# Material Waste in Building Industry: Main Causes and Prevention

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**Abstract:** Material waste has been recognized as a major problem in the construction industry that has important implications both for the efficiency industry and for the environmental impact of construction projects. Moreover, waste measurement plays an important role in the management of production systems since it is an effective way to assess their performance, allowing areas of potential improvement to be pointed out. This paper describes the main results of two research studies carried out in Brazil that investigated the occurrence of material waste at 74 building sites located in different regions of that country. Some typical figures for the waste of some key construction materials are provided, and the main causes of waste in the sector are discussed. The results indicate that the waste of materials in the Brazilian building industry is fairly high and that a large variability in waste incidence is found across different projects. Most of this waste can be avoided by implementing inexpensive preventive measures, mostly related to managerial improvements.

**DOI:** 10.1061/(ASCE)0733-9364(2002)128:4(316)

**CE Database keywords:** Wastes; Construction materials; Buildings.



## Introduction

In general, a very high level of waste is assumed to exist in construction. Although it is difficult to systematically measure all wastes in construction, partial studies from various countries have confirmed that waste represents a relatively large percentage of production costs. A wide range of measures have been used for monitoring waste, such as excess consumption of materials (Skoyles 1976; Bossink and Brouwers 1996), quality failure costs (Cnudde 1991), and maintenance and repair costs, accidents, and nonproductive time (Oglesby et al. 1989).

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. This kind of waste typically accounts for between 15 and 30% of urban waste (Brooks et al. 1994; Bossink and Brouwers 1996; Forsythe and Marsden 1999). Building materials waste is difficult to recycle due to high levels of contamination and a large degree of heterogeneity (Bossink and Brouwers 1996), and often there is insufficient space for its disposal in large cities. Wyatt (1978) stressed the consequences of high levels of waste, both in reducing the future availability of materials and energy and in creating unnecessary demands on the transportation system. In fact, some building materials and components use large amounts of nonrenewable sources of energy, as well as resources that are in danger of depletion, such as timber, sand, and crushed stone (Bossink and Brouwers 1996).

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 identified. Compared to traditional financial measures, waste measures are more effective to support process management, since they enable some operational costs to be properly modeled and generate information that is usually meaningful for the employees, creating conditions to implement decentralized control.

In fact, waste elimination is a major focus for process improvement in the Lean Production paradigm. Originated in Japan in the 1950s, this is an important development trend in manufacturing, based on both the Total Quality Management (TQM) and Just in Time (JIT) production philosophies. The most prominent application of Lean Production so far is the Toyota Production System (Monden 1983), but in recent years its principles and concepts have been disseminated in other industries, including the construction industry (Koskela 2000).

This paper is concerned with waste measurement in the construction industry. Initially, waste is discussed from a conceptual point of view, and some previous studies of the waste of building materials are briefly analyzed. Then, the results of two studies conducted in Brazil regarding the waste of materials in the building industry are presented. The aim of these studies was to investigate the main causes of waste in the industry, as well as to indicate the order of magnitude of material waste in the Brazilian

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Note. Discussion open until January 1, 2003. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on November 22, 2000; approved on September 5, 2001. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 128, No. 4, August 1, 2002. ©ASCE, ISSN 0733-9364/2002/4-316–325/$8.00+$.50 per page.



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building industry. The first study, developed at the Federal Univ. of Rio Grande do Sul (UFRGS) between April 1992 and June 1993, monitored seven building materials at five different sites. The second study, which was much more ambitious, involved monitoring 69 sites and 18 different building materials. It was carried out as a joint effort by 15 Brazilian universities between October 1996 and May 1998.

Both studies used relatively similar data collection methods, so that their results are comparable. They indicated that the waste of materials tends to be far higher than the nominal figures assumed by construction companies in their cost estimates—at some sites the waste of some building materials was greater that 100%. The main causes of waste have been pointed out, indicating that improving the performance of the industry in this respect does not demand much investment from the companies.

## Concept of Waste

For many people in the industry the notion of waste is directly associated with the debris removed from the site and disposed of in landfills. The main reason for this relatively narrow view of waste is perhaps the fact that it is relatively easy to see and measure. Although such waste is very important from an environmental perspective, this approach has been criticized since the beginning of industrial engineering. Taylor (1913) pointed out that the economic loss caused by material waste is smaller than the ones related to the inefficiency of human work. Ford (1927) also suggested that human work should be the focus of waste prevention, since the value of materials depends, to a great extent, on the work that has been spent on them.

Other types of material waste beyond debris also need to be considered. Skoyles (1976) makes a distinction between direct and indirect material waste. Direct waste consists of a complete loss of materials, due to the fact that they are irreparably damaged or simply lost. In this case, the wastage usually needs to be removed from the site. By contrast, indirect waste occurs when materials are not physically lost, causing only a monetary loss—for example, waste due to concrete slab thickness larger than specified by the structural design.

The definition of waste in the Lean Production paradigm is strongly related to the concepts of process and operation. In the traditional production management paradigm, named the conversion model by Koskela (1992), a process is viewed simply as a conversion of an input into an output that can be divided into subprocesses, which are also conversion processes. This approach assumes that process improvement can be achieved by improving each of its parts and considers the difference between process and operations to be that the first refers to the work involved in the production of large units, and the second to work done in the production of small units. The conversion model has, to some extent, contributed to the lack of transparency in construction, since it abstracts away the flows between the conversion activities and does not encourage the clear identification of internal and external clients in each process (Koskela 1992). The focus of control in the conversion activities is a major cause of uncertainty in production, increasing the share of non-value-adding activities (Alarcón 1997).

