the system entered into the construction industry in the mid-1990s with similar approaches of production, distribution and strategic purchasing. Supply chain management is defined in general as follows:

> "Supply Chain Management deals with the management of materials and information resources across a network of organisations that are involved in the design and production process. It recognises the inter-connections between materials and information resources within and across organisational boundaries and seeks systematic improvements in the way these resources are structured and controlled."[8]

On the other hand, Xue, Wang, Shen and Yu (2007, in press) define it more specifically, considering the construction industry, as such:

[8] The Commonwealth Department of Industry, Science and Resources. "Executive Summary." www.industry.gov.au/assets/documents/itrinternet/BC-SCMExecSumm.pdf. [Accessed: 22 November 2006].

> "Construction supply chain management is the integration of key construction business processes, from the demands of client, design to construction, and key members of construction supply chain, including client/owner, designer, contractor, subcontractor and supplier."

In its historical development, supply chain concept has passed through five different phases as; "traditional", "functional", "lean", "agile" and finally "customised" operations (Childerhouse, Lewis, Naim and Towill, 2003, p.405). Vrijhoef and Koskela (2000, p.173) state that, supply chain management offered a methodology to get rid of the "myopic control" in the system that caused waste and problems. Similarly, Australian government has listed waste minimization as one of the advantages of adopting supply chain management (McGeorge and Palmer, 2002, p.193). In this respect, its functions fit snugly into materials management; because, in order to avoid these waste and problems, as materials management do, supply chain management system tries to control the "decisions that are made with a lack of information and understanding" (Vrijhoef and Koskela, 2000, p.175).

In the case of waste management, Pongrácz, Phillips and Keiski (2004, abstract) mention that a proper definition of this management system necessitates a good definition of waste that should specify the reasons and solutions. They state that:

> "The Theory of Waste Management represents a more in-depth account of the domain and contains conceptual analyses of waste, the activity upon waste, and a holistic view of the goals of waste management… Waste Management Theory is founded on the expectation that waste management is to prevent waste causing harm to human health and the environment."

In light of this statement and C&D waste definitions mentioned in the previous sections, we can say that, waste management concept in construction involves how the produced waste will be moved away from the site and treated. However, Teo and Loosemore (2001, p.742) state that, it is a difficult task to carry on waste management practices in the construction industry due to uniqueness of each project, uncertain context, fragmented structures of the construction companies and strict limitations of cost and time. However, they add that a company which does not adopt waste management system can be 10% disadvantageous in tendering for a new work.

CHAPTER 3

MATERIAL AND METHOD

This chapter consists of information on the material of and the method followed during the study. The material consists of eight construction projects taken as case studies and data obtained from their records. The method depicts how these data were used and analyzed to derive the findings.

3.1. Material

This section includes the descriptions of the case study projects that were included in this study. Each project is described via floor plans, construction photos and photos on completion or renderings.

There were eight construction projects of two construction companies which were built in Turkey. Among the studied construction projects were a school, a hospital, two apartment blocks, pavement, a housing project consisting of eight villas and three apartment blocks, a Turkish bath and a culvert construction. One of the case study buildings was unfinished at the time of data collection stage; but works regarding the related materials had been over in this project. Therefore, it was included in the study, too. Detailed information is given on these case study buildings in following sections.

The data was composed of the following:

- Three different quantities were collected for four different construction materials; ready-mixed concrete, rebar, brick and floor block. The first was from the bills of quantities, as calculated at the beginning of each construction project. The second was from the progress payment reports and the third from the invoices regarding these materials.

- Interviews were made with the directors and the site supervisors to obtain data about the reasons of waste in these construction projects.
- The architectural plan drawings of the construction projects and the photos taken during construction and on completion were also compiled to give the reader further insight on the case study projects.

It is worth mentioning that the companies used similar request forms for material flow as shown in Appendix D. It was filled and approved by the site supervisor and then sent to the personnel responsible for purchasing. The forms were also approved by the directors before material dispatching. This system was applied in all of the construction projects to control the traffic of material flow and the amount of materials used.

3.1.1. Case Study 1

The first case study was carried out on a private school construction with an area of 6500 m². The three-storey building with a basement floor was constructed between April and September 2005. The floor plan drawing of this project could not be included; because permission was not given by the architect. However, the photo of the building is presented below in Figure 3.1.

Figure 3.1. View of Case Study 1 building on completion.
Source: Sarılar Constr. and Excavation Co.

3.1.2. Case Study 2

This case study was a 5000 m² hospital with 3 floors above and 2 floors below ground, which was constructed between September 2005 and January 2006. Figure 3.2 shows a photo during its construction and a photo after the construction was completed while Figure 3.3 shows a typical floor plan.

Figure 3.2.a. View of Case Study 2 building during construction.

Figure 3.2.b. View of Case Study 2 building on completion.

Source: (Botam Construction Group)

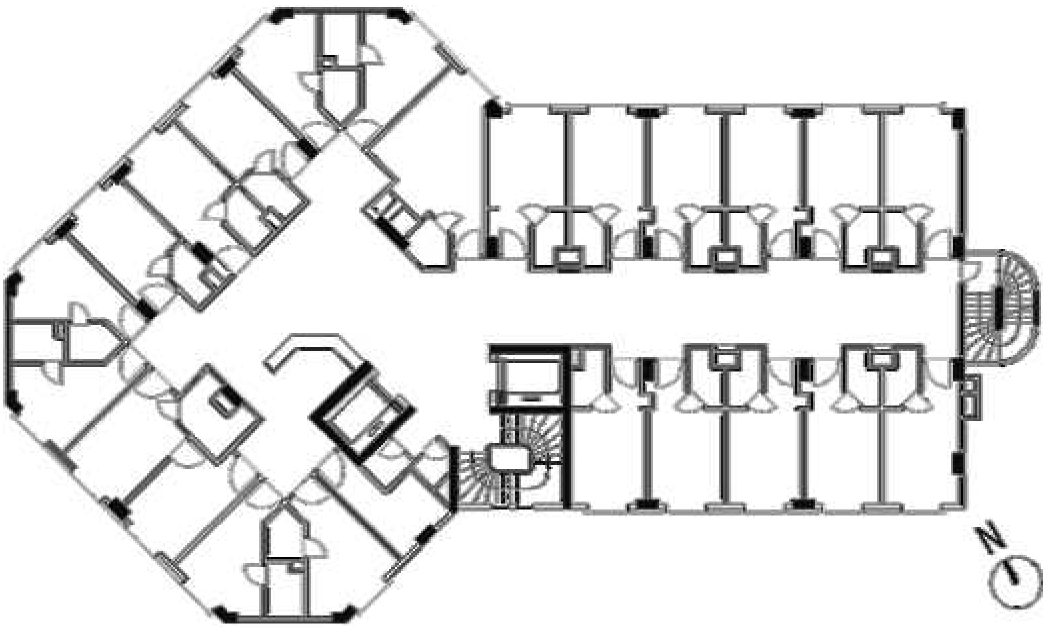


Figure 3.3. Floor plan of Case Study 2 building.

Source: Architect (H. Şenol)

3.1.3. Case Study 3

This case study concerned an apartment construction. Total construction area was 800 m² with a ground floor and two top floors. The construction took place between January and June 2006. Figure 3.4 shows the building during construction and after completion and Figure 3.5 presents a typical floor plan for this project.

Figure 3.4.a. View of Case Study 3 building during construction.

Figure 3.4.b. View of Case Study 3 building on completion.
Source: Sarılar Constr. and Excavation Co.

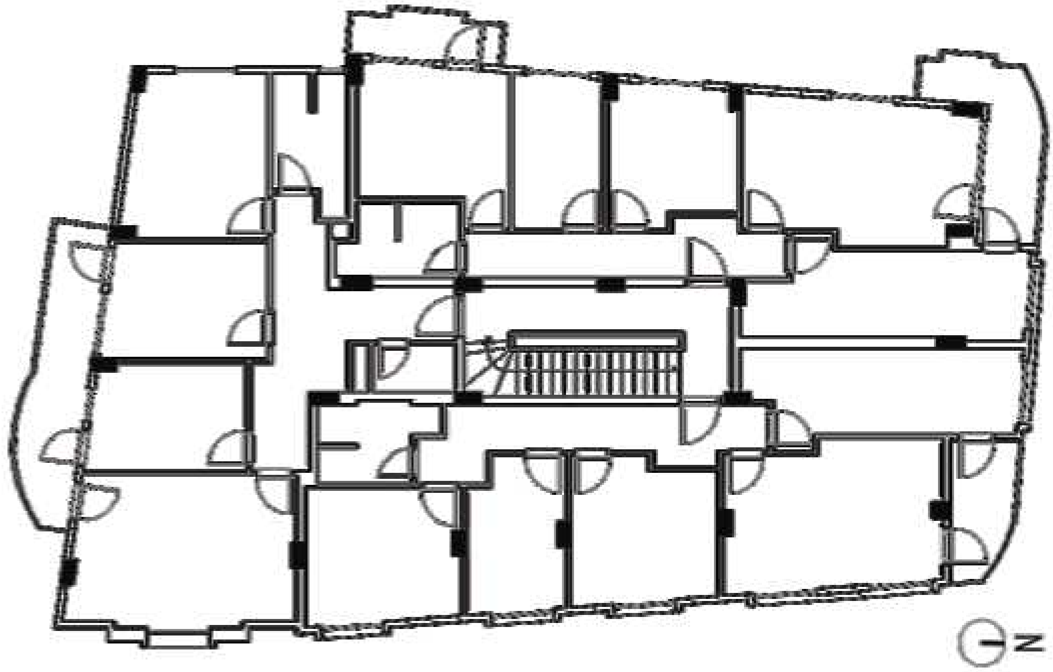


Figure 3.5. Floor plan of Case Study 3 building.
Source: Architect (F. Çalışır)

3.1.4. Case Study 4

Case Study 4 was a road and pavement construction in a recreational area of the municipality. The construction took place over 22500 m² with a length of 1100 m and between February and May 2006. Figure 3.6 presents the photos and Figure 3.7 shows the schematic cross section of this construction.

Figure 3.6.a. View of Case Study 4 on completion.

Figure 3.6.b. Detail of the materials for Case Study 4.

Source: Botam Construction Group

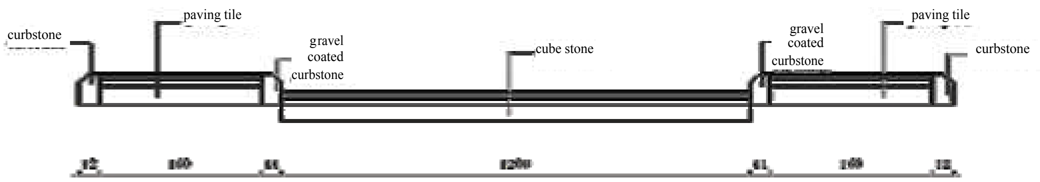


Figure 3.7. Schematic cross section of Case Study 4.

Source: Botam Construction Group

3.1.5. Case Study 5

The fifth case study, a 2910 m² housing construction consisting of eight detached houses, three apartment blocks and a swimming pool building, was built between February and July 2006. All the blocks were composed of a ground floor plus two top floors. Figure 3.8 includes a photo during construction of the buildings and a rendered image; and Figure 3.9 presents the first floor plans of the blocks, including the site.

Figure 3.8.a. View of Case Study 5 buildings during construction.

Figure 3.8.b. Rendered image of Case Study 5 buildings.

Source: Botam Construction Group

Figure 3.9. Floor plans of Case Study 5 buildings.

Source: Architect (C. Çinici)

3.1.6. Case Study 6

This case study was a Turkish bath project. It consisted of a ground floor and a basement with 560 m² of covered area; and was constructed between March and August 2006. No photo could be obtained regarding the construction phase of this project; whereas photo of the completed building is presented in Figure 3.10. The plan is also shown in Figure 3.11.

