MINIMISING CONCRETE WASTAGE IN SRI LANKA USING LEAN CONSTRUCTION TECHNIQUES

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ABSTRACT

Concrete is a major component of construction waste. The amount of concrete wasted in Sri Lanka is significant compared to the amounts wasted in other countries. Traditional strategies adapted to minimise concrete wastage have not been successful. Although lean construction can eliminate waste, there is very little research that has been done on this subject. The aim of the study was therefore to identify the suitability of lean techniques in minimising concrete waste generated during pre and post contract stages of construction in Sri Lanka. Qualitative research methods were used to achieve this aim. A literature review and a set of structured interviews with fifteen experts working in the construction industry were used to collect the required data. The data collected were analysed using content analysis. Total quality management, just in time, process re-engineering, value-based management and total productive management were identified as the lean techniques that can be used to minimise the waste of concrete in the construction industry in Sri Lanka during pre and post contract stages of construction.

Keywords: *Building Construction Projects; Concrete Wastage; Lean construction; Pre and Post Contract Stages.*

1. INTRODUCTION

Lean construction is a philosophy invented in Japan subsequent to the discovery of lean manufacturing in late 1950s. The main objective of lean construction is to provide more value to customers by using fewer resources so that the amount of waste generated is minimized (Alves *et al., 2012*). Serpell and Alarcon (1998) have revealed that construction process can be improved by reducing or eliminating altogether its non-value added activities through the adoption of lean construction principles. Howell (1999) also has considered lean construction which is focussed on the delivery process of a product, improving the performance of the product to meet customer needs, product and process design, and the maintenance of the product from its planning to delivery as a concept that can be utilized to reduce non-value added activities of construction.

Waste which is generated by activities that lead to material losses and unnecessary work incurs additional costs without bringing in any profits (Agyekum *et al.,* 2013). Therefore, the minimization of material wastage will not only improve project performance but will also positively contribute to the economy of the country.

Nellickal *et al.* (2015) have mentioned that a construction project should be considered as a "project-as-production system". Kazaz *et al*. (2015) have identified that around 10% of the budget of a construction project is assigned for concrete works. Waste of concrete is one of the major contributors to the generation of construction waste in the world (Nagapan *et al.*, *2012*). Chu (2004) discovered that incremental contribution made by waste of concrete to the total cost of a project can be as high as 4%. One of the critical negative results of wastage on a construction site is unwanted cost over-runs (John & Itodo, 2013).

The amount of concrete wasted in the construction industry in Sri Lanka is significant when compared to what is wasted in other countries (Kulatunga *et al.*, 2005). It has also been revealed that because of the excessive

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use of concrete and mortar in Sri Lanka without properly managing those, the percentage wastage of these two materials in the country are as high as 21% and 25% respectively. Therefore, a research on minimizing concrete waste in Sri Lanka will be important in today's context.

1.1. RESEARCH PROBLEM

According to Garrido and Pasquire (2011), Kalathunga et al. (2006), Ekanayake and Sandanayake (2017), Ballard et al. (2003) and Amarathunga et al. (2006), construction wastage has been the subject of several research studies done in Sri Lanka. However, most of these past research studies have been on the wastage of materials and minimization of that wastage (Silva & Vithana, 2008). Actions taken to minimize concrete waste using traditional methods have so far been unsuccessful and thus there is a need in the construction industry for a well-established mechanism that will minimize waste of concrete (Kulatunga et al., 2006). Researchers have already found that lean principles can successfully minimize waste in the manufacturing industry (G.L.D. Wickramasinghe & Wickramasinghe, 2017). Even though several research studies have already been carried out on the use of lean techniques in the construction industry, very little research has been done on minimizing concrete waste using lean principles. Thus, it is apparent that there is a research gap and that there is an emerging need and a demand in the construction industry for the further investigation of lean principles. Therefore, this research was aimed at identifying lean construction methods that will minimize wastage of concrete in the construction industry in Sri Lanka. The objectives of the research study were to identify lean principles and techniques and their applicability to Sri Lanka, concrete wastage at different stages of a project and lean techniques that are suitable to minimize concrete wastage.

