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A CONCEPTUAL FRAMEWORK FOR THE PRESCRIPTIVE CAUSAL ANALYSIS OF CONSTRUCTION WASTE

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ABSTRACT

An initial step towards a prescriptive theory (a set of concepts) to inform the elimination of waste on construction projects. The ultimate intention is to identify the most important types and causes of waste in construction and outline the principal causal relations between them. This is not a straightforward process: the relationships form a complex network of chains and cycles of waste.

Waste is defined as the use of more resources than needed, or an unwanted output from production.

A conceptual schema of Previous Production Stage > Production Waste > Effect Waste is proposed and applied to the causal analysis of two major types of waste: material waste and making do.

KEYWORDS

Waste, value, value stream, causality, networks of waste

INTRODUCTION

The aim is a theoretical contribution to a practical ambition: increased productivity in construction through a reduction in waste. Waste can be defined as the use of more resources than needed, or an unwanted output from production (Bølviken, Rooke and Koskela, 2014). In fact, the strategy to increase productivity through the decrease of waste is probably one of the common features of all so called "lean" approaches.

The paper is based on previous historical, theoretical and empirical work on waste presented at previous IGLCs: Viana, Formoso and Kalsaas (2012) review existing construction management literature, finding a lack of conceptual development; Koskela, Sacks and Rooke (2012) provide a historic overview of the term, demonstrating its strong normative dimension; Koskela, Bølviken and Rooke (2013) argue that Ohno's (1988) original list of wastes is not universal, but related specifically to manufacturing; Bølviken, Rooke and Koskela (2014) propose a taxonomy of construction wastes within a TFV framework (Koskela, 2000).

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The objective is a more thorough conceptualization, that can be used for systematic waste reduction; specifically, an initial understanding of the causal relations between different kinds of waste. The difficulty lies in the complexity of these relations; not only the sheer number of possible relations, but also the qualitatively different logistical, financial and social dimensions on which they lie (Andersen et al., 2008). For this first step, we have focussed on two types of waste (making do and material waste) and have restricted our analysis to the logistical dimension (primarily the 'physics' of production).

We first recap and update the Viana, Formoso and Kalsaas (2012) review. This is followed by a conceptual exploration of the nature of cause in production. Finally, drawing on previously published case studies, we present models of the causal networks surrounding the two types of waste.

REVIEW OF PREVIOUS STUDIES

This section presents a review of papers that have investigated waste in construction, including concepts adopted, metrics, and type of feedback provided, mostly based on a previously published literature review (Viana, Formoso & Kalsaas 2012). It is complemented by additional papers published between 2012 and 2015 (Fernández-Solis and Rybkowski, Z. 2012; Sarhan, Pasquire and King 2014; Perez and Costa, 2014, Bølviken, Rooke and Koskela 2014). The main sources were IGLC conference papers, Lean Construction Journal and seven mainstream construction management journals[5]. After the first selection of papers, a database was created in a citation manager, in order to check duplicates and apply quality criteria in the selection of papers. Some additional references cited in the selected papers were also included in the database. After several refinements, 56 papers were selected. These were analysed in detail, considering the following content: (i) the concept of waste adopted, whether it was explicit or not; (ii) the kind of waste that has been analysed; and (iii) the main contribution of the paper to the topic of construction waste. The main conclusions of the literature review follow:

(a) Many papers do not present a clear definition of waste, either explicit or implicit. Only 41% properly presented a conceptualisation of waste in a broad sense, and 16% defined only a specific kind of waste that was addressed, such as rework, making-do, or defects. Three different groups of concepts were identified in the set of papers: (i) waste as non value-adding activities (29 papers); (ii) waste as material loss (10 paper); (iii) specific types of waste (17 papers), such as rework;

(b) There are different conceptualizations of the same type of waste, which makes it difficult to perform a meta-analysis of the data. For instance, several papers discuss the incidence of rework in construction projects (e.g. Ashford, 1992; Love 2002). However, none of them contain much discussion of the concept of rework, nor a clear definition from the industrial engineering point of view. Moreover, the source of data is not always fully described, there is little contribution on how to measure rework, or investigation of its root causes.