In contrast, in the Lean Production paradigm, production is viewed as consisting of both conversion and flow (waiting, moving, and inspecting) activities. Only conversion activities can add value to the final product. This has important implications for the design, control, and improvement of production processes, since flow activities become more explicit than in the conversion model. In this conceptual model, the management of flows (work, material, and information) is emphasized. Also, a very clear distinction is made between processes and operations: production is a network formed by intersecting axes of processes and operations. Process refers to the flow of products from one worker to another—that is, the stages through which raw materials gradually move to become finished products. Operation refers to the discrete stage at which a worker (or equipment) may work on different products (Shingo 1988).

In this new paradigm, the concept of waste is directly associated with the use of resources that do not add value to the final product. This means that there are two approaches to improving processes. One is to improve the efficiency of both value-adding and non-value-adding work, and the other is to eliminate waste by removing non-value-adding activities. This second approach corresponds to the focus for process improvement in the Toyota production system (Ohno 1988) and usually results in more dramatic performance improvements.

Ohno (1988) divides the movement (operations) of workers into waste and work. Waste is the movement that does not add value and is not needed. It is often called unproductive time. Work includes both non-value-adding and value-adding work. This definition assumes that some non-value-adding work is necessary in production systems, due to current working conditions—for example, walking to another location to remove parts, removing wrappers from parts, and so on. Womack and Jones (1996) describe waste as any human activity that absorbs resources but creates no value, such as mistakes that require rectification, production of items no one wants, process steps that are not needed, unnecessary movement of employees, and people waiting for the conclusion of upstream activities.

Ohno (1988) presents seven categories of waste that were identified in the Toyota production system: (1) unnecessary movement of people (including waste of human energy); (2) waiting by employees for process equipment to finish its work or an upstream activity; (3) defects in products; (4) overproduction of goods not needed; (5) inventories of goods awaiting further processing or consumption; (6) unnecessary processing; and (7) unnecessary transport of goods. The first two categories are related to operations (work by people), while the last five refer to the flow of materials (process).

There are also other categories of waste that have been mentioned in the literature, such as accidents, working under suboptimal conditions (Koskela 2000), design of products that do not meet users' needs (Womack and Jones 1996), unnecessary capital investment (Monden 1983), and theft and vandalism (Bossink and Brouwers 1998). The main role of existing classifications of waste is to call the attention of people to the most likely problems, since not all waste is obvious: it ''often appears in the guise of useful work'' (Shingo 1988).

The waste of materials is not emphasized in the Lean Production literature. This is probably because material waste is not a major issue in the industries that represent the best practices in that paradigm, such as car manufacturing. Considering that material waste is an important issue for the construction industry, waste is defined in this paper as the loss of any kind of resources—materials, time (labor and equipment), and capital—produced by activities that generate direct or indirect costs but do not add any value to the final product from the point of view of the client. As proposed by Ohno (1988), the incidence of waste is associated with any inefficiency that results in the use of resources in larger quantities than those considered necessary, given a current level of production system development.

The two empirical studies reported in this paper are focused on material waste due to the relatively high incidence of this kind of waste that has been reported in different countries, as well as its environmental impact (Skoyles 1976; Pinto 1989; Hong Kong Polytechnic and Hong Kong Construction Association 1993; Bossink and Brouwers 1996; Forsythe and Marsden 1999).

## Previous Studies on Material Waste Measurement

### United Kingdom

The first extensive investigation of material waste in the building industry reported in the literature was carried out by Skoyles (1976) at the Building Research Establishment, U.K. This study was based on data obtained from 114 building sites during the 1960s and 1970s.

Both direct and indirect waste were investigated in that study. For each category a fairly comprehensive classification of the main causes of waste was proposed. Among the causes of indirect waste, Skoyles (1976) pointed out that material waste may be incorporated into buildings, since materials are often used in excess of designed quantities, or for a different purpose than what is specified, replacing materials of inferior quality.

Regarding the control of waste, Skoyles (1976) admitted that there is an acceptable level of waste, which can only be reduced through a significant upgrade in production system conditions. Thus, waste was classified into unavoidable waste (or natural waste), in which the investment necessary for its reduction is higher than the economy produced, and avoidable waste, when the cost of waste is significantly higher than the cost to prevent it.

Thirty-seven materials had their direct waste measured. The number of sites for each material varied from 1 to 68, most consisting of residential building projects. The percentage of wasted materials ranged from 2 to 15% in weight in relation to the amount of materials defined by design. The main conclusions of the study are presented below:

1. For most materials, the average loss was much higher than what was usually assumed in cost estimates, indicating that waste allowances were nominal figures supported by very little practical evidence;
2. The wastage is highly variable, being relatively low at some sites. This indicates that much of the existing waste is avoidable;
3. Mismanagement of materials on site emerged as one of the main causes of waste. Substantial losses were caused by incorrect unloading of materials, poor ground conditions, inadequate transportation equipment, and unsuitable packaging. In fact, stacking and handling accounted for three times more waste than other causes; and
4. Any waste is more likely to be a combination of events, rather than caused by a single incident.

### Hong Kong

The Hong Kong Polytechnic and Hong Kong Construction Association (1993) conducted research on construction waste aimed at reducing the generation of waste at the source and thereby the demand for final disposal areas, which are very scarce in that region. The main concern of the study was the environmental impact of both construction and demolition waste.

From June 1992 through February 1993, 32 construction sites were monitored, focusing on processes most likely to generate waste, such as reinforced concrete structure, bricklaying, plastering, and ceramic tiling. One of the main conclusions of the study was the lack of control of materials usage by contractors.

The final report presents only data related to concrete waste and also discusses the relative importance of the waste of six different materials: premixed concrete, steel reinforcement, mortar, bricks and blocks, ceramic tiles, and wood. It suggests that packaging waste can be as much as 5% of the volume of materials. The waste of premixed concrete was monitored at 14 sites and ranged from 2.4 to 26.5%; the average was 11%.

