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Evaluation of Waste and its Causes in Structural Design Process in South African Construction Industry

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The construction design process consists of five main phases: the inception design phase, the predesign phase, the detailed design phase, the construction phase, and the close-out phase. Each of these phases is fraught with waste that affects project performance. This research investigates such waste and its causes in the structural design process (SDP), through an analysis of in-depth interviews that were conducted among 25 consulting engineers in Bloemfontein, South Africa, in 2017. The engineers have extensive experience in the SDP, and are affiliated with Consulting Engineers in South Africa. Data was collected through face-to-face interview with semi-structured questions, and analysed thematically. The findings from the study indicate that waiting time, design error, over-processing, excessive vigilance, overproduction, and correction/rework are the main forms of waste in the SDP. Based on these findings, the research concludes that waste occurs in virtually all phases in the current practice of the SDP. The study recommends that designers and contractors should work together as a team at the design stage of projects so as to identify and reduce SDP waste for effective delivery of construction projects. The research also recommends that further studies, which go beyond merely establishing correlations, and which attempt to evaluate the causal pathways of the dominant waste in the SDP, should be conducted. Further research that explores mechanisms such as lean tools for waste identification and reduction in the SDP is thus recommended.

Keywords: Construction, Design, Engineers, Industry, Waste

Introduction

The main objective of the design phase of construction projects is to produce a structure that is capable of withstanding all imposed loads without failure during its intended lifetime (Al Nageim *et al.*, 2010). This objective is explicitly carried out by a structural design team (SDT) in the structural design process (SDP) (Nelson *et al.*, 1988). The SDP is made up of five distinct phases, namely the inception design phase (IDP), the predesign phase (PDP), the detailed design phase (DDP), the construction phase (CP), and the close-out phase (COP), (Al-Aomar, 2012; Melhado & Agopyan, 1996).

The literature shows that the abovementioned phases are full of activities and problems that constitute waste in construction (Koskela *et al.*, 2013). Such activities include design errors that require correction, and excessive waiting for employees at the site of work (Womack & Jones 2003). According to Koskela (1992), waste is any form of unnecessary work done and material loss that can increase production costs but not add value to the product itself. AbdelSalam *et al.* (2010)

maintain that of all the processes in a project, the design phase is the most critical aspect. This phase is critical, as it is in this phase that values are explored and expressed, and when this phase is well managed, waste and associated problems can be minimised in the construction phase (Li *et al.*, 2008).

Researchers have investigated how construction waste can be reduced or eliminated through the design phase of a project (AbdelSalam *et al.,* 2010; Ko & Chung, 2014). However, the findings in the reviewed literature indicate that attention is focused mainly on the architectural process (AP); the aspect of the SDP is still unexplored. Ko and Chung (2014) emphasise that AP is by nature a multidisciplinary effort that requires the consideration of many aspects, such as structural composition, water drainage, and many more. Based on this emphasis, it can be assumed that the analytical frameworks devised by previous researchers for waste elimination in the AP may be generalised to other aspects of project design. However, the desire of the SDT to produce a structure that is capable of resisting all imposed load without failure during its expected lifetime necessitates that structural design be explicitly distinguished from (AP). Hence, further studies are required to expand on the existing theories and knowledge in other aspects of project design such as SDP. Premised on this requirement, an exploratory study was conducted in Bloemfontein, South Africa, to investigate the various types of process waste that originate from the SDP.

Literature review

Waste in Construction Projects

Waste in construction projects is any form of unnecessary work done and material loss that can increase production costs but adds no value to the product itself (Koskela, 1992). Studies by Al-Aomar (2012) and Koskela *et al.* (2013) revealed that construction waste can also be defined as any activity on site that produces costs directly or indirectly and takes time, resources or requires storage, but does not add value or progress to a particular product.

Waste in the Design Phase of a Project

The literature indicates that typical forms of waste or non-value adding activities in the design phase of projects are unclear information/specification specifically in the architectural drawing, unnecessary delay, design error, omission or correction and design rework (Ko & Chung, 2014; Aka *et al.,* 2017).

