GUIDELINES FOR MANAGING PHYSICAL FLOWS IN CONSTRUCTION SITES

Thaís da C. L. Alves[1] and Carlos Torres Formoso[2]

ABSTRACT

The process model that has been mostly used in construction management tends to neglect the importance of flow activities in production. By contrast, the New Production Philosophy (Lean Production) states that both conversions and flows should be considered in production management. While the conversion management aspect of production seems to be relatively well defined, further research into the management of physical flows is required.

This paper proposes some guidelines for managing physical flows in construction sites based on case studies carried out in small sized building companies in the South of Brazil. In this research work, physical flows refer to both material and production unit flows. The authors propose that decision making concerned with such flows should be part of the production planning and control process. This means that the flows of people, equipment, and materials must be explicitly and systematically planned and controlled, considering distinct hierarchical decision making levels.

It is expected that these changes in production planning and control will increase process transparency and, at the same time, will create conditions for reducing variability in site conditions and thereby reduce waste.

KEYWORDS

Physical flows, process transparency, production planning and control, lean construction

---

1 M.Sc., Research Assistant, Federal University of Rio Grande do Sul, Building Innovation Research Group (NORIE), Brazil, e-mail: thaiscla@cpgec.ufrgs.br

2 Ph.D., Associate Professor, Federal University of Rio Grande do Sul, Building Innovation Research Group (NORIE), Brazil; Visiting Scholar at the University of California at Berkeley, USA e-mail: formoso@vortex.ufrgs.br

INTRODUCTION

In the conceptual model mostly used in production management, construction is viewed simply as a conversion of an input into an output that can be divided into sub-processes, which also are conversion processes. This approach assumes that process improvement can be achieved by improving each of its parts. 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).

By contrast, the New Production Philosophy views production as consisting of both conversion and flow (waiting, moving and inspecting) activities. This has important implications for the design, control, and improvement of production processes, since flow activities and customer requirements become more explicit than in the conversion model. In this conceptual model, the management of flows (work, material, and information) is emphasised.

The new production management paradigm is marked by the attention to details and the pursuit for waste elimination (Womack et al. 1990). In this context, waste can be defined as any loss 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.

Waste in the construction industry has been the subject of a number of research projects in several different countries, such as Hong Kong (Hong Kong Polytechnic and Hong Kong Construction Association 1993), the Netherlands (Bossink and Brouwers 1996), and Australia (Forsythe and Marsden 1999). In Brazil, a number of investigations on material waste have also been developed in recent years (Soibelman et al. 1994; Agopyan et al. 1998). Despite the importance of those previous studies in terms of both highlighting the importance of waste management and identifying major causes of waste, their contribution for establishing waste control systems has been relatively small for the reasons presented bellow:

- Most studies tend to focus on the waste of materials, which is only one of the resources involved in the construction process. This seems to be related to the fact that most studies are based on the conversion model;
- Data collection is usually very expensive, involving a large team of researchers, including people who are heavily involved in monitoring the work on site. Consequently, the procedures used for measuring waste in research studies are not easily adapted by the industry to implement waste control systems;
- The results of surveys take a long time to be produced, usually after the work being monitored has finished. This limits the impact of those studies in terms of corrective action.

The study of Formoso et al. (1999) suggested that waste control should be fully integrated in the production planning and control process. In fact, production management in construction companies tends to be limited to task control and material delivery, but often fails to consider explicitly physical flows control.

This paper describes the main results of an investigation on measures for reducing waste in building sites. Based on two case studies carried out in small sized building companies, the study proposes a set of guidelines for systematically managing physical flows as part of the production planning and control process. This means that the flows of production units and materials must be planned and controlled at distinct hierarchical levels.

The model proposed by Formoso et al. (1999) for the production planning and control process was adopted in this study. This model is strongly based on the work of Ballard and Howell (1998), in which three decision making levels are identified: initial planning, look-ahead planning and commitment planning.

This study is strongly concerned with increasing process transparency, one of the core principles proposed by Koskela (1992) for the New Production Philosophy. Transparency can be defined as the ability of a production process (or its parts) to communicate with people (Greif, 1991). A transparent (or visual) workplace is a work environment in which most problems, abnormalities, and types of waste that exist can be recognised at a single glance in order to allow immediate remedial measures to be taken (Igarashi, 1991).