Figure 3.10. View of Case Study 6 building on completion.
Source: Botam Construction Group

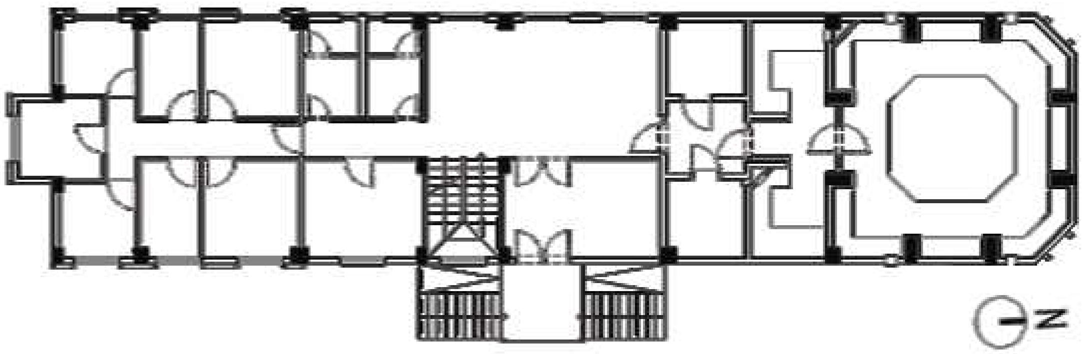
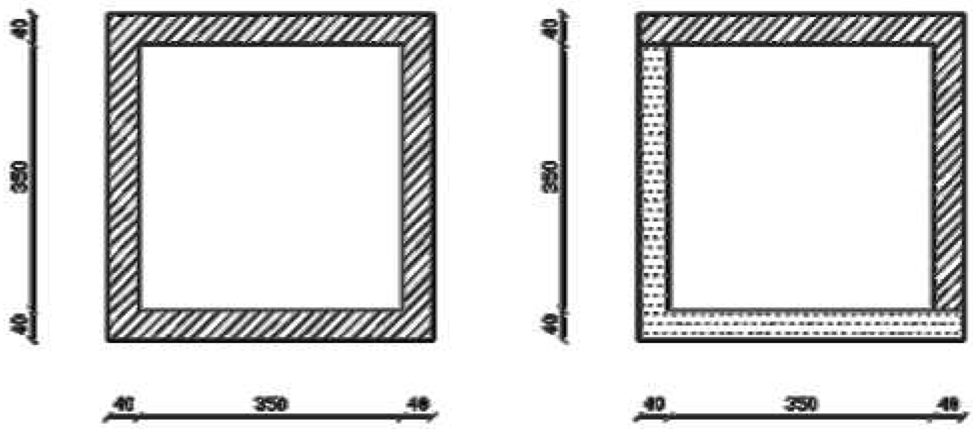


Figure 3.11. Floor plan of Case Study 6 building.
Source: Architect (M. Gürkan)

3.1.7. Case Study 7

This project consisted of a 51 m culvert and was constructed between March and April 2006. The first 21 m part was constructed on top of an existing base, and the other 30 m was constructed together with its base. The photos of this construction could not be obtained; however, the cross sections of the culvert are illustrated in Figure 3.12. In this figure, the linearly hatched areas represent the newly constructed parts and the dotted part constitutes the existing 21 m base.



Section for 30 m part Section for 21 m part

Figure 3.12. Cross sections of Case Study 7.

Source: Botam Construction Group

3.1.8. Case Study 8

This case study was another apartment construction like Case Study 3. The project included a basement, a ground, a first and an attic floor, which constituted 1000 m² of floor space. The project also included a small swimming pool in front of the building. The construction started in April 2006 and it was still going on at the time of data collection stage of this study. However, the construction works regarding the analyzed materials had been completed. Thus, it was also included in the research.

Below are a photo during construction and a rendered image in Figure 3.13 and a floor plan in 3.14.

Figure 3.13.a. View of Case Study 8 building during construction.

Figure 3.13.b. Rendered image of Case Study 8 building.
Source: Botam Construction Group

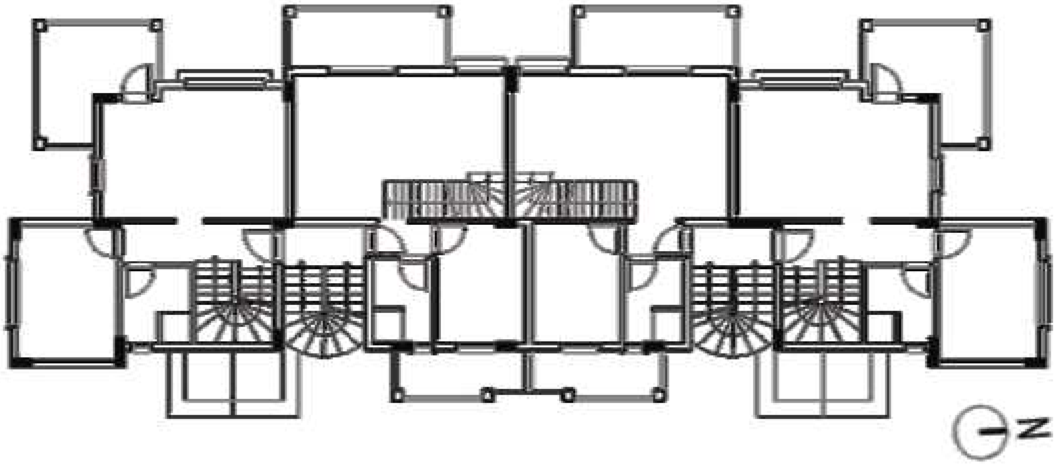


Figure 3.14. Floor plan of Case Study 8 building.
Source: Architect (H. Karaca)

3.2. Method

There were two steps of the method used in this study. Firstly, data regarding the quantities of ready-mixed concrete, rebar, brick and floor block were obtained from the construction companies. Then these data were analyzed statistically using ANOVA and regression analyses. These stages are explained in detail in the following sections.

3.2.1. Data Compilation

During the data collection phase of this study, visits were made to three different large and well-known construction companies located in Ankara, one of which had projects abroad. However, due to several reasons the required information could not be obtained from these companies. The major reason was that, they did not keep quantitative records of the materials. All the records were related to finances and expenditures. Thus, they did not have a database on how much material was used in each project. On the other hand, no permission was given for searching through the archives and calculating the necessary amounts from the contracts, progress payment reports and invoices. The companies did not wish to share the data they had. Because of this, the case study had to be delimited within the context of the construction projects whose material data could be reached via personal relationships.

As stated before, data was compiled from three different sources. The first two, the amounts in the bills of quantities and in the progress payment reports, were taken from the directors of the companies. The last one was calculated by searching through the monthly invoice archives of the company with the permission of the directors. On the other hand, the study was delimited to the aforementioned four basic construction materials, which were ready-mixed concrete, rebar, brick and floor block. This delimitation was determined firstly considering the other studies all over the world. As mentioned in the previous chapter, most studies included these materials and this research would give a chance of comparing the results with the other countries. Secondly, these materials have higher and more specific percentage of waste compared to the others. Finally, they are used almost in every construction project. However, due to their type of construction, some of the projects lacked information especially on brick and floor block.

Architectural drawings, construction photos and photos of the completed buildings were also collected for the case studies, where applicable and available. The floor plans were included in the study by getting permission from the architects. However, for one of the projects the architectural plans could not be used due to the refusal of permission. Photos were obtained from the construction companies' archives.

3.2.2. Data Analyses

In the analysis of data it was assumed that the collected data would be correct, neglecting the possible errors that could have occurred while calculating or recording the amounts during the construction stage. Regarding these data, several other assumptions were also made. First of all, the difference between the amounts in the bills of quantities and the progress payment reports was considered as the amount of change in the design during construction or after the contract was signed. On the other hand, the difference between the amounts in the progress payment reports and the invoices was considered as the wasted amount. In this context, leftover materials were also taken into consideration as waste. These assumptions were made in order to determine a percentage of waste and a percentage of design change for the projects and, if possible, establish a relationship between these two parameters together with the other reasons. In addition, these values were analyzed just in terms of material quantities; and economical aspects of waste, such as profit or loss, were not considered in this study.

Having reached these values, two different analyses were carried out. Firstly, ANOVA was used in order to determine if material type was an important factor on waste percentage among the case study projects. In relation to ANOVA, several other tests were also used such as test of normality, test of homogeneity of variances and least significant difference (LSD) test. Secondly, using regression analyses, an equation for the relation between waste percentage of each material type and total area of construction is tried to be derived and the case studies that behaved different from the others in terms of this relationship were determined. Depending on the reasons stated by the directors of the companies and the site supervisors of the projects, several aspects were mentioned that might have caused these differences.

CHAPTER 4

SURVEY ON ORIGINS AND MAGNITUDE OF WASTE IN THE TURKISH CONSTRUCTION INDUSTRY

In this chapter, data obtained on the estimated and the actual “in place” amounts of the construction materials, namely ready-mixed concrete, rebar, brick and floor block, and derived data regarding these quantities for eight different construction projects are presented in tabular and graphical format. Additionally, discussion on the origins of waste for each project is presented.

Raw data on material quantities consisted of the amounts in the bills of quantities, the progress payment reports and the invoices. Several other variables were also used regarding the projects and their material amounts such as; total area of construction and derived design change percentage, waste per meter square and waste percentage values. In this respect, “total area of construction” meant the covered area of the project. On the other hand, “design change percentage” was calculated as the percentage of the quantity difference between the progress payment reports and the bill of quantities on the quantity existing in the bill of quantities. In other words, the difference between the material quantities that was planned to be used and that was actually used in the construction was assumed to occur due to design change. Similarly, “waste percentage” levels were also derived by calculating the percentage of the quantity difference between the invoices and the progress payment reports on the quantity existing in the progress payment reports. In this respect, the difference between the purchased and the used amounts was considered as waste. Finally, “waste per meter square” was arrived at by dividing the amount of waste for each material to the total area of construction.

Tabular information on the data for each case study includes the following seven variables:

- Total area of construction (in m^2)
- Material type (ready-mixed concrete, rebar, brick and floor block)
- Material quantities in the bill of quantities
- Material quantities in the progress payment reports
- Material quantities in the invoices
- Derived design change percentage
- Derived waste per meter square value

In addition to these variables, waste percentage levels of the four construction materials are presented in graphical format to depict the situation more clearly. On the other hand, the probable reasons of the differences between these quantities are also stated depending on the interviews made with the directors of the companies and the site supervisors of the projects.

In this context, the construction periods of the case studies, the quantities of the purchased materials on a monthly-base and the collected data on the material quantities together with the derived values for design change percentage, waste percentage and waste per meter square are presented in Appendix E, Tables E.1, E.2 and E.3, respectively. Detailed information on the magnitude of waste for each case study project is presented in the following sections, along with the reasons for and the origins of this waste.

4.1. Data Evaluation of Case Study 1

Data on ready-mixed concrete, rebar, brick and floor block was obtained for this project. Table 4.1 presents the total area of construction, the quantities of these materials in the bill of quantities, the progress payment reports and the invoices and the derived design change percentage and waste per meter square values for Case Study 1. It is seen that the materials had very high design change percentages that reached to 45%. Additionally, brick and floor block had also higher waste per meter square values with respect to ready-mixed concrete and rebar.

Table 4.1. Material data for Case Study 1.

Total Area of Construction (m²) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)	Waste/m² ((d-c)/a)
		Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)		
6500	ready-mixed conc. (m³)	2220	3173	3320	42.93	0.023
	rebar (t)	225	325	342	44.44	0.003
	brick (each)	50300	72225	81560	43.59	1.436
	floor block (each)	31250	40025	46060	28.08	0.928

Taking into account the quantities in the progress payment reports and the invoices, Figure 4.1 was composed for waste percentage values of the materials. It is apparent that floor block and brick were the most wasted materials.

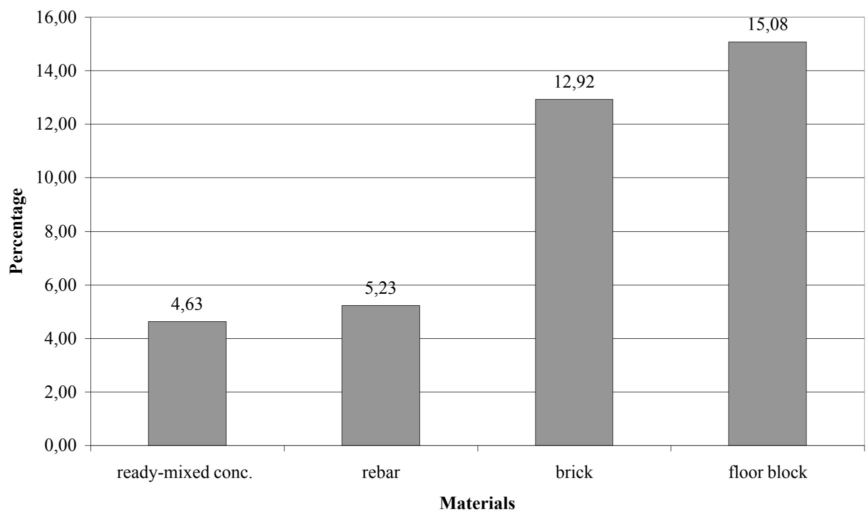


Figure 4.1. Waste percentages of materials for Case Study 1 ((d-c)/c*100).