### United States

Gavilan and Bernold (1994) described an empirical study in which five homes at four separate construction sites were observed from July to August 1992. Three processes were analyzed: masonry foundations, timber frames, and sheetrock drywall. The main causes of waste were investigated, based on a model that generically describes the flow of solid waste in building sites and on a proposed classification of waste according to its sources.

One of the major sources of waste was the residual scrap resulting from cutting materials, such as bricks, blocks, dimensional lumber, and sheetrock panels. In the case of wood, much of the waste involved nonreusable consumables, that is, materials that aid in the production process but do not end as part of the building. Packaging and improper handling were also identified as fairly important causes of waste.

### The Netherlands

Bossink and Brouwers (1998) conducted a research project in The Netherlands that was concerned with the measurement and prevention of construction waste with regard to meeting sustainability requirements stated by Dutch environmental policies. Waste from seven materials was monitored in five house-building projects between April 1993 and June 1994. During the study, all material waste was sorted and weighed. The amount of direct waste by weight ranged between 1 and 10% in weight of the purchased amount of materials.

Based on brainstorming sessions involving contractor representatives, the main causes of waste were identified. Most were related to upstream processes, such as design and material supply, as well as poor handling of materials in transportation and storage.

### Australia

Forsythe and Marsden (1999) discussed the way in which construction industry clients are responding to the need to improve environmental performance of construction projects in Australia. They proposed a model for analyzing the impact of waste in the cost of the project, including its removal and disposal. This model uses waste figures for six building materials that ranged from 2.5 to 22% in weight. These were produced as the result of an empirical study of 15 house-building sites. That study involved the quantification of waste based on the amount of materials effectively delivered on site, according to available documents and also on interviews with representatives of different trades.



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### *Brazil*

One of the first studies on material waste in Brazil was carried out by Pinto (1989). This research involved a single case study, based on data from an 18-story residential building project, that was chosen because all the records of materials supply and use were well kept by the construction company.

Both direct and indirect waste of 10 building materials were estimated. The percentage of wasted materials ranged from 1 to 102% in weight, in relation to the amount of materials defined by design. The waste percentages include both direct and indirect waste. The total waste was 18% of the weight of all materials purchased, representing an additional cost of 6%. One of the main contributions of this study was that it pointed out the importance of indirect waste in relation to direct waste. For instance, the amount of indirect waste of mortar was as much as 85% of the designed volume of plaster. This represents not only a waste of materials, but also a significant unnecessary additional load on the building structure.

Picchi (1993) also reported a relatively small study on material waste, carried out between 1986 and 1987 at three residential building sites, in which the amount of waste removed from the site was monitored. The percentage of waste was estimated to be between 11 and 17% of the expected weight of the building. This represents a waste of between 0.095 and 0.145 t/m$^2$.

The results of both studies were widely disseminated in the Brazilian press, resulting in both positive and negative reactions from the industry. On the one hand, several companies realized that there was great potential for process improvement and profit in waste prevention programs. On the other hand, a number of industry representatives, concerned with the public image of the industry, denied the results of those studies, stating that they were not representative of the sector.

### *Discussion*

The literature review indicated that the availability of data on material waste in the building industry was relatively scarce. The number of empirical studies in different countries is small, and except for Skoyles (1976), all of them investigated a fairly limited number of materials in a few construction sites.

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. Some writers focused on the direct waste (Skoyles 1976; Picchi 1993; Bossink and Brouwers 1996), while others also investigated indirect waste (Pinto 1989). Several measures were used to monitor waste, such as the percentage of wasted materials in relation to the purchased amount of materials (Bossink and Brouwers 1996), the percentage of wasted materials in relation to the amount of required materials according to design (Skoyles 1976; Pinto 1989; Hong Kong Polytechnic and Hong Kong Construction Association 1993), the volume of materials (Gavilan and Bernold 1994), or the weight of materials (Picchi 1993).

Therefore, these figures cannot be considered representative of the sector, not only because of the relatively small samples, but also because the relative importance of each material waste is likely to vary according to the building type (for example, residential, commercial, industrial, and so on) and technologies involved. In fact, these measures can be considered conservative because the motivation to obtain and share them tends to be greatest in leading companies (Koskela 2000).

## Research Method

### *First Study (1992–1993)*

This research study was developed as part of a link agreement involving UFRGS, SINDUSCON/RS (Rio Grande do Sul State Association of Construction Companies), and SEBRAE/RS, a private funding agency that supports research and development projects for small companies. Both the study's research method and its results are comprehensively presented by Soibelman (1993).

The main objective of this study was to investigate the causes of material waste in construction sites and to propose guidelines for preventing its incidence. Considering the scarcity of previous studies on this theme in Brazil, the decision was made to limit the empirical study to a small number of materials and a few sites. Therefore, the aim was not to produce average figures for the industry as a whole, but to undertake an in-depth study of the main sources of waste.

Five fairly similar sites in the city of Porto Alegre were chosen to be monitored. They all consisted of 8- to 12-story buildings, four residential and one commercial. The following materials were selected to be included in the survey: steel reinforcement, premixed concrete, cement, sand, premixed sand and lime mortar, ceramic blocks, and ceramic bricks. This choice was based on three main criteria:

1. These materials represent a significant percentage of the total cost of buildings in most traditionally built residential and commercial buildings in southern Brazil;
2. They are among the categories of materials that tend to have a high percentage of waste; and
3. They are mainly employed during the same stages of work—structure, brickwork, and plastering. So it was possible to monitor their application at the same sites during a relatively short period of time.

Once the group of materials to be investigated was defined, meetings were held between the research team and three experienced site managers. They discussed the incidence of waste for each of the materials and together established a number of hypotheses about the main causes of waste.

Each site was directly observed during a period of 4–5 months. At the beginning of this period (named date A), an initial data collection effort was carried out by the research team. This involved measuring all construction work in which any of the seven materials had been used, as well as the existing inventories for those materials. At the end of the period (date B), a similar data collection effort was undertaken. Between dates A and B data were directly collected by a group of 13 undergraduate students organized in shifts, doing site observations during most of the working hours. Additionally, the amount of materials delivered or withdrawn from the site before date A was obtained through material supply records made available by the companies.