The Categories of Waste in the Design Phase of a Project

Waste in the design process can be grouped into seven categories. They are defects (corrections), overproduction, over-processing, waiting (delay), inventory, motion, transportation and unexplored creativity of employees (Womack & Jones, 2003; Koskela *et al.,* 2013). In another study by Koskela (1992) and Alarcon (1997), it was discovered that waste in the production environment can be grouped into two categories which are waste in manufacturing and waste in construction. Typical examples of waste in manufacturing are waste due to defective products, wait periods, overproduction, over-processing and motion. While some of the examples of waste in construction are rework, design error, clarification, excessive vigilance, and work not done. These categories of waste are discussed in more details as follow:

Waiting time: Womack and Jones (2003) and Simms (2007) classify all forms of delay in processing any unit of engineering work as waiting time. Typical example of this form of waste is waiting for information or materials when design activities have already commenced (Sunjka and Jacob, 2013).

Over-processing: Nazech *et al.* (2008) explain that over-processing occurs in a project when resources are being used or applied more than is necessary or required.

Motion: According to Womack and Jones (2003), motion includes any unnecessary physical movement by workers which diverts them from actual processing work. It may include difficult physical movements which slow down the workers performances

(Womack & Jones, 2003). Motion in engineering work can also be defined as all forms of waste that can be likened to using inefficient software (Simms, 2007).

Design error: A design error refers to the failures of humans to design tasks according to the standard specifications/requirements within time limits and accuracy (AbdelSalam *et al.*, 2010; Ko & Chunk, 2014).

Overproduction: In engineering design, processing an order before it is needed, or any processing that is done on a routine basis regardless of the current demand, is known as overproduction (Ohno, 1988).

Excessive vigilance/waiting time: Excessive vigilance in the engineering design refers to all forms of unnecessary supervision in the design activities (Ohno, 1988).

Correction/rework: Hwang *et al.* (2009) and Mastenbroek (2010) contend that correction/rework implies repeating a process or step several times.

The aforementioned waste can be removed from the construction process through different lean concepts and tools (Ko & Chung, 2014).

Research methodology

This research aims to identify the various categories of waste that are significant to the SDP in the South African context. It also investigates the causes of these types of waste, as well as their impact on the design and construction phases of building projects. In order to achieve these aims, in-depth interview was conducted with consulting engineers in five different firms located in Bloemfontein. The selection of the firms was based on purposive sampling techniques (Ritchie & Lewis, 2003). That is, firms that have designers with extensive work experience in the SDP, and who are affiliated with Consulting Engineers South Africa (CESA), were chosen. Specifically, five designers were interviewed through face-to-face with semi-structured questions in each firm. The questions that were asked during the interviews were to produce in-depth understanding in the following specific aspects:

The various phases in the SDP;

The various values and non-value-adding activities at each phase;

The factors that cause non-value-adding activities, and the frequency of their occurrence in different projects; and the impact of non-value-adding activities on the design and construction phases of projects.

At the start of each interview, the respondents were reminded of the research aim and objectives. This process was followed by the actual interview questions, which were guided by a semi-structured protocol (McNamara, 2009). The interviews were conducted over a two-month period in 2017, and the duration of each interview session ranged from 45 to 55 minutes. In total, 25 engineers participated in the study. As recommend by Arksey and Knight (1999), all the interview discussions were tape-recorded and transcribed. After transcription, the resultant information was analysed using content analysis. This approach was adopted as it enables verbal information to be categorised for the purposes of classification, summarisation, and tabulation (Bryman, 2001; Krippendorff, 2012). The themes that were obtained from the analysed data were then validated through a follow-up interviews, which were conducted with the chief engineer of each of the studied firms (McNamara, 2009). Table 1 shows the demographic information of the selected firms in this study. Due to ethical considerations, the names of the studied firms are referred to by letters of the alphabet, as shown in the table.