According to the information obtained as a result of the interviews made with the directors and the site supervisor, the reason for such a great amount of design change was that, one more storey was added to the original project during the construction, which included a conference hall. Similarly, a sports hall of steel construction and two open basketball fields were also included later on in the project during its construction. On the other hand, the reason for material waste was declared by the directors to be incorrect calculation of material quantities.

4.2. Data Evaluation of Case Study 2

Floor block was excluded from the material types being studied for this case study due to the fact that the floor structure of the building was composed of two-way slabs with surrounding beams. Table 4.2 shows the quantities of the other materials, which were ready-mixed concrete, rebar and brick, existing in the bill of quantities, the progress payment reports and the invoices and derived design change percentage and waste per meter square values, together with total area of this construction. As the table displays, rebar had a very high design change percentage with 33.04%. On the other hand, in terms of waste per meter square values, brick had a significant difference compared to the other materials.

Table 4.2. Material data for Case Study 2.

Total Area of Construction (m^2) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)	Waste/m^2 ((d-c)/a)
		Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)		
5000	ready-mixed conc. (m^3)	2770	2780	2890	0.36	0.022
	rebar (t)	230	306	325	33.04	0.004
	brick (each)	89813	95000	107875	5.78	2.575

Figure 4.2 presents the derived waste percentage levels for these materials. It is seen that brick had the largest waste percentage value with respect to ready-mixed concrete and rebar. On the other hand, this project had the lowest level of waste percentage among the studied cases in terms of ready-mixed concrete.

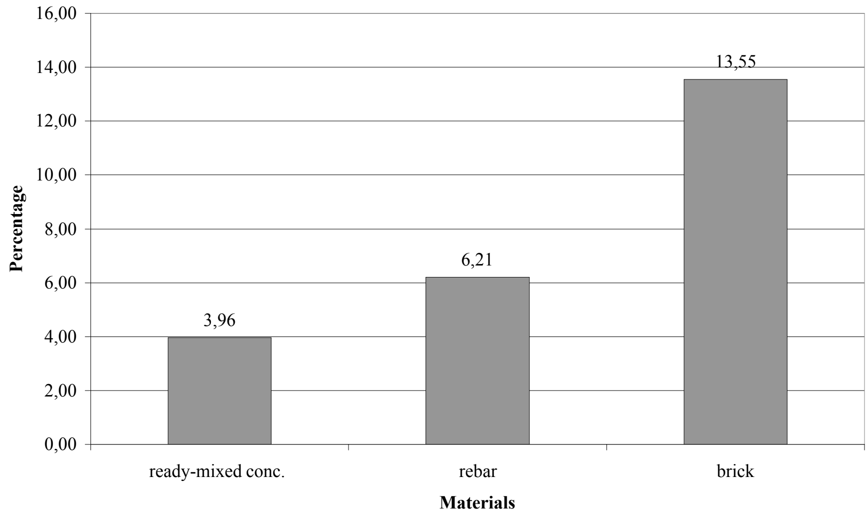


Figure 4.2. Waste percentages of materials for Case Study 2 ((d-c)/c*100).

The site supervisor of this construction project stated that, the significant level of design change percentage for rebar was the cause of incorrect calculation in the bill of quantity. Moreover, there was waste due to structural design faults, design changes resulting in demolitions and incorrect classification of rebar by the steel workers according to desired lengths. It was declared that the length of shear walls is also an increasing factor for waste of ready-mixed concrete and rebar in general; because there is a considerable amount of workmanship in shear walls and its construction requires excessive material quantities. In this project, two semi-basement floors were surrounded by shear walls, which were considered by the site supervisor as a waste-increasing factor.

The floor structure of the building, being two-way slab with surrounding beams, was a decreasing factor for ready-mixed concrete waste; because, it was stated that floor block were also another increasing factor for waste of concrete for several reasons. As indicated, the first reason is that, the volume planned to be occupied by the floor block may be filled with concrete because of disuse of a closing block on the edge. This results in excess concrete filling the holes of the last open block. Another reason may be possible breakages of the floor block occurring during pouring of the concrete and resulting in a similar waste of concrete that does not add value to the product.

4.3. Data Evaluation of Case Study 3

Data for all four of the materials within the context of this research were obtained for Case Study 3. In this respect, Table 4.3 presents the total area of construction for this case study, the obtained quantities and the derived design change percentage and waste per meter square values of ready-mixed concrete, rebar, brick and floor block. It comes out as a fact from this table that, brick had far and away the highest design change percentage and waste per meter square values. On the other hand, ready-mixed concrete and rebar had a negative value for design change percentage, which meant that there was a decrease between the estimated and used material quantities.

Table 4.3. Material data for Case Study 3.

Total Area of Construction (m^2) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)	Waste/m^2 ((d-c)/a)
		Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)		
800	ready-mixed conc. (m^3)	500	495	532	-1.00	0.046
	rebar (t)	52	48	56	-7.69	0.010
	brick (each)	15000	17813	20725	18.75	3.641
	floor block (each)	4625	4950	5875	7.03	1.156

The waste percentage values for ready-mixed concrete, rebar, brick and floor block are shown below in Figure 4.3. Ready-mixed concrete, with 7.47 %, had the lowest waste percentage value in this project; whereas, the other materials showed values changing between 16-19 %.

The reason for the variation between the design change percentage values of the materials was stated by the site supervisor as incorrect calculation for structural design (for ready-mixed concrete and rebar) and change in the architectural design during construction (for brick and floor block). On the other hand, the reason for waste was determined as poor workmanship of steel workers, demolitions during construction due to design change, the non-rectangular shape of the building and the rooms and excess of corners in the interior partitions. Additionally, as declared by the site supervisor, the floor block were newly dried in the kiln and thus many breakages occurred during transportation to and within the site. Moreover, there were leftover rebar after construction, which was transported to be used in another construction site of the company. However, as mentioned in the previous chapters, leftover materials were assumed to be wasted within the context of this research.

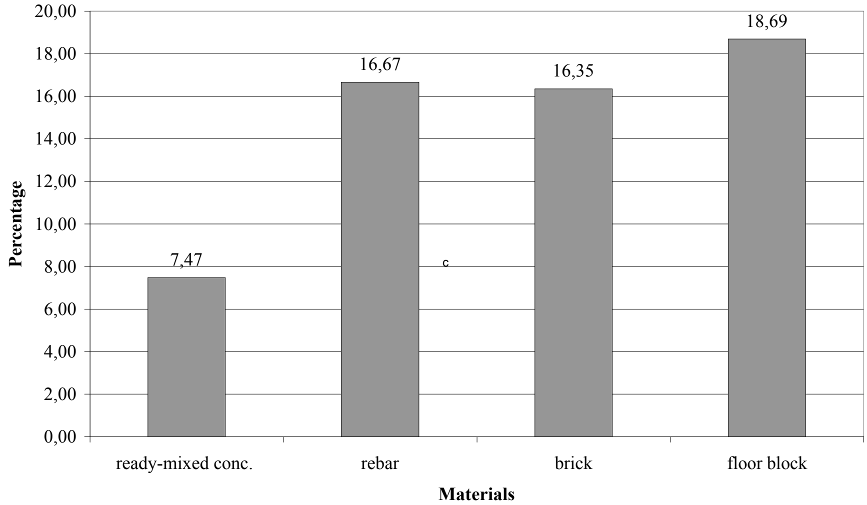


Figure 4.3. Waste percentages of materials for Case Study 3 ((d-c)/c*100).

4.4. Data Evaluation of Case Study 4

Being a different type of construction than the others, the analyzed materials also showed difference in this project. There were two types of paving tiles of pebbles and stone, two types of curbstones and granite cobblestone as material types, as shown in the schematic cross section in Figure 4.10. Because of this diversification in terms of material types, Case Study 4 was not included in the statistical analyses but mentioned separately. The amounts regarding the paving tiles, curbstone and cobblestone are presented in Table 4.4. It is apparent that, although there was a significant decrease in the estimated material quantity of the first type of paving tile, it had the highest waste per meter square value.

Table 4.4. Material data for Case Study 4.

Total Area of Construction (m²) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)	Waste/m² ((d-c)/a)
		Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)		
22500	paving tile1(m²)	3750	3035	3338	-19.07	0.013
	paving tile2(m²)	500	500	520	0.00	0.001
	curbstone (mt)	4620	5012	5110	8.48	0.004
	cobblestone (m²)	15250	15475	15730	1.48	0.011

Figure 4.4 shows the waste percentages for the above mentioned material types. As it was in waste per meter square variable, the first type of paving tiles again had the highest value compared to the other material types in terms of waste percentage.

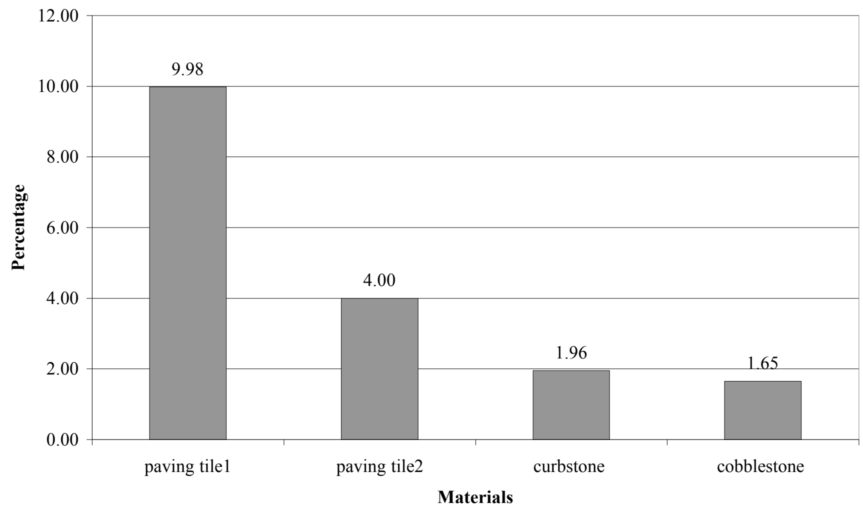


Figure 4.4. Waste percentages of materials for Case Study 4 ((d-c)/c*100).

The values for two different types of curbstones were combined in this research; because they showed similar values in terms of design change and waste. However, the paving tiles were considered separately; because their values showed differences due to two main reasons. As stated by the directors of the company and the site supervisor, the first reason was that, the first type of paving tiles were purchased more than the required amount as the excess was planned to be used in another project. However, the total of the purchased amount was recorded for this project.

Thus it was considered as waste. Secondly, the first type of paving tiles, the light ones as it can be seen in Figure 4.9.b, were wasted via off-cuts especially in the rounded corners of the pavement. Whereas, the second type, the dark ones used for pavement decoration, were not cut into pieces.

4.5. Data Evaluation of Case Study 5

The data obtained for this project included all four of the material types, as ready-mixed concrete, rebar, brick and floor block. The collected material quantities and the derived values for design change percentage and waste per meter square are presented in Table 4.5. As shown in the table, design change percentage for ready-mixed concrete and brick were over 50%. When waste per meter square values of these materials are analyzed, it is seen that, although ready-mixed concrete in this project had a high value with respect to the other case studies, the value for brick was far below the others. On the other hand, in terms of rebar and floor block, the design change percentage values were again high with 20-30%.

Table 4.5. Material data for Case Study 5.

Total Area of Construction (m^2) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)	Waste/m^2 ((d-c)/a)
		Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)		
2910	ready-mixed conc. (m^3)	1684	2548	2705	51.33	0.054
	rebar (t)	180	217	227	20.80	0.003
	brick (each)	14563	22115	24463	51.86	0.807
	floor block (each)	10875	13924	15725	28.04	0.619

Figure 4.5 shows the waste percentage values of ready-mixed concrete, rebar, brick and floor block with regard to Case Study 5. As the figure depicts, brick and floor block had waste percentage levels higher than 10%. However, they were still lower than that of the same materials in the previous case studies.

