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Abstract

The construction industry and related ones are considered the world's largest industrial employer and natural resources consumer. 50% of all materials extracted from the earth are transformed into construction materials and products. When these materials enter the waste stream, they account for some up to 57% of all waste generated prior to recycling, recovery or final disposal.

In spite of these alarming conditions, very little detailed knowledge currently exists about the origins, distributions and degrees of significance of construction wastes, although construction managers must by necessity always attempt to minimize waste (and thereby optimise the use or resources), construction materials and waste do not uniformly receive appropriate consideration in the construction industry. Those wastes and losses arise very often from inadequate design practices and management or poor housekeeping.

The main goal of the study is to gain insights into the traditional and industrialised construction processes in order to analyse the performance of the production system and its relation with the environment. This paper presents some tools that have been prepared, in order to analyse amounts of waste, causes for its production, different factors and their significance degrees that influence the production of waste.

Keywords:

Construction industry, material management, prevention, waste, material flows

1 INTRODUCTION

The construction industry and related ones are considered the world's largest industrial employer and natural resources consumer. 50% of all materials extracted from the earth are transformed into construction materials and products [1, 2].

Construction projects are intricate, time consuming undertakings. The total development of a project normally consists of several phases, participation of many stakeholders and dozens of operations. Besides, it requires human resources that should be skilled and materials and equipments available when needed. To some degree each construction project is unique, each structure is tailored to suit its environment, arranged to perform its own particular function, and designed to reflect personal tastes and preferences. The contractor sets up the "factory" on site and to a large extend and custom builds each structure. Consequently, construction projects are typified by their complexity and diversity and by the no standardized nature of their production. The use of factory made modular units may diminish this individuality somewhat, but it is unlikely that field construction will ever be able to adapt completely to the standardized methods and product uniformity of assembly line production [3].

The construction process converts materials and energy into products and residual products and when these materials enter the waste stream, they account for some 50% of all waste generated prior to recycling, recovery or final disposal [4].

Waste in the construction industry has been the subject of a number of research projects in different countries and the literature review indicated that:

1. The availability of data on material waste in the building industry was relatively scarce.
2. Construction materials, labour and waste production do not uniformly receive appropriate consideration and very little detailed knowledge currently exists about the origins and distributions of construction wastes.
3. The number of empirical studies in different countries is small and mostly from developed countries, very few studies were found from developing countries.
4. Most of the studies investigated a fairly limited number of materials in a few construction sites.
5. Comparing the results of those studies is difficult, due to the different construction technologies involved, and also because distinct measurement procedures were adopted in each of them.
6. Many of the studies have focussed on design of sustainable buildings and the end of pipe solution for waste management, mainly recycling of waste.
7. Only scarcely information was found related to the issue of material management by contractors .

Based on the literature findings, a research was planned with the objective to investigate the construction sector in a developing country, Costa

Rica, focusing on construction materials (mainly concrete, steel and wood) and processes. The research tries to look into production processes in order to determine waste quantities and to explain the major factors that influence the production of solid waste by means of analysing the situation of material management during the procurement of buildings.

A first study took place and aimed to provide a baseline understanding related to construction waste in Costa Rica, its quantities, composition, causes, as well as, motivators and barriers for achieving a more sustainable activity. Very limited information was found and the existing one has discrepancies. The survey helped to find the causes of waste generation, which are related to design factors and management of materials, according to the respondents.

A second study is planned with the objective to analyse the construction process in the Costa Rican context and identify the quantities of waste produced while the procurement of buildings, the variables that influence the production of waste and score those attributes.

This paper is about the tools that have been prepared to approach the study. Therefore, its objective is to discuss the appropriateness of the tools for the analysis of the construction processes or tools to "open the black box".

2. Process assessment or "black box" opener

The construction process is a system that contains a set of objects with mutual relationships, which are the physical flows and their transformation This system can be considered as a "black box" that when opened, it contains subsystems that are part of the original system.