Although all data were collected by the research team, both the site management and the workforce were aware of the objectives and scope of the research study. The following procedures were devised for systematically collecting data:

1. General description of the site: included the name of the company, the name of the site manager, gross floor area, construction schedule, and the list of documents provided by the company;
2. Measurement of work completed: the amount of work was



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measured on both dates A and B for a number of activities, including reinforced concrete structure, brickwork, and wall plastering;
3. Control of material deliveries and withdrawals before date A: included the specifications and quantities of materials, based on documents provided by the company;
4. Measurement of inventories: undertaken in both dates A and B for all seven materials;
5. Control of material deliveries and withdrawals between dates A and B: included the date, specifications, and actual quantities of materials delivered or withdrawn;
6. Observation of material unloading, transportation, and storage conditions: this involved qualitative data, such as the description of the equipment and procedures involved;
7. Observation of the production processes: included the preparation and use of materials, output of gangs, causes of cut and rejection of materials, and waste-disposing procedures; and
8. Measurement of final dimensions of building components (for example walls, slabs, beams, columns, and plaster).

The amount of material waste was calculated for two different periods: before date A, based on the company records, and between dates A and B, based only on direct observation. Waste was defined as the difference between the amount of materials effectively purchased by the company ($M_{\text{purchased}}$), less the amount of existing inventories (Inv), in relation to the amount of materials defined by the measurement of work done ($M_{\text{designed}}$), as follows:

$$\text{Waste}(\%) = [(M_{\text{purchased}} - \text{Inv}) - M_{\text{designed}}]/M_{\text{designed}} \qquad (1)$$

This means the percentage of material waste includes both direct and indirect waste and does not consider possible losses of materials that are implicit in the design of components. The occurrence of waste was analyzed considering four different stages of production processes: (1) before the materials are delivered on site; (2) during transport, delivery, and storage on site; (3) during conversion activities; and (4) after production was concluded, due to accidents, theft, vandalism, and other events.

## Second Study (1996–1998)

The second study was developed by a network of 15 research institutions, coordinated by the Brazilian Institute for Technology and Quality in Construction and the University of São Paulo, and financed by two Brazilian funding agencies: FINEP and SENAI. The main objective of this research project was similar to the previous one: to establish typical figures for material waste in the construction industry and investigate its main causes. However, the goal of this study was to obtain data related to a larger number of materials and from a much larger sample of building sites, located in different regions of the country. Both its research method and results are presented and discussed by Agopyan et al. (1998) and Isatto et al. (2000).

Initially, 64 construction companies were selected to participate in the study. None took part in the 1992–1993 study. Due to problems related to data collection and analysis, only 52 were able to provide data that were useful for the study. Most (74%) were small-sized companies—that is, less than 100 employees. Also, a large percentage of firms (71%) were mostly involved in the residential and commercial building market. The main criterion for choosing the companies was their willingness to participate in the study.

Sixty-nine building sites were monitored in 12 different Brazilian states, for periods typically ranging from four to six months. Most of the sites were residential building projects (78%), involving fairly traditional technologies in Brazil—reinforced concrete structure, brick or block internal and external walls, and cement, lime, and sand plastering. In this respect, these sites were fairly similar to the ones monitored in the 1992–1993 investigation.

Waste from the following materials was investigated: steel reinforcement, premixed concrete, sand, crushed stone, cement, premixed mortar, lime, soil, blocks and bricks, electrical pipes, electrical wires, hydraulic and sewage pipes, ceramic tiles, gypsum plaster, paint, and carpet. As in the 1992–1993 study, these materials were chosen because of their importance in terms of both cost and potential for generating solid waste. Timber for formwork was excluded from the list despite its importance according to both criteria due to the fact that it is a nonconsumable material (Gavilan and Bernold 1994) that is used several times, and the estimation of its waste requires a totally different procedure in relation to the consumable materials.

The procedures for data collection and analysis were jointly devised by researchers from some of the institutions involved. The same procedures were used as for calculating the amount of waste in the 1992–1993 project presented above, making it possible to compare the results of both studies. However, unlike the previous study, some of the data had to be collected on site by the companies, since there were not enough resources for monitoring all sites during each working day between dates A and B.

A wide variety of both quantitative and qualitative data on material waste was collected in the study. Besides the measures of total waste for each material, other metrics were produced in this study, including the amount of waste for specific process stages, rate of consumption of materials, and deviations in component dimensions. Qualitative data included description of site layout, process maps, checklist evaluations, and photographs of production practices. Most partial indicators and qualitative data were used for investigating the causes of waste.

Great effort was made to thoroughly document data collection and analysis procedures, considering that these had to be implemented by 15 geographically dispersed research teams. Seven sets of procedures were devised:

1. General description of the company and project: this included the size of the company, its previous experience in process improvement, whether direct or subcontracted labor was used, building gross floor area and number of floors, and main construction technologies involved. The name of the company and the site were kept confidential by assigning a code to each;
2. Measurement of inventories: this was also undertaken on both dates A and B for all materials;
3. Measurement of work completed: the amount of work was measured on both dates A and B for all activities that involved any of the selected materials;
4. Control of material deliveries and withdrawals between dates A and B: included the date, specification, and actual quantities of materials delivered or withdrawn. These data were collected by employees of the construction companies;
5. Observation of material unloading, transportation, and storage conditions: a "yes or no" checklist was used for collecting data related to each material. Such checklists briefly described good practices used by the industry for handling materials. These allowed material-handling procedures adopted in each site to be evaluated. At the same time, these tools could be proactively used by the companies for benchmarking;