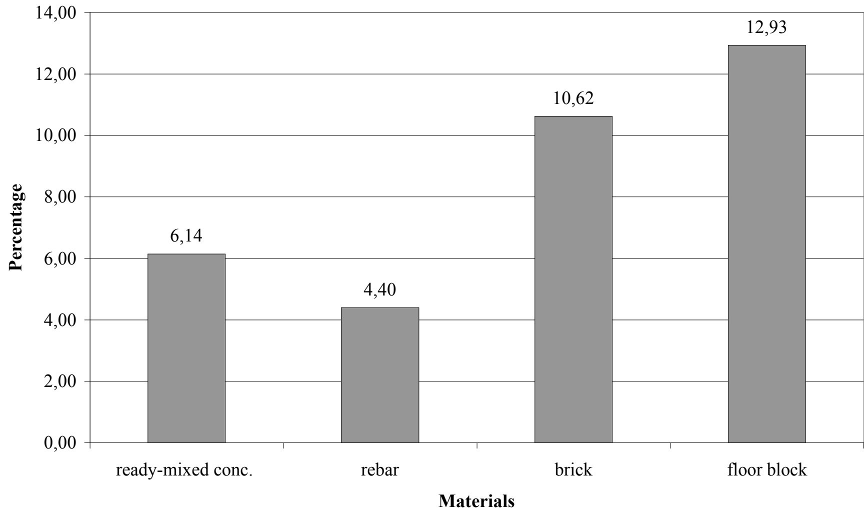


Figure 4.5. Waste percentages of materials for Case Study 5 ((d-c)/c*100).

The site supervisor indicated that, the reason for ready-mixed concrete and rebar waste was the length and the design of shear walls, which rose up in steps. The strict time limitation of this construction was another important factor for waste, which necessitated concrete workers to work at night and rapidly. It was also stated that, steel workers were very skilled in this construction, which was a decreasing factor for waste of rebar. In addition, wasted brick were considered to be less than the estimated; because damaged brick were used, wherever possible, in order not to exceed the predetermined quantities.

4.6. Data Evaluation of Case Study 6

The material data obtained included ready-mixed concrete, rebar, brick and floor block. Regarding these data, material amounts in the bill of quantities, the progress payment reports and the invoices are presented together with design change percentage and waste per meter square values below in Table 4.6. As it is observed, rebar had the highest design change percentage with 22.86%. On the other hand, there was no change in design in the case of floor block.

Table 4.6. Material data for Case Study 6.

Total Area of Construction (m²) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)	Waste/m² ((d-c)/a)
		Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)		
560	ready-mixed conc. (m³)	390	424	450	8.68	0.047
	rebar (t)	35	43	47	22.86	0.007
	brick (each)	8125	9113	10337	12.15	2.187
	floor block (each)	3500	3500	4000	0.00	0.893

Waste percentage levels of the materials are shown below in Figure 4.6. As it is seen, although design change percentage for floor block was 0%, waste percentage was calculated as 14.29%, the highest of the four materials for this case study. On the other hand, ready-mixed concrete had the lowest waste percentage value with 6.17%.

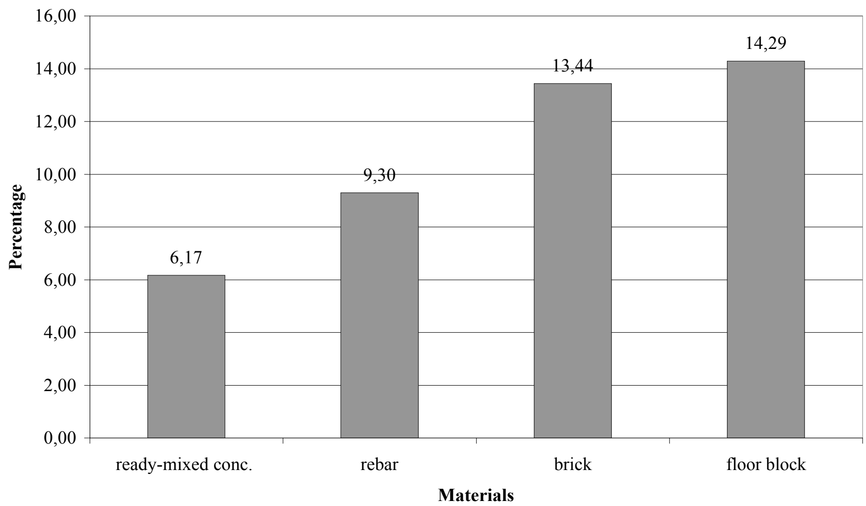


Figure 4.6. Waste percentages of materials for Case Study 6 ((d-c)/c*100).

There was a considerable amount of design change in this construction, which resulted in demolition of some of the constructed brick walls. When ready-mixed concrete and rebar were considered, it was mentioned that there was design change in the project, too; but in the form of addition this time. Thus, it did not affect the amount of waste much. However, there was a mistake in the construction of the foundations, which resulted in a significant amount of waste in terms of these two materials. Long shear walls around the basement and around the site were another factor that increased waste, as declared by the site supervisor.

4.7. Data Evaluation of Case Study 7

Due to the type of construction, brick and floor block were not required in this project; and only ready-mixed concrete and rebar were used. Table 4.7 shows the obtained material quantities, and derived design change percentage and waste per meter square values from these quantities. It is seen that, both of the materials had almost similar design change percentage levels. On the other hand, due to the type of construction, "total area of construction" variable was modified as "total length of construction" for this case study. Therefore, this case study was not included in the analyses that required the variable "total area of construction".

Table 4.7. Material data for Case Study 7.

Total Length of Construction (m) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)
		Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)	
51	ready-mixed conc. (m^3)	266	313	340	17.86
	rebar (t)	16	19	20	17.42

In the case of waste percentage, ready-mixed concrete had a higher value than rebar for this case study as seen in Figure 4.7. However, both of the materials showed high values when compared to the other case studies.

The reason for waste in ready-mixed concrete was stated as a casting fault. There was waste because of a breakage in the formwork while pouring of the concrete. On the other hand, there was also excess amount of rebar at the end of this project, which was transported to another site as it was in the third case study. However, this was considered as waste for this project.

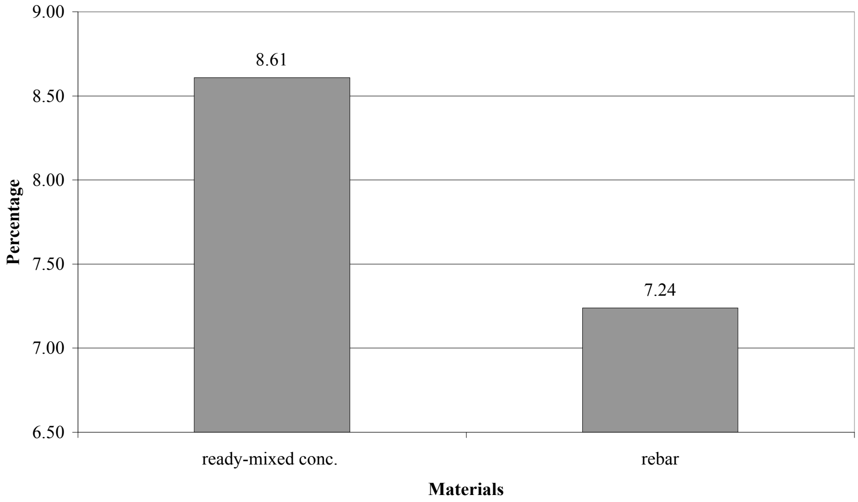


Figure 4.7. Waste percentages of materials for Case Study 7 ((d-c)/c*100).

4.8. Data Evaluation of Case Study 8

The construction of Case Study 8 included all of the four materials; ready-mixed concrete, rebar, brick and floor block. Data regarding the obtained quantities of these materials together with the derived values for design change percentage and waste per meter square are presented in Table 4.8. As it is seen, brick had far and away the highest design change percentage level with 13.18%. On the contrary, the value was very close to zero, meaning no change, in the case of ready-mixed concrete. However, waste per meter square value of ready-mixed concrete was not as low as design change percentage when compared to the other case studies.

Table 4.8. Material data for Case Study 8.

Total Area of Construction (m²) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)	Waste/m² ((d-c)/a)
		Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)		
1000	ready-mixed conc. (m³)	588	595	630	1.19	0.035
	rebar (t)	56	58	60	3.57	0.002
	brick (each)	17451	19750	21950	13.18	2.200
	floor block (each)	4813	5020	5625	4.31	0.605

Figure 4.8 presents the waste percentage values for ready-mixed concrete, rebar, brick and floor block. Although brick and floor block had values over 10%, it was between 3-6% in the case of ready-mixed concrete and rebar.

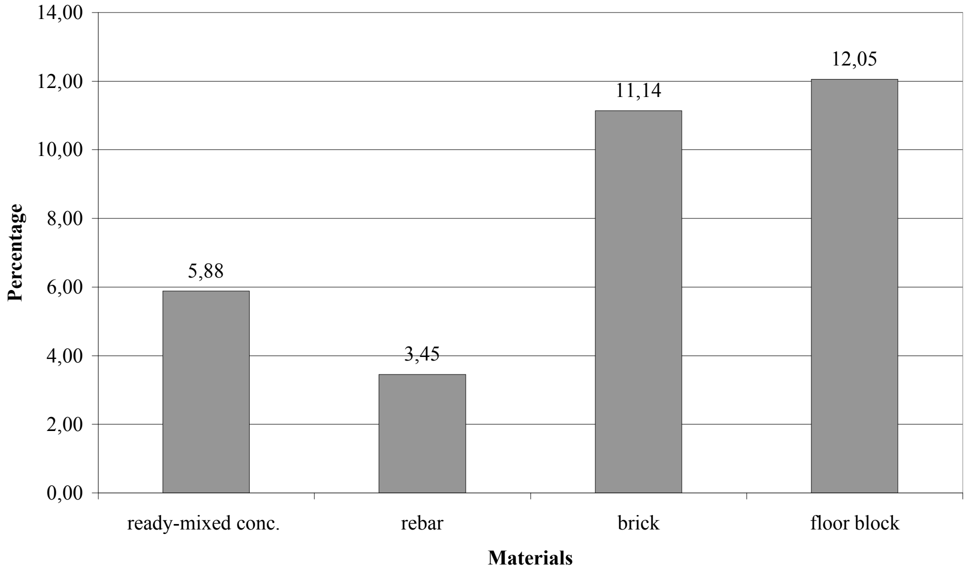


Figure 4.8. Waste percentages of materials for Case Study 8 ((d-c)/c*100).

The site supervisor stated several specific reasons for waste. The first one was that, the stairs were demolished and re-constructed because of a design fault. Similarly, gabled dormer spaces were opened in the roof after its construction, which also resulted in a waste of concrete and rebar. On the other hand, it was indicated that an unknown amount of rebar was transferred to this project, which was leftover in other construction projects of the company, without recording; and this would decrease the amount of waste for rebar for this case study. However, as there was no information on the amount of the transferred rebar, the obtained data was considered to be correct. In addition, there were also slight changes in the design which resulted in brick waste.

CHAPTER 5

DISCUSSION OF RESULTS

In this chapter, the results of the statistical analyses carried out on waste percentage levels of the construction materials, which were ready-mixed concrete, rebar, brick and floor block, and total areas of construction are presented and discussed.

5.1. Hypotheses Tested

This section includes the results of statistical analyses on waste percentage. In this respect, the test of normality result is presented first. Then the results of ANOVA are discussed. Finally, LSD (least significant difference) test outcomes are presented together with test homogeneity of variances. Case Study 4 was excluded in all of these analyses due to its material types being different from the other case studies.

5.1.1. Test of Normality

The test of normality was applied to each material type in order to find out the waste percentage distributions. This test was necessary to determine the applicability of ANOVA. In this respect, the hypothesis tested was:

H_0 : There is no difference between the distribution of the variables and normal distribution (the null hypothesis).

Kolmogorov-Smirnov test was applied taking the conventional level of significance (α=0.05). Table 5.1 presents the results of the test.

