AEDM

ARTICLE

Management of Waste in the Building Design Process: The Ghanaian Consultants' Perspective

E. Zoya Kpamma[1]* and T. Adjei-Kumi[2]

[1]Department of Building Technology, Sunyani Polytechnic, Sunyani, Ghana
[2]Department of Building Technology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract

Waste associated with building design is one of the causes of the high cost and slow progress of construction projects in Ghana. Proper management of waste at the design stage is therefore a fundamental step towards achieving speedy delivery of building projects at minimum cost. This paper seeks to examine the level of awareness of sources of waste and the application of waste reduction tools in the building design process by Ghanaian consultancy firms. Data on the design activities of the firms were collected by distributing questionnaires to consultants, while contractors and clients were interviewed. Involvement in various building design processes was also used to obtain data for the study. Results revealed a generally low recognition of sources of waste in the building design process and little awareness of waste reduction tools such as design structure matrix, batch size reduction and set-based design. It was also found that inadequate familiarity of the firms with lean thinking was among a number of limitations to the application of waste reduction tools in Ghana. This suggests that there is a need to improve the awareness of lean design management in both education and practice in Ghana.

■ *Keywords* – Design management; Ghana; lean thinking; value; waste

INTRODUCTION

One of the banes of the construction industry in Ghana is the inability of firms in the industry to deliver products and services on time and within lower cost limits. Construction project delivery in Ghana is seen to be associated with high cost and time overruns as well as poor quality (Westring, 1997; World Bank, 1996, 2003). A survey conducted by Nicco-Annan (2006) on the construction of some office buildings in Accra reveals cost overruns of between 60 and 180%, not taking inflation into account. Time overruns of between 12 and 24 months were also observed in a survey conducted on the construction of some office buildings in Accra (Nicco-Annan, 2006).

The growing need for speedy delivery of value, associated with less waste, in the construction project delivery process makes it imperative for firms in the construction industry in Ghana to adopt measures towards reducing waste and maximizing value for their clients in the project delivery process. A great deal of attention is given to design management in the architecture–engineering–construction (AEC) sector due to its strong impact on the entire project (Chua and Tyagi, 2001). Several investigations have indicated that a large percentage of defects in buildings arise from decisions or actions at the design phase (Cornick, 1991). It has also been established that design has a lot of impact

■ *Corresponding author: *E-mail*: evanskpamma@yahoo.co.uk

doi:10.1080/17452007.2011.582333 ©2011 Earthscan ISSN: 1745-2007 (print), 1752-7589 (online) www.earthscan.co.uk/journals/aedm

on the level of efficiency during the production stage of construction projects (Ferguson, 1989).

According to Undurraga (1996), about 20–25% of total construction time is wasted as a result of design deficiencies. Around 78% of quality problems of AEC projects are design related (Koskela, 1992). In relation to cost overruns, design-related causes constitute the major category (Josephson and Hammarlund, 1996). In the case of Ghana, Westring (1997) attributes delays in construction projects, among others, to delays in preparation of drawings and technical specifications.

One of the problems that design management practice has to address is the waste associated with the design process. Seemingly intangible and subtle, waste in design arises out of delays, waiting, design errors, overprocessing and negative iteration (Ballard, 2000). The waste arising out of these sources in the design process can have far-reaching implications by undermining efforts towards delivering valuable construction products on time to clients. This article will review some waste-in-design management practices and discuss the results of a survey conducted on the operations of some consultancy firms in Ghana to assess the extent to which they are familiar with waste management practices in the building design process in line with lean thinking.

DESIGN MANAGEMENT AND WASTE

DESIGN MANAGEMENT PRACTICE

Melhado (1994) defines building design as 'an activity or service that is an integral part of the building construction process, dealing with development, organization, documentation and transmission of information on the specified physical and technological characteristics that must be considered in the construction phase of a particular project'. To transmit information on the characteristics of a building, in line with this view of building design, requires design to be considered as much more than drawing and description (Melhado, 1998). Design must be considered as a multifunctional process involving not only architectural and engineering tasks but also ranging from marketing and cost analysis to technological choices and production process specifications (Melhado, 1995). Searching for a new way of considering the difficulties mentioned above, at the same time including the necessary changes to achieve efficiency improvement objectives in design, leads us to the need for design management.

The management of design and engineering is generally seen to be problematic in AEC projects (Ballard and Koskela, 1998). The main problems in design management have generally been identified as poor communication, lack of adequate documentation, deficient or missing input information, unbalanced resource allocation, lack of coordination between disciplines and erratic decisions (Cornick, 1991; Austin *et al.*, 1994; Huovila *et al.*, 1997). According to Coles (1990), design problems are significantly a result of poor briefing and communication, insufficiency in the technical knowledge of designers and a lack of confidence in pre-planning for design work. Common effects of this, which could result in waste arising from delays, include slow approvals from clients, late appointments of consultants and inadequate time to complete design documents carefully (Ballard and Koskela, 1998). The most common causes of deviations when designing are deficient planning and/or resource allocation, deficient or missing input information, and changes (Sverlinger, 1996).

