CONSTRUCTION WASTE MANAGEMENT SYSTEM: A CASE STUDY IN A CONSTRUCTION PROJECT IN CHILE

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ABSTRACT

Construction waste forms the majority of waste disposed in landfills. It originates from various sources and is produced throughout the duration of the construction projects. The Chilean Chamber of Construction has taken actions to reduce waste generation through mechanisms such as the Clean Production Agreement and the Guide to Good Environmental Practices, among others. However, they have had poor results in terms of reducing the rate of waste generation. For this reason, it is important to view construction waste management as a series of procedures to improve production methods and not just as a process of classification, collection and disposal of waste. This article describes a waste management system (WMS) at a construction operations level and the results of its implementation during the execution of the structural work on a real project. While the procedures that make up the WMS were the result of a series of interviews with construction experts, some of the support elements necessary for its implementation in the field were the authors' own developments. The results show a high participation and involvement of all who took part in the project. The implementation of the WMS raised awareness towards waste minimization and its effectiveness was demonstrated by the amount of waste reduction achieved. Preliminary findings indicate that some of the most important components for a good performance of the WMS are staff training, leadership by the project manager and control through the partial measuring of the performance of its components.

Keywords: system, management, waste, construction, case study.

1. INTRODUCTION

Construction is the industry that generates the greatest quantity of solid waste in the world (Xiao-shuang, et al., 2010; Spoerri et al., 2009; Kourmpanis et al., 2008, Deng et al., 2008 and Wang et al., 2004). With the current population growth rate, the demand for construction will continue to rise, thereby causing a significant increase in the rate of waste generation.

According to Chile's Environment Ministry (2010), 5 million tonnes of construction waste are generated annually. According to the Chilean Chamber of Construction, building permits in

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2011 increased by 55% in comparison to 2010, in a year which saw the highest number since 1992 (Report Mach-35, April 2012). In many cases the waste produced by this construction is being taken to illegal landfills located mainly in poorer peripheral neighborhoods in the metropolitan area, generating increasingly greater environmental and social impacts. In January 2010, the Ministry of Health recorded more than 70 illegal dumps in the metropolitan region of Chile alone, not counting all of the micro landfills. The vast majority of these are located in peripheral municipalities of Santiago where there are scarce resources for control and management.

Construction waste comes from various sources involved in the execution of building projects (Shen et al., 2004). Waste management on site is becoming an important part of the construction process (Wimalasena et al., 2010). In the construction phase, specific plans have been put forth for waste management, such as those proposed by McDonald and Smithers (1998). Additionally, McGrath (2001) developed a project called SMARTWaste, Chen et al. (2002) used barcode technology and Shen et al. (2004) employed the Waste Management Mapping Model (WMMM). Furthermore, Cha et al. (2009) have proposed utilizing the Waste Management Performance Assessment Tool (WMPAT) to assess waste management in advance from four perspectives: labor, equipment and materials, construction methods and management practices. However, a WMS is not currently available for construction operations that incorporate management actions for waste that has already been generated or for the management hierarchy of waste avoidance, reduction, reuse and recycling, as proposed by Deng et al. (2008), Shen et al. (2004) and Kartam et al. (2004). Therefore, in this study a WMS to support construction operations has been developed and implemented in a construction project of a Chilean company.

This article describes a WMS for a construction project in Chile, at a construction operations level, with all of the involved processes, activities and records. The results of the WMS implementation are also shown to demonstrate its benefits in terms of reducing the amount of waste its contribution to economic utility of the project.

2. PREVIOUS RESEARCH

The literature review focused on three major topics: waste management plans and case studies, manuals of good waste management practices and public initiatives in Chile developed for construction waste. The following chapter describes the findings in each of these cases.

2.1 Waste management plans and case studies

McDonald and Smithers (1998) implemented a waste management plan for the construction site of a two floor building with a floor space of 10,600 m^2. The plan's objectives were to reduce, reuse and/or recycle waste. The main strategies used to achieve the objectives were: to prepare an inventory of wasted materials and to asses their potential for reuse and recycling, to evaluate the costs of waste disposal, to develop a practical method for the collection of waste and to use recycled materials in temporary work. Although waste reduction costs were estimated, the only the management operations studied were those concerning the handling of waste. Additionally, specific practices implemented in the project, such as the use of cranes, workers, trucks, and waste handling facilitators, among other details, were not explained.

