AN EFFECTIVE WAY TO REDUCE RESIDENTIAL CONSTRUCTION WASTE: A CASE STUDY IN TEXAS

A Thesis

by

CRISTIANO R. CASTELO BRANCO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Construction Management

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Co-Chairs of Committee:	Jose L. Fernandez-Solis
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ABSTRACT

An Effective Way to Reduce Residential Construction Waste: A Case Study in Texas.

(December 2007)

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Co-Chairs of Advisory Committee: Dr. Jose L. Fernandez-Solis
Dr. Richard A. Burt

This research consists of an investigation on the incidence of residential construction waste in Texas. Construction waste has proved to have a negative effect on the economic health of construction companies and on the environment. To evaluate the current methods two waste diagnostic questionnaires were developed to identify the most frequent waste categories present in the job site affecting the final cost of the residential projects, the types of waste and their possible causes. The questionnaires were sent to one hundred and twenty construction companies. Three criteria were used to select companies for the study. First, only private companies were chosen. Second, only companies doing predominantly residential construction works were chosen. Third, only companies who are operating in Texas were chosen. The results showed that *wood, drywall and concrete* are the most frequent waste categories affecting the final cost in residential projects and *waste of materials, over allocation of materials, rework, clarifications, unnecessary handling of materials, inefficient movement of workers, waste of space on site, and delays* are the most dominant types of waste occurring in these categories.

DEDICATION

To my loved wife, Verônica, who has dedicated tremendous patience and support to my research, and my son, Caio, who has given me so much happiness in my life.

ACKNOWLEDGMENTS

I would like to thank all of those who have assisted me with this research, without their time and efforts, this endeavor would not have been possible. Dr. Jose Solis and Dr. Richard Burt, the co-chairs of my thesis committee have been always present to help me growing as a student and as a researcher. Their dedication in helping me succeed is deeply appreciated. Dr. Sarel Lavy and Professor Rodney Hill, the other members of my thesis committee have been both munificent and cooperative. Their confidence in my capacity has been unwavering, and has helped to make this a solid project. Finally, I must express my sincere thanks to the construction industry professionals who participated in my survey. They have been welcoming and have shared of themselves to make this project possible.

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1. INTRODUCTION

1.1 Background

The construction industry represents one of the most important sectors in the economy of the United States with ten percent of the gross national product (Clough *et al.*, 2000). The residential segment represents 40 to 45% of all new construction in the country. However this sector is commonly characterized as a "backward industry" if compared with other sectors of the economy as a result of factors such as: (i) application of traditional processes, (ii) used low quality products, (iii) large amount of produced waste, and (iv) high costs, including rework costs (Opara, 1993).

Homebuilders, in the recent years, are facing serious difficulties. Over the past few years, they have habitually been in a position that did not require a rigorous pursuit for lower prices since they were enjoying record closings and excited buyers. However, as the market slowdown and inventories rise, builders now find themselves in a situation that they have to reduce costs to have a place in this new competitive market (Build it Green, 2005).

According to Texas Commission of Environmental Quality (2006), the construction and demolition (C&D) debris accounts for 19% of the solid waste stream in Texas. The toxic nature of some of these materials, such as solvents and adhesives, has a significant impact on the environment. During the construction phase, a negative impact on the

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This thesis follows the style of *Construction Management and Economics*.

environment will occur, whether indirect or direct (Yahya and Boussabaine, 2006).

Despite the importance of the impact on the environmental that the construction waste causes, this study will concentrate its efforts on the effects of waste on construction cost reduction.

The construction of a single family home in the United States, on average, generates between two and four tons of waste (Donnelly, 1995) what can accounts for up to 35% of the production costs (Josephson and Saukkoriipi 2005) in the worst cases. According to NAHB (1997) for every single-family home built in the United States, approximately 8,000 pounds of waste are produced. Wood waste corresponds to 3,000 pounds, or 38 percent, and drywall corresponds to 2,000 pounds, or 25% of that waste.

The results of a survey with home construction firms showed that 65% of the respondents indicated that the costs for disposing of construction debris negatively influence the economic health of their companies (Austin, 1991). Finding a way to reduce such amount of produced waste could help construction firms to have cost benefits in the areas of reducing waste, removing waste, and tipping costs and consequently increase the competitiveness of the builders.

1.2 Problem Statement

The purpose of this study is to identify the most frequent waste categories affecting the final cost of residential projects in Texas and analyze the causes of these occurrences.

1.3 Research Objectives

- Identify the most frequent waste categories affecting the final cost in residential projects;

- Identify the types of waste occurring on the top three waste categories affecting the final cost and determine their possible causes;

- Find solutions to be put into effect at residential construction sites to reduce waste productions.

1.4 Definitions

In order to better understand the current proposal some definitions are necessary.

- *Productivity* is the rate of output of a worker or group of workers per unit of time, usually compared to an established standard or expected rate of output.

- *Debris* is solid waste from construction, remodeling, repair or demolition of buildings, roads or other structures. Examples of debris are: rest of wood, concrete, drywall, masonry, roofing, siding, structural metal, wire, insulation, asphalt, packaging materials related to construction or demolition and other materials applied in construction.

- *Jobsite* is the site where the construction is going to take place.

- *Lean Construction* is a design and construction administration process based on Japanese "lean manufacturing principles" which is designed to promote efficiency and eliminate waste.

- *The Toyota Production System (TPS)* is a combination of techniques developed at the Toyota Motor Company that focus on setup, lead time and lot size reduction and systematic ways to improve quality.

- *Bill of Quantities is* a document typically prepared by a quantity surveyor which details the terms and conditions under which a contract is to be let, and lists all works to allow a builder to price the work for which he is bidding.

1.5 Delimitations

This study is restricted to residential construction in the state of Texas in United States. The current research gathered information from builders who are members of the Bryan-College Station Home Builders Association.

1.6 Assumptions

- There is a lack of concern in residential construction job sites with waste of materials;

- The survey applied in this research is valid;

- The builders who responded to the study survey were able to provide correct, complete and timely information pertaining to the study.

2. LITERATURE REVIEW

The waste of materials is due to its use in construction. According to Walid (1998), only eleven percent of the total cost correspond to phases that there is almost no chance of construction waste production, while the percentage left, 89 of that cost, correspond to phases in which there is a good possibility to produce waste.

According to Skoyles and Skoyles (1987), construction companies are not concern about the waste of materials because they believe that its occurrence is unavoidable and not significant in quantity. The builders are used with those facts but do nothing to find out the causes, accepting its incidence as a normal characteristic of the project.

2.1 Lean Construction

Before we understand what Lean Construction (LC) is, we have first to understand what Lean Thinking is. The concept of Lean Thinking is based on the Toyota Production System, TPS, and was developed in a manufacture environment, more specifically, in the automobile industry (Picchi and Dos Reis, 2003). The origin of the Lean Thinking is the elimination of waste. Eiiji Toyoda and Taiichi Ohno, the creators of the TPS, studied the production systems of Ford Motor that used the mass production system. They concluded that to copy or improve this system would be impractical, due the conditions of Japan at the time so they adapted those concepts into the Japanese reality where there was a scarcity of resources, creating then the Toyota Production System developed throughout decades by means of attempts and errors elimination (Fujimoto, 1999).

The LC concepts were based on the concepts developed for the auto industry and adapted to the environment of the Civil Construction. This term is an adaptation of the Toyota Production System (TPS) principles to construction and was described initially by Koskela (1992) that perceived alteration occurred on that industry due the use of this system and considered its application in construction. According to Koskela (1992), to implement the concepts of the Lean Thinking in the Civil Construction is necessary, initially, understand the existing concepts, and then implement them in the new environment. Koskela (1992) also presents eleven principles for flow process design and improvement:

- *Reduce activities that do not add value:* According to Koskela (1992) value-adding and non value-adding activities can be classified as follows: value-adding is the activity that transforms material and/or information in what is required by the customer and non value-adding activity also called waste is the one that takes time, resources or space but does not add value.