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[5] Architectural Engineering and Design Management; Building Research & Information; Construction Management and Economics; Engineering, Construction and Architectural Management; Journal of Architectural Engineering; Journal of Construction Engineering and Management; Journal of Management in Engineering

(c) Two main types of contribution can be identified: investigation of causes; and production of metrics. However, nearly half of the papers were mainly based on surveys. A wide range of indicators has been used, ranging from physical quantities, such as the volume of debris taken from the site (Gavilan and Bernold 1994; Poon et al., 2004), to costs, such as defective products (Ledbetter, 1994) and rework (Hwang et al., 2009). Time has often been used, especially to identify the share of non-value adding activities (Horman and Kenley 2005; Forsberg and Saukkoriipi 2007; Yu et al. 2009; Kalsaas 2010), as well as the number of non-value adding steps (Lapinski, Horman and Riley 2006; Mao and Zhang, 2008).

(d) Proposed actions for reducing or eliminating waste are also very diverse. Some papers describe attempts to change practices by implementing lean techniques (Nahmens and Ikuma, 2011), while others use simulation models to support decision making, by testing measures to reduce the share of non value-adding activities (e.g. Tommelein, Riley and Howell 1999; Sacks, Esquenazi and Goldin 2007).

(e) The number of papers on the development of methods for identifying and measuring waste is relatively small and most focus on two types of method: the measurement of material loss, including direct and indirect waste (e.g. Sloyles 1976; Formoso et al., 2002) and value stream mapping for assessing the share of non value-adding activities and designing a future state (e.g. Choi et al., 2002; Yu et al 2009).

Overall, the number of papers is small, considering its relevance for the field of construction management. Some studies from the Lean Construction community pointed out the need to use a broader conceptualization of waste, based on the idea that it is necessary to remove activities that do not add value from the perspective of the client (Formoso et al., 2002; Koskenvesa, 2008; Koskela, 2004). Most studies do not discuss the conceptualization of waste at an abstract level. Some simply adopt an operational definition in order to guide data collection.

STATIC, DYNAMIC AND COMPLEX WASTE

Waste in construction can be divided into static and dynamic. Static waste is additive, whereas dynamic waste propagates in complex and emergent ways. The relationships between wastes can take several forms, including linear chains, cycles, and networks. The relationships between wastes can be either uni-directional or interactive.

STATIC WASTE

Static waste can be divided into two types: point-wise, occurring in the framework of an individual tasks, adding to the use of resources, but always in the same way; system-wide, consisting of sub-optimal work-flows, e.g. unnecessary tasks.

The salient feature of static waste is that it does not increase unpredictability (variability). It has been designed into a task or production system, i.e. is a question of bad design. Thus, the solution is to redesign the task or production system.

DYNAMIC PROPAGATION OF WASTE

This section is based on Hopp and Spearman (1996, 2000).

There are two types of variability in flows of production: process-time variability and flow variability. Process-time is the time required to process a task at one workstation. It is subject to: natural variability (minor fluctuation due to differences in operators, machines and material); random outages; setups; operator availability;

and rework (due to unacceptable quality). Waste is a major cause of this variability. Flow determines the arrival of jobs at a particular workstation. Where this deviates from an agreed schedule, waste is also a major, though perhaps not the only cause.

It can be shown that variability increases lead time. If it is not possible to reduce variability, one or more of the following have to be accepted: long lead times and high WIP levels, wasted capacity, lost output.

Queuing theory is useful in demonstrating how waste generates other waste in the temporal dimension of production. Another important result contribution is to show that variability early in the line is more disruptive than variability late in the line.

Countermeasures against dynamic waste include continuous improvement and optimal production control (e.g. pull/push decisions, location and sizing of buffers).

CHAINS, CYCLES, NETWORKS AND PATTERNS OF WASTE

Both Ohno (1988:55) and Shingo (2005:154) introduce a conceptualization of causal relationships between the different wastes where one type of waste (overproduction) is a 'primary' waste generating other wastes. Koskela, Bølviken and Rooke (2013) refer to this phenomena as a chain of wastes with one waste acting as a core or lead waste. The reasoning of all three is that by attacking this core, one can also eliminate the wastes caused by it. There can however be good reasons to focus on the resulting waste. For example, if overproduction is the effect of one or more chains of waste, an operational strategy focusing on the reduction of this effect can trigger a root cause analysis leading to the core wastes in the system. In this example, overproduction can be seen as both core and result waste; instead of a linear chain, we see a cycle of waste generating waste (Ohno, 1988, p. 55).