Table 1: Demographic information of the various firms in this study

Name of the firm	Participants' experience (years)	Number of participants
A	> 15	5
B	> 10	5
C	> 15	5
D	> 15	5
E	> 10	5

Findings and discussion

Activities and waste in the inception design phase

From the study, it was discovered that the inception design phase (IDP) of the SDP is important, as issues related to imprecision, requirements, and needs are addressed in this phase by the SDT before the start of a new project. It is at this phase that the necessary agreements between the architect/the client and the SDT are established. Such agreements include the nature (scope/appearance) of the work, the basic professional charges, and the method and time of payment. Once the necessary agreements have been established, the SDT conducts a topographical survey of the proposed site, using the services of a professional Land Surveyor. This enables the team to acquire a hands-on understanding of the conditions of the site, to determine its nature/size, and to obtain necessary information on its terrain. A review of other existing structures/projects in the vicinity of the site is also conducted by the surveyor during this visit, so as to enable the SDT to analyse their impact on the proposed project. After the site topographical survey, the SDT often executes a site soil test, using the services of a geotechnical engineer, and it oversees the compilation process of the site report.

To be precise, the different types of waste, otherwise known as non-value-adding activities in the IDP of a project can be summarised as: waiting for fund specifically from the clients due to slow decision making by the project's actors; ineffective site workflow or difficulties in accessing the site freely due to gaps in the topographical survey (sloping, rocky, valley or high-hill surfaces); excessive soil tests or site visits when the proposed site has unstable soil; waiting to establish the scope of the work due to poor architectural briefing and too many changes in the architectural drawings, and poor site report which occur when the information supplied by the geotechnical engineer conflicts with the existing knowledge of the SDT.

In the interviews conducted, all the respondents agreed that the above highlighted waste occur in virtually every construction project, with the exception of ineffective site workflow which occur only occasionally.

Activities and waste in the predesign phase

The predesign phase (PDP) is the second stage in the SDP, and its main objectives, according to the responses from the focus group interviews that were conducted to finalise the project concept, and to clearly lay out the procedures needed by the designers in order to complete the next phase of work. This means that in the PDP, the SDT thoroughly studies the architectural plan and draws attention to the general layout and the preliminary sizing and stability of the proposed structural elements. Hence, the preliminary sizing and stability of structural elements such as columns, column footings, the foundation, slabs, the beams, and the roof are computed in this phase. The computations are performed in accordance with the requirements of the applicable building codes, as well as the outcome of the site soil tests. The study shows that the architectural drawings are often defective, particularly with regard to specifications for column sizes, footings, and slab thickness. The PDP therefore allows room for comments and interactions between the SDT and the architect, for necessary corrections/adjustments in the architectural drawings. Once consensus has been reached between the architect and the SDT, the predesign activities will be finalised and passed on to the chief engineer of the consulting firm, for final assessment.

To be succinctly put, some of the waste discovered in the PDP of a projects during this study are: ambiguities in the architectural drawings due to inadequate communication between the architect and the SDT during the architectural process; excessive meetings between the client, the architect, and the SDT so as to attain consensus on issues relating to the architectural drawing; design modifications due to changes in client requirements;

lengthy and repeated structural computations due to lack of suitability of the existing technology i.e., every structural work is unique in nature.; design error due to human error during the computation of structural elements; excessive printings of paperwork due to design complexity, and excessive supervision due to stipulation of procedures in the case study consulting firms.

It is worth noting that all the respondents in the interview conducted agreed that ambiguities in the architectural drawings are the main challenges in the PDP of SDP, as they are responsible for most of the problems encountered by the SDT. One of these ambiguities is specification for a large floor size. The respondents explained that a large floor size could lead to long beam specification, with a consequent increase in project costs. The respondents argued that when this occurs, it is the responsibility of the SDT to instruct or advise the architect to revise the architectural drawings.