MODELS OF DESIGN MANAGEMENT

A number of design management models have been developed (Chua and Tyagi, 2001). One of the benefits of formulating design models is the possibility of effectively planning and controlling the process (Tzortzopoulos and Formoso, 1999). Some of the popular models are Pugh's 'total design' model, the VDI model of engineering design and the Pahl and Beitz design model (Austin *et al.*, 1999). Another commonly used building design model that models the tasks to be performed by various design players during each stage, but does not however model the relationships between the tasks, is the RIBA Plan of Work for Design Team Operation (1973) (Austin *et al.*, 1999).

A variety of modelling techniques have also been employed to model information flow in design (Chua and Tyagi, 2001). They include data flow diagrams, IDEF techniques (including IDEF0), entity-relationship diagrams, object-oriented modelling techniques, Petri nets and a dependency matrix (AdePT) (Austin

et al., 2000). Design collaboration frameworks such as design agent-based collaboration (Khedro *et al.*, 1994) and collaborative construction agents (Jones and Riley, 1995) have also been developed.

In Ghana, the design process largely follows the RIBA Plan of Work and is one of the preliminary stages in the entire building construction project delivery process. Traditionally, the design process is preceded by a stage of the client's briefing (or inception) and is broadly made up of the conceptual design stage and the detail design stage. It is at the briefing stage that the intentions and requirements of the client system are established to inform the decisions to be taken at the conceptual and detail design stage (Emmitt, 2002). The process in AEC projects is conventionally led by the architect who transforms the client's abstract intentions into a preliminary layout and the layout used by engineering design specialists to prepare their designs (Chua and Tyagi, 2001).

LINEAR AND ITERATIVE DESIGN PROCESS

According to Emmitt (2002), the conceptual design stage involves an expression of the idea underlying the designer's vision and helps to channel the multitude of design decisions that follow. Concepts, he further explains, embody the architectural and cultural symbolism, and may be expressed in a few sets of lines on a piece of paper that form a sketch, or in a diagrammatic form through to quite elaborate drawings.

The detail design phase is the period during which technology is applied to abstract ideas and concepts to realize the design vision. Practically, the detail design stage is a complicated process made up of the coordination of diffuse information, the management of different consultants and the making of several decisions that will affect the appearance, durability and cost of the product (Emmitt, 2002). During the detail design stage, each engineering discipline works in isolation to prepare its designs, while the design specialists collaborate with each other to prevent any potential conflict or to confirm their designs with one another (Chua and Tyagi, 2001). The confirmation of designs is done after the drawings have been prepared by the design specialists, by which time a number of resources have gone into preparing the drawings and any change needed in them implies expensive rework (Chua and Tyagi, 2001).

Going by the RIBA Plan of Work leads us to a linear model, as shown in Figure 1. Here the design process is adversarial to the principles of lean design (where integration of processes and involvement of participants is key) since the separation between conceptual design, detail design and site operations is definite. The iterative nature of design is also ignored in the model. The traditional design process is plagued by long rework loops, and transparency is at the stage of design whereby a number of resources have been exhausted up to that stage (Chua and Tyagi, 2001). Collaboration is mainly passive and only occasioned by a potential conflict predicted by a design specialist or a conflict discovered during collaboration at the drawings level (Chua and Tyagi, 2001). The traditional design gives priority to task management and puts value management into secondary position (Ballard and Koskela, 1998). All the foregoing issues about the traditional design process motivate the application of lean principles to the design process in building design (Chua and Tyagi, 2001).

The implication of the linear project delivery model, as observed by Emmitt (2002), is that the designer (architect) deals with the creative stage; the technologist (detailer) handles the more technical aspects and contract documentation, while the builder assembles the components specified by the detailer to produce the finished product. This model clearly does not include the manufacturers and suppliers of products at the design stage and could lead to waste generation resulting from delays due to uncertainties during the design and construction of building products.

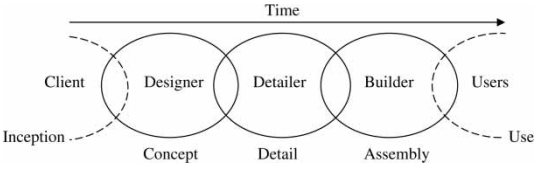

FIGURE 1 The linear project delivery model
Source: Emmit (2002).