- *Increase output value through systematic consideration of customer requirements:* This principle establishes that the necessities of the external and internal clients must be identified clearly and this information must be considered in the project of the product and the production management Isato et al. (2000).

- *Reduce variability:* Longer is the cycle time greater will be the amount of activities that do not add value to the end item. Koskela (1992) affirms that a possible form to reduce the variability consists of working with standardized activities.

- *Reduce cycle times:* One of the objectives in LC is to compress the cycle time, which forces the reduction of inspection, move and wait time. According to Koskela (1992) progression of cycle time reduction is done through successive process such elimination of the WIP (Work in Process), reduction of the batch size, changing plant layout so that moving distances are minimized, synchronizing the flows, reduction of variability, changing activities from sequential order to parallel order, isolating the main value-adding sequence from support work.

- *Simplify by minimizing the number of steps and parts:* According to Koskela (1997) simplification can be understood as reducing of the amount of components in a product or reducing of the amount of steps in a material or information flow. Koskela (1997) also affirms that simplification can be done, on the one hand, by excluding non value-adding activities from the production process, and on the other hand by reconfiguring value-adding parts or steps.

- *Increase output flexibility:* At first glance, increase of output flexibility seems to be contradictory to simplification. However, many companies have succeeded in realizing both goals simultaneously. According to Isato et al. (2000), the increase on the output flexibility is related to the process concept, as value-adding, and refers on the possibility to modify the outputs characteristics without substantially increase the cost of the product.

- *Increase process transparency:* The increase process transparency makes the identification of errors in the production system easier (Koskela, 1992). The transparency of planning makes possible the evaluation of the interference of the productivity of the teams.

- *Focus control on the complete process:* The control of the complete process is very important, and someone in the team must be responsible for that control. Depending on the complexity of the project, may be necessary to involve not only the company but also the entire productive chain on this effort. For inter-organizational flows, long term co-operation with suppliers and team building have been established with the objective of getting mutual benefits from a better total flow (Koskela, 1992).

- *Build continuous improvement into the process:* The effort to minimize waste and maximize value of the product is an internal, incremental, and repetitive activity that must be carried out always (Koskela, 1992). It is necessary to analyze possible divergence in each party of the process.

- *Balance flow improvement with conversion improvement:* According to Koskela (1992) there is a great potential of improvements in activities of flow considering that generally in construction these activities tends to be neglected. Koskela (1992) affirms that bigger is the complexity of the process of production, higher is the impact of the improvements in the activities of flow and if the waste is inherent to the production process, the improvements will bring better resulted if is directed to the activities of flow.

- *Benchmark*: The process of benchmarking does not have to be considered only as stimulation for better performance, but also as a mechanism that contributes to the learning of the company, because it induces the company to collect data and to analyze its own processes and its competitors and leaders on the market as well.

According to Koskela (2000), the most important principles for flow process design and improvement are divided into three types. The first and principal is theory related:

- Reduce the share of non value adding activities

The second is composed of two principles that derive from the theory:

- Reduce lead time
- Reduce variability

The third, and the last one, is more practice than theory related and is composed of the following principles:

- Simplify by minimizing the number of steps
- Increase flexibility
- Increase transparency

According to Howell (1999), LC projects are very different compared to traditional construction projects management where Lean approach aims to maximize performance for the customer at the project level, set well-defined objective clearly for delivery process, design concurrent product and process and applies production control throughout the life of project. According to Koskela (1999) to reach better results in construction through LC, is necessary to struggle the variability that occurs in the activities performed in the sector. Koskela (1999) attributes the existence of this variability in the construction due to four essential characteristics of the sector, which are:

- The completion of activities is strong dependent of the flows whose progress is dependent of the completion of the activities;
- The construction can be described as the production of a prototype, that, normally, presents in its formularization a series of errors of project, planning and control (Koskela, 1999);
- In construction, one task can be worked by different crews at the same time, what generally it decreases the productivity of these crews;
- The work can be performed in bad conditions, such weather, resulting in a reduction of productivity.

This variability on the activities, according to Koskela (1999), must be struggled by: i) reducing the activities performed on the jobsite; ii) increase the control on the activities performed on the jobsites with the adoption of Last Planner techniques; iii) increase the productivity in this sector.

2.2 Long and Short Term Planning in Construction

According to Ballard (2000) to minimize waste a construction project must have an efficient planning and control. Different people accomplish these two tasks in different phases of the project. The macro or the long term planning focuses on the global objectives and the restrictions that each project has. Another important one is the short term planning, which define what tasks will be done on the next day of work.

2.2.1 Long Term Planning

The long term planning is formed by master schedules that deal with all the tasks scheduled for a project. The combination between planning and cost estimating was improved by producing the initial version of the long-term plan before the bill of quantities. This has contributed to increase the precision in cost estimation and to make cost control more successful. It became easier to set up a clear link between the time frame of different projects and the company overhead costs (Formoso et al., 1999).

2.2.2 Short Term Planning

According to Laufer et al. (1992) the short term or operational planning in construction consists on the ability of an organization in collecting information, identifying and deciding problems, and implementing operational changes, going very beyond of a simple interpretation of the project. The employment of an efficient short term planning is excellent, since a number of factors in the jobsites can only be identified when the construction if starts. In this direction, the decision on the execution of these factors passes to be taken in a base of short period of time. According to Laufer et al. (1992) the preparation of operational planning long time prior the execution is impracticable because conflict in numerous uncertainties, such as the dispersion of information related to the environment of the jobsite, availability and supply of resources, unexpected problems of coordination between teams and the relative conflicts of unknown techniques.

2.3 Construction Waste

If a method for minimize the existing waste in the jobsites is considered, builders have to know exactly what waste is, as well as the forms of its occurrence in the jobsites.

Paliari (1999) defines construction waste as all resource consumed beyond a pre determined value of reference for one determined period of the construction.

According to Freitas (1995), the construction waste can be defined as every resource that is spent in excess, further than the strict necessary to execute a service

2.3.1 Construction Waste Classification

The waste in construction can be originated due to different causes and situations. The following classifications consider all these factors to group the construction waste forms of occurrence into it.

2.3.1.1 Waste according to the type of resource consumed

According to the consumed resource, the waste can be classified in physical and financial waste as shown in Figure 2.1 (Andrade, 1999). This classification considers the following examples:

- *Physical waste of materials*: additional amount of material relative to the one specified in the project;
- *Physical waste of man-hour*: men hours increased due to the delay in the arrival of materials and overproduction;
- *Physical waste of equipment*: equipment hours increased in function of the problem cited for the man power;
- *Financial waste in result of the physical waste*: determine the costs associated with the physical waste;
- *Financial waste in result of material purchase*: relative additional cost to the use of a material with superior value of the specified one.

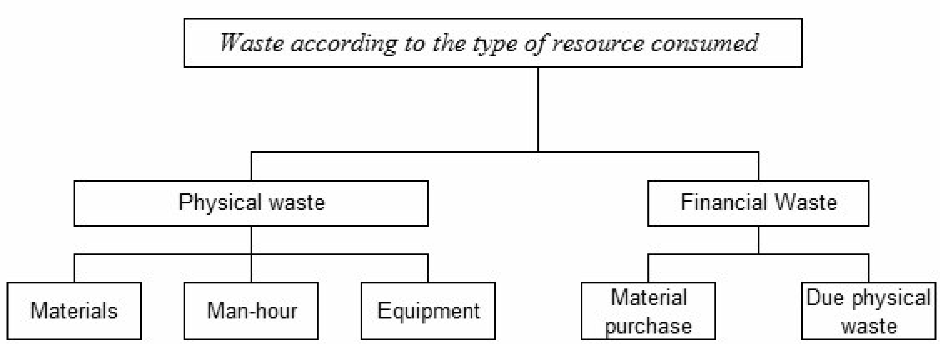

Figure 2.1 Waste according to the type of resource consumed (source: Andrade, 1999)

2.3.1.2 Waste according to its nature

According to Andrade (1999), there are two types of waste: (i) indirect waste, related to the financial waste and the use in excess of material, and (ii) direct waste, related to the physical waste of material, more specifically, the debris.

