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The Construction Industry's Material Waste: The Root Causes and Solutions

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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.

Introduction

The building industry is often believed to produce a great deal of trash. Waste accounts for a comparatively substantial proportion of manufacturing expenses, according to partial studies conducted in different nations, even though it is difficult to systematically assess all building wastes. Materials consumption, quality failure costs, maintenance and repair expenses, accidents, and nonproductive time are some of the many waste metrics that have been studied (Skoyles 1976; Bossink and Brouwers 1996; Cnudde 1991; Oglesby et al. 1989). Construction waste is significant for reasons other than

From an efficiency standpoint, there has been an increasing amount of worry over the negative impact of construction waste on the environment in the last several years. The percentage of urban garbage that falls into this category usually ranges from fifteen percent to thirty percent (Brooks et al. 1994; Bossink and Brouwers 1996; Forsythe and Marsden 1999). There is often not enough room for the disposal of construction debris in big cities, and recycling it is challenging because of the high contamination levels and great degree of variety (Bossink and Brouwers 1996). According to Wyatt (1978), excessive waste reduces future energy and material availability and puts an extra strain on the transportation system. Wood, sand, and crushed stone are only a few examples of the construction materials and components that consume up finite resources and rely heavily on fossil fuels (Bossink and Brouwers 1996). Because it often reveals places for possible improvement and the primary reasons of inefficiency, measuring waste is an efficient method to evaluate the performance of production processes. In order to support process management, waste measures are preferable to traditional financial metrics. This is because waste measures allow for the proper modeling of some operational costs and provide information that is typically meaningful for employees, which in turn creates conditions for the implementation of decentralized control. Actually, the Lean Production paradigm places a heavy emphasis on reducing or eliminating waste as a means of improving processes. The Total Quality Management (TQM) and Just in Time (JIT) production tenets formed the basis of this significant industrial growth trend, which began in Japan in the 1950s. Although the Toyota Production System has been the most publicized use of Lean Production so far, its ideas and principles have been spreading to other sectors, such as the construction industry, in recent years (Koskela 2000). Measuring construction waste is the focus of this article. At the outset, we take a conceptual look at waste and quickly review some prior research on construction material waste. Afterwards, the findings from two Brazilian studies on construction material waste are provided. The research set out to quantify the amount of material waste in Brazil's construction sector and identify its primary sources of waste. Seven construction materials were observed at five separate locations in the first investigation, which spanned from April 1992 to June 1993 and was conducted at the Federal University of Rio Grande do Sul (UFRGS). Much more extensive monitoring of 69 locations and 18 distinct construction materials was required in the second, more ambitious research. From October 1996 to May 1998, fifteen different Brazilian institutions collaborated on it.
Since the two research utilized equivalent methodologies to gather data, their findings are also comparable. At certain locations, they found that the waste of various building materials was more than 100%, indicating that construction firms often anticipate significantly lower percentages when estimating costs. Now that we know what causes waste, we can see that corporations don't need to spend much to

improve the industry's performance in this area.

Concept of Waste

When most people in the field think of garbage, they picture the materials hauled away from a construction site and dumped in a landfill. This myopic perspective of waste is likely due to the fact that it is simple to see and quantify. Even though this kind of waste is crucial from an environmental standpoint, industrial engineers have been critical of this method since its inception. Material waste causes less economic loss than human job inefficiency, as Taylor (1913) found out. Because the value of resources is heavily dependent on the labor that has gone into them, Ford (1927) argued that human activity should be the center of waste reduction efforts.