According to Ballard (2000), design, by its nature, is an iterative and generative process and that iteration is essential for generating value in the design process (Figure 2). Building design is a difficult process to manage and involves thousands of decisions, probably over a period of years, with several interdependencies, in a highly uncertain environment (Formoso *et al.*, 1998). It has, however, been observed that not all iteration generates value, since iteration that can be eliminated without loss of value is classified as waste (Ballard, 2000).

WASTE IN THE DESIGN PROCESS

According to Ohno (1978), sources of waste in production include overproduction, waiting, transportation, processing, inventory, movement and making defective products. More sources of waste have, however, been suggested by Koskela (2004) and Macomber and Howell (2004). Whereas Koskela (2004) identifies 'make do' as one other source of waste, Macomber and Howell (2004) suggest 'not listening' as another source of waste. According to Koskela (1992), there are four kinds of activities involved in the design process: conversion, waiting, moving and inspection. Only conversion is regarded as a value-adding activity, but waiting, moving and inspection are non-value-adding activities and should be eliminated (Koskela, 1992). Part of the conversion activities are not value adding, since they cause rework due to errors, omissions and uncertainty (Huovila *et al.*, 1997). Design, viewed as an iterative and generative process, has the waste associated with it being explained by Koskela and Huovila (1997) as that which is unnecessary for task completion and value generation. Thus, iteration in design is wasteful and negative when it can be eliminated without loss of value or causing failure to complete the project (Ballard, 2000). Informal surveys of design teams have revealed estimates as high as 50% of design time spent on needless (negative) iteration (Ballard, 2000).

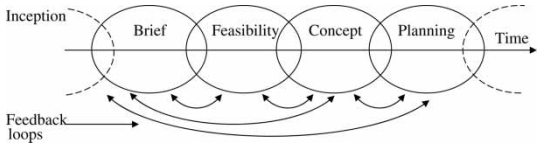

FIGURE 2 The iterative process of design
Source: Emmitt (2002).

Apart from negative iteration, there are other forms of waste associated with the design process. One of them is design errors (Ballard, 2000). According to Reinertsen (1997), design outputs are classified as defective when they fail because something previously known was forgotten or neglected. Design outputs can, however, be failures but not errors if they fail because of a lack of knowledge not previously possessed (Ballard, 2000). Waiting, overprocessing and overproduction are some other forms of waste in design.

REDUCING WASTE IN THE DESIGN PROCESS

Three methods have been proposed for eliminating waste in the design process based on the view of design as a flow (Huovila *et al.*, 1997). The first method is reduction of uncertainty, being one of the main origins of rework particularly in the early stage of design. This method can be implemented by stepping up the effort in spelling out the project boundaries and the requirements of clients. The second method involves reducing waiting time by adequately breaking down the design tasks so that they can be properly planned, and also allowing for the transfer of information in smaller batches. The last method has to do with reduction in effort needed for information transfer. This can be done through teamwork and by rearranging the design tasks.

Negative iteration is an important source of waste in design, but can be minimized by the application of techniques such as team problem solving, design structure matrix (DSM), batch size reduction, least commitment and set-based design (Ballard, 2000). These techniques can be categorized as restructuring the design process, reorganizing the design process, managing the design process differently than traditionally and lastly overdesigning, when there is no better solution (Table 1).

LEAN PROJECT DELIVERY

Lean project delivery builds cooperation in the context of a single integrated team involving the owner,

TABLE 1 Strategies for reducing negative iteration

Restructure the design process
Use DSM to resequence
Use pull scheduling to reduce batch sizes and achieve greater concurrency
Reorganize the design process
Make cross-functional teams the organizational unit
Use team problem solving (call a meeting)
Share ranges of acceptable solutions
Change how the design process is managed
Pursue a least-commitment strategy
Defer this decision (defer commitment)
Practice set-based design
Use the last planner system of production control
Overdesign (design redundancy) when all else fails

Source: Ballard (2000).

architect, constructor and other critical players as equals in the pursuit of a shared goal (Mossman *et al.*, 2010). The lean project delivery system (LPDS) has been designed to support a new and better way of designing and building capital facilities. This model recognizes the design and construction process as both linear and iterative, thus supporting a parallel rather than a sequential approach to design and construction. The various waste reduction strategies, such as DSM, are applied in the lean project delivery process at the lean design phase to ensure minimization of waste in the design process.

RESEARCH METHOD

The research involved representative samples of selected Ghanaian consultancy and construction firms located in various parts of Ghana. This was an opportunity to critically explore and examine the steps in the pre-contract activities of Ghanaian consultancy and construction firms. These stages include site survey, design brief formulation, sketch and detail design, obtaining permits, preparation of bills of quantities, tender documentation and contract documentation.

The LPDS model was used as the basis for assessing the extent to which the various steps of the pre-contract activities (especially the design process) of Ghanaian consultancy firms fall in line with the concept of lean thinking towards waste reduction. The steps were examined and assessed within the broad framework of lean project definition, lean design, lean supply, lean assembly and use. The level of familiarity and application of the various waste-in-design reduction techniques, such as DSM, was also assessed.