The indirect waste is characterized by materials that are used in excess in the building, for example:

- Waste caused by substitution, where materials are applied for purposes other than those specified;

- Waste caused by over allocation, where materials are applied in superior quantity of those indicated or not clearly defined in contract documents;

- Waste caused by negligence, where materials are used in addition to the amount required by the contract due to the construction contractor's own negligence.

The direct waste corresponds to materials damaged during the execution or rest of material. This waste type cannot be reused. They have some forms of occurrence, according to Andrade (1999):

- Waste in delivery: during the transport and the unloading;

- Waste as a result of overproduction: associated to the production of a quantity superior than necessary or earlier than needed. This may cause waste of materials, man-hours or equipment usage;

- Waste in supply and internal transport: incorrect storage of the materials and passage and equipment of inadequate internal transports;

- Waste during the execution: materials knocked down or discarded during the application;

- Waste as result of replacement: financial waste caused by the replacement of a material by a more costly; the execution of simple tasks by an over-skilled worker; or the use of very sophisticated equipment where a much simpler one would be enough;

- Waste caused for other teams: due to lack of relationship on the stages of execution, causing rework and delays;

- Others: examples such as robbery, vandalism and accidents are included in waste according to its nature as well.

2.3.1.3 Waste according to its control

Considering the possibility of controlling or reducing the index of waste detected, the waste is classified in two categories (Paliari, 1999): (i) avoidable or (ii) unavoidable.

The unavoidable waste is the one that the necessary investment for its reduction is superior to the economy obtained. Generally, this waste category represents an acceptable level of waste that its factors escape to the control of the builder, depending on the development of each company. On the other hand, is the one that its reduction is economically viable because the cost of waste is significantly higher than the cost to prevent it. According to Santos et al. (1996) the avoidable waste is consequence of a process of low quality, in which resources are used inadequately. Figure 2.2 shows the actual situation in which there is a significant amount of avoidable waste and non value-adding activities and the desired situation in which there is only unavoidable waste and value-adding activities.

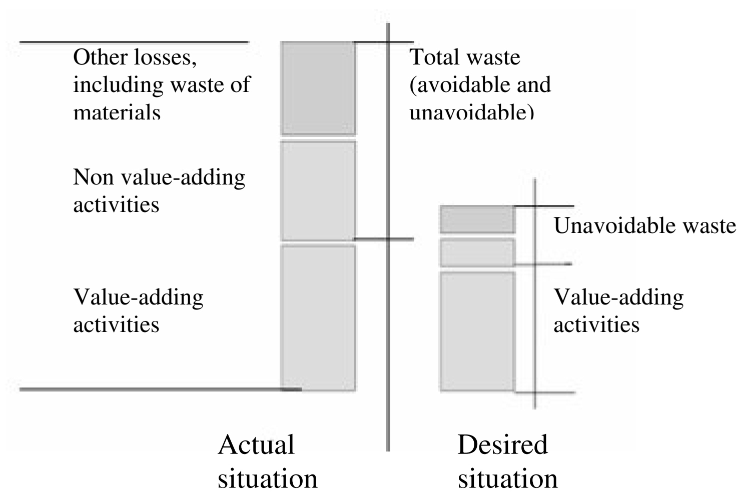

Figure 2.2 Waste according to its control (source: Formoso et.al., 1996)

2.3.1.4 Waste according to its origin

Although waste is typically identified throughout the production phase, also it can be originated by processes that go before production such as: materials manufacturing, design, materials supply, and planning. Examples of waste that can occur in the different stages of the construction are:

- Use of a smaller space between the studs in relation to the considered correct standards or the extreme breaking of blocks during the execution, for example, can have origin in the lack of modulation (conception phase);

- Lack of necessary material in the moment of execution (planning);

- Low quality components (acquisition);

- Cement mortar production in superior amount that the one that will be used in the day of work or the use of inadequate techniques (execution phase);

- Repainting the building after one year of use, to modify the color of the facade, when, in durability terms, it could be done every 3 years (maintenance phase).

The execution phase, the most exploited in this study, is related to the course of the material as shown in Figure 2.3, since its arrival to the jobsite until becoming part of an executed product. Such course is, generically: (i) act of receiving, (ii) stocking, (iii) transporting, (iv) intermediate processing, and (v) application, on which losses can happen.

According to Santos et al. (1996), during the construction execution, the following examples can be pointed: real weight of the bags lesser than the specified one (act of receiving); rotten lumber due to humidity (stocking); bigger cement consumption per CY of concrete (intermediate processing); material that falls in the soil (transporting); and over thickness (applying).

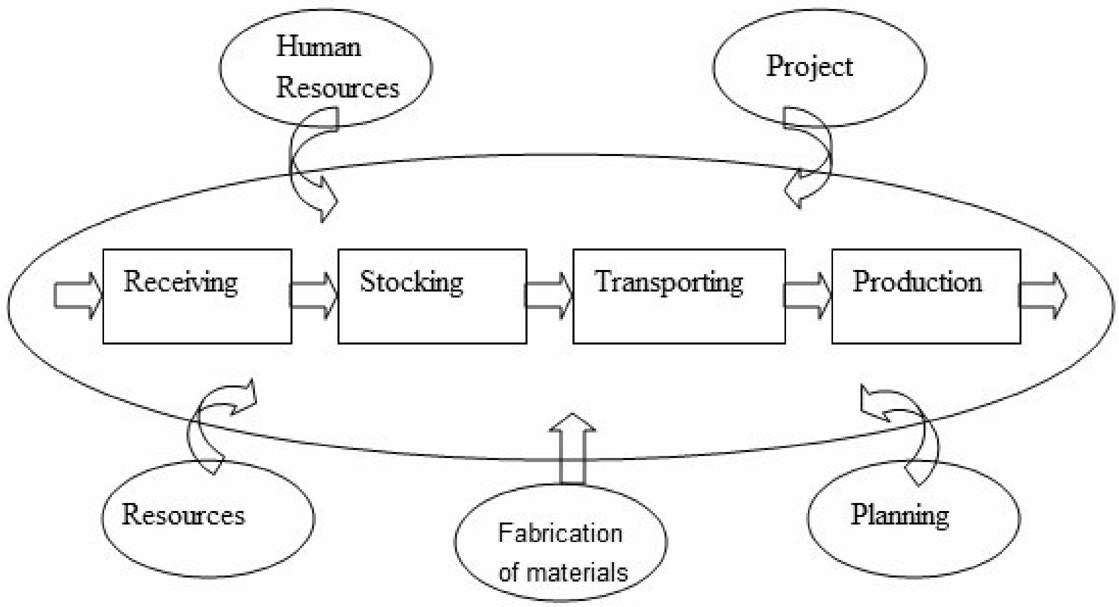

Figure 2.3 Waste according to its origin (source: Formoso et al., 1996)

2.4 Actions for Waste Control Recommended in Previous Studies

The construction waste is directly related with construction management, the lack of it can result in an increase of that waste and decrease of productivity. According to Harris and McCaffer (2001), the construction companies pay more attention and spend more time with control of labor and plant than they do with control of materials. However, there are evidences that losses due materials are often higher than those due to other causes. Consequently better attention to materials control may have significant influence in the pursuit of increase profit. Harris & McCaffer (2001) suggest some methods to be applied in material control:

- Employ a reliable storekeeper, possessing clerical experience and well trained in stores controls;
- Maintain a well-kept bookkeeping system, either manually or using computer system;
- Double signing of delivery notes, particularly ready-mixed concrete;
- Keep a well laid-out site with adequate storage space and room for movement;
- Insist on palletized delivery of bricks;
- Check thoroughly all deliveries against the delivery notes as the goods are being unloaded.