2. LITERATURE REVIEW

2.1. CONSTRUCTION WASTE

According to Bodkhe and Waghamare (2016), construction taking place in a country will significantly contribute to the country's economy. Thus, if construction waste could be minimized, it will impact not only on the client and the contractor but also on the country's economy. E. Skoyles and Skoyles (1987) have stated that if a project is to be profitable, it will be important to understand how waste could be reduced and that for a project to be successful the waste margin will have to be acceptable. Construction waste is usually generated throughout the construction of buildings, their remodelling, refurbishment and renovation (Nitivattananon & Borongan, 2007). This waste can be categorized as solid, liquid or other substances. According to Patil et al. (2013), construction waste indicates the loss of materials and unnecessary work which adds extra cost to a project without adding any value to the product and this waste can be measured in terms of costs including opportunity costs. John and Itodo (2013) have stated that the contribution made by construction material wastage to the cost overrun of a project is between 21% and 30%. Agyekum et al. (2013) have revealed that the construction industry in USA had generated 170 million tons of waste in 2003. Chu (2004) discovered that material waste such as concrete, block work and those arising from screening, plastering and packaging contribute 4%, 10%, 15 % and 5% respectively to the total cost of a project.

According to Kazaz et al. (2015), concrete wastage is the most important type of wastage in the construction industry. Their study has revealed that concrete waste by weight accounts for approximately 50-55% of the waste that is generated during construction. There are several types of waste that can be identified such as poor workmanship and losses that occur when transporting materials to construction sites and those that occur during placing activities. What is most critical among the different types of concrete waste is the quantity of excess material found in them (V. Tam & Tam, 2007). Marco and Rabinder (1998) have stated that a significant quantity of ready-mixed concrete gets disposed due to reasons such as high slump losses caused during transportation or because the quantity that has been ordered is more than what is required.

2.2. CONSTRUCTION WASTE IN SRI LANKA

Sri Lanka is a developing country where construction is taking place all over the country. According to Kulatunga *et al*. (2005), cost of construction wastage has a significant impact on the construction industry in the country. Furthermore, according to them, the main reasons for the material wastage in the construction industry are the design changes made during construction, lack of dimensional coordination of projects and

poor workmanship. They have also revealed that the percentage wastage of concrete and mortar in the country are 21% and 25% respectively which are a result of their excessive usage without careful handling. Kulatunga *et al*. (2006) have found that the percentage wastage of sand, lime, cement, bricks, ceramic tiles, timber, rubble, steel, cement blocks, paint and asbestos sheets in Sri Lanka are 25%, 20%, 14%, 14%, 10%, 10%, 7%, 7%, 7%, 5% and 3% respectively. Kumara (2009) identified six main reasons for the material wastage in the construction industry in Sri Lanka, namely design errors and design changes made during construction, procurement system errors, improper material handling, operational errors, and bad weather conditions.

One of the commonly used methods for dividing construction process into stages is the Royal Institute of British Architects (RIBA) Plan of Work. According to RIBA Plan of Work (2007), the simplest and the most common classification of the construction stages are preparation, design, pre-construction, construction and use which were considered in this research as well. Past research have identified different stages of construction during which concrete wastage can take place.

2.3. HISTORY OF LEAN CONCEPT AND LEAN CONSTRUCTION

A considerable number of technologies and management changes were introduced to the manufacturing industry after the Second World War (Womack & Jones, 1996). There are fourteen principles which formed the basis on which quality and efficiency of Toyota productions were to be increased. Those principles which have been divided into four groups are applicable to other industries as well (Liker & Meier, 2006). Lean production is one concept introduced by Taiichi Ohno in the 1950s to minimize wastage in Toyota productions (Howell, 1999).

Womack and Jones (1996) have found sharing experience with others and re-use of knowledge to be the best ways to learn lean principles. Ballard and Howell (1998) have stated that the term "value" can be called as the most appropriate formation of a product or service provided to the customer at the right time at a reasonable price while adhering to correct quality standards. The main idea underlying the lean concept is producing more value for customers using fewer resources (Hines *et al*., 2004 and Glenn *et al., 2003*). Construction activities can be divided into two groups: conversion activities and flow activities (Koskela, 1993). Conversion activities add value to the product while flow activities do not add any value. Flow activities deal with activities such as waiting and inspection. Maximizing of the performance and the delivery process has been identified as a significant feature of lean construction.

Womack *et al*. (1991) have stated that compared to mass production, lean construction uses fewer resources in terms of man hours spent in the factory, manufacturing space, investment in tools and engineering hours spent on developing the product. Aziz and Hafez (2013) have stated that the productivity in the construction industry has been on the decline all over the world for almost 40 years now. One way to overcome this situation is to implement lean construction in the construction industry as well.