TARGET POPULATION

The core target population for data collection using questionnaires consisted of consultants (architects, engineers, quantity surveyors, etc.). The focus on consultants in the distribution of the questionnaire was due to the key role that consultants play in design activities. Contractors (building and civil) and clients (public and private) were also interviewed as a follow-up, specifically to confirm the consultants' responses on the level of participation of clients and contractors in the design process.

PROCEDURE FOR DATA COLLECTION

A sample of 25 firms providing design and documentation services at the pre-contract stage of construction projects across Ghana was selected. Three professionals (architect, quantity surveyor and engineer) in each firm were identified and given the questionnaire. In the case of firms that did not have all the professionals in-house, their associate professionals were contacted and given the questionnaire. Out of a total of 75 questionnaires given out, 68 were returned completed. A personal observation of some activities of some of the selected firms also provided an opportunity to obtain additional information for the study. In addition to the questionnaires that were given out to the consultants, 10 major clients of some of the selected firms, as well as about 15 contractors who worked with them, were interviewed to obtain confirmatory data, especially on their level of involvement by the consultancy firms at the design phase of the project delivery process.

FINDINGS

CONSULTANCY FIRMS' FAMILIARITY WITH THE CONCEPT OF LEAN THINKING

It was found that there was some level of awareness among consultants regarding basic principles of

managing production systems to minimize waste and maximize value for clients in the project delivery process. There was, however, a gap between the awareness of these basic principles of waste minimization and value maximization on the one hand, and a conscious effort by the firms to establish project delivery systems that focus on waste minimization and value maximization on the otherhand.

The respondents reported a lack of familiarity with the concept of lean thinking. Only 5% of the sample had been involved in the application of lean thinking, 58% claimed to be 'just aware' of it and the remainder of the sample claimed not to be aware of it at all. It is worth noting that even though about 5% of the respondents indicate that they had been involved in the application of the concept of lean thinking, they admitted that no special lean production tool, such as the LPDS, was applied to reduce waste in the design process. Their rationale was that once they try to ensure that waste was reduced, even in the conventional project delivery system, they were applying the concept of lean thinking.

APPLICATION OF THE LPDS

The survey showed that most activities carried out by the consultants at the pre-contract stage are outside the context of the LPDS. Process design at the design phase is a very important activity in the LPDS. However, Figure 3 shows that only 13.2% of the respondents gave an indication that they undertook process design at the design phase of projects. The study also showed that product design was undertaken only at the design phase by most consultants, contrary to a requirement by the LPDS that the product design process be balanced between the design and supply phases. While about 80% indicated that they undertook product design exclusively at the design phase, only about 20% gave an indication that they undertook some form of product design at the supply phase of the project delivery process (Figure 3).

The minimal integration of design and supply activities by Ghanaian firms is further manifested in the indication by 69.1% of the respondents that they undertook detailed engineering only at the design phase while only 20.6% indicated carrying out detailed engineering at the supply stage, as shown in Figure 3. Another significant deviation from the requirements of the LPDS is reflected in the fact that design criteria are not only uncommon in the activities of the consultants, but also mostly concentrated at the design stage by the few who undertake it. The requirement of the LPDS is that design criteria formulation should be carried out at the project definition phase.

Work structuring and production control are required by the LPDS to be carried out across all the phases of the project delivery process to ensure minimization of waste. The survey showed, however, that work structuring and production control are undertaken by very few consultants especially at the project definition, design and supply phases of the project delivery process. Figure 3 shows that only 7.4% and 20.6% of the respondents indicated that at the design stage they undertook work structuring and production control, respectively.

LEVEL OF PARTICIPATION/INVOLVEMENT OF PROJECT PARTICIPANTS IN PRE-CONTRACT ACTIVITIES

According to Harris and McCaffer (2001), achieving good results with lean thinking to reduce waste requires some common tools of production management such as the integration of design and construction, multifunctional task groups and employee participation. All these production management tools require a high level of involvement and participation among such key stakeholders in the project delivery process as consultants, clients, contractors and specialists/suppliers.

