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A CASE STUDY ON CAUSES AND CONSEQUENCES OF TRANSPORTATION WASTE

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ABSTRACT

Transportation is a waste category that has not been much explored in the literature on construction management. Moreover, the existing studies about it have focused mostly on its impacts and not on the causes. This paper aims to present the results of a second implementation of a method in order to identify, measure and characterize the transportation waste on physical flows of construction processes. A case study was performed in a residential building project, which involved the use of the Light Steel Frame technology. The research methods comprised the following sources of evidence: direct observation on site (work sampling and time studies), participant observation in planning meetings, and analysis of existing production control data. A database was produced containing a description of each transportation event, including pictures, causes, consequences, and its relationship with other types of waste, such as making-do, unfinished work, work-in-progress and rework. The main contributions of this study are concerned with the understanding of the nature of this type of waste, highlighting the classification of transportation waste causes, its main consequences and the relationships between this kind of waste and other ones.

KEYWORDS

Waste, transportation waste, making-do, physical flow.

INTRODUCTION

Waste is any human activity, which absorbs resource, but creates no value, such as mistakes, which require rectification, waste of time, production of items no one wants, inventories (Womack and Jones, 2003. Since 2011, a group of researchers from the International Group of Lean Construction (IGLC) has been involved in a project called "Understanding Waste in Construction" aiming to conceptualize waste in construction theory (Understanding Waste in Construction, 2015) with the publication of important contributions towards the development of such theory (Viana, Formoso

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and Kalsaas, 2012; Koskela, Sacks and Rooke, 2012; Koskela, Bølviken and Rooke, 2013; Bølviken, Rooke and Koskela, 2014; Perez, Costa and Gonçalves, 2014).

Viana, Formoso and Kalsaas (2012) put forth that many studies about waste in construction have mostly focused on the consequences and not on the causes, showing that further studies are necessary to increase the existing knowledge. In addition, transportation is a waste category that has not been examined much in those studies and in the literature on construction management.

In the present study, it was understood as the real problem the large amount of transportation waste found in construction processes. This statement was perceived by three exploratory studies and by the literature review (Thomas, Sanvido and Sander, 1989; Alarcón, 1994). These exploratory studies indicated that 36% to 46% of the activities of the mortar coating process were related to transportation activities.

Therefore this paper aims to identify different causes and consequences of transportation waste, associating them with other waste categories such as making-do, unfinished work, work-in-progress and rework. These four additional waste categories are included in the study due to their relevance at jobsites (Fireman, Formoso and Isatto, 2013). In order to achieve this objective, a case study in a Light Steel Frame (LSF) building project was carried out. This paper presents the results of the second implementation of a proposed method that aims to identify, measure and characterize transportation waste on physical flows of construction processes, made up of tools, indicators and definition of concepts to measure such waste from the viewpoint of their incidences, causes, consequences and the association with other categories of waste.

TRANSPORTATION WASTE AND OTHER CONSTRUCTION WASTE CATEGORIES

Transportation waste is described by Ohno (1997) as materials handling activities that generate cost and do not add value. Formoso, et al. (1997) state that waste is due to inefficiencies, which occur during the use of equipment, material, labor and capital in values superior to that required for the production. For these authors, transportation waste concerns excessive or inappropriate use of materials and components due to poor planning or inefficient jobsite logistics. Bølviken, Rooke and Koskela (2014) corroborate with Formoso, et al. (1997), defining transportation waste as waste that happens in the flow perspective, related to unnecessary movement of people or unnecessary transportation of materials.

The authors of this paper seek to contextualize transportation waste in construction, understanding that despite the fact that transport is a non-value adding activity, and efforts for its reduction and elimination are possible, transport activities are unlikely to be eliminated from the construction process. Therefore, due to the understanding that certain types of transport activities are necessary to guarantee the efficiency during the complete process, this paper considers that transportation wastes are due to the unnecessary transportation of materials, i.e. consuming resources such as time, which creates additional cost, but does not add value to the product.