2.4. LEAN CONSTRUCTION PRINCIPLES / TECHNIQUES

The most important lean construction principles / techniques are Just In Time (JIT), Total Quality Management (TQM), Time Based Competition, Concurrent Engineering (CE), Process Redesign (or Reengineering), Value Based Management (VBM), Visual Management (VM), Total Productive Maintenance (TPM) and Employee Involvement (EI).

The technique, Just in time, which was developed and applied by engineers who worked in the Toyota manufacturing plant in the 1950's eliminates or reduces non-value added activities (inventory) (Salem *et al.*, 2006).

Total quality management, a technique that refers to the continuous improvement of the production of goods and services, is basically divided into three areas: expanding quality control from the production department to all departments, expanding quality control from workers to management, and expanding the concept of quality to cover all operations. (Koskela, 1992).

Time based competition is a technique that shortens lead time and provides benefits such as the decrease or the elimination of the works that are not related to the production process, decrease of the inventory and easy identification of problems.

Concurrent engineering deals basically with the design phase of a product (Rouibah & Caskey, 2003). It is similar to just in time and total quality management although it has not originated from either of them.

Process redesign or re-engineering refers to the primary re-configuration of tasks and processes of a project (Reijers & Mansar, 2005). Re-engineering breaks down tasks into several smaller tasks using fundamental assumptions so that they can be designed for maximum effectiveness.

Value based management is a principle (VBM) that focuses on maximizing the value of a product at its conceptual stage itself to make it competitive. Firms that use value based management strategies are focussed more on the interests of customers. One of the main characteristics of value based management is the continuous improvements made to increase the benefits provided to the customers (Christopher & David, 2001).

Visual management is focussed on visual control, standardization and workplace organization (Bell & Davison, 2013). The main objective of visual management is to establish standards that can be understood easily by all employees.

Total productive maintenance gets multi skilled workers to independently handle the maintenance of equipment. It mainly focuses on maximizing production by maintaining the operating system at its best condition (McKone *et al.*, 2001).

Employee involvement empowers workers to take decisions on their own on matters affecting their work. Here, in order to avoid waste, multi skilled workers or teams of self-directed operators take responsibility for customers or product driven production (Wilkinson *et al*., 1992).

All these lean principles and techniques are used in construction projects to minimize waste (Salem *et al*., 2006; Koskela, 1992; Rouibah & Caskey, 2003; Reijers & Mansar, 2005; Christopher & David, 2001; Bell & Davison, 2013; McKone *et al*., 2001; and Wilkinson *et al.*, 1992)

2.5. APPLICABILITY OF LEAN CONSTRUCTION TO MINIMIZE CONCRETE WASTE

Nowotarski *et al.* (2016) have stated that in the construction process, 57% of the resources are wasted and that a considerable portion of this waste is concrete. They have further mentioned that JIT is being applied in more and more companies and that the implementation of the 5S method reduces wastages. According to Rybkowski (2013), lean techniques reduce concrete waste and provide more benefits.

According to Madushan *et al*. (2016), since Sri Lanka is still a developing country, its construction industry is yet to become familiar with lean construction. They have further identified the absence of programs to educate professionals about lean principles and the absence of discussions on the benefits of lean principles as the factors that make it difficult to implement lean concepts in the country. Senaratne and Wijesiri (2008) have discussed the applicability of lean construction to Sri Lanka and their findings reveal that lean construction is acceptable to the construction industry of the country. They have recommended that lean concepts be implemented within the construction industry and have verified the feasibility of their application by making available these concepts to several companies. Therefore, it is worth studying the use of lean techniques in the Sri Lankan construction industry.

3. RESEARCH METHODOLOGY

There are three different approaches for research: quantitative, qualitative and mixed approaches (Creswell, 2007) and in any research the approach that is most appropriate to the research requirements has to be selected (Dawson, 2002). Willis (2007) recommends proceeding with qualitative information when an in-depth analysis is required.

Most professionals in the construction industry in Sri Lanka do not understand the use of lean techniques and only a few have theoretical and practical knowledge of the subject. Therefore, data could be collected from only fifteen experts all of whom had more than fifteen years of experience in the construction industry and more than five years of experience/ knowledge in lean practices.