Furthermore, if one waste in a cycle is causing several others and these result wastes are also interconnected, we can conceive a complex network of wastes. The network is characterized by the causal interconnections between its nodes.

Finally, the causal connections between nodes as not necessarily uni-directional. They can be reciprocal, A leading to B while at the same time B leads to A.

Our line of reasoning has taken us from the conceptualization of a linear chain with clear causes and effects to a complex network with both uni-directional and interactive connections between the nodes. In such a complex network we may not be able to identify and analyse all the connections. We see a pattern, but are not able to decompose or decode the network in all its components and interconnections.

CONCEPTUAL MODEL

Here, a conceptual model is proposed for representing causal relationships between different types of waste. The model is concerned with production control, pointing out categories of waste that should be the focus of waste elimination in production management. If the focus is another stage of construction projects, such as design, procurement, supply chain management, other waste categories should be identified.

The conceptual model is represented as a network of constructs, as shown in Figure 1, being divided into three main zones:

1. Effects (terminal or result waste): these are formed by traditional categories of waste that are strongly related to the effects of wasteful production processes. Some of these categories have been the focus of several measurement studies, such as material losses, and non value-adding time.

2. Production waste: these are the categories that are relevant for production control. Some of them represent concepts that are not widely known or used as a focus for improvement in the industry, such as making-do, work in progress, unfinished work. In fact, its inclusion is due not only to its importance in performance improvement, and also because these concepts might be useful to show non-obvious problems. Waste is not always obvious: it "often appears in the guise of useful work" (Shingo 1988:71). Each production waste category has cause-effect relationships not only with terminal waste categories, but also with other production waste categories.
3. Previous production stages: in this zone some of the previous production stages are represented, since failures in those stages are the root causes for the production waste categories. Understanding the relationships between previous production stages and production categories is important for devising strategies for waste elimination.

This model is relatively consistent with other conceptualisations. Fernandez-Solis and Rybkowski (2012) proposed three different waste concepts: discrete; synergistic; and systemic. The first corresponds to terminal waste; the second includes production waste, plus categories related to some of the previous production stages at the project level; the third mostly relates to the loose coupling of stakeholder organizations, resulting in duplication of effort and miscommunication. The concept of institutional waste (Sarhan, Pasquire and King 2014), though based on a different theoretical framework, is similar to synergistic waste, existing at the supply chain level.

Figure 2 presents constructs and connections identified in a case study by Formoso et al. (2002), Figure 3 presents a similar network for a study of making do (Formoso et al., 2011).

CONCLUSION

The causal models provided in the previous section represent a first step towards a systematic and comprehensive analysis., providing a three part conceptual framework and outlining some causal relationships between major categories of waste. They represent waste as a complex and dynamic causal network in which waste generating further waste, sometimes in a uni-directional, but often in an interactive and/or cyclical manner. Figures 2 and 3 demonstrate the application of the generic model to empirical studies of actual waste generated on site.

The models are limited to a logistical analysis, but are capable of being extended to include financial and organizational dimensions. The conceptual model does not, as yet, include a measurement of magnitude which would show the increase in downstream waste generated by upstream waste. Perhaps for this reason, it does not yet indicate any candidates for a core waste or wastes. Alternatively, it may be that such central wastes are not to be identified in construction and that the causal mechanisms are much more diffuse than in manufacturing.

The next step will be to build on these models, supplementing them with further conceptual development and additional empirical data.