This principle plays an important role in managing the physical flows since the lack of visualisation of flows has been pointed out as a major cause of waste. Moreover, Galsworth (1997) pointed out that process transparency, when applied adequately, forms a base on which other improvement approaches can be built. It can be used, for instance, to make explicit and communicate the share of non value adding activities; customer requirements; process variability; and the need for minimising steps. For this reason, visual management plays an important role at the initial stages of improvement programmes.

Koskela (1992) highlighted six practical approaches related to the principle of increasing process transparency. These are: (a) reducing the interdependence between production units; (b) using visual devices to enable immediate recognition of process status; (c) making the process directly observable; (d) incorporating information into the process; (e) keeping a clean and orderly workplace; and (e) rendering invisible attributes visible through measurements. The present research work is mostly concerned with incorporating information about physical flows into the production planning and control process, and rendering invisible process attributes visible through the measurement of production efficiency and effectiveness.

RESEARCH METHOD

The study was divided in two main stages. Initially, an exploratory study was undertaken, which aimed to investigate the use of tools to make physical flows transparent as well as to understand how they are typically managed in the industry. Two small building companies were involved at this stage, and data were collected in two sites, an industrial building and a multi-story residential building.

The second phase involved two case studies carried out in two different companies. Their aim was to investigate how to integrate the management of physical flows in the production planning and control process, as well as to identify the main difficulties faced by the site management for carrying out that task.

In both sites, the planning and control model proposed by Formoso et al. (1999) have been partially implemented. In fact, one of the criteria for selecting the companies was the need to be successfully implementing short term planning, based on the Last Planner method of planning (Ballard and Howell, 1998).

At the beginning of each case study, a thorough analysis of the production system was made, including the site layout, materials storage and transportation conditions. A number of processes were chosen to be the focus of the case study in each site. Table 1 presents the main characteristics of each site, as well as the processes that were investigated.

Table 1 – Brief description of case studies

Case study	Type of project	Area (sq.m)	Processes investigated	Period
A	Six storey residential building, reinforced concrete structure, external and internal block walls	2,326	Floor ceramic tiling, and granite stones, facade tiling	June to September 1999
B	Religious temple, reinforced concrete structure, external block walls and internal light partitions	1,612	Walls and fences, reinforced concrete structure, roof structure and tiling	September to December 1999

The emphasis in each of case study was slightly different. In the first one, the investigation focused on the management of flows related to specific processes, aiming to develop and adapt existing tools and indicators for providing process transparency. By contrast, the second case study emphasised the necessary changes in the production planning and control process for improving flow management.

Data were collected by the research team during several short term planning and control cycles using participant observation as the main source of evidence (Yin, 1994). Both the planning and control process and the production processes were monitored.

Some additional sources of information were also used in the research. These included tools for modeling and documenting production processes, and performance indicators related to the production efficiency and effectiveness, which are presented in the following items.

TOOLS FOR PROVIDING TRANSPARENCY TO PRODUCTION

A number of tools were chosen for improving process transparency in the case studies, mostly based on the exploratory study and bibliography review. The main requirements for selecting the tools were simplicity and low cost of implementation. A brief description of such tools is presented below:

- Process diagram: was used to map processes, making explicit the share of non value adding activities.
- Flow diagram: maps processes but also shows the places where each task is performed and indicates the main flows of materials and operations (Ishiwata, 1991). Figure 1 presents some very simple examples of both process and flow diagrams.
- Documentation using images: photographing and video recording were used to document production processes. They provide a powerful basis for discussion and were also used to disseminate good practices among production personnel. They played an important role in the case study in terms

of communication between members of the planning team and also as an additional source of evidence (Yin, 1994).

- Performance indicators: were related to both production effectiveness (production rates), and efficiency (productivity rates, material waste). They were compared to nominal rates used by the companies in cost estimating.
- Work flow chart: was used to map the flow of operations (production units) for a specific process. The daily location of the floor tiling crew and the work content for each location in case study A is presented in Table 2.