Table 5.1. Test of normality.

Material Type		Kolmogorov-Smirnov*		
		Statistic	df	Sig. (α)
WASTE %	ready-mixed conc.	.202	7	.200**
	rebar	.237	7	.200**
	brick	.228	6	.200**
	floor block	.227	5	.200**

* Lilliefors Significance Correction.
** This is the lower boundary of true significance.

For each material type, the significance values were greater than 0.05. Thus the null hypothesis was accepted. In other words the variable "waste percentage" was normally distributed with 95% confidence for ready-mixed concrete, rebar, brick and floor block among the case studies. The waste percentage frequency distributions for each of these material types are graphically presented in Appendix E, Figures E.1, E.2, E.3 and E.4, in the form of histograms.

5.1.2. ANOVA for Material Type

The level of significance was 0.05 in this test; and the hypothesis was stated as follows:

H_0 : There is no difference between the mean values; $\mu_1 = \mu_2 = \mu_3 = \mu_4$ (the null hypothesis).

Table 5.2 shows the descriptive values of ANOVA for ready-mixed concrete, rebar, brick and floor block. As it is shown, rebar had a higher standard deviation value with respect to the other materials. It also had a wider interval of mean than the others, which changed within a range of around 8%. Additionally, the total mean value was very close to 10%, which is accepted as a general waste percentage level by many contractors in making the estimations, as mentioned in the previous chapters.

Table 5.2. Group statistics for waste percentage of materials.

WASTE %

Material Type	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
ready-mixed conc.	7	6.1229	1.57949	.59699	4.6621	7.5836	3.96	8.61
rebar	7	7.5000	4.47635	1.69190	3.3601	11.6399	3.45	16.67
brick	6	13.0033	2.04201	.83365	10.8604	15.1463	10.62	16.35
floor block	5	14.6080	2.56640	1.14773	11.4214	17.7946	12.05	18.69
Total	25	9.8568	4.52374	.90475	7.9895	11.7241	3.45	18.69

Considering these statistics, the results of ANOVA for the waste percentage levels of the materials were as in Table 5.3, below.

Table 5.3. ANOVA for material type.

WASTE %

Source of Variation	Sum of Squares	df	Mean Square	F	Sig. (α)
Between Groups	308.751	3	102.917	11.850	.000
Within Groups	182.389	21	8.685		
Total	491.141	24			

As shown in this table, significance came out to be 0.000 at the end of the test. Because that it was smaller than 0.05, the null hypothesis was rejected, meaning that at least one of the mean values was different from the others with 95% confidence. In other words, these four materials did not show similar mean values when their waste percentage levels were considered.

5.1.3. Test of Homogeneity of Variances and Multiple Comparisons

Having found out that materials had different waste percentage levels, another test was applied in order to analyze which material types showed similarity in terms of their waste percentage mean values, in pairs. Firstly, homogeneity of the variances was checked as seen in Table 5.4 in order to determine if LSD test was applicable.

The significance level was taken again as α=0.05 in this test and the following hypothesis was developed:

H₀ : There is no difference between the variances - The variances show homogeneity (the null hypothesis).

Table 5.4. Test of homogeneity of variances.

WASTE %

Levene Statistic	df1	df2	Sig. (α)
1.502	3	21	.243

As the significance level was found to be 0,243, which was greater than 0.05, the null hypothesis was accepted with 95% confidence. LSD test was applicable in making the difference analysis between the mean values of multiple groups due to the fact that the variances were homogenous. The results of LSD test are shown in Table 5.5.

Table 5.5. Multiple comparisons of waste percentages of materials.

Dependent Variable: WASTE %
LSD

Material Type (I)	Material Type (J)	Mean Difference (I-J)	Standard Error	Sig.	95 % Confidence Interval Lower Bound	95 % Confidence Interval Upper Bound
Ready-mixed conc.	Rebar	-1.3771	1.57527	.392	-4.6531	1.8988
	Brick	-6.8805*	1.63960	.000	-10.2902	-3.4707
	Floor block	-8.4851*	1.72563	.000	-12.0738	-4.8965
Rebar	Ready-mixed conc.	1.3771	1.57527	.392	-1.8988	4.6531
	Brick	-5.5033*	1.63690	.003	-8.9131	-2.0936
	Floor block	-7.1080*	1.72563	.000	-10.6966	-3.5194
Brick	Ready-mixed conc.	6.8805*	1.63690	.000	3.4707	10.2902
	Rebar	5.5033*	1.63690	.003	2.0936	8.9131
	Floor block	-1.6047	1.78454	.379	-5.3158	2.1065
Floor block	Ready-mixed conc.	8.4851*	1.72563	.000	4.8965	12.0738
	Rebar	7.1080*	1.72563	.000	3.5194	10.6966
	Brick	1.6047	1.78454	.379	-2.1065	5.3158

* The mean difference is significant at α=0.05 level.

Depending on these results, it can be said that ready-mixed concrete and rebar did not show significant differences among their mean values for waste percentage. Similarly, brick and floor block also did not show any difference at a 5% level of significance. The reason for the similarity between ready-mixed concrete and rebar may be attributed to the fact that they are used together in the composition. Therefore, it is expectable that they would show similar values. On the other hand, the situation for brick and floor block may be explained by the fact that they are both produced with the same raw material and therefore have similar endurance against exterior effects to which they may be exposed during transportation and construction.

5.2. Regression Analysis for Waste Percentage Levels of Materials and Total Area of Construction

A second analysis was carried out in terms of the relationship between waste percentage (amount of waste as a percentage of the used material quantities) and total area of construction (covered area) in order to state a coefficient of determination (R^2) and an equation for the least square regression line for each material type as well as determining the difference between the projects. In addition, this analysis was used to point out the probable reasons of such a difference depending on the interviews made with the directors of the company and the site supervisors. However, because of the type of building for Case Study 7, it was not possible to calculate total area of construction, as mentioned in the previous sections. Therefore, it was excluded in this part of the analysis, in addition to Case Study 4. The results regarding the rest of the case studies are presented in the following sections.

5.2.1. Regression Analysis for Ready-Mixed Concrete

The relationship between waste percentage of ready-mixed concrete and total area of construction of the case studies were analyzed using scatter plot diagram and regression analysis. Following the analysis, a coefficient of determination R^2 and an equation for the least square regression line was formulated. Due to the material type and the applicability of "total area of construction" variable, case studies 4 and 7 were not included in this analysis. The regression analysis graph is presented in Figure 5.1.

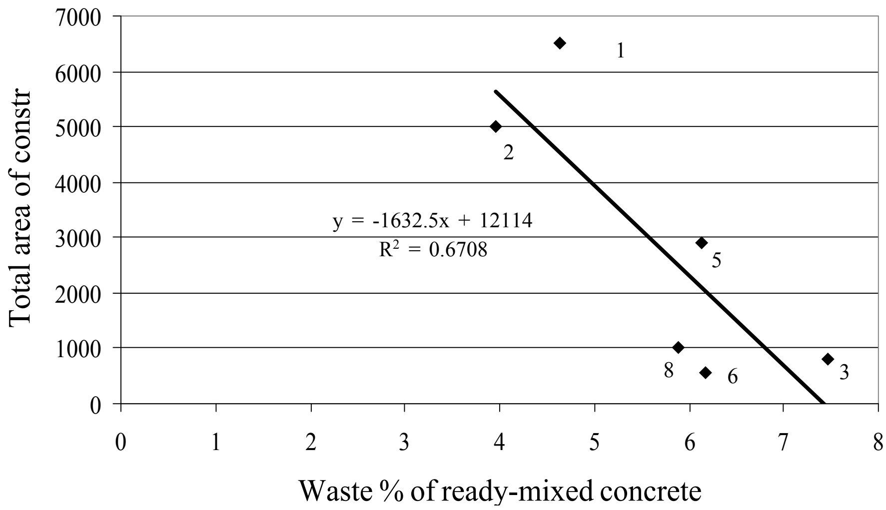


Figure 5.1. Scatter plot and regression analysis for ready-mixed concrete.

As the R^2 value was equal to 0.6708, which was over 0.5000, it can be said that the values were consistent. In other words, the equation can be generalized among the projects. In this respect, the relationship between waste percentage of ready-mixed concrete and total area of construction was defined by the following equation:

$$y = -1632.5x + 12114$$

As the diagram and the regression line indicate, waste percentage of ready-mixed concrete decreases as total area of construction increases. This means that, there is an inverse relation between waste percentage and covered area in the case of ready-mixed concrete. Moreover, when the case studies were analyzed separately, it was seen that case studies 1, 3 and 5 fell over the line; and within these case studies, Case Study 1 was slightly outside the trend. The reason for this may be stated as that, there was a significant amount of design change in this project that resulted in an extra floor with a conference hall. Such a difference might have caused mistakes in the calculations.

When the probable reasons of waste as indicated by the site supervisor for Case Study 5 are analyzed, the major reason for ready-mixed concrete comes out to be the design and the length of shear walls. As indicated by the site supervisor, the shear walls rose up in steps due to the design of the building. Although shear walls were themselves a waste-increasing factor for concrete, addition of steps and corners in their design increased waste more and more. Moreover, different from the other projects, concrete works were executed mostly at night in this project because of the time limitations of the contract. In this context, tiredness of the workers and their desire to finish the work as soon as possible might have been another reason of waste for ready-mixed concrete.

It is also seen that Case Study 3 had a very high waste percentage level compared to the others. However, there were no specific reasons for ready-mixed concrete waste stated by the site supervisor for this project.

On the contrary, it is seen that Case Study 2 had the lowest waste percentage level. As stated by the site supervisor, the major factor that decreased ready-mixed concrete waste was the floor structure, being two-way slab with surrounding beams; because, as mentioned before, use of extra concrete, which would fill in the broken parts and the holes of the floor block, was eliminated by this floor structure.

5.2.2. Regression Analysis for Rebar

In the case of rebar, case studies 4 and 7 were again not included in the analysis due to “material type” and “total area of construction” variables. The diagram showing the results of this analysis are presented in Figure 5.2.

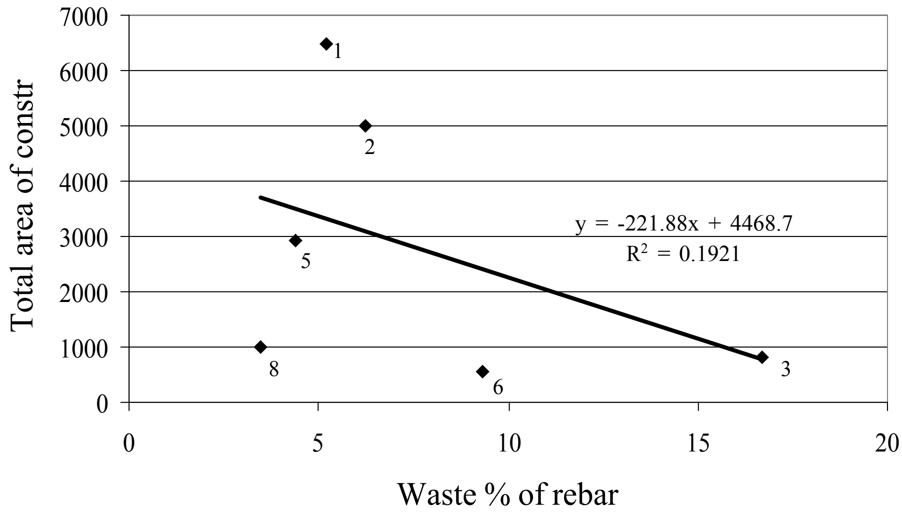


Figure 5.2. Scatter plot and regression analysis for rebar.

Regression analysis for rebar yielded R^2 to be 0.1921. The equation therefore was not considered to be reliable. The values were interdependent at a low level. Additionally, the values for rebar constituted a line with a negative slope, similar to ready-mixed concrete. In other words, total area of construction and waste percentage were again inversely related in the case of rebar.

As seen from the diagram, case studies 1 and 2 were over the least square regression line. In the case of the first case study, incorrect calculation of material quantities may be accepted as one reason for waste of rebar; this was also ststed by the site supervisor. On the other hand, for Case Study 2 the reason was stated as incorrect classification of rebar according to the required lengths and thus inefficient use of rebar lengths. Additionally, long shear walls were considered as another waste-increasing factor for rebar, as it required excessive use of the material and thus caused waste. Structural design faults were also a waste-increasing factor for Case Study 2, as declared by the site supervisor.