Poon et al. (2004) also recommend some control procedures and principles to be respected in a pursuit of waste reduction:

- Notify the suppliers of the construction process requirements;
- Implement just-in-time ordering and guarantee that the materials will be delivered on site when they are required, thereby avoiding damage while stored on site and additional moving of materials;
- Arrange proper material sizes to minimize cutting, and in appropriate quantities to avoid excess;

- Inspect the materials when they enter at the site in order to minimize losses due poor packaging;

- Arrange appropriate vehicles or delivery plants for moving material from the storage area to the workplace in order to make the minimum damage;

- Stay away from double handling, the areas of unloading should be the final position of stacking area;

- Select central areas for cutting and storage so reusable pieces can easily be found;

- The storage area has to be in a position that is well-located for the operators to draw materials but away from transitory areas to avoid damage;

- Offer appropriate protection for the different categories of materials during storage and stacking;

- Limit the amount of materials stacked on site by matching phased delivered to the programmed needs.

NAHB (2006) recommends the following actions to be applied in a pursuit of waste minimization:

- Create an efficient floor plan that maintains a home's functionality;

- Use advanced framing techniques that reduce the amount of building material while maintaining the structural integrity of the home;

- Use building dimensions and layouts that maximize the use of the resources by minimizing material cuts;

- Create a detailed framing plan and detailed material takeoffs. Provide an onsite cut list for all framing and sheathing material;

- Use building materials that require no additional finish resources to complete application onsite;

- Use pre-cut or pre-assembled building systems or methods.

2.5 Significance of Study

Compared with other sectors of the economy, residential construction has a reputation of low productivity, antiquated technology and waste production (Opara, 1993). Those factors together contribute to increase the construction costs significantly. This study will identify the most frequent waste categories affecting the final cost in residential projects and try to minimize the waste and consequently reduce construction costs to increase the competitiveness of the homebuilders.

3. METHODOLOGY

In this study, questionnaires (see Appendix A) were used as one tool for collecting data for quantitative analysis. The cause for using a questionnaire is that the opinions of respondents can be acquired in a structured manner, according to Vaus (2002) questionnaires are the most common method used to identify the practice of companies. Although designing a questionnaire appears to be relatively simple, it is a complex process. The questions must be formulated and selected carefully and the aim of the research must continuously be borne in mind.

Due to the nature of the research, it was important to ensure respondents of confidentiality with which answer would be treated as it could drastically influence the accuracy of results. This aspect therefore enjoyed a high priority during the instruction phase.

3.1 Selection of Companies

The first step was the companies' selection. The companies were chosen from the Bryan-College Station Home Builders Association website because it provides complete information of about 180 companies affiliated with it. Three criteria were used to select companies for the study. First, only private companies were chosen. Second, only companies doing predominantly residential construction works were chosen. Third, only companies who are operating in Texas were chosen. The population selected for this study was all residential general contractors in Texas.

According to the Center for Strategy Research (2006), the minimum sample size required to accurately estimating the reality in a questionnaire survey is 30 or more companies. However, according to Majumdar (1991), the minimum sample size of 20 is required to satisfy the condition of large sample statistics.

In a previous study, fewer than 2 percent of the surveys were returned to the researchers by the post office because of incorrect addresses (Hutchings & Christofferson, 2000). By predicting a 25 percent response rate of those sampled in mail surveys (McGlynn, 1998), and by applying this 98 percent contact rate, a sample size of approximately 120 companies was required to achieve the research goals. The formula applied was Sample Size = 30 / (.25 x .98).

3.2 Data Collection

At this phase, two questionnaires were designed to collect data an approval from the Institutional Review Board (IRB) at Texas A&M University, regarding human subjects in research was obtained before the surveys were sent to the subjects (see Appendix C).

The questions were created based on the concepts acquired on the literature review. They were also designed in such a way that companies did not have to spend much time to answer. The first questionnaire was designed to identify and rank the most frequent waste categories (such as wood framing, painting, drywall, siding and so on) present in the job site affecting the final cost of the residential projects. The questionnaire along with an invite letter was post mailed to 120 companies in Texas. The mailing list was obtained from the Bryan / College Station Home Builders Association website.

The second questionnaire was designed, based on the waste identification survey demonstrated on Alarcon's (1997) study, to rank the types of waste (such as delays, waste of materials, deterioration of materials, inefficient movement of workers and so on) for the top three categories, identified on the first questionnaire, according to their influence in affecting final residential construction project cost and determine their possible causes (such as poor design and specifications, poor jobsite layout, unnecessary requirements, lack of control and so on). The questionnaire was post mailed to the same companies used on the first questionnaire.

For the first questionnaire, a total of 4 surveys were returned with undeliverable addresses and the overall response rate, after a telephone follows up, was 31.6 %, with a median time to response of 28 days. Among questionnaires received, 2 were considered invalid due to incomplete answers, so the total of valid questionnaires was 36, satisfying the minimum sample size required for this study.

The second questionnaire, a total of 23 surveys were returned and the overall response rate, after a telephone follows up, was 19.2 %. All responses were considered valid, so the obtained sample was 23, satisfying the minimum sample size required for this study

3.3 Method of Data Analysis

The first step on data analysis is to rank the most frequent waste categories present in the job site affecting the final cost. The data for this phase was collected from the first questionnaire. The unweighted frequency from Statistical Package for the Social Science (SPSS) will be applied at this moment to rank the categories. The top three waste categories will be identified and the second questionnaire will be based on them.

The second step is the analysis of the data collected from the second questionnaire. Severity index (SI) is a computation that is used to rank the types of waste for each category according to their degree of influence in affecting final project cost. In order to evaluate the degree of influence of each type of waste a three-point scale was used as follows:

- 1 = (not significant);
- 2 = (moderately significant);
- 3 = (highly significant).

It is illustrated by Equation (1) below:

$$SI = \left(\sum_{i=1}^{3} wi \times fi\right) \times \frac{1}{n}, \qquad (1)$$

Where (i) represents the ratings 1–3, (fi) the frequency of responses, (n) the total number of responses and (wi) the weight for each rating. The types of waste with higher SI have more influence in affecting final residential construction project.

The third and last step of the data analysis is to determine the possible causes of the occurrence of the types of waste for the top three waste categories. The unweighted frequency from SPSS will be applied again at this moment to rank the causes and determine which ones are more related with each type of waste.

3.4 Results Validation

The measure of the relationship between rankings of type of waste and its causes for each category will illustrate the agreement or concordance between the companies in their opinions. Kendall's coefficient of concordance gives a measure of agreement between companies, and concordance between rankings of type of waste and its causes. It ranges between ''0'' and ''1'', with ''0'' indicating no agreement and ''1'' designating perfect concordance. The SPSS software will be used to do Kendall's concordance test. It is illustrated by Equation (2) bellow (Siegel, 1987):

$$w = \frac{12 \times s}{k^2 \times n \times \left(n^2 - 1\right)}, \qquad (2)$$

Where (s) is the sum of squares of deviations of factors, (k) the number respondent groups and (n) the number of categories for the first questionnaire analysis and the number of types of waste for the second questionnaire analysis.

Since the goal of this phase was to validate the questionnaire results, the data was analyzed by testing hypothesis as well. This was achieved by developing the "null hypothesis" (Ho), that there are no agreement between respondents, and the "alternate hypothesis" (Ha), that there is agreement between respondents.

4. DATA ANALYSIS

4.1 Analysis of the Data Obtained from the First Questionnaire

Data obtained from the first questionnaire were managed and statistically analyzed by the researcher using the Statistical Package for the Social Science (SPSS). This analysis ranked the factors based on the frequency analysis and the Kendall's concordance test was performed to measure the agreement between the companies.