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**Table 1.** Waste of Materials in Weight in 1992–1993 Study

| Material | Site A (%) | Site B (%) | Site C (%) | Site D (%) | Site E (%) | Mean (%) | Nominal (%) |
|---|---|---|---|---|---|---|---|
| Steel reinforcement | 18.8 | 27.3 | 23.0 | 7.9 | 18.3 | 19.1 | 20,0 |
| Cement | 76.6 | 45.2 | 34.3 | 151.9 | 112.7 | 84.1 | 15,0 |
| Premixed concrete | 10.8 | 11.8 | 17.4 | 0.8 | 25.2 | 13.2 | 5,0 |
| Sand | 27.1 | 29.7 | 21.0 | 109.8 | 42.2 | 45.8 | 15,0 |
| Premixed sand and lime mortar | 103.0 | 87.5 | 40.4 | 152.1 | 73.2 | 91.2 | 15,0 |
| Ceramic blocks | 39.9 | 8.2 | 36.0 | 26.5 | —[a] | 26.7 | 10,0 |
| Ceramic bricks | 45.2 | 15.2 | 20.0 | 27.3 | —[a] | 29.9 | 10,0 |

[a]Final figure could not be obtained due to data collection problems.



6. Observation of the production processes: a ''yes or no'' checklist was also used for evaluating each process; and
7. Performance indicators: each of the performance indicators was described, including their objectives, formula, measurement criteria, and data collection forms.

As in the previous study, producing the final research report took a relatively long time, due to the large amount of both qualitative and quantitative data produced. In several projects, it was not possible to obtain a final figure for the waste of some materials, due to failures in data collection, mostly in the control of material deliveries and withdrawals carried out by the construction companies.

## Main Results

### *General Results*

Table 1 presents the main results of the 1992–1993 study: the percentage of waste for each site, the average waste, and the nominal waste for each material, that is, the waste allowances typically used by construction companies in their cost estimates.

The results indicated that the waste of materials at those five sites was far higher than the nominal figures assumed by construction companies in their cost estimates—for instance, in the case of premixed mortar the actual waste was as much as six times the nominal allowance. Although it is not possible to establish a direct comparison to studies undertaken in other countries, the level of magnitude of the waste found in those sites is considerably higher than at the sites analyzed by Skoyles (1976), Bossink and Brouwers (1996), and Forsythe and Marsden (1999). The magnitude of the waste of concrete, however, is similar to that in the study developed in Hong (Hong Kong Polytechnic and Hong Kong Contractors Association 1993).

There was a large variation in waste indices at different sites for the same material. For instance, the wastage of ceramic blocks at site A was nearly five times higher than at site B. Similar proportions were also found by Skoyles (1976). Considering that all companies and projects investigated were fairly similar, the small percentages of wastage at some sites provide an indication that a relatively large proportion of material waste is avoidable.

Furthermore, a large variation of wastage was also found at a single site for different building materials. For instance site D had a good performance controlling the waste of steel reinforcement and premixed concrete, but a poor performance in the consumption of cement. This indicates that companies are able to control the waste of some materials, but are not able to extend this control to all materials on site.

A very simple cost estimate exercise was carried out by Soibelman (1993), based on a typical cost structure for residential building projects in Brazil, aiming to estimate the average cost of waste in the 1992–1993 study. Considering that the group of seven materials corresponded to approximately 20% of construction costs, the cost of waste was estimated in 8.0% of the total cost, ranging from 5.1% at site C to 11.6% at site E. This figure has the same level of magnitude as the percentage of material waste estimated by Pinto (1989). In terms of cost, cement had the most important impact on waste. At four of the sites, the cost of cement waste was estimated as approximately 50% of the total cost of waste.

Table 2 displays the results of the 1996–1998 study. For some materials, such as sand, cement, premixed concrete, and blocks and bricks, the sample of building sites is much larger than in the 1992–1993 study. Although the range of waste indices is wider, the average results of this study have the same level of magnitude observed in the previous one, confirming that the percentage of material waste in the industry is fairly high. A high variability of performance was also found for all materials at different sites. For instance, the waste of cement ranged from 6.4 to 247.1% in a sample of 41 building sites.

Data analysis indicated that the distribution of waste indices was asymmetric for most materials—for example, Fig. 1 presents the distribution of cement waste in a sample of 41 sites. The hypothesis of symmetry of the distribution was examined and rejected at the 5% level of significance for the two-tailed test for all materials, except for steel reinforcement. For that reason, Table 2 presents the median value and the coefficient of dispersion, instead of only the mean value and the coefficient of variability.

In the following section the main causes of waste are discussed for some of the materials investigated in both studies, focusing on the ones for which more data were available.

### *Main Causes of Waste*

#### Steel Reinforcement

Controlling the use of steel reinforcement in building sites is relatively difficult because it is cumbersome to handle due to its weight and shape. Also, this material is sold by weight, and most building sites in Brazil cannot afford to have a scale for weighing steel reinforcement. For that reason, most companies use a conversion table to calculate the weight of each lot delivered to or withdrawn from the site.

Three main reasons can be pointed out for steel reinforcement waste: some short unusable pieces are produced when bars are cut; some bars may have an excessively large diameter due to fabrication problems; and trespassing. In both studies, the worst-performing sites were usually the ones in which the structural design was poor in terms of standardization and detailing, causing