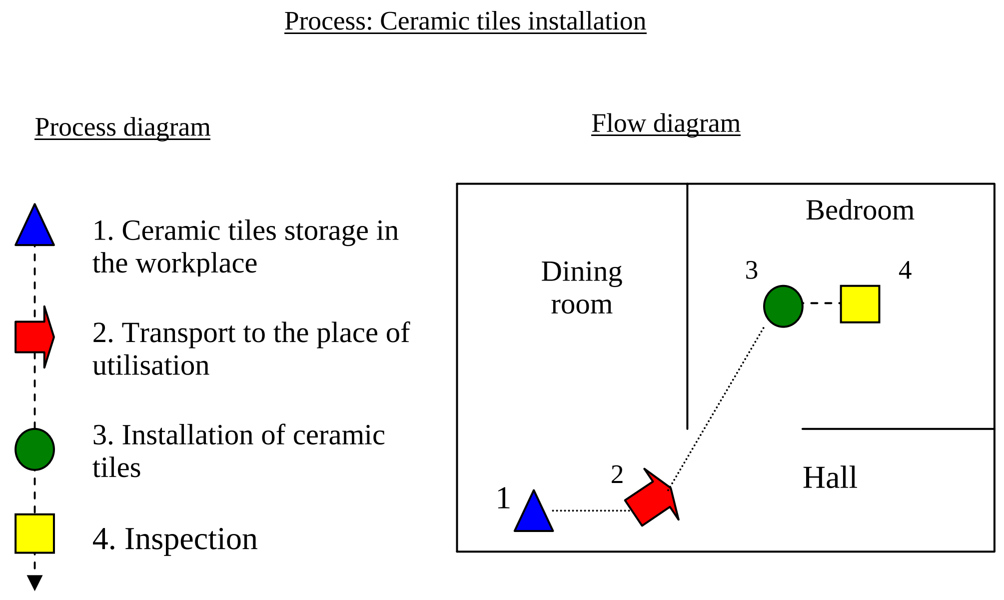

Figure 1 – Process diagram and flow diagram

CASE STUDIES

CASE STUDY A

Production control consisted mainly of a weekly operational planning cycle, which entailed a meeting every Friday morning, typically involving the site manager, foreman, and gang leaders. In this meeting, the previous week plan was evaluated and the following week was planned, using the Last Planner tool. Milestones from the project master schedule were used as starting points for producing the weekly plans, since no look-ahead plan was made in this construction project.

Production data was systematically collected by the research team on the day before the meeting. These data were processed and analysed, and then brought to discussion in the weekly planning meetings.

The process of floor tiling was monitored in this case study by using a work flow chart (Table 2). This tool was very useful in terms of supporting decision making in the weekly planning meetings. At the finishing stages of the building process, the crews tend to spread over a relatively large working area, and there are many visual barriers consisting of product components, such as walls and slabs, which cannot be removed. Work flow charts increased process transparency by incorporating information on the flow of production units into production planning.

Table 2 indicates that there was a lack of work flow planning at a tactical level. Often, workers were involved in the execution of the same task in several different floors. The crews had to return two or three times to the same flat to do the work that was left behind. In flat 402, for instance, floor tiling started in the first week and finished in the seventh week. This makes site supervision more difficult, increases variability and work in progress, and tends to demand more effort from the production system in terms of delivering materials to the workplace and cleaning. There is also a lack of process continuity, limiting the learning effect and increasing the share of non value adding activities. The main cause for this problem was the fact that the sequence of handovers from the previous process - waterproof treatment - was not properly planned. Figure 2 illustrates the resulting variability of production rates in the floor finishing process. All floors have approximately the same work content and room layout.

Table 2 - Work flow chart for the floor finishing process

Work flow chart										
Work place	**Amount executed per room for each flat (sq.m)**									
	201	202	301	302	401	402	501	502	601	602
Bathroom 1	**3,35**	**3,35**	**3,35**	**3,35**	**3,35**	**3,35**	**3,35**	**3,35**	**3,35**	**3,35**
Bathroom2	**2,63**	**2,63**	**2,63**	**2,63**	**2,63**	**2,63**	**2,63**	**2,63**	**2,63**	**2,63**
Service bathroom	**2,30**	**2,30**	**2,30**	**2,30**	**2,30**	**2,30**	**2,30**	**2,3**	**2,3**	**2,3**
Service room	**4,09**	**4,09**	**4,09**	**4,09**	**4,09**	**4,09**	**4,09**	**4,09**	**4,09**	**4,09**
Laundry	**3,45**	**3,45**	**3,45**	**3,45**	**3,45**	**3,45**	**3,45**	**3,45**	**3,45**	**3,45**
Kitchen	**9,65**	**9,65**	**9,65**	**9,65**	**9,65**	**80% ***	**9,65**	**9,65**	**9,65**	**9,65**
Balcony	**11,74**	**11,74**	**11,70**	**11,74**	**11,70**	**11,74**	**11,74**	**11,74**	**11,74**	**11,74**
Bathroom 3										