Figure 1 represents the production process under study, in which semi-finished materials and products are transformed into products (edifices). Every production process needs ancillaries such as energy carriers and materials. This production process not only creates products, but also unintended residuals, such as byproducts and waste.

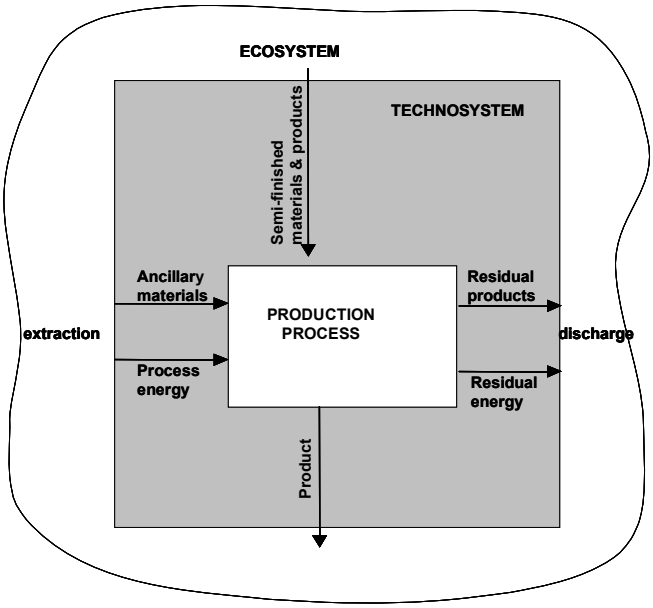

Figure 1. Simple linear technosystem. (Based on Lambert) [5]

A way to analyse the flows and stocks in this so called technosystem is by using Material Flow Analysis (MFA), which is a systematic procedure that connects the sources, the pathways and the intermediate and final sinks of materials [6]. A MFA delivers a complete and consistent set of information about all flows and stocks of a particular material within a system. Through balancing inputs and outputs, the flows of wastes and environmental loadings become visible, and their sources can be identified [7]. But measuring just flows is insufficient to understand the processes that take place in a production system. Therefore, the description of the flows is important as well as the comprehension of the processes behind those flows.

In order to describe the internal transformations of materials and energy to assess the efficiency (and sustainability) of the technosystem a survey and explanatory multi-method case studies have been developed with the purpose to apply the tools in a real life context. The assessed projects will be in Costa Rica, and they will have the peculiarity of projects built with traditional and industrialized (up to some pre-fab extend) systems. The projects will be selected for residential middle size constructions, located in the Great Metropolitan Area.

2.1 Tools development

The tools developed are based on an extensive literature research in which various authors pointed out that design factors and management are the main sources of miuse of resources and production of waste. Five research propositions are developed in order to analyse the sub-processes, as well as, a quantitative method to analyse the amount of waste produced during the procurement of buildings.

2.1.1 Cause 1: design factors

The literature review demonstrates that the lack of quality in construction activities and the waste generated on site can be attributed to: the imperfections on the design and specifications [8], to structural design being poor in terms of standardization and detailing, change of orders, detailing mistakes, the need to cut blocks or other materials due to the lack of modular coordination in design, poor integration of building subsystems during the design stage, poor detailing of design, lack of optimisation during design in the use of resources, imprecise specification of components, and lack of site layout planning [9, 10, 11, 12, 13, 14, 15, 16, 17, 18].

Research Proposition 1: The use of design measures and concepts can reduce construction waste. (Modular coordination and standardisation, minimizing the use of temporary works, avoiding late design modifications, providing more detailed design, introduction of improved design, dimensions to match with the material size standards).

The aim of this sub-study is to examine the aspects presented in the research proposition 1, which according to some authors influence and motivate the design of the projects and the importance given

by the designers of projects to environmental issues.

The information will be collected using a questionnaire, which will be applied to architects, designers, civil engineers or professionals in charge of the design of the buildings on the companies where the case studies will take place.