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**Table 2.** Waste of Materials in Weight in 1996–1998 Study

| Materials | Mean (%) | Median (%) | Coefficient of variability (%) | Coefficient of dispersion (%) | Minimum (%) | Maximum (%) | Number of sites |
|---|---|---|---|---|---|---|---|
| Steel reinforcement | 10.3 | 10.6 | 39.5 | 32.5 | 4.0 | 16.5 | 12 |
| Premixed concrete | 9.5 | 8.6 | 56.8 | 49.7 | 2.4 | 23.3 | 35 |
| Cement | 73.7 | 45.2 | 84.6 | 109.3 | 6.4 | 247.1 | 41 |
| Sand | 47.5 | 40.7 | 71.9 | 67.6 | 6.8 | 118.0 | 24 |
| Crushed stone | 31.3 | 37.1 | 61.7 | 48.4 | 8.7 | 56.1 | 5 |
| Lime | 48.0 | 32.8 | 78.3 | 100.5 | 6.4 | 247.1 | 11 |
| Premixed mortar | 59.8 | 32.6 | 116.0 | 143.2 | 5.3 | 207.4 | 8 |
| Soil (mortar constituent) | 182.2 | 173.9 | 30.2 | 35.0 | 133.9 | 247.1 | 4 |
| Ceramic blocks | 18.0 | 13.8 | 75.8 | 76.6 | 2.0 | 60.7 | 53 |
| Concrete blocks | 11.3 | 7.7 | 98.4 | 95.8 | 1.2 | 43.3 | 30 |
| Normal bricks | 52.2 | 78.0 | 74.2 | 45.7 | 4.2 | 82.6 | 5 |
| Ceramic tiles | 15.6 | 14.4 | 74.1 | 63.0 | 1.8 | 49.7 | 18 |
| Electrical pipes | 15.4 | 15.1 | 17.1 | 17.3 | 12.9 | 18.1 | 3 |
| Electrical wires | 25.4 | 26.7 | 42.6 | 40.3 | 13.9 | 40.3 | 3 |
| Hydraulic and sewage pipes | 19.9 | 14.8 | 84.4 | 71.8 | 7.6 | 56.5 | 7 |
| Gypsum plaster | 45.1 | 29.5 | 151.2 | 223.3 | −13.9 | 119.7 | 3 |
| Paints | 15.3 | 14.6 | 43.0 | 44.6 | 8.2 | 23.7 | 4 |
| Carpet | 14.0 | 14.0 | — | — | — | — | 1 |

waste due to nonoptimized cutting of bars. Many problems related to poor handling of materials were also observed, resulting in large disorganized stocks, which often caused waste for substitution—that is, unnecessary replacement of some bars by others of larger diameter.

In recent years many companies in Brazil have opted to purchase off-site preassembled steel reinforcement. One of the advantages of this alternative is that it drastically reduces waste mainly by optimizing the cutting of bars, although no systematic study on the extent of this economy has been published so far.

### Premixed Concrete

Despite having one of the lowest waste indices among all materials, the relatively poor performance of premixed concrete in both studies was fairly surprising, due to the relatively high cost of this material. In contrast, most construction companies in Brazil assume that the waste of premixed concrete is negligible.

Site managers often complain about the difficulty of controlling the amount of premixed concrete deliveries. In fact, in the 1996–1998 study, as many as 64% of the sites in which the waste of this material was investigated had no control of this kind. In the same study, the research team monitored the difference between the purchased amount of concrete and the amount actually delivered at 12 sites. An average difference of 3.6% was found—this means that indeed some suppliers often deliver quantities of material smaller than what the construction firms are actually paying for. The obvious solution seems to be the installation of a site scale to control the delivery of materials or to place an inspector in the concrete plant—however, this might not be economically feasible for small companies. One alternative adopted by some Brazilian companies was to establish a deal with the suppliers whereby the purchased premixed concrete is paid for based on the amount measured in loco, that is, after the concrete is placed in the formwork.

Deviations in the dimensions of cast-in-place structural elements (slabs, beams, and columns) are an important source of concrete indirect waste. Based on the analysis of 30 sites, the slab thickness was on average 5.4% larger than specified in the design. Beams also had similar problems—their width was on average 2.7% larger, considering a sample of 29 sites. The excessive thickness of slabs seems to be the most serious problem because of shape, and also due to the relatively high percentage of this element in the volume of the whole structure—usually around 50 to 60%. The main causes for this problem were lack of constructability of some structural elements, poor design of the concrete formwork system, imprecision of the measuring device, and flaws in the formwork assembling process.

Fairly often, some waste of concrete was also observed during the handling and transportation operations on site, mostly related to site layout problems and to the use of inadequate equipment, although it was difficult to quantify its magnitude due to the relatively high cost of measurement. At a few sites, the excessive dimensions of concrete foundation piles and curtain walls also caused unexpected waste. This problem was mainly related to the lack of precision in excavation methods.

Finally, due to uncertainty related to material consumption, site managers often order an additional allowance of concrete in order to avoid interruptions in the concrete-pouring process. Sometimes this results in a surplus of concrete that is not used.

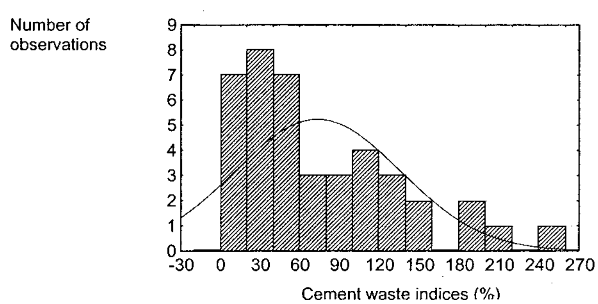


**Fig. 1.** Cement waste indices in 1996–1998 study

### Cement

Analyzing the waste of cement is relatively complex due to the fact that this material is used as a component of mortar and cast-in-place concrete in several different processes, such as brick-



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work, plastering, and floor screed. By contrast this is a relatively expensive material that has high levels of waste in Brazil, according to both studies. Its main sources of waste are as follows:

