Reducing construction and demolition waste through lean production: Observations from Tel-Aviv, Israel

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The growth and complexity of construction projects have motivated the construction industry to implement cutting-edge technologies and new approaches in design and construction, including advanced computer-based design and project management methods like building information modeling (BIM) and lean construction. This paper evaluates multiple construction projects in the Tel-Aviv area of Israel and compares the effects of implementing the lean construction method to reduce construction waste over time. The authors focus on the lean concept of 5S (sort, set in order, sustain, standardize and shine), which is a systematic method for organizing the work environment, and just-in-time (JIT) delivery. In the case study reviewed, a centralized mixing operation that adheres to 5S principles and just-in-Time (JIT) delivery was implemented for supplying cement mortar, plaster, and glue to multiple finishing operations in a high-rise residential construction project. The research is divided into two stages. The first stage is qualitative analysis for the centralized mixing station, while the second stage is quantitative analysis, collecting data from the company to quantify the environmental and economical improvements that occur due to the centralized mixing implementation. This paper presents the first stage of the research. Results show that centralized mixing reduces the material and the operation waste. It keeps the construction site clean and organized. It improves the quality of the material mixing by satisfying the standard ratios. Also, it improves the safety of the construction site.

Introduction

The construction industry is one of the most polluting industries in the world. According to the U.K. Green Building Council [1], the construction industry uses more than 400 million tons of material per year, the majority of which imposes significant environmental burdens the environment. For example, 60 million tons goes directly to landfill simply due to overordering, mis ordering or poor handling and breakages. Moreover, the U.S. construction industry accounts for 160 million tons, or 26%, of non-industrial waste generation each year [2]. It additionally contributes to 23% of air pollution emissions, 50% of greenhouse gas emissions, 40% of drinking water pollution, and 50% of landfilled waste [3].

Construction waste forms about 60% of the total solid waste in Israel [4]. It consists mainly of concrete, steel reinforcement, steel sections, blocks, tiles, wood, plastic materials, gravel, and soil [4]. The finishing phase in construction generates wastes that are about three times the wastes generated during construction of the structural frame [5]. The amount of construction waste exceeds 7 million tonnes each year [6]. This motivates the reuse, recycle and effective management of construction and demolition waste (CDW).

In recent years, governments, real estate developers, design firms, and construction companies have begun to recognize the benefit of recovering CDW [7-9]. Some countries have realized the benefits of recycling and reuse since the 1990s.Denmark, Holland, and Belgium recycled 80-90% of their construction wastes [10]. Unlike the select few European countries that have achieved high CDW recovery rates, Israel has very low recycling rates, estimated at about 20%, with a large fraction disposed in legal and illegal landfill sites [4, 11, 12].

The number and location of recycling plants affects a country's potential for recycling. In Israel, there are only three CDW recycling plants distributed across the country [13]. On the other hand, there are 22 landfill sites in the country.

Lean production principles aim to improve construction through focusing on value and waste elimination, which also can result in environmental benefits through the reduction of life cycle greenhouse gas (GHG) emissions and other environmental waste. To date, researchers have studied the relationship between lean and environment for some processes and activities in construction projects [15-20]. They found that there is a strong relationship between lean and environment that can lower the carbon footprint of completed buildings through avoiding and reducing waste generation. However, there are some contradictions between lean and green building rating systems. Lean is process-oriented, whereas green building rating systems can be product-oriented. In some cases, achieving some points may require an investment of time and effort that does not bring direct value to the client. There may also be some lean practices that require more energy - such as just-in-time deliveries in small batches [21].

Lean production has had a transformative effect on the productivity of construction projects in which it has been applied [22, 23]. [19] presented a study for measuring the impacts of lean and virtual design and construction (VDC) in three residential construction projects that had different combinations of VDC and lean practices. They monitored worker activities associated with building masonry blocks and classified them as value-adding and non-value-adding activities. The results were eye-opening. Applying lean principles and VDC improved the value-adding activities from 35.8% in a traditional project to 68.4%. The study demonstrated the impact of lean principles in improving construction operations.

Our objective was to investigate the effects of lean 5S (sort, set in order, sustain, standardize and shine) principles in construction operations of mortar, gypsum, and glue in high rise residential construction projects. We begin with a concise literature review about waste in construction, the 5S lean construction technique and JIT.

Literature review

This chapter discusses research on waste in construction, 5S and JIT. It outlines the relation between them by presenting the effects of 5S and JIT in reducing construction wastes.