In order to cover the research objectives, the expert interviews had to be based on guidelines that focused on three broad areas: identification of the applicability of lean principles to Sri Lanka, identification of the types

of concrete wastage and the identification of lean principles suitable to minimize concrete wastage during each stage of construction. "NVivo 11" content analysis software was used to analyse the findings.

4. ANALYSIS AND RESEARCH FINDINGS

The main objective of the expert interviews was to ascertain the relevance of the findings of the literature review to construction projects in Sri Lanka. Table 1 presents the profiles of the experts who took part in the expert interviews.

Table 1: Details of the Expert Interviewees

Code	Organization	Designation	Profession	Experience in years
I1	Consultant	Director	Chartered Quantity Surveyor	> 25
I2	Contractor	Contracts Manager	Chartered Quantity Surveyor	> 25
I3	Contractor	Contracts Manager	Chartered Quantity Surveyor	21-25
I4	Contractor	Managing Director	Chartered Engineer	> 25
I5	Contractor	Senior Project Manager	Chartered Engineer	> 25
I6	Contractor	Project Manager	Chartered Engineer	> 25
I7	Contractor	Managing Director	Chartered Engineer	21-25
I8	Contractor	Chief Quantity Surveyor	Quantity Surveyor	21-25
I9	Consultant	Chief Quantity Surveyor	Quantity Surveyor	21-25
I10	Consultant	Chief Quantity Surveyor	Quantity Surveyor	16-20
I11	Consultant	Chief Quantity Surveyor	Quantity Surveyor	16-20
I12	Consultant	Quality Assurance /Quality Control Manager	Civil Engineer	21-25
I13	Contractor	Civil Engineer	Civil Engineer	16-20
I14	Contractor	Civil Engineer	Civil Engineer	16-20
I15	Contractor	Civil Engineer	Civil Engineer	16-20

4.1. IDENTIFICATION OF LEAN PRINCIPLES, TECHNIQUES AND THEIR APPLICABILITY TO SRI LANKA

Nine lean principles identified from the literature and expert interviews were subsequently used to identify their applicability to Sri Lanka. Table 2 presents the results of the interviews.

Table 2: Identification of Lean Principles and their Applicability to Sri Lanka

Lean principle	Applicability of lean principles														
	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15
JIT	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TQM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TB	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CE	✓	×	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
PR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VBM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×	✓	✓
TPM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EI	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OSHAS	×	✓	×	×	×	×	×	×	×	×	×	×	×	×	×
CIC	×	✓	×	×	×	×	×	×	×	×	×	×	×	×	×

All interviewees agreed that JIT, TQM, TB, PR, VBM, TPM and EI can be applied to reduce waste in all stages of construction projects in Sri Lanka. For example, JIT can be applied to reinforcements as the required amount of reinforcements can be ordered and stored at the construction site during the first stage itself. JIT is important

in the case of concrete as it has to be transported to the site at the required time to prevent it from getting rejected due to delays.

Two of the interviewees considered CE and VM as being not suitable to every stage of construction since according to them the dynamic nature of the projects will not permit their practical implementation in Sri Lanka.

Two new lean principles, Occupational Health and Safety Assessment Series (OSHAS) and Continuous Improvement Circle (CIC), were identified by one interviewee (I2) who was confident of their benefits because of his experience in the industry.

Interviewees stated that there are barriers to applying the identified lean principles to the Sri Lankan construction industry. According to them, the introduction of new technologies in Sri Lanka is always a challenging exercise as there is hesitancy on the part of the industry to adapt and adjust, the country being still a developing country. Moreover, employees are so much familiar with the existing systems that they tend to resist change. According to the experts, absence of proper guidance to apply these lean principles to the construction industry is a barrier to implementing lean principles in the country. They opined that it is often found that new concepts and technologies are difficult to implement as they incur additional costs thereby becoming a barrier to applying lean principles in Sri Lanka. They were also of the view that professionals are often too busy to study and experiment with new philosophies. However, they considered that lean construction being a management strategy, lean principles should be applicable to the construction industry of any country as they will improve productivity and efficiency of material usage, reduce the idling time of machinery and get optimum service and higher productivity from the labourers.

The interviewees further mentioned that adopting lean techniques may create logistic problems such as the difficulties encountered during transportation, difficulties caused by government agencies, scarcity of resources, lack of knowledge of managing lean principles and reluctance on the part of management to adopt lean techniques.