Frequency analysis normally made through the analysis of an arrangement of data that displays the number of times or frequency of occurrence of different values of a data set. It is used to show frequency of each variable or item outlined in the questionnaire form.

The surveyors ranked the waste categories from 1 to 10, with 1 being the most frequent category present in the job site affecting the final cost of the project and 10 the least one (Table 4.1).

Table 4.1 Statistics for the First Questionnaire

		Wood Framing	Painting	Drywall	Siding	Cardboard	Flooring	Concrete	Tile	Metals	Trim
N	Valid	36.00	36.00	36.00	36.00	35.00	36.00	35.00	36.00	36.00	36.00
	Missing	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00
Mean		1.66	9.00	2.55	4.50	5.40	6.30	3.11	6.69	8.36	7.69
Std. Deviation		1.21	1.26	1.44	1.57	1.70	1.19	1.87	1.92	2.04	1.73
Minimum		1.00	6.00	1.00	1.00	2.00	4.00	1.00	2.00	2.00	3.00
Maximum		7.00	10.00	8.00	9.00	10.00	10.00	10.00	10.00	10.00	10.00

Table 4.2 Ranking Top 3 Waste Categories

	Mean Rank
Wood Framing	1.66
Drywall	2.55
Concrete	3.11

Table 4.2 presents the ranking of the top 3 most frequent waste categories present in the job site affecting the final cost of the residential projects, as perceived by construction managers. The managers emphasized the importance of waste generated by *wood framing* affecting the final cost; these tied as the most frequently selected category chosen as the number 1 affecting the final cost by 23 (63.9%) of them and obtained a mean of 1.66 as shown in Table 4.3.

Table 4.3 Wood Framing Frequencies

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	23	63.9	63.9	63.9
	2.00	7	19.4	19.4	83.3
	3.00	4	11.1	11.1	94.4
	4.00	1	2.8	2.8	97.2
	7.00	1	2.8	2.8	100.0
	Total	36	100.0	100.0	

The second category on the rank was *drywall* chosen by 14 (38.88%) of them as shown in Table 4.4 and obtained a mean of 2.55.

Table 4.4 Drywall Frequencies

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	7	19.4	19.4	19.4
	2.00	14	38.9	38.9	58.3
	3.00	10	27.8	27.8	86.1
	4.00	1	2.8	2.8	88.9
	5.00	3	8.3	8.3	97.2
	8.00	1	2.8	2.8	100.0
	Total	36	100.0	100.0	

The third category on the rank was *concrete* chosen by 16 (44.44%) of them as shown in Table 4.5 and obtained a mean of 3.11.

Table 4.5 Concrete Frequencies

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	3	8.3	8.6	8.6
	2.00	10	27.8	28.6	37.1
	3.00	16	44.4	45.7	82.9
	4.00	1	2.8	2.9	85.7
	5.00	3	8.3	8.6	94.3
	9.00	1	2.8	2.9	97.1
	10.00	1	2.8	2.9	100.0
	Total	35	97.2	100.0	
Missing	System	1	2.8		
Total		36	100.0		

Kendall's test was used to identify whether there was consensus among companies regarding the way in which they ranked those categories and validate the data. It varies between ‘‘0’’ and ‘‘1’’, with ‘‘0’’ demonstrating no agreement and ‘‘1’’ designating perfect agreement.

According to Munro (2001), the levels of agreement resulted on Kendall’s test are divided as follows:

- Little if any agreement - 0.00 to 0.25
- Weak agreement - 0.26 to 0.49
- Moderate agreement - 0.50 to 0.69
- High agreement - 0.70 to 0.89
- Very high agreement - 0.90 to 0.99
- 1.00 = perfect agreement

For the first questionnaire, Kendall’s coefficient of 0.74 was obtained as shown in Table 4.6, which indicates a high agreement between the respondents. The significance level was less than 0.05, this value indicates that, the null hypothesis: there is no agreement between respondents, has to be rejected.

Table 4.6 Kendall's Coefficient of Concordance for the First Questionnaire

N	34
Kendall's W(a)	.741
Chi-Square	226.781
Df	9
Asymp. Sig. (p)	.000

4.2 Analysis of the Data Obtained from the Second Questionnaire

The researcher applied the SPSS software once again to manage and statistically analyze the data obtained from the second questionnaire. This analysis ranked the types of waste, for each category identified on the first questionnaire, which were: *delays, waste of materials, deterioration of materials, inefficient movement of workers, material purchased with superior value, work not done, waiting or idle, unnecessary work, rework, over allocation of materials, waste of space on site, unnecessary handling of materials, inefficient movement of workers, abnormal use of equipment, accidents and clarifications*, according to their severity index (SI) and selected the top five.

After the top five types of waste were identified for each category, the researcher analyzed the answers of the second questionnaire and identified their possible causes such as poor design and specifications, poor jobsite layout, unnecessary requirements, lack of control and so on, which were selected by the respondents from Table 1 (see Appendix A) attached on the second questionnaire.

Kendall's test was calculated again to identify whether there was consensus among companies regarding the way in which they ranked those types of wastes and validate the results obtained on the second questionnaire.

4.2.1 Wood Framing Category

The first category analyzed was *wood framing* and according to the responses, the managers emphasized the incidence of *waste of materials, over allocation of materials, rework, clarifications, and unnecessary handling of materials* on this category as shown in Table 4.7.

Table 4.7 Severity Index for the Types of Waste on Wood Framing Category

Waste of Materials	2.83
Over Allocation	2.70
Rework	2.65
Clarifications	2.57
Unnecessary Handling	2.17
Inefficient Movement	2.13
Unnecessary Work	2.13
Waiting	1.74
Work not Done	1.74
Delays	1.70
Waste of Space	1.57
Deterioration	1.43
Purchase Superior Value	1.26
Abnormal use of Equipment	1.17

The causes for the occurrence of these five types of waste identified as the most common in *wood framing* category were recognized as follows:

- *Poor design and specifications*: Waste of materials, Over allocation of materials, Rework, Clarifications, Unnecessary handling of materials;
- *Lack of control*: Waste of materials, Over allocation of materials, Rework;

- *Inadequate use of materials*: Waste of materials, Rework, Over allocation of materials;
- *Not enough information*: Over allocation of materials, Rework, Clarifications;
- *Excessive quantity*: Waste of materials, Unnecessary handling of materials;
- *Ineffective work methods*: Waste of materials, Rework;
- *Lack of integration between design and production*: Rework, Clarifications;
- *Ambiguous information*: Rework, Clarifications;
- *Inadequate storage*: Waste of materials, Unnecessary handling of materials;
- *Poor qualification of production team work*: Over allocation of materials, Rework;
- *Unnecessary information*: Clarifications;
- *Poor distribution of materials*: Unnecessary handling of materials;
- *Poor jobsite layout*: Unnecessary handling of materials;
- *Poor arrangement of the working in place*: Unnecessary handling of materials.

Kendall's coefficient of 0.57 was obtained as shown in Table 4.8, which indicates a moderate agreement between the respondents. The significance level was less than 0.05, this value indicates that, the null hypothesis: there is no agreement between respondents, has to be rejected.

Table 4.8 Kendall's Coefficient of Concordance for Wood Framing Category

N	23.00
Kendall's W(a)	0.57
Chi-Square	182.10
Df	14.00
Asymp. Sig. (p)	0.00

The following matrix (Table 4.9) summarizes the potential causes for each type of waste identified as the five most common in *wood framing* category.