Activities and waste in the detailed design phase

With regard to DDP, it was discovered that this phase involves detailed consideration, determination and selection of the most suitable alternative solution in terms of the proportions, dimensions, and connections of structural elements defined in the predesign phase, in order to create the complete, perfect, and final structural drawings/specifications for the proposed project. In addition, comments/observations made by the chief engineer at the predesign phase are incorporated into the work before the final structural drawings are produced. Once the final drawings have been produced, the designer (the junior structural engineer) passes the drawings on to the senior engineer for approval, and then to the project director of the firm. Approval of work by the senior engineer takes approximately two weeks for minor work, and four to five weeks for major work. After approval, the SDT compiles the detailed design documents. The team then prepares the construction drawings, which will be handed over to the contractors. To be concisely put, the various forms of waste in the DDP of a project are: design correction due to mistakes made by the SDT in critical areas in the production of structural drawings; redesign due to wrong computation of a structural element in the predesign phase; excessive printing of paper work for necessary corrections and contributions before proceeding to the next stage of work; inability to complete work as earlier scheduled due to excessive contributions, corrections, and adjustments in the course of the work, and waiting to establish detailed design documents due to all the problems experienced in the DDP phase by SDT.

In the interviews study, all the respondents asserted that excessive printing of paperwork and inability to complete tasks as earlier scheduled constitute the main waste in DDP of a project. Some of the respondents argued that these problems will persist in the system for as long as work hierarchy remains a priority for the design firms.

Activities and waste in the construction phase of projects

In an ideal situation, it is anticipated that construction contractors should be able to effectively handle the execution of projects without the presence of a representative of the SDT. However, from the study it was discovered that a member of the SDT of the consulting firm is at one time or another needed on site, particularly at the start of every new task. The reason for this is to answer questions and to provide interpretations for aspects that are not clear to the contractors. Consequently, most of the engineers in the studied firms make it obligatory to visit their sites at least twice a month, in order to control the measurement/quality of work, with the idea being that this will keep the number of on-site requests for information (RFIs) to a minimum. However, the interviews study reveals that due to the many construction issues, the number of RFIs at the time that this study was conducted was still very high. In brief, the various forms of structural design waste associated with the

construction phase of a project are: excessive RFIs due to several unclear structural information/specifications by the contractors; excessive waiting time during structural reinforcement due to complexity of the structural drawings; variation or changed orders due to sudden changes made by the client during site activities; redesign due to unavailability of the materials specified in the structural drawing; wrong fabrication of formwork, rebar cages, and reinforcing steel due to wrong interpretation of the structural drawing, and excessive supervision due to the need for the construction contractor to comply with the necessary regulatory authorities.

According to some of the respondents of the interview study, excessive RFIs constitute the main problem in the construction phase, and RFIs may occur as many times as possible, particularly in a large project, such as the construction of a commercial or non-residential (multi-storey) building or an industrial building.

The categories of waste in structural design process

In this study, the categories of waste discovered in each phase of SDP are presented in Table 2, 3, 4 and 5.

In the current study, most of the respondents agreed that unnecessary waiting in the IDP of a project leads to delays in the start of site activities, which increases the overall costs of a project. This is consistent with the findings of Sunjka and Jacob (2013) regarding the impact of delays on construction costs in the design phase of a project. All the respondents further asserted that over-processing, in the form of several soil tests in order to determine the exact bearing capacity of the soil in the proposed site, wastes time, resources, and money. The respondents maintained that this could lead to delays in the commencement of site activities. Some of the respondents asserted that motion in form of ineffective site workflow could lead to delays in completion of the site topographical survey.

Table 2: The categories of waste in the inception design phase

Waste categories	Waste type
Waiting time	1. Waiting for fund release from the clients; 2. Waiting for the start of structural work; 3. Waiting for the site report; 4. Waiting to establish the scope of the work; 5. Waiting to execute contract agreement between the clients and the designers, and 6. Waiting for the compilation of inception design documents
Over-processing	1. Several soil tests, and 2. Several site visits
Motion	1. Ineffective site workflow