It is not enough to only think about debris when considering material waste. Skoyles (1976) differentiates between two types of material waste: direct and indirect. The total destruction of an item as a result of its irreparable damage or loss constitutes direct waste. It is common practice to re-move the waste from the site in such a situation. Concrete slabs that are thicker than required by structural design are an example of indirect waste, which happens when resources are not physically lost but only financially.
In the Lean Production paradigm, process and operation are closely associated with the waste definition. A process is defined in the conventional paradigm of production management as the conversion model proposed by Koskela (1992) and further subdivided into other 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 (Alarco´n 1997).
In contrast, in the Lean Production paradigm, production is viewed as consisting of both conversion and flow (waiting, mov- ing, 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 dis- tinction is made between processes and operations: production is a network formed by intersecting axes of processes and opera- tions. Process refers to the flow of products from one worker to another—that is, the stages through which raw materials gradu- ally 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 associ- ated 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 cor- responds to the focus for process improvement in the Toyota pro- duction 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 nec- essary 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 rec- tification, 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 move- ment of people (including waste of human energy); (2) waiting by employees for process equipment to finish its work or an up- stream activity; (3) defects in products; (4) overproduction of goods not needed; (5) inventories of goods awaiting further pro- cessing or consumption; (6) unnecessary processing; and (7) un- necessary 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 men- tioned in the literature, such as accidents, working under subop- timal 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 Produc- tion 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 mate- rial 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; Bos- sink 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 ex-
cess 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 re- duction 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 con- sisting 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 avoid- able;
3. Mismanagement of materials on site emerged as one of the main causes of waste. Substantial losses were caused by in- correct unloading of materials, poor ground conditions, inad- equate 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 Asso- ciation (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, plaster- ing, 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, mor- tar, bricks and blocks, ceramic tiles, and wood. It suggests that packaging waste can be as much as 5% of the volume of materi- als. 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 ob- served 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 re- sulting 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 build- ing. 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 pre- vention 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 repre- sentatives, 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 stor- age.

Australia

Forsythe and Marsden (1999) discussed the way in which con- struction 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 em- pirical study of 15 house-building sites. That study involved the quantification of waste based on the amount of materials effec- tively delivered on site, according to available documents and also on interviews with representatives of different trades.

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

According to the reviewed literature, there is a dearth of information on construction sector material waste. There is a dearth of international empirical research, and all of the ones that did exist, with the exception of Skoyles (1976), only looked at a tiny subset of building materials at a few of locations.
Because of the varied building technologies and measuring methods used in each study, it is difficult to draw meaningful comparisons between them.
Researchers have looked at both direct and indirect waste; some have concentrated on the former (Skoyles 1976; Picchi 1993; Bossink and Brouwers 1996; Pinto 1989). Many metrics were employed to track waste: the ratio of materials lost to purchase price (Bossink and Brouwers 1996), the ratio of materials lost to design requirements (Skoyles 1976; Pinto 1989; Hong Kong Polytechnic and Hong Kong Construction Association 1993), material volume (Gavilan and Bernold 1994), and material weight (Picchi 1993).

Since the samples were small and the relative importance of each material waste is likely to vary depending on the building type (such as residential, commercial, industrial, etc.) and technologies involved, these figures cannot be regarded as representative of the sector. Because top organizations often have a significant deal of incentive to gather and disseminate these measurements, they might be seen as conservative (Koskela 2000).

Research Method

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.

1. Observation of the production processes: a ‘‘yes or no’’ checklist was also used for evaluating each process; and
2. Performance indicators: each of the performance indicators was described, including their objectives, formula, measure- ment 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 quali- tative and quantitative data produced. In several projects, it was not possible to obtain a final figure for the waste of some mate- rials, due to failures in data collection, mostly in the control of material deliveries and withdrawals carried out by the construc- tion companies.

Main Results

General Results

Table 1 shows the key findings from the research conducted between 1992 and 1993. These include the proportion of waste at each site, the average waste, and the notional waste for each material. The nominal waste refers to the waste allowances that construction firms usually use when estimating costs. The findings showed that construction firms' cost projections were significantly based on substantially lower material waste at those five sites. For example, when it came to premixed mortar, the real waste was up to six times more than the nominal permitted. Waste levels at those locations are much greater than those at the sites studied by Skoyles (1976), Bossink and Brouwers (1996), and Forsythe and Marsden (1999), but direct comparisons to studies conducted in other countries are not feasible. But the scale of the concrete waste is comparable to what was found in the Hong Kong research (Hong Kong Contractors Association 1993; Hong Kong Polytechnic 1993).
Different locations showed a wide range of waste indices.

with regard to the same subject. 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 consump- tion 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 Soi- belman (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 construc- tion 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 disper- sion, instead of only the mean value and the coefficient of vari- ability.
In the following section the main causes of waste are dis- cussed 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 rela- tively 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 con- version 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

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 re- lated 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 pur- chase off-site preassembled steel reinforcement. One of the ad- vantages 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 mate- rials, 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 Bra- zil assume that the waste of premixed concrete is negligible.