Though on the line, Case Study 3 also showed significantly high amount of waste compared to the other projects. As indicated by the site supervisor, the reason for such a high waste percentage for rebar was the unskilled labor force, together with the leftover quantity due to incorrect calculation.

Case Study 8 had the lowest waste percentage value compared to the others. However, as indicated before, this might be misleading because of an extra amount of rebar transferred to this project without recording.

5.2.3. Regression Analysis for Brick

Case studies 4 and 7 were not included in the regression analysis of brick due to the aforementioned reasons. Figure 5.3 presents the results of this regression analysis carried out between waste percentage levels of brick and total areas of construction.

The regression analysis gave an R^2 value, which was 0.0212, very close to zero. The values were not consistent; therefore the outcome equation could not be stated as reliable. However, it can be said that, similar to ready-mixed concrete and rebar, there was an inverse relation between waste percentage values of brick and total area of construction or the covered area.

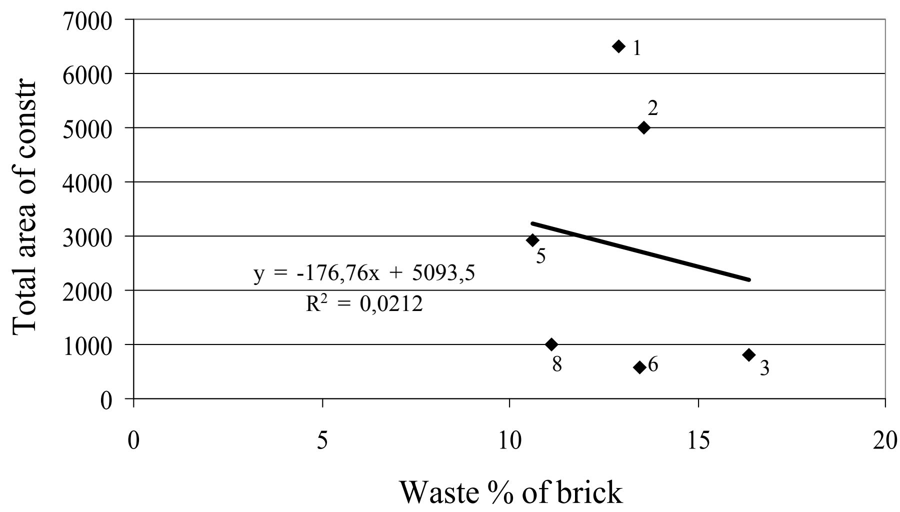


Figure 5.3. Scatter plot and regression analysis for brick.

As mentioned above, the R^2 value proved that it was difficult to determine a trend among the waste percentage levels of brick. The scattered diagram also shows that the values were very distinct. Case studies 1 and 2 were again above the line. In this case, incorrect calculation of material quantities was again in effect for Case Study 1. For Case Study 2, the reason was declared as demolitions due to design change. On the other hand, Case Study 3 again had the largest waste percentage value for brick. Similar to the second case study, the reason was design change, which resulted in demolition of some of the constructed walls. In addition, the design itself was a source of waste for this case study with its excessive number of corners in the interior spaces.

Case Study 5 had the lowest waste percentage value among the studied projects. The reason for such a low level of waste was that, the damaged brick were also tried to be used, where possible, in order to stay within the estimated quantity levels. In addition, the standardization among the housing blocks and their uncomplicated rectangular shapes were another waste decreasing factor; because both the easiness of construction and standardization in design increased the efficiency of workmanship.

5.2.4. Regression Analysis for Floor block

Due to the specified reasons - variation in material type and inapplicability of total area of construction- Case studies 4 and 7 were not included in the regression analysis of floor block, too. In addition to these case studies, Case Study 2 was also not included; because its construction did not require this material type. The results of the analysis are presented below in Figure 5.4.

As the results of the regression analysis indicate, the R^2 value was almost equal to zero (0.0025). There was high divergence between the case studies; thus the equation for the least square regression line could not be accepted. Moreover, floor block also showed similar trend with the other materials. There was an inverse relation between total area of construction and waste percentage values of floor block among the case studies.

Case studies 1 and 5 were above the regression line, as seen on the diagram. For case Study 1, the reason was similar to that for ready-mixed concrete, rebar and brick; incorrect calculation of material quantities. In the case of the fifth project, there were no specific reasons stated by the site supervisor for waste of floor block. In fact, considering the distance of the point of Case Study 5 to the regression line on the diagram, the difference of this project is negligible.

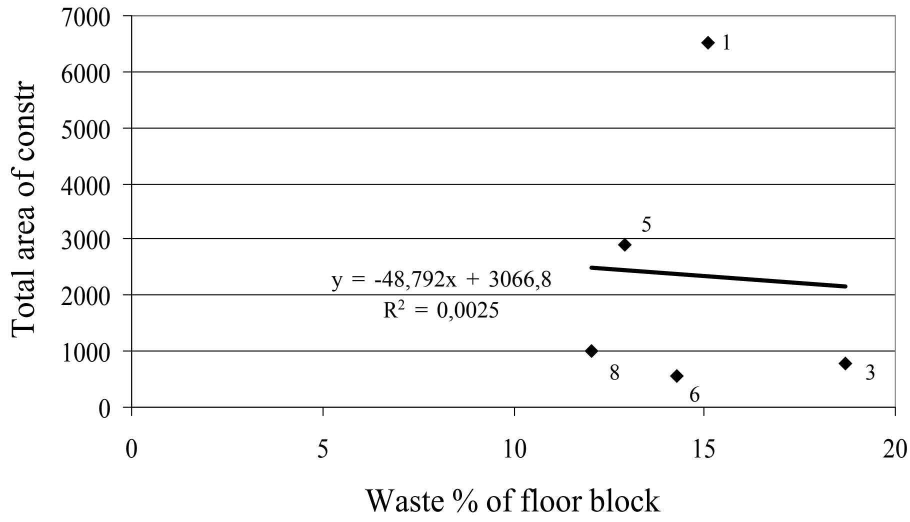


Figure 5.4. Scatter plot and regression analysis for floor block.

Case Study 3 again showed a high level of waste percentage in the case of floor block. As mentioned in the previous sections, waste of floor block was due to material itself in this construction project. The blocks were newly dried in the kiln before use. Their composition was weak; thus they were wasted due to breakages during transportation. On the contrary, Case Study 8 had the lowest waste percentage level, though there were no definite reasons stated by the site supervisor and the company directors for this situation.

5.3. Discussion of Results

There were two different analyses applied to the collected data on material quantities of ready-mixed concrete, rebar, brick and floor block. The first was ANOVA, together with LSD. They were used to determine whether different material types showed similar waste percentage levels or not. The second was regression analyses. These were done for waste percentage levels and total areas of construction in order to determine which projects showed differences and why these differences existed. In light of the results of these analyses, several interpretations were made.

In general, when the results of ANOVA were analyzed, it is seen that different materials showed different waste percentage values, differing within a range of around 8%. On the other hand, when the mean values obtained for waste percentages of the materials, ready-mixed concrete, rebar, brick and floor block, and waste allowances in the world are compared, another fact is revealed. The total mean value of the materials, as presented in Table 5.2, was calculated as 9.86%, which was very close to the generally accepted waste percentage of 10% in the world and in the Turkish construction industry. However, when the material types are analyzed separately, it is seen that brick and floor block showed higher mean values than 10%.

A comparison between the results of ANOVA and the waste allowance values presented in section 2.2.1 reveals that, although waste of ready-mixed concrete among the case studies showed similar values with the ones existing in literature, waste of rebar, brick and floor block had higher values than the accepted. The reason for this situation may be that, rebar, brick and floor block are used in units that should be adjusted, cut-off and joined for their construction; and these actions cause waste that depend on the workmanship, which is not valid for ready-mixed concrete. Thus, the waste percentages of these materials may change due to the quality of workmanship.

When the results of regression analyses are analyzed, it is seen that total area of construction has a significant effect on waste percentage levels of the materials. In fact, there is an inverse relation between these two variables. It means that, as covered area of a construction increases, waste percentage of materials decreases. This fact was seen in all of the material types analyzed; ready-mixed concrete, rebar, brick and floor block.

Several reasons may be stated for this relation between waste percentage and total area of construction. First of all, it is a known fact that the efficiency and productivity in a construction is the lowest at the beginning and at the end of the construction process. This efficiency and productivity is valid for all people involved in the construction, from the labor to the site supervisor. As the total area of construction increases, the duration of construction will also increase, increasing the efficient and productive period, too; and efficiency means less waste. Therefore, there will be more time spent with less waste. Secondly, as the total area of construction increases, the number of professionals involved in the construction will also increase; and each personnel will be responsible from a specific part of the construction. Therefore, supervision, which is a decreasing factor for material waste, will be more effective.

The reasons that increase and decrease material waste, as stated by the directors and site supervisors for each case study, are presented in Appendix E, Table E.4. When the table is analyzed it is seen that design-related reasons were dominant in each project. In most of the projects, design itself was a major problem of waste. Therefore, the architect and the structural engineer were the sources of waste. In relation, design faults and demolitions due to design change during construction had also significant effects in most projects. It is even very interesting that design change percentage reached up to 50% among the case studies in terms of material quantities. This is a general problem seen in the construction industry; and two major reasons can be pointed out for such a high percentage of design change. Firstly, the bills of quantities are calculated considering the preliminary design, in order to save time; and while the constructional drawings are prepared, many changes occur that effect the material quantities. Secondly, because that most of the design programs are not prepared professionally and in detail, some additions and removals occur during design and even construction phase. This attitude results in demolition of the constructed walls or even floors.

Worker's skill and attitude and incorrect calculation of quantities were also other important factors that affected the quantity of waste among the case studies. Labor force was seen both as an increasing and a decreasing factor of material waste in this study. On the other hand, incorrect calculation contributed to waste mostly in terms of excess and unused amount of materials. Though not very usual, contractual clauses and material defects were also effective on waste within the analyzed projects.

Although Case Study 4 was not included in the analyses, the reasons of waste considered for this project were important. When the general waste percentages are analyzed in Appendix E Table E.3, it is seen that curbstone and cobblestone had very low values with respect to all the other material types. The major reason for this may be stated by their prefabricated structure. They were used in the construction without modifying the dimensions and shapes of the units. Thus, cut-off waste was eliminated.

The effect of modification of material dimensions was also visible between two different types of paving tiles for Case Study 4. As mentioned before, the first type of paving tiles were cut-off especially in the rounded corners of the pavement in order to align the layout to the road; and this increased waste. On the other hand, cut–off waste was eliminated in the case of the second type of paving tiles as they were used for decoration.

An interview made within the scope of this study with one of the largest construction companies in Turkey, which had projects abroad, revealed the fact that cost had significant importance for the companies. However, the effect of waste on cost was mostly ignored. It was stated by the personnel of the purchasing department of the company that, in bidding process, the waste percentages added to the bill of quantities differed in each project. The important point was to reach an estimated cost and profit in total; and in order to decrease or increase the cost these percentages were adjusted in the personnel's own initiative, without considering the actual waste allowances mentioned above. On the other hand, the first three important reasons of waste in a construction were stated by the same personnel as incorrect calculation, design change and theft. Although theft was not considered as a significant reason within the case studies, the other two reasons verify the results obtained at the end of this research.

The effect of waste on the cost of a project became more evident during another interview made with one of the site supervisors of the case study projects. It was declared that, in general, the cost of waste was paid by the source that caused waste. For instance, if there was waste during transportation of the materials to the site, it was paid by the transporter; if there was waste due to incorrect calculation of material quantities, it was paid by the responsible personnel. Similarly, cost of waste due to labor was paid by the sub-contractor. However, in none of the case study projects, such cost was paid by the source generating it. All waste was financed by the companies themselves. As mentioned before, 50-60% of the project costs depend on materials; and if we assume that there was 10% waste, then we face with enormous amounts of expenditure that was paid by the companies but did not add value to the projects.

Though larger companies did not wish to share the data they had, it may be expected that the results of such an analysis, regarding the construction projects of these companies, would show less values for waste; because they would have more organized structures and teams, they would have their own labor to construct and thus the effect of sub-contractors' attitude towards the work and his unconsciousness on waste would have been eliminated. In addition, such companies would have more specific management strategies on materials and waste, which was absent in the discussed companies and the case study projects.