Involvement of contractors across the stages of pre-contract activities by consultants was minimal. The highest indication of involvement of contractors by consultants was at the contract documentation stage, which stood at 46.7%. The rest of the indications of involvement of contractors ranged between 6.7% and 13.3%. None of the respondents involved contractors in conceptual design, sketch design and detail design as shown in Figure 4. The indication of involvement of specialists/suppliers,

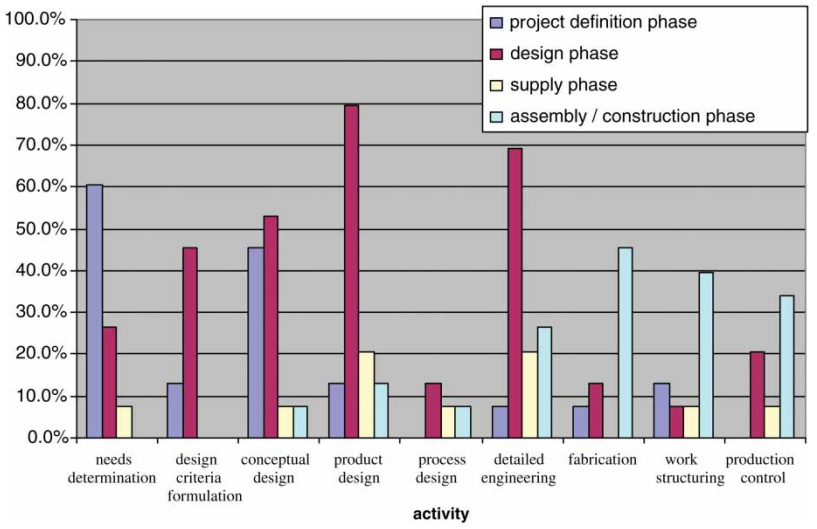

FIGURE 3 Activities undertaken in the project delivery process at various phases

although higher than that of contractors, was also minimal. While 46.7% of the consultants indicated that they sought the participation of specialists/suppliers in scheduling and specification, only 33.3% involved specialists/suppliers at the detail design phase of pre-contract activities.

The dominant role of clients in the choice of site and selection of project participants was reflected in

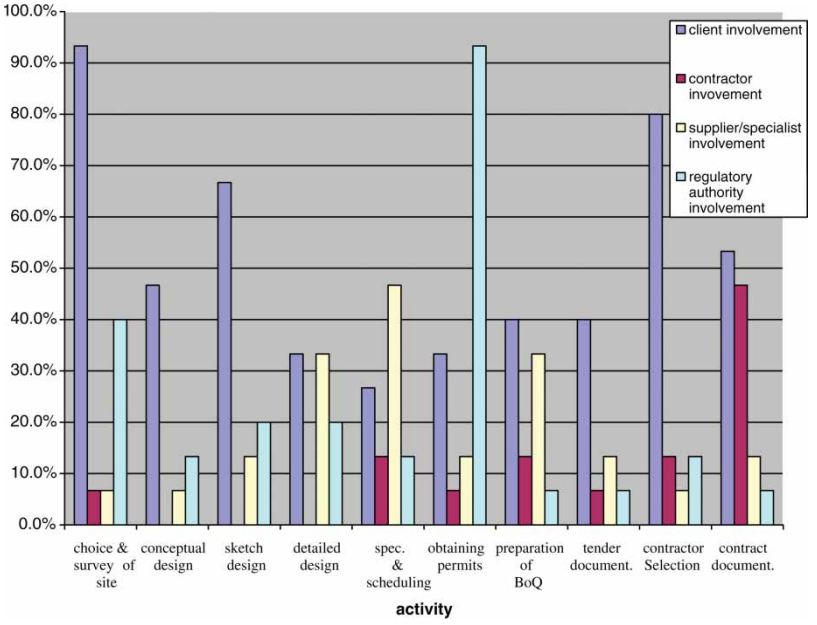

FIGURE 4 Involvement of project participants in pre-contract activities by consultants

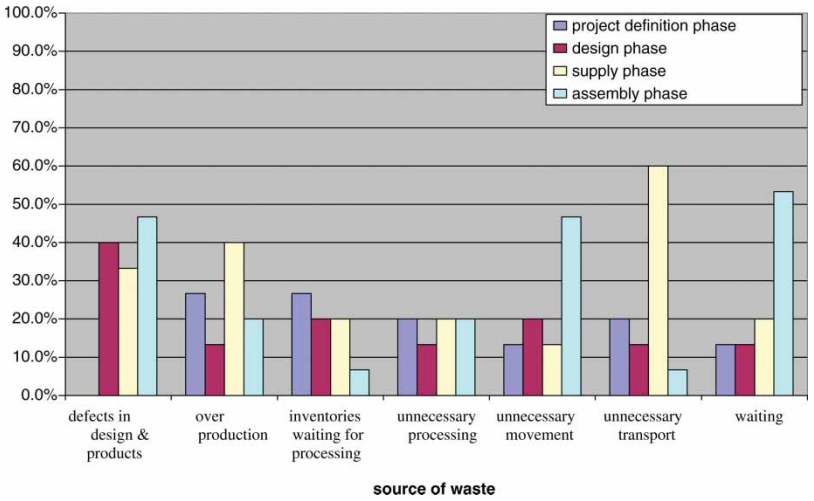

FIGURE 5 Recognition of sources of waste by consultants in the project delivery process

the indication by more than 93% of the respondents that clients participate in the selection of site and 80% indicating that they involve clients in the selection of contractors and suppliers/specialists. The significant influence by regulatory authorities in the acquisition of development permits and certificates, sometimes seen as limitations to continual flow, was confirmed by more than 93% of the consultants (Figure 4).