Site managers often complain about the difficulty of control- ling 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 be- tween 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

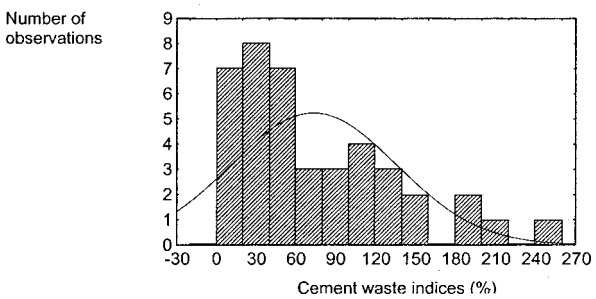

Fig. 1. Cement waste indices in 1996–1998 study

material smaller than what the construction firms are actually pay- ing for. The obvious solution seems to be the installation of a site scale to manage the flow of supplies or to station an inspector at the concrete batching plant—but this may be out of reach for smaller businesses financially. A further approach that some Brazilian enterprises have taken is to negotiate with their suppliers a payment plan where the quantity of bought premixed concrete is paid for in loco, or after it has been put in the formwork. One major cause of concrete indirect waste is the deviance in size of structural elements that are cast in situ, such as slabs, beams, and columns. The average slab thickness was 5.4% more than what was required in the design, according to the research of 30 locations. Taking into account a sample of 29 locations, beams also had comparable issues, with an average width that was 2.7% wider. As a result of their design and the relatively large proportion of this element in the total construction volume—typically around 50 to 60%—excessive slab thickness seems to be the most significant issue. Several factors contributed to this issue, including structural parts that were not constructable, a poorly designed concrete formwork system, an inaccurate measurement instrument, and a flawed method of building the formwork.

It was difficult to estimate the quantity of the concrete waste that occurred during the handling and transportation activities on site because of the relatively high cost of measuring. The waste was largely caused by difficulties with the site layout and the use of unsuitable equipment. Unanticipated waste was also created at certain locations by the excessive proportions of the concrete foundation piles and

curtain walls. The fundamental cause of this issue was the carelessness with which the excavation was carried out. Lastly, site managers often request an extra allotment of concrete to prevent delays in the concrete-pouring process, which is caused by uncertainty over material consumption. There are instances when this leads to an excess of concrete that goes unused.

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-

work, plastering, and floor screed. By contrast this is a relatively expensive material that has high levels of waste in Brazil, accord- ing 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, in- cluding 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 prob- lems, lack of properly maintained pathways, and use of in- adequate equipment.
3. Brickwork joints: the production of brickwork was also re- sponsible 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 infor- mation available about process standards, inadequate super- vision, 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 struc-

   tural elements, flaws in the integration between different de- signs, lack of modular coordination in design, and omissions in the design in terms of defining the exact sizes of compo- nents, 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 ce- ment 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 trans- portation. Although not enough data are available, there are indi- cations 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 deliv- ered 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, han- dling, 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 han- dling 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 associ- ated with conversion activities (rejection of blocks, labor mis- takes, and cutting blocks).

Ceramic Tiles

Ceramic tiles' dismal showing in the 1996–1998 research came as a surprise, given the material's comparatively expensive price tag. On average, 35% of the floor pieces (15 sites) and 27.4% of the wall pieces (23 sites) had to be trimmed, making tile cutting the primary cause of waste. There is a problem with the integration of architectural and

The incisions were mostly caused by structural design. An further factor that led to increasing waste at certain locations was the absence of planning in the distribution of supplies. In most cases, the demand from the work crews determines whether full packages of ceramic tiles—typically 1.5 m2 each—are provided to the installation sites. As the group goes on to the next task, some parts are left as trash after being chopped as needed.

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 sub- contractor. 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

Both studies' findings corroborate the significant (and mostly predicted and preventable) amount of material waste in Brazil's building sector. It seems that construction managers are unaware of how their sites are doing since they have not put into place certain easy and cheap preventative measures. Actually, a number of company managers were taken aback by their poor performance when they participated in the study.

Companies' failure to recognize the extent of waste at their facilities is indicative of a lack of openness about the efficiency of their production processes (Greif 1991). Almost no locations included in either study kept systematic records of materials' actual delivery, storage, or use. In such businesses, financial performance measures—which are often backward focused—form the backbone of project control.