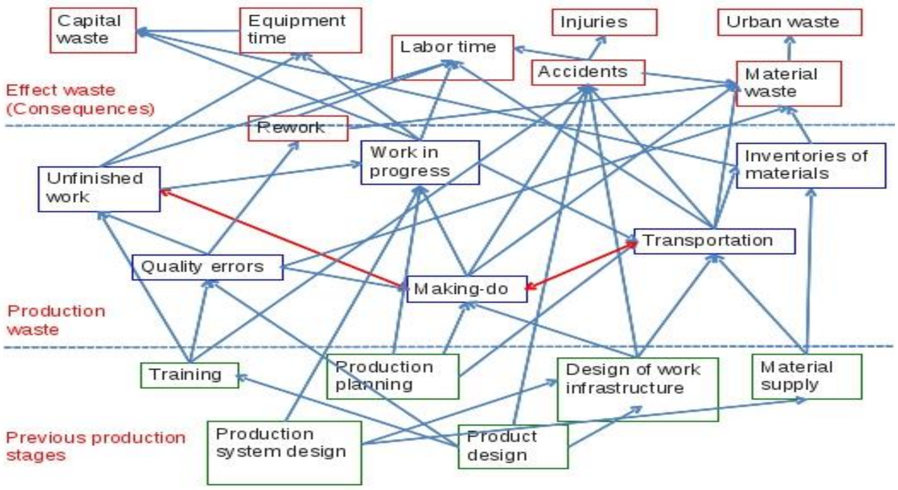

Figure 1: Taxonomy of waste – preliminary proposal

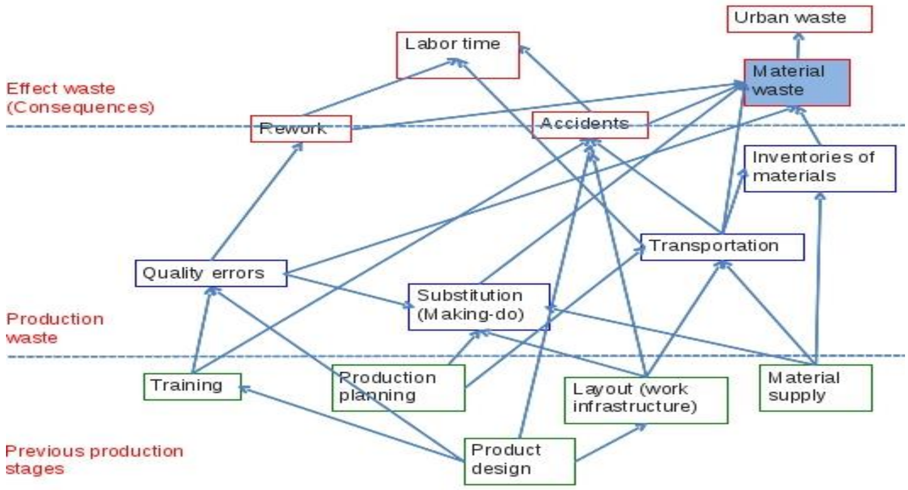

Figure 2: Causal network for material waste (based on Formosa 2002)

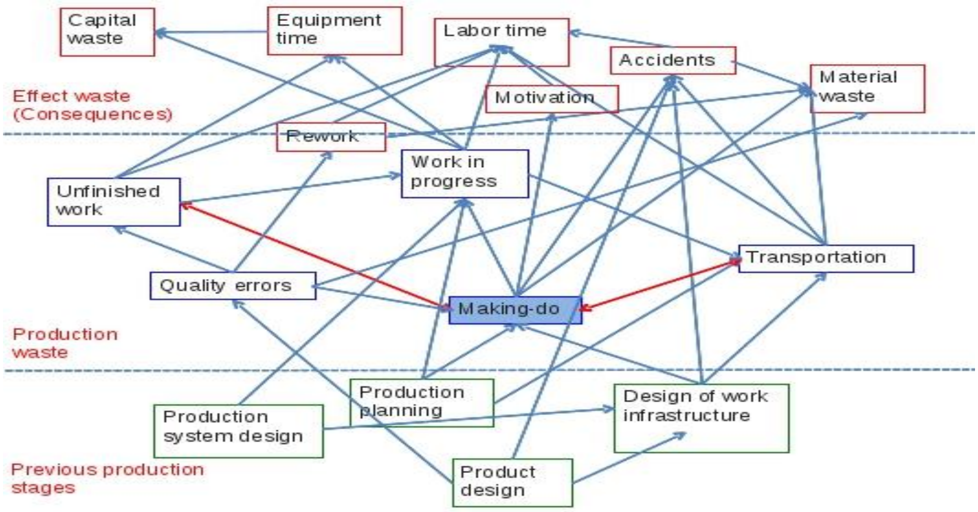

Fig 3: Causal network for making do waste (based on Formoso, Sommer, Koskela and Isatto 2011)

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