Other kinds of waste have recently been examined in construction and they could potentially be associated as causes or consequences of transportation waste, such as making-do, unfinished work, rework and work in progress. Those waste categories and transportation waste unleash similar consequences, such as reduction of the working safety conditions, waste of material and increase in the share of non-value adding activities. Table 1 presents the current definition of these categories of waste and their main references.

Table 1: Possible associated wastes categories to transportation waste

Waste category	Definition	References
Making-do	It refers to a situation where a task is started without all its standard inputs, or the execution of a task is continued although the availability of at least one standard input has ceased.	Koskela (2004)
Rework	Doing something at least one extra time due to non-conformance to requirements.	Love, Mandal and Li (1999)
Work in progress	Working on fairly small tasks left from the previous plan	Hopp and Spearman (1996)
Unfinished work	It includes rework and small finishing tasks that are left over after a crew leaves a workstation.	Fireman, Formoso and Isatto (2013)

RESEARCH METHOD

Design Science Research was the research approach adopted in this investigation. This is a form of scientific knowledge production that involves the development of innovative constructions, intended to solve problems confronted in the real world, and simultaneously makes a prescriptive scientific contribution (Lukka, 2003). An important outcome is an artifact that solves a domain problem (March and Smith, 1995).

This investigation is part of a broader research project, which aims to propose an artifact represented by a method to identify, measure and characterize the transportation waste on physical flows. This paper presents the second stage of this research, in which the method proposed is implemented. The artifact was developed along the first case study in Project A, which was carried out on a traditional construction process, the mortar coating process with mechanical application, in a residential building project, located in the city of Salvador, Northeast of Brazil.

The second case study which is presented in this paper involved the implementation of the method in a residential housing project in Canoas, in the south of Brazil, called Project B. This project was chosen due to the use of LSF technology, a relatively new building system in Brazil, allowing the comparison of the causes of transportation waste in two different technologies, a traditional and an industrialized one. Project B consisted of 178 LSF houses built on shallow type raft foundation. The case study took place from November to December 2014, over a period of six weeks. Four processes were monitored: structure assembly; Oriented Strand Board (OSB) installation; roof execution; and facade execution. Twenty-five site visits of 4-6 hours each were conducted by the research team. Three types of data were collected during the site visits: (i) mapping physical flows; (ii) work sampling; and (iii) monitoring of transportation waste events. Additional data was collected from 6 weekly work meetings, such as Percentage of Plan Complete and causes of non-completion of the work packages. Some additional qualitative data were obtained through informal interviews and meetings with field project personnel, such as workers, crew leaders, field engineers and project manager. A seminar was carried out at the end of the study with the field team, in order to present and discuss the results.

DESCRIPTION OF THE PROPOSED METHOD

STAGE 1: MAPPING PHYSICAL FLOWS

The first stage of the method consists of mapping physical flows by using a process diagram and a layout diagram to document the processes (Ishiwata and Katō, 1991). The process diagram represents the sequence of various activities that make up a process. The layout diagram shows the places where each task is performed and indicates the main flows of materials and operations (Ishiwata and Katō, 1991).

STAGE 2: WORK SAMPLING

Work sampling was used to measure the amount of productive, contributory and non-contributory work. Productive tasks are the value-adding ones. Contributory works are the ones that support value-adding tasks, such as transportation. Non-contributory or unproductive tasks do not contribute at all for project execution (Picard, 2002). As the focus of this investigation is on transportation waste, the worksheet adopted involved a detailed breakdown of transportation activities. In this study it was adopted a 94% confidence level and 6% relative error, it was taken 1873 observations.

Throughout the modeling of flows, some transport activities have been identified that could be deemed necessary, avoidable and unnecessary. Thus, in order to identify those activities and measure the waste of time, the definitions of Santos, Formoso and Hinks (1996) were taken as a basis and adapted to the transportation activities, as delineated below:

a) **Necessary Transport Activity**: this refers to a transport activity that needed to occur for the flow of the process. Those were identified as the contributory tasks.
b) **Avoidable Transport Activity**: this refers to an inefficient transport process that causes waste of time, caused sometimes by lack of process control and can be easily reduced. This occurs due to planning flaws, inadequate sizing labor teams, supplies or equipment failures, omissions or design errors, rework, etc, and as a consequence those activities generate obstruction in the flow. Those were identified in the contributory tasks.
c) **Unnecessary or Idle Transport Activity**: this refers to unnecessary transport activity that caused waste of time, which was not planned and should be eliminated or complete inactivity of the workers on some transport activity, which may be intentional or the result of a physical state of predisposition. Those were identified as non-contributory work.