4.2. IDENTIFICATION OF CONCRETE WASTAGE DURING DIFFERENT STAGES OF CONSTRUCTION

The main stages of a construction project, causes of concrete wastage during each stage and the lean techniques that can be applied to each stage that were revealed from the findings of the literature review and the interviews are presented in Table 3. From the literature review, three stages of construction projects, design stage, pre-construction stage and construction stage, were identified in accordance with the RIBA Plan of Work (2007). All the interviewees confirmed that the stages in local projects are same as the stages identified from the literature review.

4.2.1. IDENTIFICATION OF CONCRETE WASTE GENERATED IN DIFFERENT CONSTRUCTION STAGES

Most of the interviewees stated that all types of waste are generated during the design stage. Communication errors were identified to be the most critical cause of concrete waste occurring during this stage. Selection of incorrect admixtures and incorrect design mixes was also identified as generating waste during this stage (Table 3).

From the literature review, poor workmanship and selection of unsuitable transportation methods were identified as the two causes of concrete waste generated during the pre-construction stage. All of the interviewees agreed that poor pre planning is the cause of most of the waste generated. Furthermore, selection of incorrect admixtures also was identified as generating concrete waste (Table 3).

All the interviewees identified the same types of wastage for the construction stage. They further stated that rejection due to delay in transportation is one type of wastage that often occurs during construction. The other types of wastes that were identified were excess concrete orders, incorrect placing methods, and negligence of workers or labourers (Table 3).

4.2.2. IDENTIFICATION OF THE LEAN TECHNIQUE MOST APPLICABLE TO EACH CONSTRUCTION STAGE

Total quality management, process re-design or re-engineering and total productive maintenance were identified by all the interviewees as techniques applicable to the design stage. Six of the interviewees were of the view that value based management can also be used during this stage (Table 3).

Table 3: Applicability of Lean Techniques to Each Construction Stage

Types of concrete wastage identified from the literature / interviews		**Construction stage**	**Lean principles/techniques that can be applied to minimize concrete wastage based on the interviews**														
Literature	Interviews		Lean Principle / Technique	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15
Poor workmanship	Poor workmanship Incorrect mix design Incorrect admixtures Communication errors Poor pre-planning	Design stage	TQM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			PR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			TPM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			VBM	×	✓	×	×	×	✓	✓	×	✓	×	✓	✓	✓	×	✓
			JIT	×	✓	×	×	✓	✓	×	×	×	×	✓	×	✓	×	✓
			TB	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
			CE	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
			VM	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
			EI	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Poor workmanship	Poor workmanship Overdose or under dose of admixtures Unsuitable ready mix plant Negligence Unsuitable transportation methods	Pre-construction stage	TQM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			VBM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			JIT	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×	×
			TB	✓	×	✓	✓	✓	×	×	✓	×	✓	×	✓	✓	×	✓
			TPM	✓	✓	×	×	✓	×	✓	✓	×	×	✓	✓	✓	×	✓
			EI	✓	×	×	✓	✓	×	✓	×	✓	×	✓	✓	✓	×	✓
			PR	✓	×	✓	×	✓	×	×	×	✓	✓	×	×	✓	×	✓
			VM	✓	×	×	×	✓	×	×	×	×	✓	×	×	✓	×	✓
			CE	×	×	×	×	✓	×	×	×	×	×	×	✓	✓	×	✓
Poor workmanship Excess material order Placing methods Losses during transport	Poor workmanship Excess material orders Incorrect placing methods, Losses during transport Re-work and rejections Poor quality of concrete Defective transportation methods Rejection due to delay in transportation, Wastage during placing Curing failures & machine waste Incorrect levels, Insufficient formwork Reinforcement failures	Construction stage	TQM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			PR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			TB	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
			VM	✓	✓	✓	×	×	✓	×	✓	✓	✓	✓	✓	✓	×	✓
			EI	✓	×	×	×	✓	×	✓	✓	✓	×	✓	✓	✓	×	✓
			JIT	×	✓	✓	×	×	×	✓	✓	×	×	✓	×	✓	×	✓
			TPM	✓	✓	×	×	✓	×	×	✓	✓	✓	×	×	✓	×	×
			CE	×	×	×	×	✓	×	×	×	×	✓	✓	×	✓	×	✓
			VBM	×	✓	×	×	×	×	×	×	×	×	×	×	✓	×	×

All interviewees agreed that just in time, total quality management, and value based management can be applied in pre-construction stage. Time based competition; total productive maintenance; and employee involvement were also identified by more than six interviewees as lean techniques applicable in this stage (Table 3).