CHAPTER 6

CONCLUSION

Closer observations of design and construction industry indicate that uncertainties make the construction dynamic and unstable, mostly by creating non value-adding changes due to its structural problems, in particular when construction is performed concurrently. These changes mostly result in material waste. However, it is an explicit fact that, waste reduction or prevention is not considered as an integral part of the related management systems in most parts of the world and especially in the Turkish construction industry. Non-existence of proper documentation on this issue and lack of consideration given to management practices reveal this problem.

As indicated by many researchers, especially in developing and under-developed countries, it is a difficult task to obtain quantitative data on waste due to the lack of coordination and control. Besides the controlled and permitted areas, there are a number of uncontrolled landfill areas used by many contractors in almost every city. In addition, it is difficult to analyze the contents of C&D waste once it is generated and landfilled; because waste is not sorted in most of the construction sites. On the other hand, because that cost has more importance than waste for most of the company directors, it was also difficult to derive waste percentages depending on the interviews made within the scope of this study. In such a case, determining a realistic waste percentage was a matter of estimation based on the accessible information for this research.

In order to obtain a guide for construction waste generation in Turkey, a small calculation can be made. According to the data by Turkish Statistical Institute, the floor area of new buildings constructed in Turkey in 2004 was 69.719.611 m².[1] Its details are represented in Appendix F. On the other hand, a research done in Greece brings up that 1000 m² construction generates 50 m³ of waste and the density of construction waste is considered to be 1.5 tons/m³ (Fatta et al. 2003, p.84). Taking into account these values, it can be easily calculated that just construction activities generated 3.485.980 m³ of waste in İstanbul in 2004, corresponding to 5.228.970 tons/year. With an optimistic approach, if we assume that demolition activities also generate an amount close to this value, then yearly C&D waste generation of just İstanbul becomes around 10.5-11 million tons. Considering that 12 million people live in İstanbul, the number makes around 0.88 tons/inhabitant/year, corresponding to 2.4 kg/inhabitant/day. Compared to the aforementioned values for the other European countries, this value is far and away the highest, with no recycling percent.

If we are to approach from materials point of view, we face with a similar result. According to Düzyol (1997, p.88) 104.357.000 tons of cement, 14.000.000 tons of steel, 1.722.635.000 roofing tile, 29.103.645.000 bricks, 5.364.103.000 ceramic tiles and 34.172.000 m³ of timber is estimated to be needed by the construction sector in Turkey between 2005 and 2010. Considering the results of ANOVA applied to the case studies and the general waste allowance ratios all over the world, which take the total material waste percentage as around 10%, we face with enormous amounts of waste as shown in Appendix G.

In such a context of the industry, materials management should be seen as an indispensable concept, together with supply chain management and waste management; and contractors should renew their organizational structures considering these management systems. In addition, it can be said that, the integrated concepts of supply chain management, materials management and waste management will be used differently in each organization, depending on the organization's development level, its vision and goals in the industry. However, it is

[1] Republic of Turkey, Prime Ministry, Turkish Statistical Institute, 2005, "Kullanma Amacına Göre Yapılacak Yeni ve İlave Yapılar, 2002-2004,"
http://www.tuik.gov.tr/PreIstatistikTablo.doistab_id=385, [Accessed: 8 January 2007].

certain that managing materials and construction waste is a struggle to increase construction productivity and safety for everybody acting in the construction industry.

The minimization strategies change from country to country, so do the quality and the amount of waste. From this point of view, it is disputable whether all of the mentioned strategies in literature could be applied to the Turkish construction industry, considering the cultural, economical and social context. In this respect, several case studies were analyzed in this study to constitute a documented example and to determine more specific waste prevention and minimization strategies according to the obtained results.

Although the analyzed case studies do not draw a general picture of the situation in Turkey, they constitute an example of the sector in terms of material waste. Therefore, considering the analyzed case studies, it is possible to mention several reduction and minimization strategies for construction waste in general such as:

- The buildings should be designed considering the waste that the design itself may cause. In this respect, although not actively involved in the construction phase, the architect and the structural engineer should feel responsible for probable material waste and take into account the design's effect on waste. In relation to this consciousness, these professionals should also have a wide material knowledge. Professional education, together with studies revealing the fact of waste, will be effective in providing this consciousness.
- The design program should be complete and consistent in order to eliminate demolition waste due to design change. Therefore, the programs need to be prepared by the professionals, considering the needs of the inhabitants.
- The design should completely be finished to the smallest detail in order to prevent demolition waste due to incorrect construction. In this respect, revision of the existing regulations and preventing construction of unfinished projects via increased controller services will be helpful.

- Skilled labor should be employed or labor should be educated on waste prevention strategies. IRP, in which both the labor and the contractor takes advantage of waste prevention, can be used as an effective strategy.
- Supervision should be considered as a continuous activity that is carefully executed throughout the whole construction process.
- The material quantities should be carefully calculated. Estimating excess materials is not a precaution to speed up the construction but it is the quantity already planned for waste.
- Appropriate management systems should be introduced into the organization for proper planning, control and execution of material related activities such as; procurement, transportation, storage, *etc*.

Waste minimization and prevention is a responsibility that should be shared by the individuals involved in any part of a construction, from design to construction, from the architect to the least skilled labor. Every member in this chain, individual or company, should have an understanding of waste and be conscious about the economical and environmental disadvantages of it. It is certain that waste minimization and prevention is related to change in understanding and attitude at first place rather than new technological advances and techniques. It is an organizational philosophy and, in theory, it can only be achieved via effective coordination and practice of management.

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APPENDIX A

Table A. Average wastage rates of construction materials on site.

Material	Average wastage (%)					
	USA [31]	UK [16,32]	Mainland, People's Republic of China [38]	Brazil [3]	Seoul [30]	Hong Kong (site surveys)
Brick/block	3,5	4,5	2,0	17,5	3,0	
Concrete	7,5	2,5	2,5	7,0	1,5	6,7
Drywall	7,5	5,0	Not specified	Not specified	Not specified	9,0
Formwork	10,0	Not specified	7,5	Not specified	16,7	4,6
Glass	Not specified	Not specified	0,8	Not specified	6,0	2,3
Mortar	3,5	Not specified	5,0	46,0	0,3	3,2
Nail	5,0	Not specified	Not specified	Not specified	Not specified	Not available
Rebar	5,0	Not specified	3,0	21,0	Not specified	8,0
Tile	6,5	5,0	Not specified	8,0	2,5	6,3
Wallpaper	10,0	Not specified	Not specified	Not specified	11,0	Not available
Wood	16,5	6,0	Not specified	32,0	13,0	45,0

Source: Chen et al., 2002, p. 522.

APPENDIX B

Table B. Estimated C&D waste generation for USA-1996*.
(Roadway, bridge and land clearing waste not included)

Source	Residential		Nonresidential		Totals	
	Thou tons	Percent	Thou tons	Percent	Thou tons	Percent
Construction	6,560	11	4,270	6	10,830	8
Renovation	31,900	55	28,000	36	59,900	44
Demolition	19,700	34	45,100	58	64,800	48
Totals	58,160	100	77,370	100	135,530	100
Percent	**43**		**57**		**100**	

* C&D debris managed on-site should, in theory, be deducted from generation. Quantities managed on-site are unknown.

Source: Franklin Associates, 1998, p. ES-3.

APPENDIX C

Table C. C&D and domestic waste generated in European Union countries (1995).

Country	Population	C&D Waste (million tons)	C&D Waste (kg/inhabitant/ year)	Domestic Solid Waste (kg/inhabitant/ year)	Recycled or Reused (%)	Burned or Landfilled (%)
Belgium	10	7	700	350	87	13
Denmark	5.2	3	575	460	81	19
Finland	5	1	200	620	45	55
France	56	24	420	460	15	85
Greece	10	2	200	300	<5	>95
Netherlands	15	4	270	500	90	10
Ireland	3.5	1	285	310	<5	>95
Italy	58	20	350	350	9	91
Luxemburg	0.4	0	-	450	n/a	n/a
Portugal	10	3	300	300	<5	>95
Spain	39	13	340	320	<5	>95
England	57	30	530	350	45	55
Switzerland	8.5	2	240	370	21	79
Germany	79	59	750	360	17	83
Austria	7.7	5	650	430	41	59
European Union	**364**	**180**	**495**	**390**	**28**	**72**

Source: Öztürk, 2005, p.8.

APPENDIX D

Table D. The request form used by the companies to control materials flow.

TALEP FORMU							
	MASRAF YERİ					FORM NO	
	TARİH						
MALZEMENİN							
S. NO	CİNSİ	BR.	MİKTAR	FİYAT	TUTAR	FİRMA	ÖDEME TARİHİ
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

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APPENDIX E

Table E.1. Construction periods of the projects.

Case Studies	Type of Building	Months																				
		2005									2006											
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	School	■	■	■	■	■	■															
2	Hospital						■	■	■	■	■											
3	Housing-Apartment										■	■	■	■	■	■						
4	Road-Pavement											■	■	■	■							
5	Housing-Villa											■	■	■	■	■	■					
6	Turkish Bath												■	■	■	■	■	■				
7	Culvert												■	■								
8	Housing-Apartment													■	■	■	■	■	■	■	■	■

Table E.2. Monthly purchased quantities of materials.

Case Studies	Material Type	Months																					Total Purchased Quantities
		2005									2006												
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	ready-mixed conc. (m^3)	847	1135	782	496	60																	**3320**
	rebar (t)	95	112	69	66																		**342**
	brick (each)		34500	26700	20360																		**81560**
	floor block (each)	23400	15500	7160																			**46060**
2	ready-mixed conc. (m^3)						768	1190	636	296													**2890**
	rebar (t)						91	134	85	15													**325**
	brick (each)							36200	28750	25400	17325												**107875**
3	ready-mixed conc. (m^3)										123	251	134	24									**532**
	rebar (t)										25	31											**56**
	brick (each)											9870	6540	4065	250								**20725**
	floor block (each)										2750	2250	875										**5875**
4	paving tile1(m^2)										975	815	826	722									**3338**
	paving tile2(m^2)										40	42	32	406									**520**
	curbstone (mt)											1352	1706	1332	720								**5110**
5	cobblestone (m^2)										1169	4765	3470	3111	899	110	2206						**15730**
	ready-mixed conc. (m^3)											475	692	660	534	219	125						**2705**
	rebar (t)											50	41	82	54								**227**
	brick (each)												9413	7014	6651	1260	125						**24463**
6	floor block (each)											2016	6689	4570	2450								**15725**
	ready-mixed conc. (m^3)												98	153	110	89							**450**
	rebar (t)												47										**47**
7	brick (each)													3870	3250	2870	347						**10337**
	floor block (each)												1230	1450	1320								**4000**
	ready-mixed conc. (m^3)													61	279								**340**
	rebar (t)													20									**20**
8	ready-mixed conc. (m^3)													182	304				29			115	**630**
	rebar (t)													12	32				11			5	**60**
	brick (each)														9500	8250			3140			1060	**21950**
	floor block (each)													5625									**5625**

Table E.3. Collected material quantities.