McGrath (2001) proposed a using piece of software called SMARTWaste (Site Methodology to Audit, Reduce and Target Waste). Its purpose is to identify sources of waste generation and quantify the amounts generated. The system is based on collecting information by periodically analyzing waste disposal containers. It analyses the possible causes of waste generation by entering information such as type, size and quantity of waste, as well as the location it was collected, among other data. SMARTWaste requires a person on site once or twice a week, whose task is to collect the details of waste generation and to talk with workers and project managers to determine the origin of this waste. The implementation costs and efficiency of the plan with regards to the reduction of waste were not evaluated.

Chen et al., (2002) presents a rewards program based on giving incentives to building site workers (IRP - Reward Incentive Program). It uses a bar code system to identify materials and obtain real time information on the amount of material exchanged between the warehouse and the workers. In this way the consumption of each type of material is controlled and it can be identified whether a material has been either saved or consumed excessively. Workers can then be rewarded according to the quantities and values of the materials they have saved when carrying out their work. Although this incentive program is able to reduce the amount of material consumed, it does not identify which waste management procedures have been implemented by the workers, nor does it calculate the economic benefit of this reduction.

Shen et al., (2004) propose using a program known as the WMMM, which was employed to implement good waste handling practices in Hong Kong. The proposed model focuses on strategies to deal with waste on construction sites once it has been generated. The idea is to reduce costs by minimizing and simplifying handling processes, cutting back on staff (by using mechanical waste handling methods) and abolishing the double handling of waste products, among other strategies (Shen et al., 2004). While this model proposes specific action to minimize the generation of waste at the handling stage, it does not quantify the economic impact of such action.

Cha et al. (2009) propose employing the WMPAT. This is an application developed using Excel and Visual Basic to facilitate the evaluation process of waste management in projects concerning labor, materials and equipment, methods of construction and management practices. The WMPAT gives a total index that indicates the level of performance of the project in terms of waste management (Cha et al, 2009). This index has been classified into four levels: excellent, good, fair and poor. For example, for a project classified as “poor” waste management is of little importance to the workers and they have little training in this area. In terms of materials, the recycling of materials is rarely implemented. Regarding building methods, little effort is made on the site to decrease waste. Finally, from a management perspective, there is no incentive for waste reduction. While the WMPAT is a tool that evaluates the performance of waste management, it does not evaluate each factor influencing the economic impact of construction waste.

2.2 Manuals of Good Environmental Practices

The United States Environmental Protection Agency (EPA) has proposed strategies and practices to reduce construction waste and demolition debris from buildings. It has published the results of a series of cases where there is an emphasis on cost/benefit and has made suggestions for the use of such results in other projects. One strategy is to educate contractors and workers in material recovery techniques. Another is to make subcontractors responsible for the recovery of materials through the inclusion of contractual clauses which can be paid only after it has been certified that the outsourcer has made efforts to recover materials. Finally, incentives are provided for the recovery of materials.

The Master Builders Association of Victoria and Ecorecycle Victoria, also in the United States of America (2004), have published a brochure to provide guidance to reduce waste. They propose six ways to work smarter, to reduce waste and to save money. These are: (1) To prepare a waste management plan, (2) to design and order only what you need, (3) to use pre-manufactured products, (4) to work together with other builders to recycle, (5) to provide waste recipients, and (6) to separate waste for recycling. Additionally, they provide a template to check each of the above components before, during and after construction.

Laquatra and Pierce (2002) propose using spreadsheets to audit waste. These will help control the disposal of waste by volume and by weight, identify companies that recycle specific materials and their costs, calculate the rate of waste generation per material, register the organizations involved in waste recycling, register identify the current costs of waste disposal, and take note of other important observations.

The Chilean Chamber of Construction, specifically the Commission on Sustainable Development, has prepared a guide to good construction practices that is especially oriented towards the erection of buildings. It proposes mitigation measures to moderate the following effects that may be generated by construction activities: air emissions, noise, waste and complaints by neighbors (Chilean Chamber of Construction, 2010). Regarding the waste issue alone, there are 13 mitigation measures that have been proposed for building constructions. Only 5 of these aim to prevent the generation of waste, while the others focus on its handling once generated. However, these measures are only outlined. Some are generic and it is not shown in detail how they would be executed. Each requires operational planning for its proper implementation in the field.