Legend:
- Standard flat
- Executed 06/18/99 - 06/24/99
- Executed 06/25/99 - 07/01/99
- Executed 07/02/99 - 07/08/99
- 80% * : 80% executed 06/25/99 - 07/01/99 and 20% executed 07/02/99 - 07/08/99
- Executed 07/09/99 - 07/15/99
- Executed 07/16/99 - 07/22/99
- Executed 07/23/99 - 07/29/99

Material flows in the same process was negatively affected by the combined effect of variability and lack of resource planning. Boxes of ceramic tiles were delivered to the work places based only on the demands of the crews. At the end of the task in each workplace, a surplus of material usually had to be moved back to the warehouse. Since the work flow was not properly defined, it was not possible to send non used parts immediately to the next workplace. As a result, ceramic tiles were handled and moved several times before being installed in the final position. This also made it difficult to control inventories.

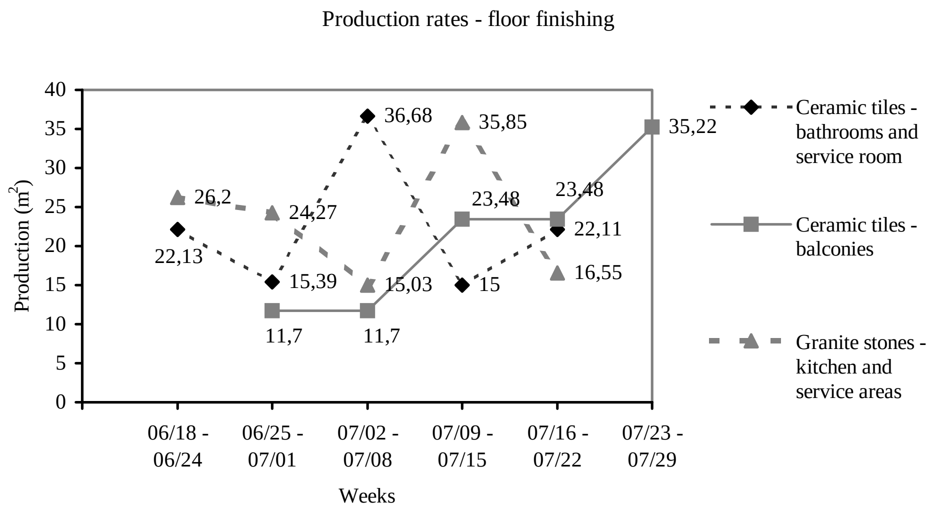

Figure 2 – Variability of production rates

CASE STUDY B

Production planning also focused on weekly operational planning cycles, using the Last Planner tool. The starting point for these plans was usually the milestones established in the master plan. There was also a medium term planning level, but the look-ahead plans had to be updated too often, sometimes weekly, due to changes imposed by the client.

An analysis of the site conditions was performed by the researchers at the beginning of the case study, using the same tools as in case A. During the planning cycles the role of the researchers was limited to collecting data through participant observation. No data from production processes were systematically collected, since the focus of this case study was the planning and control process itself.

Although there was plenty of space in the site, many problems were detected in the site layout. There was no well defined storage area for bulky materials such as rebars, sand and bricks. There were also problems related to the distribution of gangs in the workplace. Most gangs were concentrated in a relatively small area, while parts of the building being produced were relatively empty.

Regarding the planning process, the main conclusions of the study are presented bellow:

- Physical flow restrictions were not properly considered in production planning, although it was relatively easy to see the problems on the site, since there were not many visual barriers. Moreover, no special consideration was given in relation to activities that had a high degree of difficulty, such as the execution of tasks in elevated places.

- The quality criteria proposed by Ballard and Howell (1998) for assigning tasks in the weekly work plans were not adequately considered.

- Uncertainty due to client changes and delays imposed enormous difficulties to the implementation of the look-ahead plans, resulting in much work in progress. As a result, physical flow management at that level was very difficult to be carried out.

GUIDELINES FOR MANAGING PHYSICAL FLOWS IN CONSTRUCTION SITES

The main conclusions of the study are presented as a set of guidelines, which are presented below. Some of them are related not only to physical flows management, but to the production planning and control process as a whole.

MINIMISATION OF UNCERTAINTY AND VARIABILITY IN THE FLOWS

Both the uncertainty and variability related to the availability of resources and site conditions must be reduced. This can be achieved through process analysis and standardisation, using process and flow diagrams as a starting point, as well as by using a shielding mechanism for increasing the reliability of task assignments. This demands site layout planning for different stages of the construction project, and also the use of visual devices, such as signs, borders, and location addresses. Considering that the layout of building sites is continuously changing, a critical issue for implementing visual devices is the need for mobility. This means that the effort to assemble and dismantle visual devices in each workplace should be relatively small.