WASTE IN THE DESIGN PROCESS

One of the important requirements in the practice of lean thinking is the ability to identify and eliminate waste in the project delivery processes. Waste, according to Koskela and Huovila (1997), refers to what is unnecessary for task completion and value generation. Unnecessary or non-value-adding steps are seen to be associated with various design and documentation processes, thus leading to a lot of waste generation.

RECOGNITION OF SOURCES OF WASTE IN THE DESIGN PROCESS BY CONSULTANTS

The survey revealed a low level of recognition by consultants of the sources of waste across the phases of the project delivery process. A small fraction of the consultants associated waste with project definition and design activities. As shown in Figure 5, the highest recognition of waste in the design process was 40%, and this was seen to arise from defects in design. Only 13.3% of the respondents saw waiting as a source of waste that could arise during design and documentation activities. Unnecessary processing was the least recognized source of waste, with only 13.3–20% of respondents associating this source of waste with the various project phases (Figure 5).

CONSULTANTS' UNDERSTANDING OF WASTE

The understanding of waste as that which is unnecessary for task completion was highly recognized. Of the respondents, 73.5% understood waste in design and documentation to be 'that which is unnecessary for task completion and value generation' (Table 2). Understanding waste to be negative iteration and design errors was, however, low among the consultants. While 39.7% of the consultants understood design errors as a form of waste, only 26.5% saw negative iteration as a form of waste in design.

NEGATIVE ITERATION REDUCTION TECHNIQUES

Although negative iteration is one of the major forms of waste in the design process, it was understood by only 26.5% of the respondents (Table 2). It was

TABLE 2 Understanding waste in design and documentation

WASTE IN DESIGN AND DOCUMENTATION	CONSULTANTS $N = 68$	
	NUMBER	PERCENTAGE
That which is unnecessary for task completion and value generation	50	73.5
Negative iteration (non-value-generating design options)	18	26.5
Design errors	27	39.7
Other	0	0
Mean	23.7	34.9

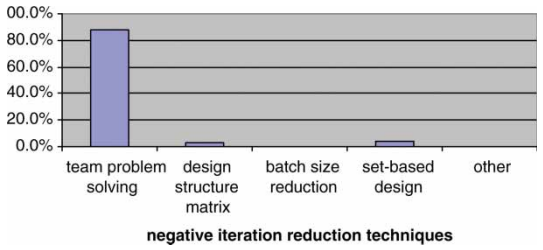

FIGURE 6 Techniques for reducing negative iteration in design

discovered, however, that if negative iteration or non-value-generating design options are understood to be waste, the popular technique of reducing it will be team problem solving. About 88.2% indicated familiarity with the team problem solving technique, while less than 5% showed familiarity with techniques such as DSM and set-based design (Figure 6). No one was familiar with batch size reduction as a technique of reducing negative iteration.

DISCUSSION OF FINDINGS

LEVEL OF FAMILIARITY WITH THE LEAN THINKING CONCEPT

The questionnaire survey and interview showed that there exists a low level of familiarity with the concept of lean thinking as a tool for minimizing waste in the project delivery process. The few consultants who were even aware of the concept of lean thinking had never adopted a special system such as the LPDS to consciously reduce waste and maximize value to clients. The traditional procurement system whereby the design and documentation activities are completely separated from construction activities is still the most widely used system in the project delivery process. Public sector projects are particularly limited by the provisions of the Public Procurement Act of 2003 in an attempt to adopt more integrated systems. Procurement systems such as design and build, even though they fall short of some lean thinking principles, are the common alternatives to the traditional system towards ensuring speedy delivery of projects.

WASTE IN THE PROJECT DELIVERY PROCESS

Even though we found that some level of consciousness regarding the waste associated with project delivery steps exists, design and documentation processes at the pre-construction stage still typify sources of waste such as waiting, delays, defects and inventories. These sources of waste, despite having serious adverse effects on the speedy delivery of value to clients, appear to be too subtle to be tracked by consultants. Responses from consultants during the survey indicated that about 73% and 60% were unaware of negative design iteration and design errors, respectively, as sources of waste. Given that one of the primary activities in the effective application of lean thinking requires identifying and eliminating waste, the inability to recognize waste in design and documentation is a huge setback towards implementing lean thinking principles at the design stage.