2.3 Public initiatives in Chile

On 28 January 2000, the construction sector's Clean Production Agreement (CPA) for the metropolitan region of Chile was signed. It came into effect on May 1 of that year and ended on April 30 2002, adhering to the 34 construction company members of the Chilean Chamber of Construction. The CPA's study of the environmental and economic impact determined that the goals of the CPA in relation to solid waste had not been completely accomplished. However, it did show that average waste generation was reduced by 20% through the use and acquisition of standardized or precast products and the reuse of excavation waste as fillers in other building work. The study also determined that it is not possible to say whether this reduction is due to the CPA or not because the total construction area developed by the companies who signed the agreement in 1999 (the year of the initial signing of the agreement) and 2005 (when the study of the environmental and economic impact of the agreement took place) is not known. This is due to the fact that companies tend to treat such data as confidential information. Therefore, the true effectiveness of waste management in construction projects cannot be identified. Secondly, other good environmental practices that would indicate how to avoid, reduce, reuse and/or recycle waste before it ends in a landfill were not incorporated.

3. FRAMEWORK AND METHODOLOGY

The generation and management of waste in a project are closely related to production processes and support activities (procurement management, quality control system, material control and cost control, among others.). Previously, when thinking about procedures to reduce waste and emissions from certain activities, the first thing that was focused on were tactics like the replacement of materials and equipment. The possibility of reducing waste by implementing simple and inexpensive measures to improve operations management in a project had not been considered. For this reason, in this study a WMS was designed that proposes some changes to the traditional patterns of management operations and also articulates some of the activities that support the implementation of a project. In this way it is hoped that the generation of waste can be reduced and environmental and economic benefits for construction projects can be obtained.

Based on the list of the sources and causes of waste generation and the procedures and/or waste management strategies proposed by Aldana et al., (2011), a list of 33 measures was generated that can be implemented in construction projects and contribute to the reduction of waste. Additionally, by reviewing the literature regarding materials wasted in construction projects, a list of 34 waste materials was obtained. Subsequently, interviews were given to 11 professionals from 6 construction and real estate companies. These people were asked which 10 procedures and/or strategies they considered most relevant to implement in a construction project that would contribute to a reduction of waste. Finally, they were asked which 5 materials are wasted the most on such projects. The professionals surveyed consisted of builders (7) and civil engineers (4) who have an average of 19 years experience in the industry and who currently hold the following positions: technical manager (1), project manager (2), site manager (6), construction manager (1) and technical inspector (1).

After an analysis of 123 publications on construction waste management, it was found that only 26 of them talk about waste management procedures and/or strategies. Based on this, a ranking was performed taking the frequency that these strategies were mentioned in the literature (see Table 1) as a parameter. This frequency ranking was taken from Aldana and Serpell (2012).

Table 1. Waste management procedures and/or strategies most cited in the literature.

Procedures and/or strategies	Number of citations
Sorting waste at construction sites, assigning locations and recipients for each type.	9
Use of precast materials.	8
Training and educating staff on management tools and on-site waste management.	8
Buying and ordering materials efficiently.	7
Establishing centralized cutting areas to identify parts that can be reused.	4
Storing materials in good condition.	4
Making orders and receiving deliveries in good time	4
Encouraging subcontractors and workers to save materials.	3
Requiring the reuse of materials to be stated in contracts, demanding the amount of waste to be recorded and the generated levels to be reported as the construction process is carried out, requiring materials to be ordered with the correct sizes by adequately reviewing supplier catalogs, changing the design of construction processes, using metal formwork.	2
Cutting steel in the factory not on site, using modern technologies, committing workers to use good material handling, requiring subcontractors to purchase their own materials, maintaining machinery and equipment, handling materials correctly, reviewing materials when workers arrive on site and returning deteriorated materials to the supplier, preparing transport systems suitable for each material, unloading materials at their final site and avoiding stacking and double handling, locating warehouses near the construction site, limiting the quantity of stockpiled materials to avoid excess inventory, returning material packaging to suppliers for reuse, negotiating the return of unused materials with suppliers, avoiding suppliers that over package materials, providing recipients that separate trash (food, drink containers, etc.), carrying out material inventories as planned, buying materials that have reusable packaging, using technologies that generate little waste, using materials before their expiry dates, requiring subcontracts to dispose of their own waste.	1