1. In situ production of mortar: much waste of cement was observed in the production of mortar on site. Cement and other materials are usually loaded manually in the mixer using inadequate equipment. For instance, in the 1992–1993 study, 14 different combinations of equipment and tools, including shovels and buckets, were found at only five sites during the data collection period. This also indicates the lack of process standardization. Another typical cause of waste in this stage is the lack of information available to construction labor for producing different mixes of mortar.
2. Handling and transportation of mortar: in both studies, waste of mortar was observed in most sites during the handling and transportation operations, although no quantification was possible. Multiple handling of the same batch of mortar, due to intermediate stocks along the process flow, is also fairly common. Such waste was mostly related to site layout problems, lack of properly maintained pathways, and use of inadequate equipment.
3. Brickwork joints: the production of brickwork was also responsible for some waste of cement, due to the excessive consumption of mortar in joints. In the 1992–1993 study, the average thickness was 19.1% greater in the vertical joints and 35.6% in the horizontal joints. In the 1996–1998 study, in a larger sample of sites, the average deviation in thickness was 52% for horizontal joints (20 sites) and 56% for vertical joints (21 sites). There is usually a combination of reasons for the excessive thickness of joints, which may include lack of modular coordination between concrete structure and brick walls, inadequate training of labor, insufficient information available about process standards, inadequate supervision, variations in the size of blocks, and lack of process standardization.
4. Plaster thickness: the excessive thickness of plaster was identified in both studies as a major cause of cement waste. In the 1992–1993 study, the actual thickness exceeded the designed one by, on average, 17.8% for ceilings, 76% in internal walls, and 93.3% for facades. In the 1996–1998 study, this waste was on average 46.8% for internal plaster (15 sites) and 32.7% for external plaster (6 sites). The same problem was also observed by Pinto (1989). The main causes for this problem are deviations in the dimensions of structural elements, flaws in the integration between different designs, lack of modular coordination in design, and omissions in the design in terms of defining the exact sizes of components, such as door frames and blocks.
5. Floor screed: excessive thickness for concrete floor screed was also detected in the 1996–1998 study. On average, the actual thickness of this element exceeded the designed one by 47%, based on a sample of seven sites. The main causes for this problem were deviations in the concrete slab level in relation to design and the need to inlay pipes in the floor.

### Sand, Lime, and Premixed Mortar

The waste of mortar used in brickwork and plastering has already been discussed in the previous section. The main causes of cement waste can also explain most of the problems related to sand, lime, and premixed lime and sand mortar. Sand and mortar are usually delivered in trucks, and so there may be additional losses related to the lack of control in the delivery operation and the necessary handling it demands.

In recent years, some companies in Brazil have started using packed ready-to-use mortar mix, which tends to eliminate many of the problems related to delivery control, handling, and transportation. Although not enough data are available, there are indications that such changes have reduced the waste of mortar, in comparison to the traditional method of producing mortar on site.

### Bricks and Blocks

In most poorly performing sites, a combination of causes were related to the waste of bricks and blocks. At several sites, there were problems related to the delivery of materials, such as the lack of control in the amount of bricks or blocks actually delivered and the damage of bricks or blocks during the unloading operation.

In both studies, poor handling and transportation were the major sources of waste for bricks and blocks. As in the case of mortar, multiple handling of the same batch of bricks, due to intermediate stocks along the process flow, was observed at many sites. Insufficient planning of the site layout, lack of properly maintained pathways, and the use of inadequate equipment were among the main causes of waste.

It seems that most of the problems related to delivery, handling, and transportation could be eliminated by supplying bricks and blocks on pallets. In fact, some of the sites in the 1996–1998 study adopted this strategy and were able to reduce waste to some extent. However, it was also observed in the same study that the use of pallets does not improve performance on its own. They have a positive impact only if other measures related to flow management are also implemented, such as planning the layout, keeping pathways unobstructed, and minimizing inventories.

Another source of waste was the need to cut blocks and bricks, due to the lack of modular coordination in design. Indeed, the percentage of cut pieces at some sites was relatively high—considering a sample of 40 sites, the percentage of cut ceramic blocks in relation to the total number of blocks was, on average, nearly 18%. In this context, the waste tends to be higher if the cutting operation is not planned and needs to be executed at the installation locale.

Table 3 presents the main sources of waste for ceramic blocks, considering data collected at four building sites in the 1992–1993 study. The high percentage of waste caused by poor internal handling and transportation (4.74%), and excessive cutting (4.67%) is remarkable. By contrast, the percentage of waste produced due to labor mistakes is negligible (0.28%). It also can be observed that the waste related to flow activities (delivery, transportation and handling, and storage) is more than 50% higher than that associated with conversion activities (rejection of blocks, labor mistakes, and cutting blocks).

### Ceramic Tiles

The poor performance of ceramic tiles in the 1996–1998 study was unexpected, considering the relatively high cost of this material. The main source of waste was the need to cut tiles—on average, 35% of the pieces on floors (15 sites) and 27.4% of the pieces on walls (23 sites) had to be cut. Lack of modular coordination and flaws in the integration between architectural and structural design were the main causes of the cuts.

At some of the sites, it was also observed that the lack of planning in the distribution of materials contributed to increased waste. In most instances, whole packages of ceramic tiles (typically 1.5 $m^2$ each) are sent to the installation places, based on the demand by the work crews. When necessary, pieces are cut, and some are left as debris when the crew moves to the next work



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**Table 3.** Sources of Ceramic Block Waste (in Weight) in 1992–1993 Study

| Source of waste | Minimum waste (%) | Maximum waste (%) | Average waste (%) |
|---|---|---|---|
| Delivery | | | |
| Lack of quantity control | 0.3 | 5.8 | 2.6 |
| Handling | 0.1 | 0.2 | 0.2 |
| Damaged inventories | 0.6 | 1.6 | 1.1 |
| Internal transportation and handling | 0.0 | 14.2 | 4.7 |
| During conversion | | | |
| Rejection of defective blocks | 0.2 | 0.9 | 0.6 |
| Damage due to labor mistakes | 0.0 | 1.0 | 0.3 |
| Damage during cutting | 2.2 | 10.9 | 4.7 |
| Sporadic events | 0.3 | 2.2 | 1.3 |
| Nonquantified sources | — | — | 12.2 |
| Total waste | 8.2 | 39.9 | 27.6 |

face. In contrast, a few companies adopt the strategy of sending to the work face the exact amount of tiles in a kit, including all necessary precut pieces. This allows the operation of cutting tiles to be centralized and thereby optimized and avoids unnecessary handling of wasted parts.