Total quality management, time based competition and process re-design or re-engineering were identified by all the interviewees as being the lean principles applicable in the construction stage while more than 6 interviewees considered visual management, total productive maintenance and employee involvement as being also applicable in this stage (Table 3).

4.3. USE OF LEAN PRINCIPLES IN CONSTRUCTION PROJECTS

By reviewing literature, nine lean principles were identified as being suitable for use in construction projects. Two additional principles were identified by one interviewee (Table 2).

The interviews were used to validate the applicability of the lean principles identified through the literature review, to Sri Lanka (Table 3). Eight of the twelve interviewees agreed that all nine principles are applicable to the Sri Lankan construction industry while four did not agree with the applicability of one or two principles.

Construction stages that could contribute to concrete waste were identified from both the literature review and the interviews. All the interviewees agreed with them based on their experience (Table 3). The construction stages that were identified from both the literature and interviews as being suitable for consideration in reducing concrete waste are design, pre-construction and construction stages.

From the literature review, one type of concrete waste was identified to occur in the design stage while the other types occurring in this stage were identified from the interviews. The interviewees agreed with all types of concrete wastage identified through the literature review. They wanted to include three additional types of waste for the design stage (Table 3): incorrect mix design, incorrect admixtures and communication errors.

For the pre-construction stage, only a few types of concrete waste were identified from the literature review and all the interviewees were in agreement with them. The interviewees wanted several other types of waste also to be included for this stage (Table 3).

For the construction stage, three types of concrete wastage were identified from the literature review and the expert interviews. The experts identified eleven types of wastage additionally for this stage (Table 3). Findings reveal that the construction stage can generate more concrete waste than other stages.

The interviewees also identified the lean principles that are suitable to minimize wastage at each stage of construction. Just in time and value-based management, according to them, are the most suitable lean principles that can minimize concrete wastage at the stage of preparation (Table 3). Total quality management, process re-design or re-engineering and total productive maintenance are the lean principles most suitable to minimize concrete wastage during the design stage of construction as per the findings (Table 3). Just in time, total quality management, and value-based management are identified to be the lean principles most suitable to minimize concrete waste during the pre-construction stage (Table 3).

It is also revealed that total quality management, time based competition and process re-design or re-engineering are the lean principles most suitable to minimize concrete wastage during the construction stage (Table 3).

Total quality management principle was identified to be the most suitable method for minimizing concrete wastage during all three stages of construction. Therefore, on the whole, total quality management can be considered as the most suitable and most applicable technique that will minimize concrete wastage.

5. CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

5.1. CONCLUSIONS

The aim of this research was achieved by identifying the lean principles that can minimize concrete wastage in Sri Lanka. Poor workmanship, incorrect mix design, poor pre-planning, communication errors, and negligence were identified as causing concrete wastage in all stages. Total quality management was found to

be the lean technique most suitable for minimizing concrete wastage during all three stages of construction (Table 3).

The research findings indicate that there is an imperative need to implement lean construction in the Sri Lankan construction industry because of the large amount of concrete waste generated daily. Sri Lanka being a developing country, only few professionals working in the construction industry in the country are knowledgeable about lean construction. Although several companies have already implemented lean construction, most companies are yet to implement it.

5.2. RECOMMENDATIONS

This study covered several aspects related to minimization of concrete wastage using lean construction techniques. Therefore, the following recommendations will assist in implementing lean principles in the Sri Lankan construction industry and minimize concrete wastage.

1. Educating professionals and all others engaged in the construction industry about lean construction.
2. Implementing lean construction with regard to wastage of other types of material such as cement and reinforcements.
3. Encouraging cooperation between contractors and clients in applying lean concepts to minimize wastage.
4. Changing the negative attitudes towards the implementation of new systems

5.3. LIMITATIONS

The dearth of professionals knowledgeable in lean construction was the main concern during the study. Only few professionals were aware of this new philosophy while others were totally ignorant of it. Therefore, only fifteen experts could be interviewed during the study which can be considered as a limitation of the study.

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