After analyzing the results of the interviews and the ranking in the literature, it was possible to conclude that of the 14 procedures most frequently listed in the literature, 12 of them were selected by experts in the interviews. An analysis was also done considering the specific influence of the experts' responses, leading to the conclusion that of the 15 procedures most mentioned in the literature, 12 were selected by experts. Finally, an incremental revision of the interviews was carried out to verify the stability of the answers and to determine whether more interviews were needed to select the procedures that would be the basis of the WMS. It was concluded that of the 15 procedures mentioned in the literature, between 10 and 13 were selected by respondents in all the iterations analyzed. Therefore, it was decided to take the procedures identified by the experts as a reference point for planning the WMS. The results of the survey yielded the following order of importance of waste management actions:

(1) committing workers to use good material handling, (2) encouraging subcontractors and workers to save materials, (3) training and educating staff about management tools and waste management, (4) sorting waste on site by assigning locations and recipients for each type, (5) buying and ordering materials efficiently, (6) using precast materials, (7) establishing centralized cutting areas to identify parts that can be reused, (8) handling materials correctly, (9) providing garbage containers, (10) cutting steel in the factory rather than on site, (11) recording the amount of waste and reporting generated levels as the construction process progresses, (12) requesting appropriately sized materials through the study of supplier catalogs, (13) using metal formwork, (14) changing the designs of construction processes, and (15) using modern technologies and those that generate little waste.

Based on the 15 procedures selected, aspects that were applied at the operational level required for their successful implementation in the field were reviewed. This included taking a performance measurement for the WMS implementation to control its execution in the field, as proposed by Aldana et al., (2011). Finally, once the system had been designed, verification of the project support activities was carried out (quality control system, procurement system, cost control system, etc.) to see which were common to the WMS. In this way, the same work was not done twice and information was not over-recorded.

The WMS was validated by the technical manager of the construction company who provided the building project and two project managers for the case study. The particularities of the project and restrictions made by the person in charge resulted in minor changes to some records and the incorporation and/or elimination of some of the proposed procedures.

According to Aldana and Serpell (2012), the construction waste most widely reported in the literature is: concrete, wood, brick, plastic, metal, steel, and gypsum board. According to the interviews with the experts, the most frequently generated waste is: concrete, wood, steel and gypsum board. Based on this, the materials selected for the implementation of the WMS were those reported by both the experts and the literature, and which are present during the structural stage of the project.

4. FINDINGS

An overview of the case study project, the WMS, some specific aspects of the WMS process, a performance measurement of the WMS implementation, and the effectiveness of the WMS are presented below.

4.1 Overview of the case study project

The case study project chosen for the WMS implementation was the construction of a pre-school with a building area of 12,603 m^3. The structure is of reinforced concrete, with foundations and roof beams in concrete runs and vegetation cover. To measure the effectiveness of the project, the WMS was divided into four areas, each having the same distribution. Rhythmic planning was used. In zone 1 the amount of waste was measured without having implemented the WMS. In zone 2 the deployment had already begun and served as a transition for zones 3 and 4 where the effectiveness of the WMS was measured once implemented.

4.2 Waste Management System

The 15 measures selected for the WMS were grouped into the following ten processes: (1) 3D modeling, (2) training, (3) efficient purchasing of materials, (4) steel prefabrication, (5) materials handling, (6) donating materials, (7) rewarding workers, (8) recycling time, (9) material storage areas, and (10) recording and reporting residue levels. Each process was planned in such a way that all the elements necessary for proper execution and implementation in the field were developed. This included a flowchart, forms, records and supporting documents.

4.3 Description of the WMS processes

The following section will explain some of the processes that generated the most significant WMS changes at an operational level when compared to how the company was run before.