Table 4.9 Causes for Each Type of Waste Identified in *Wood Framing* Category

CAUSES / **TYPES OF WASTE**	Waste of materials	Over allocation	Rework	Clarifications	Unnecessary handling
Project					
Poor design and specifications	X	X	X	X	X
Poor jobsite layout					X
Management					
Lack of control	X	X	X		
Production					
Poor qualification of team work		X	X		
Ineffective work methods	X		X		
Poor arrangement of the working place					X
Resources					
Excessive quantity	X				X
Inadequate use	X	X	X		
Poor distribution					X
Inadequate storage	X				X
Information systems					
Unnecessary information				X	
Not enough information		X	X	X	
Ambiguous information			X	X	
Lack of integration between design and production			X	X	

4.2.2 Drywall Category

The second category analyzed was *drywall* and according to the responses, the managers emphasized the incidence of *waste of materials, inefficient movement of workers, waste* *of space on site, unnecessary handling of materials and rework* on this category as shown in Table 4.10.

Table 4.10 Severity Index for the Types of Waste on Drywall Category

Waste of Materials	2.87
Inefficient Movement	2.74
Waste of Space	2.74
Rework	2.35
Unnecessary Handling	2.30
Clarifications	1.65
Over Allocation	1.65
Accidents	1.30
Waiting	1.30
Abnormal use of Equipment	1.26
Unnecessary Work	1.26
Delays	1.17
Deterioration	1.17
Work not Done	1.09
Purchase Superior Value	1.04

The causes for the occurrence of these five types of waste identified as the most common in *drywall* category were recognized as follows:

- *Ineffective work methods*: Waste of materials, Inefficient movement of workers, Unnecessary handling of materials, Rework;
- *Excessive quantity of materials*: Waste of materials, Waste of space on site, Unnecessary handling of materials;
- *Inadequate storage of materials*: Waste of materials, Waste of space on site, Unnecessary handling of materials;

- *Poor planning*: Waste of materials, Inefficient movement of workers, Waste of space on site;
- *Poor arrangement of the working place*: Inefficient movement of workers; Waste of space on site, Unnecessary handling of materials;
- *Poor jobsite layout*: Inefficient movement of workers, Waste of space on site, Unnecessary handling of materials;
- *Inadequate use of materials*: Waste of materials, Rework:
- *Poor design and specification*: Waste of materials, Rework;
- *Lack of control*: Waste of materials , Inefficient movement of workers;
- *Poor qualification of production team work*: Inefficient movement, Rework;
- *Lack of work place available*: Waste of space, Unnecessary handling of materials;
- *Lack of integration between design and production*: Rework.

Kendall's coefficient of 0.61 was obtained as shown in Table 4.11, which indicates a moderate agreement between the respondents. The significance level was less than 0.05, this value indicates that, the null hypothesis: there is no agreement between respondents, has to be rejected.

Table 4.11 Kendall's Coefficient of Concordance for Drywall Category

N	23.00
Kendall's W(a)	0.61
Chi-Square	196.56
Df	14.00
Asymp. Sig. (p)	0.00

The following matrix (Table 4.12) summarizes the potential causes for each type of waste identified as the five most common in *drywall* category.

Table 4.12 Causes for Each Type of Waste Identified in *Drywall* Category

CAUSES / **TYPES OF WASTE**	Waste of materials	Inefficient movement	Waste of space on site	Rework	Unnecessary handling
Project					
Poor design and specifications	X			X	
Poor jobsite layout		X	X		X
Management					
Lack of control	X	X			
Poor planning	X	X	X		
Production					
Poor qualification of team work		X		X	
Ineffective work methods	X	X		X	X
Poor arrangement of the working place		X	X		X
Lack of work place available	X				X
Resources					
Excessive quantity	X		X		X
Inadequate use	X			X	
Inadequate storage	X		X		X
Information systems					
Lack of integration between design and production				X	

4.2.3 Concrete Category

The first category analyzed was *concrete* and according to the responses, the managers emphasized the incidence of *waiting, delays, clarifications, over allocation of materials, inefficient movement of workers* on this category as shown in Table 4.13.

Table 4.13 Severity Index for the Types of Waste on Concrete Category

Waiting	2.78
Delays	2.65
Clarifications	2.52
Over Allocation	2.35
Inefficient Movement	1.74
Waste of Materials	1.30
Rework	1.26
Waste of Space	1.17
Unnecessary Work	1.17
Unnecessary Handling	1.17
Purchase Superior Value	1.17
Work not Done	1.13
Accidents	1.09
Abnormal use of Equipment	1.09
Deterioration	1.00

The causes for the occurrence of these five types of waste identified as the most common in *concrete* category were recognized as follows:

- *Waiting:* Lack of control, poor planning, poor arrangement of working place, bureaucracy and poor qualification of team work;
- *Lack of control*: Waiting, Delays, Clarifications, Over allocations of materials;
- *Poor planning*: Waiting, Delays, Over allocation of materials, Inefficient movements of workers;
- *Ineffective work methods*: Delays, Over allocation of materials, Inefficient movements of workers;
- *Poor qualification of team work*: Waiting, Delays, Over allocation of materials;

- *Excessive quantity of materials*: Over allocation of materials, Inefficient movements of workers;
- *Poor arrangement of working place*: Waiting, Inefficient movements of workers;
- *Lack of work place available*: Delays, Waiting;
- *Poor design and specifications*: Clarifications;
- *Poor jobsite layout*: Waiting, Inefficient movements of workers;
- *Weather conditions*: Delays;
- *Not enough information*: Clarifications;
- *Lack of integration between design and production*: Clarifications;
- *Bureaucracy*: Waiting;
- *Unnecessary information*: Clarifications;

Kendall's coefficient of 0.67 was obtained as shown in Table 4.14, which indicates a moderate agreement between the respondents. The significance level was less than 0.05, this value indicates that, the null hypothesis: there is no agreement between respondents, has to be rejected.

Table 4.14 Kendall's Coefficient of Concordance for Concrete Category

N	23.00
Kendall's W(a)	0.67
Chi-Square	215.04
Df	14.00
Asymp. Sig. (p)	0.00

The following matrix (Table 4.15) summarizes the potential causes for each type of waste identified as the five most common in *concrete* category.

Table 4.15 Causes for Each Type of Waste Identified in *Concrete* Category

CAUSES / **TYPES OF WASTE**	Waiting	Delays	Clarifications	Over allocation	Inefficient movement
Project					
Poor design and specifications			X		
Poor jobsite layout	X				X
Management					
Lack of control	X	X	X	X	
Poor planning	X	X		X	X
Bureaucracy	X				
Production					
Poor qualification of team work	X	X		X	
Ineffective work methods		X		X	X
Poor arrangement of the working place	X				X
Lack of personal equipment	X	X			
Weather conditions		X			
Resources					
Excessive quantity				X	X
Information systems					
Unnecessary information			X		
Not enough information			X		
Lack of integration between design and production			X		

5. SUMMARY AND CONCLUSIONS

Waste reduction is the best and usually the most economical of the different waste management alternatives (Gavilan and Bernold, 1994). To implement an efficient waste reduction program in construction projects is necessary to identify what is generating waste and its causes. As established at the beginning of this study, the objectives of this study were to identify the most frequent waste categories affecting the final cost in residential projects, identify the types of waste occurring on the top three waste categories affecting the final cost and determine their possible causes, and recommend guidelines to be applied in conduction projects and reduce waste. To accomplish these goals, construction companies responded two questionnaires, the data obtained from it was analyzed and guidelines to reduce waste are recommended based on these findings.

5.1 Findings from Data Analysis

The data obtained in this research is based on personal views of respondents and on their perceptions, and not on any quantitative measure of the waste or its causes. The results indicate that the most frequent waste categories affecting the final cost in residential projects are: *wood framing, drywall and concrete*. According to Gavilan and Bernold (1994), dimensional lumber, drywall and masonry are the top three types of waste occurring in residential construction and the NAHB Research Center (1995) prepared a report to the U.S. Environmental Protection Agency which shows that wood, drywall and masonry are the top three types of waste occurring in residential.