Waste in construction

Waste is one of the central concepts that lean aims to eliminate. It represents any exhaustion of time, money, equipment, and energy that does not bring value to the customer. The construction industry produces a significant amount of waste [23, 24]. As such, researchers from all over the world have studied waste generation related to construction, identifying and attempting to measure this waste and trying to find methods to eliminate it [25-29]. Eliminating wastes plays an important role in providing the customer with the product in an efficient way, by reducing the cycle time, time to market, solid waste, and saving costs for the whole supply chain. Taiichi Ohno identified seven types of process wastes: transportation, inventory, motion, waiting, over-production, over-processing, and defects [30].

Transportation: represents any unnecessary movement of materials from their manufacturing until becoming a finished product. It results from excessive handling, lack of material flows planning.

Inventory: represents any products or materials that are sitting without any processing.

Motion: represents any worker movement that does not add value. Any construction process consists of many operations, which are generally associated with worker activities. Eliminating the unnecessary movement of workers is a key point in lean thinking.

Waiting: represents any worker or machine that has been employed but prevented to perform their specific job since not all perquisites are ready. For example, there are no drawings, equipment, materials, unsafe workplace or the predecessor activity is not ready.

Over-production: represents completing a task before it is required from the next step in the process. Ohno mentioned that over-production is the worst type of waste because it causes different types of wastes like inventory, transportation, motion, waiting, and defects.

Over-processing: represents any effort that is spent on a product but it is not required from the customer. The customer is not willing to pay for these features.

Defects: represent any quality problems that cause the product to be discarded and rejected. This leads to rework or to the incorporation of unnecessary materials and additional worker's effort.

[31] defined waste as "Waste – the expense of labouring force to overcome resistance, such as friction, which is necessary due to physical or mechanical phenomena, but does not produce value". And "Waste – the expense of time,

or waste of the potential labouring force.” Also, they defined waste as “Work – the expense of labouring force to change the composition of materials and produce products of value.”

[32] estimated the wastes of production in construction based on the Transformation-Flow-Value theory (TFV). They defined three main categories of waste: Material waste in transformation, time loss in the flow, and value loss. They proposed a definition of waste as the use of more inputs than needed and unwanted output. So, this definition can be related to both aspects inside production by exhausting more than needed and to producing unwanted things. They classified the transformation waste as material waste, non-optimal use of material, and non-optimal use of machinery, energy, or workers. For the waste, they mentioned two types of waste in the workflow and the product flow. Workflow waste includes the unnecessary movement of people, unnecessary work, waiting, and inefficient work, while product flow waste includes space not being worked in, materials not being processed, and unnecessary transportation of material. Finally, for value waste, they defined two waste categories related to the main product and by-products. The main product waste is lack of quality and lack of intended use. By-product wastes are harmful emissions or injuries and work-related sickness.

[19] presented a study that identifies the relationship between lean, VDC, and sustainability. They compared masonry works in two construction projects with similar scope, one of them implemented a combination of lean and VDC while the other used traditional building construction methods. Partition walls were built in the lean-VDC project using gypsum blocks while in the traditional project they were built from autoclaved aerated concrete (AAC) blocks, marketed as Ytong. The findings were significant: implementing lean and VDC contributed to reducing environmental pollution and greenhouse gases (GHG) from 169 CO_2e/m^3 of partition built to 112 kg CO_2e/m^3, a reduction of 34%. Moreover, they proposed a hypothetical case in which both projects used the gypsum block to normalize the effect of lean and BIM. They found that the lean-BIM project consumes a smaller amount of materials and generates less material waste and GHG emissions and concluded that lean and VDC are dominant management approaches in reducing waste and improving sustainability.

[33] presented local materials waste in the Egyptian construction industry. They conducted a waste survey among 35 public and private contractors. They found that the highest waste rate related to timber frameworks were approximately 13%. However, the steel and cement waste rates were 7% and 5%, respectively. They found that the materials waste occurred due to changes of design, lack of coordination between various trades on the construction sites, and damages during the transportation of material to the site. The most dominant cause of waste is untrained labor.

5S

5S is a method to organize and clean up the workplace. According to [34] the 5S process is referred to as “a place for everything and everything in its place”. The name consists of five Japanese words: seiri, seiton, seiso, seiketsu, and shitsuke, which are translated into English as sort, set in order, shine, standardize and sustain [35].

Sort: the first step is to sort everything in the work areas and to identify what is required to perform the work.

Set in order: in this stage all the materials and equipment are set in order using planning and labelling. In this stage the main focus is on site storage areas.

Shine: cleaning the workplace. This includes placing waste bins, and make system for evaluation the individual works, like cleaning the workplace daily after finishing their work.

Standardize: requires the operations in the workplace to be in a standard fashion and according to the specifications and codes.

Sustain: to make sure that the standards are committed from the workers. Weekly checking is performed to guarantee the standards remain.