### Pipes and Wires

Keeping track of the causes of waste of electrical pipes, electrical wires, and hydraulic and sewage pipes is a fairly complex task. Both electrical and plumbing services are usually subcontracted, and the materials are sometimes provided by the specialist subcontractor. As this activity tends to be very fragmented on site, such materials are often moved into and out of the site. Another difficulty related to the measurement of waste is the fact that both plumbing and electrical service designs are often poorly detailed, and many changes in the routings of pipes are made during the installation.

The most important causes of waste for these materials are short unusable pieces produced when pipes are cut; poor planning in the distribution of materials, which does not encourage cutting optimization; and replacement of elements by others that have superior performance.

## Discussion

The results of both studies have confirmed that the level of material waste in the Brazilian construction industry is fairly high and that much of this waste is predictable and avoidable. The fact that some relatively simple and inexpensive preventive measures have not been implemented indicates a lack of knowledge among construction managers about the performance at their sites. In fact, several managers from the companies that took part in the research were surprised by their low performance.

The fact that most companies were unaware of the magnitude of waste at their sites indicates a lack of transparency (Greif 1991) in the performance of their production systems. Indeed, very few of the sites involved in both studies had organized records on the actual delivery, storage, and consumption of materials. Project control in those companies is mostly based on financial performance measures, which tend to be backward focused and do not make it easy to trace operational costs (Berliner and Brimson 1988).

The analysis of sources of waste indicated that a large proportion of material waste occurs because flow activities, such as material delivery, inventories, and internal transportation and handling, are often neglected by site management. A similar conclusion was found by Skoyles (1976). This is probably a result of the conceptual model of production currently used by the industry, which encourages the management effort to be focused on the conversion activities (Koskela 1992).

It must be pointed out that the waste of materials tends to increase the amount of non-value-adding activities and thereby the waste of other resources such as labor and equipment time. For instance, the excess of material that needs to be purchased tends to increase stocks, the demand of the transportation system, and the effort necessary to remove debris from site. These problems might also negatively affect health and safety conditions.

One obvious strategy for reducing the waste in the Brazilian industry seems to be to encourage the use of precut, preassembled components, instead of producing materials such as mortar, concrete, and steel reinforcement on site. Indeed, the 1996–1998 study indicated that this is already happening in several companies. However, much waste can be reduced even in companies that continue to adopt traditional building technologies, since most causes of waste are related to flaws in the management system and are not intrinsic to the technology used. Moreover, most of the necessary corrective actions are relatively inexpensive.

Although insufficient training of the work force is a problem in the Brazilian construction industry, the research provided no strong evidence that the lack of qualification of the workers was a major cause of material waste. In fact, the occurrence of waste for most materials is usually the result of a combination of factors, rather than originated by an isolated incident, as suggested by Skoyles (1976).

Managerial problems in stages that precede production are among the most important causes of waste. These include lack of modular coordination in design, poor integration of building subsystems during the design stage, poor detailing of design, lack of optimization during design in the use of resources (for example, steel bar cutting), imprecise specification of components, lack of site layout planning, mistakes in the procurement of materials, and lack of planning in the delivery of materials on site and their distribution to the workplaces.

Finally, much indirect waste was observed in both studies. This was mostly related to deviation in the dimensions of components, such as concrete slabs and beams, plaster, and floor screed. In addition to the cost of waste, this problem also results in unnecessary additional loads on the structure, and for some



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elements, such as external plaster, tends to increase the incidence of building pathologies. In this respect, preventing dimensional deviation requires corrective actions both at the design and production stages. Another frequent cause of indirect waste was the substitution of elements by others of superior performance, usually caused by poorly managed inventories or failure in the material supply process.

## Conclusions

This paper discusses the main results of two research studies carried out in Brazil, aimed at measuring the waste of materials in building projects and at identifying its main causes. The paper suggests that the level of material waste is very high, but that improving the performance of the industry in this respect does not demand much investment from the companies. Some general strategies for reducing waste are proposed. These are mostly related to improving the managerial capacity of companies at the design, procurement, and production stages.

Further work needs to be undertaken in order to reduce the levels of waste, not only in Brazil, but also in other countries. In general, companies need to improve their control systems so that their waste becomes apparent and easier to eliminate.

The data collection and processing procedures developed for the 1992–1993 and 1996–1998 studies were fairly successful as research methods, but were not intended to be used by construction companies. In fact, they are too expensive to be directly adopted by construction companies. Therefore, further work must address waste control implementation in construction companies. Based on this study, a number of guidelines can be proposed for developing such controls:

1. Both financial and nonfinancial waste measures must be used concurrently. On the one hand, financial measures are necessary for supporting decision making at a strategic level and could be used for investigating the economic impact of waste and the cost of waste reduction. On the other hand, nonfinancial measures are important to identify the causes of waste at the operational control level.
2. A broader view of waste should be considered that includes not only material waste, but also waste related to other resources, such as labor, equipment, and capital.
3. Corrective action must involve not only the site management team, but also people involved in processes that precede production, such as design, material supply, and site planning.
4. Waste control should be fully integrated in the production planning and control process, in order to avoid the establishment of separate control systems.

## Acknowledgments

Thanks to SEBRAE/RS and FINEP for the financial support, and to fellow researchers from the following institutions, who took part in the development of the research method, data collection and processing in the 1996–1998 study: USP, UFRGS, UNIFOR, UPE, UEFS, UEMA, UFBA, UFPB, UFMG, UFSM, UFSCar, UFS, UFC, UFES, UFPI e UFRN.

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