STAGE 3: OBSERVING TRANSPORTATION WASTES EVENTS

In order to characterize the transportation wastes, three constructs were defined based on data obtained on the previous steps, as follows:

a) **Transportation Waste Event:** this is defined as an unexpected phenomenon that happens in a transport activity, referring to an observable and registered fact in a particular place and at a particular time that affects the physical flows, causing a waste of time, the execution of unplanned tasks, and producing inefficiencies to the process.

b) **Cause:** this is defined as the origin of a certain transport waste event in a certain situation.
c) **Consequence**: this is defined as the effect or the result of a certain transport waste event or fact found.

The transport waste events identified were registered on a worksheet, including the following information: (i) photo; (ii) date; (iii) number of record; (iv) number of the same event per day; (v) people involved in the transport; (vi) type of transport; (vii) recurrent case; (viii) waste description; (ix) cause; and (x) main consequences.

Table 2 shows the classification of the main causes identified based on the nature of each waste, and Table 3 shows the classification with the main consequences of transport wastes identified throughout the study in Project B. It was considered that each transportation waste event could be related to one cause and to more than one consequence, but not exceeding three.

Table 2: Causes of transportation wastes' classification

Cause	Definition
Access/ Mobility	It refers to any kind of route obstruction, which makes the transport activity difficult.
Storage	It refers to inappropriate space for material storage or material stored in an inappropriate manner.
Equipment	It refers to unavailable, damaged or inappropriate equipment for transportation, generating the adaptation of other equipment for this transportation or appropriate equipment, but used in an inappropriate manner.
Team	It refers to insufficient number of workers to perform the transportation activity.
Packing material	It refers to the poor packing condition of the material, which makes the transportation slow and difficult.
Information	It refers to the lack of necessary information for the employees for correct transportation performance.

Table 3: Categorization of transportation wastes' consequences

Main consequences	Definition
Damage of material	The material being transported is damaged during the transportation activity.
Unsafe work conditions	Unsafe work conditions were caused due to the transportation activity.
A new transport operation	Anew transport operation would be required in the near future
A longer distance	A worker must move greater distance than it was planned.
Ergonomic problem	The ergonomic conditions of transportation operations are inadequate.

STAGE 4: ASSOCIATION BETWEEN TRANSPORTATION WASTE WITH OTHER WASTE CATEGORIES

Direct observation was performed in order to associate the transportation waste events with the work-packages from which they came from. Work-packages include both formal (planned) and informal work-packages. These were classified according to their nature (unfinished work or new package), as suggested by Fireman, Formoso and Isatto (2013). The metrics used for measuring the incidence of informal work-packages were the percentage of informal work-packages in relation to the total number of work-packages. These work-packages were categorized in: (i) completed formal work-packages; (ii) incomplete formal work-packages; and (iii) informal work-packages. Therefore, the percentage of transportation waste events in each group could be measured taking the number of events observed as part of completed formal work-packages, incomplete formal work-packages or informal work-packages. If the transportation waste events could not be related to any work package that was associated with an inventory or a logistic operation depending on the activity they supported.

In addition, each transportation waste event was related to another type of waste occurring at the same time, such as making-do, unfinished work, rework and work in progress. All the transportation waste events were analyzed to check if another kind of waste was involved or not.

RESULTS

PROCESS CHARACTERIZATION AND PHYSICAL FLOWS

The materials to be used in the following days were stored near by the proper raft. Horizontal transport was performed with a telescopic handler and with a tractor. The vertical transport was performed by hand through the facade scaffoldings. A facade scaffolding was used for the execution of the facades.