2.1.2 Management factors

One of the first studies found in literature related to materials wastage dates from 1976 in which Skoyles started to analyse the misuse of materials by the construction sector. His conclusion was that materials and labour spent on handling them to the fixing position, account for nearly half the cost of traditionally constructed building and the waste occurring in practice is, on average, about double the losses generally assumed or allowed for in estimating. Since then, the importance of materials management and control has been established. Wyatt (1978) suggested that wastage of materials arise from inadequate monitoring or administration, or poor housekeeping [20]. He mentioned the importance of monitoring the flow of materials and the data associated with them, such as their quantities and inventory levels, they asserted that the main problem is the lack of up to date relevant information.

Material management and labour productivity has also been studied and it has been estimated the work-hour losses resulting from ineffective practices. The authors argued that formal material management programmes have the potential to yield significant construction cost savings due to the fact that material resources constitute a large portion of a project's total costs [13, 20, 21, 22]. Some authors have explained the benefits of the application of materials management and control systems in order to: increase productivity and avoid delays due to the availability of the right materials prior to work commencement and the ability to plan the work activities according to the availability of materials [23, 24].

Gavilan and Bernold [18] emphasized that waste reduction is the best and generally most economical way to improve the use of materials. They concluded that more detailed planning of materials and process requirements and better material handling are needed in order to reduce construction waste. Bossink and Brouwers [9] came to the same conclusion in which they analysed different causes for the production of waste and the most significant ones are related to management, being the most important material handling and operational issues.

Research Proposition 2. Materials' control and management do not have enough attention at the company level.

The aim of this sub-study is to analyse the material management system present at the company level with the participation of professionals from the head office, personnel on site, manufacturers and suppliers.

A checklist has been prepared that will be used as a guide to check on site material management practices, as well as a guiding tool to ask questions about management practices to managers at the head office, on site, manufacturers and suppliers.

Research Proposition 3. Various sources have a different yet significant effect on construction site waste generation

The aim of this sub-study is to determine main sources of construction waste and to ascertain the levels of importance of those waste sources.

The information will be collected by means of a survey applied to senior workers from construction companies' engineers, academics and practitioners at construction sites. They will be asked to rate pre-determined attributes according to their potential contribution to the generation of waste on site, from the experience of their companies. The respondents will be invited to add new attributes if necessary.

2.1.3 Material flow analysis

Materials pass through a number of handling processes from their use to their final disposal. These processes can induce various factors affecting materials management effectiveness, thus the proper flow of these processes is important.

Shen et al [26] developed a descriptive model for analysing the flow of materials in the construction sites, which provides with a systematic way for describing the generation of waste during the building processes. Ming Lu et al [28] indicated that the model fails to show the matching, queuing, and transit of various resources and the intricate interdependencies between different processes. Instead they used the free flow-mapping model as a basis to develop a process mapping technique that could represent the intricate logical and technological constraints and complex interdependent relationships between components of a typical handling system in construction.

In the case study of Costa Rica, the free flow mapping technique is chosen for observing and drawing the movements of the materials (wood, steel and concrete). Attention will be paid to matching, queuing and transit of the various materials trying to reduce the gap between the simple mapping of the materials and the failures stated by Min Lu et al.

Material Mismanagement

Mismanagement of materials on site emerges as one of the main causes of waste. Substantial losses are caused by inadequate transportation, unloading and stacking of materials, unsuitable packaging, poor ground conditions, equipment mal functioning and due to craftsmen's errors. Field data indicated that most material wastes came from one of 2 sources: leftover from cutting stock materials to fit and nonreusable of materials that are not part of the building (nonconsumables) [13, 15, 18, 25, 26].

Research Proposition 4: Material management has a positive influence in the reduction of construction waste.

Research Proposition 5. Waste is produced due to a combination of events rather than an incident occurring in one operation.

The aim of this sub-study is to examine the flow processes of construction materials (wood, steel and concrete) on site by using a free-flow mapping

presentation technique and a checklist. The information in mapping includes 5 elements: material supply, waste source, waste facilitator, waste processing and waste destination. The observations with the checklist and discussions (with site management staff or building workers) on the practices will be oriented to the following topics and other ones arising during the study: coordination and information, waste handling and sorting actions, reduction, reuse and recycling of waste practices, pollution and safety.