INVOLVEMENT OF PROJECT PARTICIPANTS

Management of design and documentation activities at the pre-contract stage falls short of what is required by the tenets of lean thinking to minimize waste and maximize value to clients. The level of involvement of many project participants in the various stages of design and documentation processes is low, thus limiting continual flow in design and documentation, as well as resulting in waiting, delays and unnecessary processing.

The activities of the architect at the design stage, for instance, were found in most cases to be separated from that of the structural engineer and services engineer. The architect would therefore usually complete his designs without the

involvement of the structural engineer and services engineer and then give the completed detail architectural designs to them for the structural and services details. This practice will clearly inhibit continual flow in the design process and result in waiting and delays.

PLANNING AND CONTROL OF DESIGN AND DOCUMENTATION PROCESSES

Most of the projects in all the surveyed consultancy firms were designed and documented without reference to any activity programme or work plan specifically drawn for the design and documentation processes. Most of the consultants admitted that even though, as a result of demands from some clients, they tried to provide an activity schedule for some design and documentation activities, it was not part of their usual practice to draw activity schedules and work plans when designs were undertaken. It was therefore not surprising that lean design techniques involving the use of the activity definition model, set-based design and DSM were completely unfamiliar to virtually all the consultants.

CONCLUSION AND RECOMMENDATIONS

The process of building design is associated with some form of waste generation. The waste generated during the building design process is, in most cases, subtle and appears to be difficult to track and manage by consultants in Ghana. The failure of the sample to identify and manage waste in the design process is due to the fact that they still approach project delivery in a linear fashion without recognizing the iterative nature of the construction project delivery process. Negative iteration, which is seen as one of the major forms of waste in the design process, is not well understood or recognized by the consultants who took part in this research. Design errors and unnecessary processing are other forms of design waste that are less recognized as forms of waste. Given that the majority of the sample have not applied lean thinking, it is not surprising that they are also unfamiliar with waste reduction techniques such as DSM, set-based design and batch size reduction.

The procurement process in Ghana, especially for public sector projects, is largely through the traditional procurement route, in which case there is not only less involvement of team members, but also design and construction processes are treated as linear processes and not iterative. Regulations on procurement processes in Ghana should therefore be modified to accommodate more involvement of team members as well as recognize the iterative nature of design to enhance waste management in the design process. This requires a shift towards a lean culture, which will involve promotion, training and education initiatives. For example, there is the need for professional bodies like the Ghana Institute of Architects and the Ghana Institution of Engineers to get members exposed (through continuous professional development programmes) to the concept of lean thinking as well as various waste reduction techniques in the design process.

The inability of most consultants to identify and manage the waste associated with the design process is partly attributable to the fact that design process management and the concept of lean thinking are currently not given much attention in the training of professionals such as architects and engineers in Ghana. There is, therefore, the need for the teaching of the concept of lean thinking to be introduced or strengthened in the academic and professional training of students pursuing construction-related disciplines such as architecture, structural engineering and surveying at both the undergraduate and postgraduate level. This will enhance the familiarity of these trainees with the concept and make them more conscious of managing waste in the building design process after their training.

REFERENCES

Austin, S., Baldwin, A. and Newton, A., 1994, 'Manipulating the flow of design information to improve the programming of building design', *Construction Management and Economics*, *London, Spon* **12**(5), 445–455.

Austin, S., Baldwin, A., Li, B. and Waskett, P., 1999, 'Analytical design planning technique: a model of the detailed building design process', *Design Studies* **20**(3), 279–296.

Austin, S., Baldwin, A., Li, B. and Waskett, P., 2000, 'Analytical design planning technique (AdePT): a dependency structure matrix tool to schedule the building design process', *Construction Management and Economics* **18**(2), 173–182.

Ballard, G., 2000, 'Positive vs negative iteration in design', paper submitted to the 8th International Conference on Lean Construction, Brighton, 2–7 [available at: www.leanconstruction.org/pdf/05.pdf].

Ballard, G. and Koskela, L., 1998, 'On the agenda of design management research', *Proceedings of the 6th Annual Conference of the International Group for Lean Construction*, *Guarujá, Brazil*, 13–15 August 1998.

Chua, D.K.H. and Tyagi, A., 2001, 'Process–parameter–interface model for lean design management', *Proceedings of the 9th Annual Conference, International Group for Lean Construction*, *Singapore*, 1–12.

Coles, E.J., 1990, *Design Management: A Study of Practice in the Building Industry*, The Chartered Institute of Building, Occasional Paper No. 40, 32pp.

Cornick, T., 1991, *Quality Management for Building Design*, Butterworth, Rushden, 218.

Emmitt, S., 2002, *Architectural Technology*, Blackwell Science, Oxford, 37–66.

Ferguson, I., 1989. *Buildability in Practice*, Mitchell, London, 175.