The study revealed that the most dominant types of waste occurring on these categories are: *waste of materials, over allocation of materials, rework, clarifications, unnecessary handling of materials, inefficient movement of workers, waste of space on site, and delays.* The most common causes, for the occurrence of these types of waste, identified in this research were: *poor design and specifications, not enough information, ambiguous information, poor jobsite layout, poor planning, lack of control, excessive quantity of materials, lack of work place available, weather conditions, poor qualification of production team work, and ineffective work methods.*

5.2 Solutions to Be Put into Effect in Residential Construction to Reduce Waste

Some of these causes can be solved at the conception phase. *Poor design and specifications* cause types of waste such *waste of materials, over allocation of materials, rework, clarifications, and unnecessary handling of materials.* It can be improved by designing homes with standard sized dimensions. Wood, drywall, plywood, and other materials cut to standard sizes reduce cutoff waste and improve materials use and reuse. For example, considering that drywall and plywood are usually produced in four by eight panels, waste and labor are reduced when the exterior perimeter dimensions of the walls are designed in multiples of two. Another action that can be done at this phase is to make sure that the projects contain accurate and clear information needed to accomplish all tasks, this can be done by selecting a person who totally understands the entire construction process to inspect the projects to avoid *insufficient and ambiguous information.*

Another cause identified on the data analysis that can be solved at the conception phase was *poor jobsite layout*; this is a problem that generates waste such *unnecessary handling of materials, inefficient movement of workers* and waste *of space on site*. Jobsite layout is usually highlighted in hindsight in construction and seldom captured through lessons learned. An efficient jobsite layout must include requisites such production areas, access roads for equipment and materials, office trailers, materials and equipment storage, toilet and parking areas for workforce. Builders can develop a checklist to make sure that the layout adequately includes all these vital elements.

Poor planning and lack of control were also identified as responsible for the incidence of waste in residential projects. According to Ballard (2000) different people accomplish these two tasks in different phases of the project. Two actions that can be done to improve planning are developing a long term or formal planning at the beginning of the project and short term or informal planning during the execution. The long term planning focuses on the strategic objectives and the restrictions that each project has. Another important one is the short term planning, which defines what tasks will be done on the next day of work. The formal planning has to be updated as the informal planning changes and these differences or variability between them have to be eliminated through receiving and transmitting these lessons learned to future projects (Fernandez-Solis, 2006). The control of the complete process is very important as well, and someone in the team must be responsible for that control and have to quantify and illustrate the variability of productivity and waste rates during each cycle. Depending on the complexity of the project, may be necessary to involve not only the company but also the entire productive chain on this effort.

Excessive quantity of materials on site is another factor identified on this study that causes waste such *inefficient movement of workers, over allocation of materials, unnecessary handling of materials, waste of space on site and waste of materials* in residential construction. It can be solved by implement just-in-time ordering and guarantee that the materials will be delivered on site when they are required, thereby avoiding damage while stored on site and additional moving of materials.

Weather condition was identified as the principal reason for delays in concrete works. Theses conditions can be predicted and included into project schedules using historical weather data for the particular location. All exterior construction activities must be schedule using a separated weather calendar, which has a number of non-work days each month based on the average of rain for that month.

Problems such *poor qualification of production team work and ineffective work methods* result in inefficient movement of worker, unnecessary handling of materials and rework according to the respondents. Koskela and Vrijhoef (2006) as quoted by Fernandez-Solis (2006), state that craft mentality has no motivation to share learning experiences for the sake of re-applying them in future projects by a differing crew for the sole benefit of the builder. To eliminate such problems builders have to implement training programs for their employees and introduce procedures with the idea of build continuous improvement into the process, increase process transparency, simplify by minimizing the number of steps and parts, reduce activities that do not add value and according to Fernandez-Solis (2006) by eliminating variability and the distribution of variability through getting and transmitting lessons learned. Another approach to minimize those wastes of productivity is automation and robotics. According to Richard (2004), a research about Swedish wood-framed panels assembled by automation indicates an economy up to 27% compared with conventional construction methods. With robotics, the same machine has the ability to complete by itself diversified tasks, but the robot is too expensive to use for nailing studs or hanging drywall. However, in the future, robots will enter into mass production and sweep through the society into common use.

5.3 Recommendations for Future Studies

The following recommendations for future studies are relevant and related with this research:

- Conduct a similar study with wider sample sizes and with a wider sample type such as considering residential builders outside Texas and compare the results with the findings of this research.
- Apply the concepts and the recommendations established in this study in residential construction jobsites to verify the impact of them in the reduction of construction waste and consequently final cost.
- Conduct a similar study with other segments of construction industry to figure out which waste categories are most affecting the final cost in these segments, the types of

waste occurring in these categories and its causes, then recommend actions to reduce waste and cost.

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APPENDIX A

QUESTIONNAIRES

QUESTIONNAIRE 1

The purpose of this questionnaire is to identify the top 3 waste categories according to their cost impact in residential construction.

1) Name (not required):

2) Position:

3) Company:

4) Rank the categories of waste present in your jobsite according to their cost impact (start with the most influent):

	Rank
1 - Wood Framing	1-
2 - Painting	2-
3 - Drywall	3-
4 - Siding	4-
5 - Cardboard (OCC)	5-
6 - Flooring	6-
7 - Concrete and Masonry	7-
8 - Tile	8-
9 - Metals	9-
10 - Trim	10-
11 - Other (specify):	11-

QUESTIONNAIRE 2

The purpose of this questionnaire is to identify the possible causes of waste generation for the top 3 categories of waste selected from the results of the previous questionnaire.

1) Name (not required):

2) Position:

3) Company:

4) Identify the most frequent types of waste that you perceived and their possible causes in the following categories:

Instructions:

Column 1 - Select the degree of influence, for each type of waste, in affecting final project from the three-point scale as follows:

1 = (not significant)
2 = (moderately significant)
3 = (highly significant)

Columns 2, 3, 4 and 5 - Select the possible cause(s) of its occurrence from TABLE 1 on page 4

EXAMPLE

Types of waste:	1	Cause(s) 2	3	4	5
1- Delays	2	b.1	b.4		
2- Waste of materials	1	b.2			
3- Deterioration of materials	3	a.2			
4- Inefficient movement of workers	3	c.3	b.3	e.2	
5- Material purchased with superior value	1	a.1			
6- Work not done	1				
7- Waiting or idle	2	b.3			
8- Unnecessary work	1				
9- Rework	3	a.1	b.2		
10- Over allocation of materials	1	d.1			
11- Waste of space on site	1	a.2			

...

1st CATEGORY : **WOOD FRAMING**

Types of waste:

Types of waste	Cause(s) 1	2	3	4	5
1- Delays					
2- Waste of materials					
3- Deterioration of materials					
4- Inefficient movement of workers					
5- Material purchased with superior value					
6- Work not done					
7- Waiting or idle					
8- Unnecessary work					
9- Rework					
10- Over allocation of materials					
11- Waste of space on site					
12- Unnecessary handling of materials					
13- Abnormal use of equipment					
14- Accidents					
15- Clarifications					
16- Others (specify)					

2nd CATEGORY: **DRYWALL**

Types of waste:

Types of waste	Cause(s) 1	2	3	4	5
1- Delays					
2- Waste of materials					
3- Deterioration of materials					
4- Inefficient movement of workers					
5- Material purchased with superior value					
6- Work not done					
7- Waiting or idle					
8- Unnecessary work					
9- Rework					
10- Over allocation of materials					
11- Waste of space on site					
12- Unnecessary handling of materials					
13- Abnormal use of equipment					
14- Accidents					
15- Clarifications					
16- Others (specify)					

3rd CATEGORY: **CONCRETE**

Types of waste:

Types of waste	Cause(s) 1	2	3	4	5
1- Delays					
2- Waste of materials					
3- Deterioration of materials					
4- Inefficient movement of workers					
5- Material purchased with superior value					
6- Work not done					
7- Waiting or idle					
8- Unnecessary work					
9- Rework					
10- Over allocation of materials					
11- Waste of space on site					
12- Unnecessary handling of materials					
13- Abnormal use of equipment					
14- Accidents					
15- Clarifications					
16- Others (specify)					