CONSIDERATION OF TIME AND SPACE RESTRICTIONS

More effort must be made in terms of considering time and space conflicts during the planning and control process, in order to eliminate or reduce congestion and interference between work flows. Both flow diagrams and scheduling techniques that make work flows explicit, such as the line of balance, should be used for providing transparency for the planning team.

SPATIAL CONTINUITY AND TASK COMPLETION

The sequencing of assignments at the medium term (look-ahead) planning level must consider the need to provide spatial continuity to the work of different production units. In this context, spatial continuity means that the gangs move continuously from each work place to the next one following the physical sequence of workplaces in the building. This avoids unnecessary movement of gangs among workplaces that are far from each other. It is also important to define the work packages properly so that the assigned tasks are effectively completed when a gang leaves the workplace. This will encourage the gangs to make the smaller possible number of visits to each work place. In this respect, the definition criteria proposed by Ballard and Howell (1998) for the operational plans play a very important role, since they protect production against the effect of variability. Both spatial continuity and task completion tend to reduce the share of non-value adding activities, and reduce the degree of control complexity.

HIERARCHICAL LEVELS OF PHYSICAL FLOW MANAGEMENT

The effect of uncertainty in the physical flows should be minimised by distributing planning decisions and control at different levels of planning. In this context, it is important to identify at each level of planning who should be responsible for such decisions and the necessary tools for supporting decision making. For instance, a general layout of the site must be designed at the master plan level, while the work flows for repetitive processes must be decided at the look-ahead planning level, and decisions concerned with the cleanliness and order of the workplace must be managed at the operational level. Table 3 presents the most important decisions that affect the physical flows, according to the hierarchical planning levels which they mostly refer to.

Table 3 - Main physical flows related decisions at different planning and control levels

MAIN PHYSICAL FLOWS DECISIONS	PLANNING LEVEL	DECISION MAKER
Qualification and selection of suppliers: besides the price of acquisition, other performance criteria must be considered in the selection of suppliers, such as delivery time, reliability of delivery, packaging and unloading conditions).	Initial planning for long lead items, usually once in the project, and look-ahead for other items	Project manager or site manager
Selection of transport equipment (e.g. cranes, lifts, etc.) and their location	Initial planning (decisions are not usually updated)	Project manager and site manager
Production capacity, pace of key activities, deadlines and general sequence.	Initial planning	Project manager and site manager
Definition of materials storage areas: these must be defined in the site layout, at different stages of the production process. Some key decisions of site layout have to be made before the project starts. However, there are some decisions that have to be made as the site changes its configuration	Initial planning (before production starts) and look-ahead planning (usually at the beginning of each production phase)	Site manager and foreman
Time and space restrictions: the identification of these restrictions can be supported by work flow charts, and flow diagrams, and other tools.	Look-ahead planning (every planning cycle)	Site manager, foreman
Process planning: sometimes a specific investigation of process planning is necessary – for instance, by carrying out a first run study (Ballard and Howell, 1998)	Look-ahead planning (usually once for each in the project)	Site manager, foreman, gangs
Process efficiency and effectiveness: performance indicators can be used to monitor production along time. These can be used as a basis for estimating duration.	Look-ahead planning and operational planning (every planning cycle)	Site manager, foreman, subcontractors
Materials consumption rates: these indicators can be used as a basis for resource scheduling.	Look-ahead planning and operational planning (every planning cycle)	Site manager, foreman, subcontractors
Flow control: images, check-lists, flow and process diagrams can be used for monitoring and controlling the flows on the site.	Operational level (every planning cycle)	Site manager, foreman, subcontractor

USE OF DATA FOR INCREASING PROCESS TRANSPARENCY

A number of tools and performance indicators can be used for providing information that are necessary to increase the transparency of the production system, by rendering process invisible attributes visible. Some tools can be directly involved in production control – these must be relatively simple to use, and the data produced must be processed and presented in planning meetings in a way that effectively supports decision making (for instance, by using graphs, maps, and photographs). Some other tools, such as process and flow diagrams, can be used in specific opportunities to carry out a process evaluation or first run studies.