Formoso, C., Tzortzopoulos, P., Jobim, M. and Liedtke, R., 1998, 'Developing a protocol for managing the design process in the building industry', *Proceedings of the 6th Annual Conference, International Group for Lean Construction*, *Guarujá, Brazil*.

Government of Ghana, 2003, *Public Procurement Act, 2003 (Act 663)*, Ghana Publishing Corporation, Accra, Ghana.

Harris, F. and McCaffer, R., 2001, *Modern Construction Management*, Blackwell Science, UK, 31–32.

Huovila, P., Koskela, L. and Lautanala, M., 1997, 'Fast or concurrent: the art of getting construction improved', in: L.F. Alarcon (ed) *Lean Construction*, A.A. Balkema, Rotterdam, 143–160.

Jones, B. and Riley, M., 1995, 'Collaborative construction agents. Computing in Civil Engineering', *Proceedings of the Second Congress held in Conjunction with A/E/C Systems*.

Josephson, P.-E. and Hammarlund, Y., 1996, Kvalitetsfelkostnader på 90-talet – en studie av sju byggprojekt, Del I Resultat Quality defect costs in the 90s: a study of seven construction projects (in Swedish). Report No. 49. Department of Building Economics and Construction Management, Chalmers University of Technology.

Khedro, T., Genesereth, M.R. and Teicholz, P.M., 1994, 'A framework for collaborative distributed facility engineering', *Computing in Civil Engineering, Proceedings of the First Congress Held in Conjunction with A/E/C Systems*.

Koskela, L., 1992, *Application of the New Production Philosophy to Construction.* Stanford, CIFE, Stanford University. Technical Report No. 72, 35.

Koskela, L., 2004, *Making Do – The Eighth Category of Waste*, International Group for Lean Construction 12, Elsinore, Denmark.

Koskela, L. and Huovila, P., 1997, 'On foundations of concurrent engineering', in: C. Anumba and N. Evbuomwan (eds), *Concurrent Engineering in Construction CEC97*, 3–4 July, The Institution of Structural Engineers, London, 22–32.

Macomber, H. and Howell, G.A., 2004, *Two Great Wastes in Organizations – A Typology for Addressing the Concern for the Underutilization of Human Potential*, International Group for Lean Construction 12, Elsinore, Denmark.

Melhado, S.B., 1994, *Qualidade do projeto na construção de edifícios: aplicação ao caso das empresas de incorporação e construção*, Doctorate Thesis, Escola Politécnica, Universidade de São Paulo.

Melhado, S.B., 1995, *O que é qualidade de projeto?: uma discussão acerca das mudanças conceituais necessárias para a melhoria da qualidade na construção de edificações*. In: *Proc. Workshop Qualidade de Projeto/RS*, Porto Alegre. Porto Alegre, Departamento de Engenharia Civil/Escola Politécnica/PUC-RS.

Melhado, S.B., 1998, 'Designing for lean construction', *Proceedings of International Group for Lean Construction* [available at www.ce.berkeley.edu/~tommelein/IGLC-6/Melhado.pdf].

Mossman, A., Ballard, G. and Pasquire, C., 2010. *Lean project delivery – innovation in integrated design & delivery*, Draft for Architectural Engineering and Design Management Special Issue on Integrated Design & Development Systems (IDDS) [available at http://independent.academia.edu/documents/0095/5229/Mossman].

Nicco-Annan, J., 2006, 'Partnering in construction', *The Quantity Surveyor* **1**, 14–19.

Ohno, T., 1978, *Toyota Production System, Beyond Large-Scale Production*, Productivity Press, Cambridge, MA, 1988.

Reinertsen, D.G., 1997, *Managing the Design Factory*, The Free Press, New York, NY, 269.

Sverlinger, P.-O., 1996, *'Organisatorisk samordning vid projektering: en studie ur ett konsultföretagsperspektiv'*, Lic.Eng. Thesis, Report 44, Department of Building Economics and Construction Management, Chalmers University of Technology, Göteborg (in Swedish).

Tzortzopoulos, P. and Formoso, C.T., 1999, 'Considerations on application of lean construction principles to design management', *Proceedings of the 7th Annual Conference International Group for Lean Construction*, *Berkeley, CA*, 335–344.

Undurraga, M., 1996, 'Construction productivity and housing financing', *Seminar and Workshop Interamerican Housing Union*, *Ciudad de Mexico, D.F., Mexico*, 28–29 October.

Westring, G., 1997, *Ghana Public Procurement Reform*. An audit report prepared for the World Bank, Advokatfirman Cederquist KB, Stockholm.

World Bank, 1996, *Ghana 1996 Country Procurement Assessment Report*, The World Bank, Washington, DC.

World Bank, 2003, *Ghana 2003 Country Procurement Assessment Report*, Ghana Country Department, The World Bank, Washington, DC.