Conclusions

Two studies conducted in Brazil sought to quantify construction material waste and determine its root causes; this article summarizes their key findings. According to the report, material waste is rampant, yet increasing industrial performance in this area does not need substantial financial outlays from businesses. We provide some broad approaches to waste reduction. These are mostly re- lated to improving the managerial capacity of companies at the design, procurement, and production stages.
Not just in Brazil, but worldwide, more effort is required to lower trash can contents. In most cases, businesses should upgrade their management systems to make waste more visible and simpler to eradicate.
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 construc- tion companies. The truth is that building businesses cannot afford to directly implement them. 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 neces- sary 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, nonfi- nancial 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 re- sources, 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 pro- duction, 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 establish- ment of separate control systems.

References

In 1988, Berliner and Brimson published a paper. Harvard Business School Press, Boston, CAM-I: A conceptual design for cost control in modern advanced manufacturing.
In 1996, Bossink and Brouwers published a paper. "Quantification and source evaluation of construction waste." Journal of Construction Engineering and Management, 122(1), 55-60.
The authors of the article are Brooks, Adams, and Demsetz (1994). When it comes to Germany,

infrastructure for recycling construction and demolition debris: what can the United States learn from it? Cnudde, M. (1991) and Kibert, C. J. (ed.), Proceedings of the First Conference of the CIB Task Group 16, Gainesville, Florida, 647-656. In the European conference on management's Quality and Economics in Housing and Other Building Sectors, Lisbon, 508-515, the authors discuss the monetary costs associated with subpar building quality.
Originally published in 1926 by Ford, H. According to Forsythe and Marsden (1999), "Today and Tomorrow" was published by Doubleday in Garden City, New York. S. O. Ogunlana, ed., "Modeling construction waste performance—an arising procurement issue," Procurement Systems (CIB W92) and Culture in Construction (CIB TG23) Joint Symposium, Spon, London, 679-688, a profitable partnership in construction procurement.
The authors of the 1994 work are Gavilan and Bernold. "Evaluation of solid waste sources in building construction." Journal of Construction Engineering and Management, 120(3), 536-552.
For the year 1991, Greif was the author. Published by Productivity Press in Portland, Oregon, The Visual Factory by L. Lockwood is a guide on fostering engagement via the dissemination of relevant data.
The Hong Kong Construction Association and the Hong Kong Polytechnic. in 1993. Final report on construction waste reduction.
This sentence was paraphrased from an article by Isatto, Formoso, De Cesare, Hirota, and Alves in 2000. Publication: SEBRAE/RS, Porto Alegre, Portugal, "Lean Construction: Guidelines and Tools for Controlling Waste in Civil Construction" (in Portuguese).
In 1992, Koskela published it. "Bringing the New Production Philosophy to the Construction Industry," Technical Report No. 72, CIFE, Stanford, California.
The year 2000 was written by Koskela, L. An investigation into a philosophy of production and its relevance to the building industry, VTT Publications 408, Espoo, Finland.
The author of the article is Monden (1983). Production management with a focus on the Toyota system: a practical approach, Norcross, GA: Industrial Engineering Management.
This was published in 1989 by Oglesby, Parker, and Howell. Enhancing Construction Productivity, New York: McGraw-Hill.
(Ohno, 1988). Productivity, and the Toyota Production System in Cambridge, Massachusetts.
(Pichi, F. A.) 1990. "Quality systems: use in construction companies" M.Phil. dissertation, University of São Paulo, So Paulo.
T. P. Pinto (1989). Waste of materials in conventional building procedures. The research report was written in Portuguese and was submitted to the Federal University of Șo Carlos. Originally published in 1988 by Shingo, S. Productivity, Cambridge, Mass., Non-stock production, E. F. Skoyles (1976). Article titled "Material wastage: A misuse of resources" published in the July/April issue of Building Research and Practice, including pages 232 to 243.
In 1993, Soibelman published a work. Material waste in building construction: incidence and management. Porto Alegre, Brazil: Federal University of Rio Grande do Sul, Master of Science dissertation (in Portuguese).
Author: F. W. Taylor (1913). Harper & Brothers, New York, The Principles of Scientific Management.
In 1996, Womack and Jones published a paper. Simon & Schuster, New York, 2007. Lean Thinking.
As said by Wyatt in 1978. Chartered Institute of Building, Berkshire, United Kingdom, Materials Management—Part 1..