The findings of the process diagram and layout diagram of the four processes studied showed a similar relationship between the activities. Considering all process activities, 10% represent processing activities, 40% represent transport activities, 20% represent stock activities and 30% inspection activities.

DISTRIBUTION OF WORKERS TIME AND TRANSPORT ACTIVITIES

Table 4 shows the work sampling results. Concerning the productive work, frame assembly presents the highest productive time (66% observations), followed by the roof installation (37%), frame assembly (24%) and OSB installation (23%).

Table 4: Work Samplings Results

Time		Frame Assem.	OSB Inst.	Roof Inst.	Facade Execut.	Global LSF
Productive Work		24%	23%	37%	66%	33%
Contributory work	Necessary Transport	12%	12%	7%	3%	11%
	Avoidable Transport	17%	4%	4%	1%	6%
	Others	23%	25%	11%	13%	22%
Non-contributory work	Unnecessary Transport	0%	14%	0%	0%	5%
	Others	24%	22%	41%	17%	23%
Total time		100%	100%	100%	100%	100%

Analyzing all the times destined for transportation activities, the random observations revealed that the OSB installation process was one where more time was allocated to carry out transport activities (30% of observations), followed by frame assembly (29%), and the roof installation (11%) and the façade execution (4%). It was considered, in this study, that avoidable transport and unnecessary transport are a time waste factor, thus 17% of the time destined by frame assembly is a waste of time, 18% for OSB installation, 4% for roof installation and 1% for façade execution.

TRANSPORTATION WASTE EVENTS

This study identified 23 transportation waste events. Table 5 presents the transportation waste events identified, organized by their causes. Besides the five main consequences identified in this case study, the waste of time was continuously identified as an impact arising from the transportation wastes events. In terms of qualitative data, the results show that access and storage were the main causes of transportation waste events, 35% and 39% respectively of the transportation wastes events, and the creation of a new transport operation (32% of the events). In addition, the unsafe work conditions (32% of the events) were the main consequences of the transportation waste events.

Table 5: Transportation wastes events

Cause	Transportation waste events	Transport activity with waste event	N. of events	Consequences
Access/Mobility	Presence of obstacles (materials, rubble, infrastructure hole) in the access routes.	Horizontal transport of the structure by hand	6	A new transport operation Unsafe work conditions Damage of material
		Vertical transportation of the structure by hand	1	Ergonomic problem A longer distance
	Door smaller than the workbench	Workbench transportation for OSB installation	1	Damage of material
Storage	The loader driver must come down to remove other manually stocks	Loader transport to storage area	5	Damage of material
		Transport loader to the raft foundation	2	Unsafe work conditions
	Employee improvises stock	Unloading of OSB to the storage area	2	A new transport operation
Equipment	Lack of a loader	Transportation structure by hand on the ground	2	Unsafe work conditions Ergonomic problem
	Telescopic handler with difficulty	Loader transport to storage area	3	Damage of material
Team	Lack of one of the collaborators on the scaffolding	Vertical transportation of the structure	1	Unsafe work conditions

ASSOCIATION OF TRANSPORTATION WASTES EVENTS WITH OTHER WASTE CATEGORIES

The transportation wastes events were classified according to the work-package (formal or informal) or stock and logistic activity that they supported (Figure 1). The results show that 39% of the transportation waste events were not related to work-packages, due to the fact that those flow activities such as logistics and inventory are not included in the weekly work plan as an assignment. In addition, 13% of the events were observed during the performance of informal work packages, and 48% of the events happened during the performance of a formal work package.

The 23 transportation waste events collected were reanalysed in order to identify other categories of wastes, which these events could be associated with (Figure 2). In some events other waste categories studied were identified as cause, in other cases they were identified as consequence, and also in some other cases, it was possible to observe that other waste categories studied could be both cause and consequences. It means that the relationship with other waste is not always uni-directional, being often cyclical. The findings show that 39% of the transportation waste events are related to making-do waste. Although, it seems that a large percentage (35%) of the transportation waste events identified happens for other reasons, different from the existence of other waste categories.