Table 3: The categories of waste in the predesign phase

Waste categories	Waste type
Design error	1. Ambiguities in architectural work, and 2. Wrong computation
Over production	1. Several printings of paperwork
Motion	1. Several, lengthy, and repeated structural computations
Excessive vigilance	1. Several supervisions of work by the chief engineer
Waiting time	1. Unnecessary waiting time due to design modifications, and 2. Waiting to establish preliminary design documents
Clarification	1. Disagreements between the architect and the SDT

The participants of the study pointed that wrong computation and ambiguities in architectural work are the design errors or mistakes that are responsible for rework/corrections in the PDP of projects. Some of the respondents agreed that excessive printing of work (overproduction) in the PDP leads to wastage of materials (paper and ink). This is consisted with the finding of Ohno (1988) on overproduction waste in engineering design. Most of the respondents also argued that several supervisions of work by the chief engineer (excessive vigilance) disrupt the schedule of work.

Some of the respondents of the interview conducted stressed that corrections in the form of rework could reduce the overall performance and efficiency of the work, and could cause the project director to procure additional construction materials, with a consequent increase in the overall cost of a project. This corresponds to the findings of Mastenbroek (2010) regarding the impact of rework on construction projects. The participants further observed that inability to complete work as programmed by SDT due to several interruptions in DDP is another cause of delay in the start of construction phase.

The categories of waste discovered in the construction phase of projects are synonymous with the one discovered in the design phase.

Conclusion and recommendations

Based on the findings of this study, it can be concluded that waste occurs in the current practice of the structural design process (SDP), although the frequency of waste may differ from one project to another. This means that waste in construction also arises from structural design practices. Such waste is found in every phase of the SDP, namely the inception, the predesign, the detailed design and the construction phases. Typical examples of these types of waste are several site visits, excessive printing of work, design corrections, waiting for approval of structural work, wrong fabrication of formwork, and misinterpretation of the structural drawings by the construction contractor.

Table 4: The categories of waste in the detailed design phase

Waste categories	Waste type
Overproduction	1. Unnecessary printing of draft work, and 2. Several copies of final work
Corrections/rework	1. Design corrections, and 2. Redesign
Waiting time	1. Waiting for the approval of final work, and 2. Waiting to establish detailed design documents
Work interruption	1. Inability to complete work as earlier scheduled

Table 5: The categories of waste in the construction phase

Waste categories	Waste type
Correction/rework	1. Variation/changed orders; 2. Wrong fabrication of formwork; rebar cages/reinforcing steel; 3. Redesign, and 4. Inadequate spacing of structural reinforcing materials
Over-processing	1. Excessive requests for information, and 2. Excessive cutting/fabrication of structural reinforcing materials
Waiting time	1. Excessive waiting time during structural reinforcement, and 2. Ineffective communication flow between the SDT/the construction contractor
Excessive vigilance	1. Several on-site supervisions

The main causes of waste in the SDP are ambiguities in the architectural drawings and design changes due to changes in client requirements. In general, waste in the SDP can be categorised into defects or corrections, overproduction, over-processing, waiting time, and motion. It can also be argued that waste in the SDP could lead to inefficiency or poor quality of work in the design and the construction phases, extended project completion time, an increase in the estimated quantity of construction materials, and an increase in the estimated cost or agreed-upon charges for a project. The study recommends that designers and contractors should work together from the design stage so as to identify and reduce waste that are synonymous with SDP for effective projects delivery. Based on this recommendation, further research is needed to find lasting waste-elimination strategies in the SDP. Such research should explore mechanisms for waste identification and reduction in the SDP. A typical example of such mechanisms is the adoption of a lean tool known as value stream mapping in every phase of SDP.

References

AbdelSalam, S. S, Sritharan, S. and Suleiman, M. T. (2010). Current design and construction practices of bridge pile foundations with emphasis on implementation of LRFD. *Journal of Bridge Engineering*, 15(6), 49-50.

Aka, A., Emuze, F. and Das, D. (2017). Mapping waste in structural design process in South African projects. In: *LC3 2017 Volume II - Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC).* Walsh, K., Sacks, R., Brilakis, I. (eds.), Heraklion, Crete, Greece, 475-482.