4.3.1 Efficient purchase of materials

Before implementing the WMS, products offered by the material suppliers were verified by reviewing their catalogs. Through measurements in the plans of the amount of material theoretically needed for each activity and considering the supplier's recommended performance, the amount of material required was calculated. This is a procedure known as scaling. Previous to scaling, providers were consulted on the possibility of producing materials that specifically fit the project to avoid excess waste in the cuts. After finding out the dimensions made available by the manufacturers, optimization of the material was performed through the use of the appropriate software (Length Cutting Optimization 2D and 1D). Subsequently, modulation plans were generated of the activities that required the material studied. In this way, materials and cuts could be optimized. The plans indicated to the fitters how to make the cuts and where the materials should be installed. Finally, a cost analysis was carried out to compare buying materials with standard sizes with those cut to project specifications.

4.3.2 Waste control

Before implementing the WMS, the number of waste trucks leaving the site were counted in order to obtain the total waste volume. The goal was to create a methodology for measuring the amounts of materials wasted daily in project activities and to deliver information for decision-making without having to wait a considerable time. This helped control productivity and the performance of the materials.

After the implementation of the WMS, a material control table was designed (see Table 2) based on the scaling obtained after developing the modulation plans. Table 2 shows the quantity of each material to be delivered to locations in each of the preschool areas. Later, the store manager recorded the amount of each material received, following the inspection protocols of these materials. The delivery of materials to the workers was allowed only through permission slips given by the site managers. When the requested quantity exceeded the amount permitted by the control table, a warning was generated and a message was sent to the project manager to report on what had happened and initiate a procedure to identify the reason an excess amount of material had been requested.

Table 2. Example of material control box

Zone	Compound	Material	Materials stored			
			Unit	Amount allowed to be delivered (A)	Quantity delivered to workers (B)	Difference (A-B)

Finally, in order to maintain control over the volume of waste of each material for each location, the site managers carried a notebook where they recorded day by day activities with their respective units of measurement (see Table 3). In this way, by looking at the amount of material delivered and the amount used, it was possible to accurately find out the quantity of waste generated at each location and for each activity.

Table 3. Example of notebook of measurements

Compound:					
Activity					
Measuring unit:					
Measurement date	Length (m)	Width (m)	Height (m)	Total	Observations

4.4 Performance measurement of the WMS implementation

To evaluate the performance of the WMS implementation, a weekly indicator was used based on that proposed by Aldana et al., (2011). This evaluation consisted of a weekly visit to the project to find out where there was compliance with each of the control variables of the WMS processes. The structural work stage of the project lasted 14 weeks, in which time an average of 50% of the WMS implementation was achieved, with a maximum of 60% in week 6 and a minimum of 17% in week 10.

4.5 WMS effectiveness

Below are the results of the measurements of material waste in the structural work stage.

Table 4. Level of material waste in the structural work stage

Material	Waste (%)		
	Without WMS implementation (Zone 1)	With WMS implementation (Zone 3)	With WMS implementation (Zone 4)
Concrete	10	9	8
Steel	10	8	7
Wood	15	11	9

5. DISCUSSION AND CONCLUSION

Implementing the WMS required cultural and behavioral changes for workers and professionals that were part of project. Initially some resistance to the changes that were implemented was shown by certain participants. However, following procedures such as training and incentives, and after the support of the senior management of the company and project managers, this changed and a high degree of worker motivation was generated. Behavioral changes were especially apparent in the carpenters. This was due to the implementation of wood recycling collection centers, where before removing material from the stores, workers went to the collection centers to select materials that could be reused.

The integration of the WMS with processes such as cost control, procurement management and quality control were instrumental in its implementation. This is because overly long records with unnecessary information did not have to be generated. Therefore, people did not have a negative disposition towards the WMS and in return a more useful information was obtained. This helped decision making and led to improvements in construction operations.

When measuring the performance of the WMS implementation, a maximum and a minimum were presented. The maximum was due to motivational factors that coincided with system processes, thereby resulting in a proper WMS implementation. The minimum coincides with activities that were more difficult to execute and with problems of labor shortage where new workers had to be incorporated, trained and taught the WMS principals.

As a result of the implementation of the WMS, savings of approximately US $ 400,000 were achieved. This figure consists of savings on materials, with an approximate value of US $

300,000, and savings on waste collection and removal, with an approximate value of US $ 100,000. It should be noted that the project budget was US $ 4 million.

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