Case Studies	Total Area of Construction (m^2) (a)	Material Type	Material Quantities in the			Design Change % ((c-b)/b*100)	Waste % ((d-c)/c*100)	Waste/m^2 ((d-c)/a)
			Bill of Quantities (b)	Progress Payment Reports (c)	Invoices (d)			
1	6500	ready-mixed conc. (m^3)	2220	3173	3320	42.93	4.63	0.023
		rebar (t)	225	325	342	44.44	5.23	0.003
		brick (each)	50300	72225	81560	43.59	12.92	1.436
		floor block (each)	31250	40025	46060	28.08	15.08	0.928
2	5000	ready-mixed conc. (m^3)	2770	2780	2890	0.36	3.96	0.022
		rebar (t)	230	306	325	33.04	6.21	0.004
		brick (each)	89813	95000	107875	5.78	13.55	2.575
3	800	ready-mixed conc. (m^3)	500	495	532	-1.00	7.47	0.046
		rebar (t)	52	48	56	-7.69	16.67	0.010
		brick (each)	15000	17813	20725	18.75	16.35	3.641
		floor block (each)	4625	4950	5875	7.03	18.69	1.156
4	22500	paving tile1(m^2)	3750	3035	3338	-19.07	9.98	0.013
		paving tile2(m^2)	500	500	520	0.00	4.00	0.001
		curbstone (mt)	4620	5012	5110	8.48	1.96	0.004
		cobblestone (m^2)	15250	15475	15730	1.48	1.65	0.011
5	2910	ready-mixed conc. (m^3)	1684	2548	2705	51.33	6.14	0.054
		rebar (t)	180	217	227	20.80	4.40	0.003
		brick (each)	14563	22115	24463	51.86	10.62	0.807
		floor block (each)	10875	13924	15725	28.04	12.93	0.619
6	560	ready-mixed conc. (m^3)	390	424	450	8.68	6.17	0.047
		rebar (t)	35	43	47	22.86	9.30	0.007
		brick (each)	8125	9113	10337	12.15	13.44	2.187
		floor block (each)	3500	3500	4000	0.00	14.29	0.893
7	51 m	ready-mixed conc. (m^3)	266	313	340	17.86	8.61	0.528
		rebar (t)	16	19	20	17.42	7.24	0.026
8	1000	ready-mixed conc. (m^3)	588	595	630	1.19	5.88	0.035
		rebar (t)	56	58	60	3.57	3.45	0.002
		brick (each)	17451	19750	21950	13.18	11.14	2.200
		floor block (each)	4813	5020	5625	4.31	12.05	0.605

* Due to the type of building, length of the construction is given instead of total area. Similarly, "waste/m^2" values are not presented for this project.

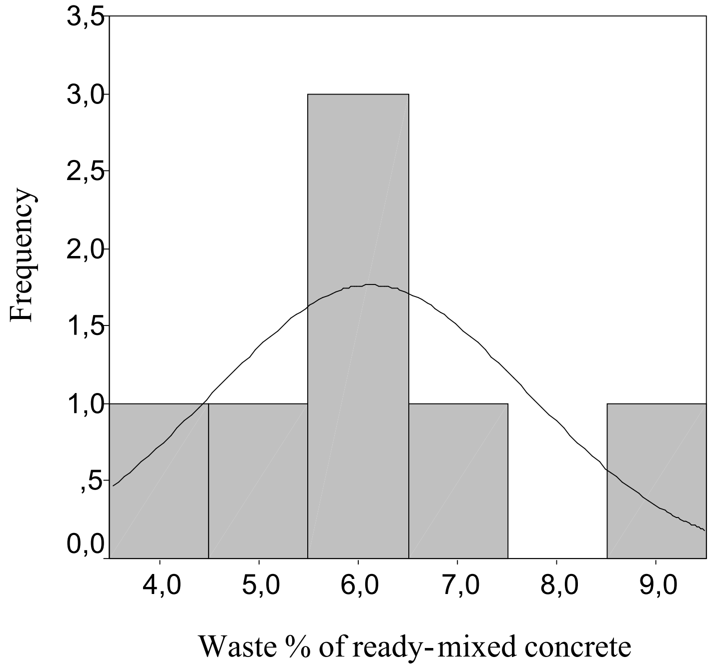

Figure E.1. Waste percentage distribution of ready-mixed concrete.

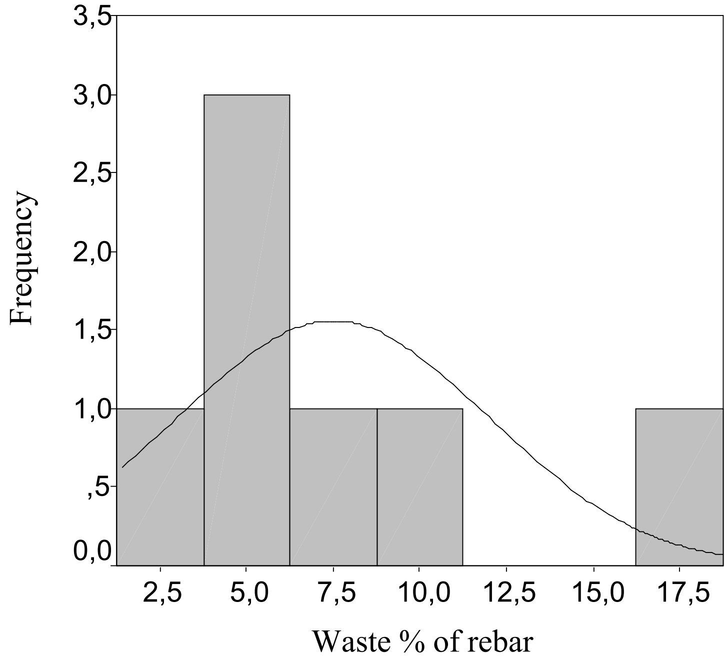

Figure E.2. Waste percentage distribution of rebar.

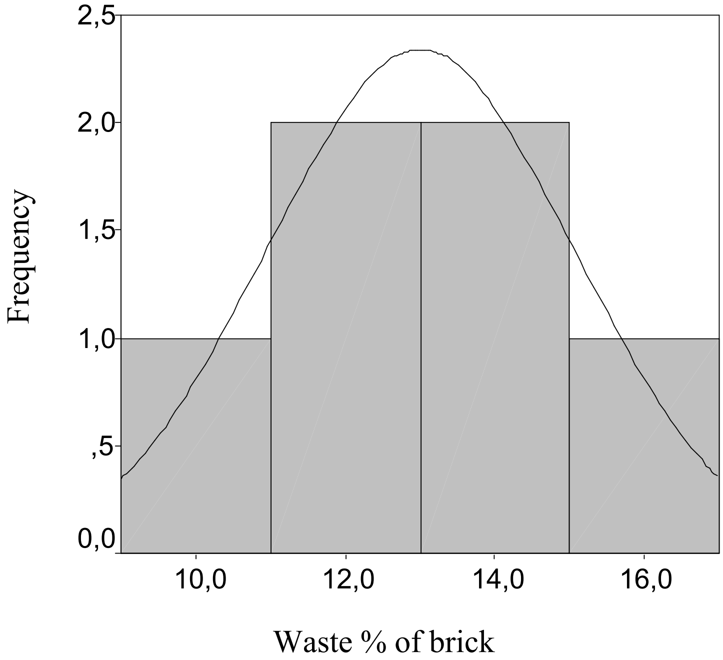

Figure E.3. Waste percentage distribution of brick.

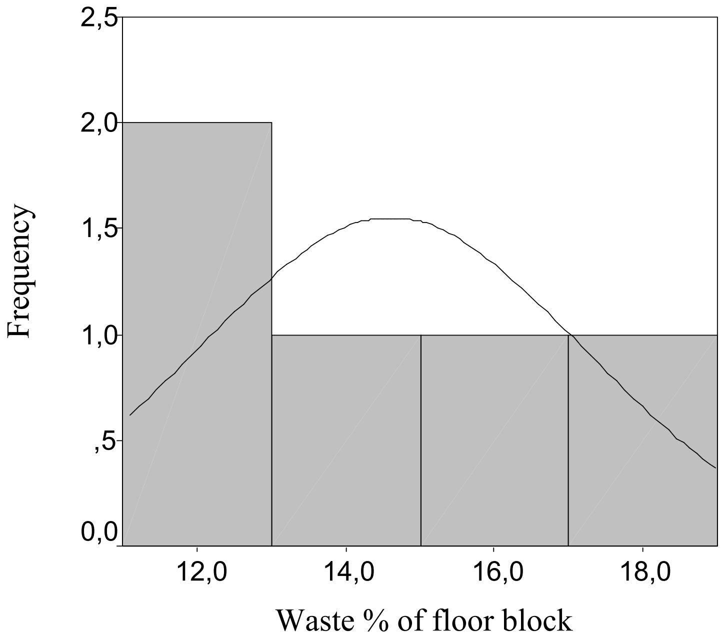

Figure E.4. Waste percentage distribution of floor block.

Table E.4. Waste increasing and decreasing factors.

Factors	Case Studies							
	1	2	3	4	5	6	7	8
Demolitions due to design change		⇧	⇧			⇧		⇧
Design itself		⇧	⇧	⇧	⇧⇩	⇧		
Design faults		⇧						⇧
Workers' skill and attitude		⇧	⇧		⇩	⇧	⇧	
Incorrect calculation of quantities	⇧		⇧	⇧			⇧	
Contractual clauses					⇧			
Material defects			⇧					

APPENDIX F

Table F. New buildings and additions by use of building, 2002-2004 (Construction permit based).

A. Number of buildings   B. Floor area   C. Value   D. Number of dwelling units

Years		Single flat residential buildings	Two or more flat residential buildings	Public Residential Buildings	Hotel and alike buildings	Office buildings	Wholesale and retail commercial buildings	Traffic and communication buildings	Industrial buildings and depots	Public, entertainment, education, hospital or care institution buildings	Buildings other than habitation purposes	Grand Total
2002	**A**	15.293	21.68 0	55	587	768	2.106	43	1.739	632	527	**43.430**
	B	3.100.288	22.361.276	160.504	733.637	1.367.163	2.208.641	164.059	3.796.0 78	1.996.917	298.458	**36.187.021**
	C	750.239.522	5.519.582.295	39.521.018	183.273.442	337.773.649	551.193.375	43.284.923	955.889.849	495.480.532	68.951.5 99	**8.945.190.204**
2003	**A**	15.65 0	26.634	90	894	779	2.921	53	2.061	478	580	**50.140**
	B	3.090.711	29.420.976	210.222	1.526.099	1.556.230	3.028.571	214.078	4.863.005	1.252.236	353.902	**45.516.030**
	C	885.810.805	8.781.170.859	62.650.836	485.032.237	470.913.485	896.792.339	62.950.951	1.500.666.450	381.288.354	99.569.457	**1.3626.845.773**
2004	**A**	22.831	42.455	140	1.061	777	3.934	46	2.712	751	788	**75.495**
	B	4.212.588	46.867.563	562.645	1.749.678	1.532.349	4.357.464	132.982	7.324.986	2.083.228	896.128	**69.719.611**
	C	1.405.807.075	16.180.457.607	194.480.055	608.193.613	539.961.371	1.526.308.443	46.081.521	2.555.160.368	732.896.195	318.852.219	**2.4108.198.467**

Source: Republic of Turkey, Prime Ministry, Turkish Statistical Institute. 2005. "Kullanma amacına göre yapılacak yeni ve ilave yapılar, 2002 -2004." h ttp://www.tuik.gov.tr/PreIstatistikTablo.doistab_id=385. [Accessed: 8 January 2007].

APPENDIX G

Table G. Estimated construction material needs and waste in Turkey between 1990 and 2010.

	Years	Cement (Thousand tons)	Steel (Thousand tons)	Roofing tile (Thousand units)	Brick (Thousand units)	Ceramic tile (Thousand units)	Glass (Thousand m²)	Lime (Tons)	Sand-Gravel (Thousand m³)	Timber (Thousand m³)
Estimated material needs*	1990-1995	52.083	6.987	859.742	14.525.209	2.677.146	26.185	2.064.050	203.631	17.055
	1995-2000	66.133	8.872	1.091.674	18.443.662	3.399.358	33.249	2.620.367	258.564	21.655
	2000-2005	81.608	10.948	1.347.111	22.759.236	4.194.763	41.029	3.234.115	319.065	26.722
	2005-2010	104.357	14.000	1.722.635	29.103.645	5.364.103	52.467	4.135.663	408.008	34.172
Estimated material wastage**	1990-1995	5.208	698	85.974	1.452.520	267.714	2.618	206.405	20.363	1.705
	1995-2000	6.613	887	109.167	1.844.366	339.935	3.324	262.036	25.856	2.165
	2000-2005	8.160	1.094	134.711	2.275.923	419.476	4.102	323.411	31.906	2.672
	2005-2010	10.435	1.400	172.263	2.910.364	536.410	5.246	413.566	40.800	3.417

* **Source:** M. Cüneyd Düzyol, 1997, "Türkiye'de Bina İnşaatı Sektörü ve 1990 -2010 Dönemi Bölgesel İhtiyaç Tahmini" SPO Expertise Thesis, Economic Sectors and Coordination General Directorate), State Planning Organization, p.88.

** Values are derived from the information taken from the sorce, considering a wastage level of 10%.