2.1.4 Quantitative analysis of waste production

Waste in the construction industry is important not only from the perspective of efficiency, but also concern has been growing in recent years about the adverse effect of the waste of building materials on the environment

Various researchers have investigated quantities of construction waste materials. Skoyles [26] and Picchi [27] used the bill of quantities but it has the limitation that some of the materials are considered as waste while they might have been used in other projects.

Gavilan and Bernold [18] presented different approaches to analyse the generation of waste as well as its limitations. Approach 1 is “Cradle to grave” in which observations of construction materials are traced. This would be the most accurate way of making the observations but it is unmanageable.

In the approach 2 the end product (construction waste) would be inspected and the sources of waste can be determined by careful scrutiny, questioning of the work crews, and deduction. It has the limitation that the piles are difficult to assess.

Approach 3 is a modification of approach 1. Instead of tracing the path of every material through the process, a selected number of bricks, or lumber pieces, could be marked and traced from the start to the end. This would place proper emphasis on the flow of the material through the construction process as well as providing a sample of manageable size. The limitation with this approach is that the causes of construction waste are not necessarily uniformly distributed throughout a stack of materials.

Approach 4 focuses on workers and not on materials. A worker would be observed for a given period of time and the amount of waste s/he produces and the reason could be carefully tracked. This was an adaptation of the method time measurement technique used in evaluating worker and crew efficiency.

The advantage of this approach is that it is simple and that the causes of the waste will be very easy to identify but it has the limitation is that direct observation is not always possible though this is the single most effective way to ascertain the causes of construction waste.

Formoso et al. [13] proposed an approach in which the sites can be directly observed during a period of the processes (4-5 months). At the beginning of the period (date A), initial data collection is carried out by the research team. This involves measuring all construction work in which the 3 materials to be analysed (concrete, steel and wood) participated as well as existing inventories for those materials. At the end of the period (date B) a similar data collection is undertaken.

Between dates A and B, data is directly collected, doing the site observations during the working hours. The amount of materials delivered or withdrawn from the site before date A is obtained by material supply records.

According to the authors the data collection and processing procedures developed for the study was fairly successful as research methods, but they are too expensive to be directly adopted by construction companies.

In the case of the Costa Rican study, this procedure will be adapted with the support of students from the Civil Engineering departments of two universities. A protocol has been developed in order to do the analysis

3. Conclusions

Disposal sites in different parts of the world show that up to 57% of the composition of the waste arriving to the site is material from construction activities.

In the literature review, the most important topics related to the generation of construction waste are associated to design factors and material management systems.

The minimisation of waste should start at the beginning of the process which means at the design stage, taking into account: modular coordination and standardisation, minimizing the use of temporary works, avoiding late design modifications, providing more detailed design, introduction of improved design, dimensions to match with the material size standards, among others.

In relation to material management, many companies do not know the amounts and causes for the generation of waste, they are unaware of the amounts of waste produced and its causes, and by understanding them effective minimisation plans can be established.

Material management practices can help to reduce the amount of waste produced while building but it is necessary to understand the complexity and the relations between materials as inputs, processes in which they take and waste as outputs. Therefore, this study might give ideas on the degrees of significance of each factor that influences the production of waste. The analysis of those significance degrees would allow focusing on some of the causes that affect the system.

As already mentioned the objective of the presentation of this paper is to discuss with researchers, working in the field of construction materials stewardship, the propositions and the tools that have been prepared in order to analyse the different subsystems present in the process of building an edifice. Besides, another objective is to talk about the different possibilities to quantify the amounts of waste produced during the procurement of buildings, its opportunities and limitations.

There are no conclusions yet, but as mentioned by Formoso et al. (2002), measuring waste is an effective way to assess the performance of

production systems because it usually allows areas of potential improvement to be pointed out and the main causes of inefficiency to be determined. That is the main goal of the whole study, to determine construction waste generation in a newly starting industrialised setting using Costa Rica as a case study.

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