Alarcon, L. F. (1997). Tools for the identification and reduction of waste in construction projects. In Alarcon, L. (ed.), *Lean Construction*, Balkema, Rotterdam, 365.

Al-Aomar, R. (2012). Analysis of lean construction practices at Abu Dhabi construction industry. *Lean Construction Journal*, 8(1), 102.

Al Nageim, H., Durka, F., Morgan, W. and Williams, D. T. (2010). *Structural mechanics: loads, analysis, materials and design of structural elements*. 7th ed. London: Pearson Education.

Arksey, H. and Knight, P. (1999). *Interviewing for social scientists: an introductory resource with examples*. London: Sage.

Bryman A. (2001). *Social research methods*. Oxford: Oxford University Press.

El Reifi, M.H and Emmitt, S. (2013). Perception of lean design management. *Architectural Engineering and Design Management Journal*, 9(3), 195.

Hwang, B., Thomas, S. R., Haas, C.T. and Caldas, C. H. (2009). Measuring the impact of rework on construction cost performance. *Journal of Construction Engineering and Management*, 135(3), 87.

Ko, C. H. and Chung, N. F. (2014). Lean design process. *Journal of Construction Engineering and Management*, 4(3), 464-468.

Koskela, L. (1992). *Application of the new production philosophy to construction. Technical Report No.72*. Stanford, CA: Centre for Integrated Facility Engineering, Stanford University.

Koskela, L., Bolviken, T. and Rooke, J. A. (2013). Which are the wastes of construction? *Proceedings, 21st Annual Conference of the International Group for Lean Construction*, Fortaleza, Brazil, 3-6.

Krippendorff, K. (2012). *Content analysis: an introduction to its methodology*. London: Sage.

Li, H., Huang, T., Kong, C.W, Guo, H.L, Baldwin, A., Chan, N. and Wong, J. (2008). Integrating design and construction through virtual prototyping. *Automation in Construction*, 17(8), 15-22.

Mastenbroek, Y.C. (2010). *Reducing rework costs in construction projects: learning from rework in realized projects and avoiding rework in the*

future. Published bachelor degree thesis. Enschede, Netherlands: University of Twente.

McNamara, C. (2009). *General guidelines for conducting research interviews.* Retrieved January 11, 2010, from http://managementhelp.org/evaluatn/intrview.htm

Melhado, S.B. and Agopyan, V. (1996). Design quality concept to improve building quality. *Proceedings, CIBW 65th International Symposium on the Organization and Management of Construction-Shaping Theory and Practice.* Glasgow, 28 August-3 September, 502.

Nagapan, S., Rahman, I.A., Asmi, A., Memon, A.H. and Zin, R.M. (2012). Identifying causes of construction waste: case of Central Region of Peninsula Malaysia. *International Journal of Integrated Engineering*, 4(2), 22.

Nazech, E.M, Zaldi, D. and Trigunarsyah, B. (2008). Identification of construction waste in road and highway construction projects. *Proceedings, Eleventh East Asia Pacific Conference on Structural Engineering and Construction (EASEC-11).* Taiwan, August 19-21, 207.

Nelson, G.L, Manbeck, H.B. and Meador, N.F. (1988). *Light agricultural and industrial structures: analysis and design*. New York: Van Nostrand Reinhold.

Ohno, T. (1988). *The Toyota Production System: beyond large-scale production*. Portland, OR: Productivity.

Ritchie J. and Lewis, J. (eds), (2003). *Qualitative research practice: a guide for social science students and researchers.* London: SAGE.

Simms, M. (2007). *The seven wastes in engineering design: a new look at lean manufacturing.* Brea, CA: KETIV.

Sunjka, B.P. and Jacob, U. (2013). Significant causes and effects of project delays in the Niger Delta Region. *Proceedings, 25th Conference of the Southern African Institute of Industrial Engineering*. Stellenbosch, 9-11 July, 644.

Womack, J.P. and Jones, D.T. (2003). *Lean thinking: banish waste and create wealth in your corporation*. 2nd ed. London: Simon and Schuster.