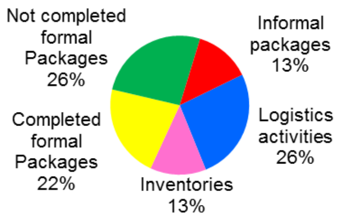

Figure 1: Association of the transportation wastes events with work packages

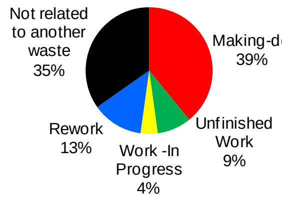

Figure 2: Wastes categories identified at transportation wastes events

The integrated use of the four tools, such as process diagram, layout diagram, work sampling and photographic records with the data collected from weekly work meetings, allowed the calculation of eight main indicators, as shown in Table 6.

Table 6: Tools, indicators and results

Tool	Indicators collected	Results obtained
Process Diagram	(1) Percentage of transport activities in relation to all process activities	40%
Work sampling	(2) Percentage of productive time	33%
	(3) Percentage of time related to transportation activities (necessary, avoidable, unnecessary)	23%
	(4) Percentage of time waste related to avoidable and unnecessary activities	11%
Worksheet with photographic records	(5) Main causes of transportation wastes	Access Storage
	(6) Main consequences of transportation wastes	Unsafe work conditions A longer distance
Worksheet and Layout Diagram	(7) Place with most occurrences of transportation waste events	Access routes
Worksheet and data collected from weekly work meetings	(8) Other main waste category identified during the identification of transportation waste events	Making-do waste

According to data collected from the seminar, it was observed that project managers and field engineers were aware of their logistic problems; however, they were surprised concerning the high percentage of time spent in transportation activities, the large amount of transportation wastes events identified, and their causes and consequences. For the project team, their major logistic problem was concerned with equipment; nevertheless the results pointed out that the greatest amount of transportation waste came from storage causes and access/mobility, because despite the project had equipment, it was difficult to used them because the route access were not adequate.

CONCLUSIONS

The first contribution of this paper is the better understanding of the meaning, identification, measuring and characterization of transportation waste in construction. The transportation waste event was defined as an unexpected phenomenon that happens in a transport activity, referring to an observable event with the possibility to register the fact, in a particular place and at a particular time, that affects the physical flows, causing the execution of unplanned tasks, and producing inefficiencies to the process. Thus, a transportation waste event can be characterized by its occurrence, its cause and its consequences.

The cause of a transportation waste event was defined as the origin of a certain phenomenon in a certain situation and a long this study, the main causes of transportation waste identified were related to the access/mobility, storage, equipment, team, packing material and information. From the perspective of the consequences of a transportation waste event, it results from facts found, such as damage of material, unsafe working conditions, a new transport, a longer distance, and ergonomic problems.

Therefore, the study identified and measured that all transportation activities are not waste, given that certain types of transport activities are necessary to make the flow possible. In order to discriminate the different types of transportation, a classification of the transportation types was proposed in this study. Necessary transport is defined as a transportation activity that needed to occur to contribute to process flow; avoidable transport, means a transportation activities which can be reduced; and the unnecessary transport refers to a transportation activity which was not planned and should be eliminated. Thus, the transportation activities that can be reduced (avoidable transport) or eliminated (unnecessary transport) were understood as a waste of time.

The practical contribution of the implementation of this method refers to the combined use of the tools and indicators to identify, measure and characterize the transportation waste from the viewpoint of its recurrence, causes and consequences. The use of the method increases the information for managing the transport waste in construction, providing a wide range of qualitative and quantitative data.

In addition, it was possible to validate that the classification of the causes identified and proposed based on a traditional process case would be tailored to an industrialized process. Most of the transportation events identified in LSF system studied originated from access/mobility and storage problems. The next stage is the assessment of its utility as an artefact and practical contribution.

Another important conclusion is the strong relationship between transportation waste and making-do, due to the fact of that both could be a main cause and main consequence of the waste events identified. It means, that this relationship is not always unidirectional, being sometimes cyclical, therefore it is difficult to distinguish which kind of waste comes first.

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