TABLE 1		
a)	**Project**	
	a.1	Poor design and specifications
	a.2	Poor jobsite layout
b)	**Management**	
	b.1	Unnecessary requirements
	b.2	Lack of control
	b.3	Poor planning
	b.4	Bureaucracy
c)	**Production**	
	c.1	Poor qualification of team work
	c.2	Ineffective work methods
	c.3	Poor arrangement of the working place
	c.4	Lack of work place available
	c.5	Lack of personal equipment
d)	**Resources**	
	d.1	Excessive quantity
	d.2	Insufficient quantity
	d.3	Inadequate use
	d.4	Poor distribution
	d.5	Poor quality
	d.6	Availability
	d.7	Inadequate storage
e)	**Information systems**	
	e.1	Unnecessary information
	e.2	Not enough information
	e.3	Ambiguous information
	e.4	Lack of integration between design and production
	e.5	Lack of sinalization on the jobsite

APPENDIX B

FREQUENCY TABLES (Waste Categories)

Wood

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	23	63.9	63.9	63.9
	2.00	7	19.4	19.4	83.3
	3.00	4	11.1	11.1	94.4
	4.00	1	2.8	2.8	97.2
	7.00	1	2.8	2.8	100.0
	Total	36	100.0	100.0	

Drywall

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	7	19.4	19.4	19.4
	2.00	14	38.9	38.9	58.3
	3.00	10	27.8	27.8	86.1
	4.00	1	2.8	2.8	88.9
	5.00	3	8.3	8.3	97.2
	8.00	1	2.8	2.8	100.0
	Total	36	100.0	100.0	

Concrete

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	3	8.3	8.6	8.6
	2.00	10	27.8	28.6	37.1
	3.00	16	44.4	45.7	82.9
	4.00	1	2.8	2.9	85.7
	5.00	3	8.3	8.6	94.3
	9.00	1	2.8	2.9	97.1
	10.00	1	2.8	2.9	100.0
	Total	35	97.2	100.0	
Missing	System	1	2.8		
Total		36	100.0		

Siding

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	1	2.8	2.8	2.8
	3.00	5	13.9	13.9	16.7
	4.00	20	55.6	55.6	72.2
	5.00	2	5.6	5.6	77.8
	6.00	3	8.3	8.3	86.1
	7.00	3	8.3	8.3	94.4
	8.00	1	2.8	2.8	97.2
	9.00	1	2.8	2.8	100.0
	Total	36	100.0	100.0	

Cardboard

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2.00	2	5.6	5.7	5.7
	3.00	1	2.8	2.9	8.6
	4.00	4	11.1	11.4	20.0
	5.00	18	50.0	51.4	71.4
	6.00	1	2.8	2.9	74.3
	7.00	4	11.1	11.4	85.7
	8.00	4	11.1	11.4	97.1
	10.00	1	2.8	2.9	100.0
	Total	35	97.2	100.0	
Missing	System	1	2.8		
Total		36	100.0		

Flooring

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4.00	1	2.8	2.8	2.8
	5.00	5	13.9	13.9	16.7
	6.00	21	58.3	58.3	75.0
	7.00	3	8.3	8.3	83.3
	8.00	4	11.1	11.1	94.4
	9.00	1	2.8	2.8	97.2
	10.00	1	2.8	2.8	100.0
	Total	36	100.0	100.0	

Tile

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2.00	1	2.8	2.8	2.8
	4.00	4	11.1	11.1	13.9
	5.00	4	11.1	11.1	25.0
	6.00	4	11.1	11.1	36.1
	7.00	15	41.7	41.7	77.8
	8.00	3	8.3	8.3	86.1
	9.00	2	5.6	5.6	91.7
	10.00	1	2.8	2.8	94.4
	11.00	2	5.6	5.6	100.0
	Total	36	100.0	100.0	

Trim

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3.00	1	2.8	2.8	2.8
	4.00	2	5.6	5.6	8.3
	5.00	1	2.8	2.8	11.1
	6.00	5	13.9	13.9	25.0
	7.00	2	5.6	5.6	30.6
	8.00	10	27.8	27.8	58.3
	9.00	13	36.1	36.1	94.4
	10.00	2	5.6	5.6	100.0
	Total	36	100.0	100.0	

Metals

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2.00	2	5.6	5.6	5.6
	4.00	1	2.8	2.8	8.3
	6.00	1	2.8	2.8	11.1
	7.00	2	5.6	5.6	16.7
	8.00	9	25.0	25.0	41.7
	9.00	9	25.0	25.0	66.7
	10.00	12	33.3	33.3	100.0
	Total	36	100.0	100.0	

Painting

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	6.00	1	2.8	2.8	2.8
	7.00	6	16.7	16.7	19.4
	8.00	3	8.3	8.3	27.8
	9.00	9	25.0	25.0	52.8
	10.00	16	44.4	44.4	97.2
	11.00	1	2.8	2.8	100.0
	Total	36	100.0	100.0	

APPENDIX C

IRB APPROVAL

TEXAS A&M UNIVERSITY
VICE PRESIDENT FOR RESEARCH - OFFICE OF RESEARCH COMPLIANCE

1186 TAMU
College Station, TX 77843-1186
1500 Research Parkway, Suite B-150

979.458.1467
FAX 979.862.3176
http://researchcompliance.tamu.edu

Institutional Biosafety Committee   Institutional Animal Care and Use Committee   Institutional Review Board

DATE: 20-Jul-2007

MEMORANDUM

TO: BRANCO, CRISTIANO RIBEIRO CASTELO
TAMU-CONSTRUCTION SCIENCE(00022)

FROM: Office of Research Compliance
Institutional Review Board

SUBJECT: Initial Review

Protocol Number:	2007-0430
Title:	An Effective way to Reduce Residential Construction Waste: A Case Study in Texas
Review Category:	Exempt from IRB Review

The Institutional Review Board (IRB) has determined that the referenced protocol application meets the criteria for exemption and no further review is required. However, any amendment or modification to the protocol must be reported to the IRB and reviewed before being implemented to ensure the protocol still meets the criteria for exemption.

This determination was based on the following Code of Federal Regulations:
(http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.htm)

45 CFR 46.101(b)(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior, unless: (a) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (b) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Provisions:

This electronic document provides notification of the review results by the Institutional Review Board.

VITA

Cristiano R. Castelo Branco

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ACADEMIC BACKGROUND

- **Master of Science in Construction Management**: **Texas A&M University**. (Expected graduation date: Dec/2007, Current GPR: 3.77).
- **Certificate in Business:** Mays Business School, Texas A&M University. (Expected completion date: Nov/2007).
- **Specialization in Construction Management**: Federal University of Ceará / Brazil (2002-2003). Dissertation: "Analysis of Planning Simulations for Family Buildings Using the Software MS Project 2000".
- **B.S. in Civil Engineering:** Federal University of Ceará / Brazil (1997-2001).

PROFESSIONAL EXPERIENCE

- **Estimator**, Stearns Construction Inc., College Station, Texas **May 06 - present**
- **Construction Supervisor**, Escarpa Engenharia, Brazil **Jul 02 -Nov 05**
- **Estimator**, Construtora Exata, Brazil **Jan 00 - Jun 02**
- **Intern,** Queiroz Galvão/Camargo Corrêa, Brazil **Oct 98 – Dec 99**
- **Intern,** Monteplan Engenharia, Brazil **Summer 98**

COMPUTER SKILLS

- Windows, Word, Excel, Access, PowerPoint,
- AutoCAD, Chief Architect,
- Microsoft Project, Primavera.

AWARDS

- Construction Law Section of the State Bar of Texas Endowed Scholarship for the 2006-2007 academic year.
- Construction Law Section of the State Bar of Texas Endowed Scholarship for the 2007-2008 academic year.