CO-ORDINATION AND COMMITMENT

Physical flow management can only be effective if there is good co-ordination under the responsibility of the general contractor, and commitment from the crews and subcontractor. Lack of commitment was one of the main difficulties that were identified in the implementation of physical flow management in both case studies. Indeed, these are factors that affect the effectiveness of the planning and control process as a whole (Formoso et al. 1999). The site administration should disseminate the necessary instructions to production personnel, as well as co-ordinate the use of space and equipment. In this respect, the operational planning level plays an important role in terms of getting the commitment of different gangs, especially when they are subcontracted.

CONCLUSIONS

This paper proposes some guidelines for managing physical flows in construction sites. It proposes that such flows must be made transparent by collecting data and using modeling tools. This means that the flows of people, equipment, and materials must be explicitly and systematically managed as part of the production planning and control process.. A number of typical decisions concerning physical flows have been identified for each hierarchical decision making level.

Further work is necessary to support the effort to improve the way physical flows are managed in building sites, such as the development of software tools for modeling and simulating physical flows, the development of visual systems and visual devices for improving transparency concerning physical flows, and the development of strategies to involve the work force and subcontractors in decision making.

REFERENCES

Agopyan, V.; Souza, U.E.L.; Paliari, J.C. and Andrade, A.C. (1998). *Alternativas para a redução do desperdício de materiais nos canteiros de obras: relatório final* (Alternatives for reducing waste of materials in building sites: final report). São Paulo, EPUSP/FINEP/ITQC. (in Portuguese)

Alarcón, L.F. (1997). "Tools for the identification and reduction of waste in construction projects." In: Alarcón, L. (Ed.). *Lean construction.* Rotterdam: A.A. Balkema, pp. 365-377.

Ballard, G. and Howell, G. (1998). "Shielding production: an essential step in production control". *Journal of Construction Engineering and Management*, 124(1): pp.11-17.

Bossink, B.A.G. and Brouwers, H.J.H. (1998). "Construction waste: quantification and source evaluation." *Journal of Construction Engineering and Management*, 122(1): pp.55-60.

Forsythe, P. and Marsden, P.K. (1999). “Modeling construction waste performance – an arising procurement issue”. In: OGUNLANA, S.O. (Ed.) *Profitable partnering in construction procurement*. CIB W92 (Procurement Systems) and CIB TG23 (Culture in Construction) Joint Symposium. Chiang Mai, Tailand, 25 - 28 Jan. 1999. London, Spon. pp. 679-688

Formoso, C.T.; Bernardes, M.M.S,; Oliveira, L.F.M. and Oliveira, K.A.Z. (1999). *Termo de referência para o processo de planejamento e controle da produção em empresas construtoras* (Guidelines for production planning and control in construction companies). Porto Alegre: NORIE/UFRGS. Research Report (in Portuguese)

Formoso, C.T.; Isatto, E.L. and Hirota, E.H. “Method for waste control in the Building Industry”. *Proc. International Conference on Lean Construction*, 7th, Berkeley, California, 26-28 July 1999. Berkeley, University of California, 1999. pp.325-334.

Galsworth, G.D. (1997). *Visual systems: harnessing the power of visual workplace.* New York, AMACOM, 320 p.

Hong Kong Polytechnic and Hong Kong Construction Association. *Reduction of construction waste*. Final report. March 1993

Greif, M. (1991) *The Visual Factory: building participation through shared information*. Portland, Productivity Press. Translated by L. Lockwood

Igarashi, R. (1991) The big picture. In: MCTIGHE, E. (Ed.) *Visual Control Systems*. Cambridge, Productivity Press. pp. 3-12. The Factory Management Notebook Series, Volume 1 (2)

Ishiwata, J. (1991) *IE for the shop floor: productivity through process analysis*. Portland: Productivity Press, 182p.

Koskela, L. (1992). *Application of the new production philosophy to construction*. Technical Report No. 72, Stanford, CIFE. 75 p.

Soibelman, L.; Formoso, C.T. and Franchi, C.C. (1994). A study on the waste of materials in the building industry. *Proc. International Conference of CIB Task Group 16 – Sustainable Construction*, Tampa, Florida, 6-9 November 1994. University of Florida. pp.555-563

Womack, J.P.; Jones, D.T. and Roos, D. (1990). *The machine that changed the world*. Rawson, New York. 323 p.

Yin, R.K. (1994) *Case study research: design and methods*, 2.ed. Thousand Oaks: Sage, 171 p.

ACKNOWLEDGEMENTS:

This research project was made possible due to the financial support of SEBRAE/RS (Serviço de Apoio às Micro e Pequenas Empresas do Rio Grande do Sul). The authors also wish to thank the companies that participated in this research project.