There are many benefits to implementing 5S in construction sites. According to[34] 5S improves quality, safety, productivity, set-up-times; it reduces lead time, improves teamwork, morale, creation of space, and contributes to continuous improvement (kaizen activities). Slips, trips, and falls are common injuries in construction sites. According to [36] slips and trips form 23% of injuries in the construction industry. Also, [37] mentioned key factors in the accident like problems arising from workers or the work team, workplace issues, shortcomings with equipment, problems with suitability and condition of materials, and deficiencies with risk management, the most critical one is workplace issues which form 49% of the accidents.

Lean and safety approach shares the goal of workplaces that are sorted and tidy. Skanska Finland has adopted the 5S-principles in developing housekeeping [38]. In Skanska, the accidents declined significantly from 57 lost time accidents per million work hours in 2005 to 9 in 2009. They found that without quality production management it is not possible to achieve low accident rates. Also, they argued that high accident rates indicate non-quality production management. However, there are no studies that measured productivity improvement quantitatively, reduction in costs, or improvement in flow due to implementing 5S. Moreover, [39] presented a 5S program launched in Skanska

Finland. The aim of the program to improve tidiness and safety performance. In this program 2770 employees at 190 jobsites participated. The workers impression for the program was satisfactory, 94% mentioned that the program beneficial. Safety performance improved in their construction sites. Number of slips and trips accidents decreased, and the weekly safety performance index increased by 3.4 percentage points.

[40] pointed out the importance of 5S in reducing pollution and environmental impacts. It eliminates any tools or materials not used in the construction process. Also, it is used for cleaning and keeping the work zone in order.

Just in Time (JIT)

Just in time refers to a method to produce goods only when there is a direct request from the customers in the required quantity and quality [41]. [42] defined the term JIT as a way for delivering materials to construction sites so that all materials will be delivered to their final locations for final erections and installations without any delay due to waiting or storage. The lean tool developed to satisfy the JIT is the "Kanban", which is a Japanese word. It is used as a pull system to guarantee material process flow [43]. They mentioned several principles to satisfy the JIT, summarized as follows: levelling of production, avoiding complex information systems on-site, avoiding start working without an ordering Kanban and avoiding sending incomplete work to the succeeding stage. Kanban achieves visibility, production control, progress monitoring, and safety control.

Many researchers tried to study the effect of implementing (JIT) in the different construction processes. [44] studied the application of JIT to the fabrication and installation of prefabricated concrete facades in buildings. They found that the project was completed three months in advance compared to a traditional project with the same scope. Also, the production rate and the worker productivity improved in a very important amount with improvement in quality with superior to the expectations of the client. [45] recommended the use of lean tools like JIT and Kanban, since they reduce the waste due to avoid excessive buying of materials.

JIT has numerous benefits for the construction industry. It reduces the need for double handling, and the opportunity for defects, damages, and losses. Moreover, it reduces site congestion and costs for unnecessary movement of materials around the construction site [46].

Methods and Goals

Method to execute the experiment

The method used to study the effect of implementing the centralized mixing and supply of bulk materials like mortar, gypsum and glue was case study research. Case study research is an appropriate method in management science [47]. One of the important characteristics of case study research is that each case has its unique features [48]. [47] defines case study research "as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not evident; and in which multiple sources of evidence are used." Here, the case study research method focuses on comparing two alternatives for mixing the material; one with the mixing in a central location with material deliver to the requested location (Fig1) and the other is mixing through traditional construction methods (Fig 2), where each subcontractor mixes in the work location without any control on the quantity or the quality.

Fig.1 The centralized mixing and supply of bulk materials in company A

Fig. 2 Illustrations of traditional mixing methods

Goals

The aim of this study was to evaluate the reduction in construction wastes due to implementing centralized mixing at a station at the construction site and, at the request of the sub-contractor, JIT delivery of the mixed material to the subcontractor.

Data collection

A combination of site visits with questionnaire interviews were conducted with the CEO, production process manager, construction manager, site engineer, and site superintendents to identify the concept and purpose of the centralized mixing station. Also, the authors took some photos describing the station scope and its components like material storage location, mixers, and visualization tools.

Case study description

Company A, which implemented innovations and cutting-edge technologies in their construction site, especially lean and BIM, decided to improve the way they mixed the material. They decided to create a centralized station with multiple mixers, each mixer for a specific material. They established these mixing stations in two high-rise residential construction projects.

The centralized mixing station consists mainly of three mixers (Fig 3a). Each mixer for a specific material. The station contains a Kanban tool represented by a digital screen (Fig 3b), which helps the subcontractor in the different work zone to send a signal for the worker in the station to prepare the proper material with the exact quantity (Fig 3c) and deliver it at the right time using a lift erected beside the station. In the station, there is a place to properly store the materials, contributing to maintaining an organized and clean work environment that is less likely to lead to contamination of the building materials.

In each workplace, there is a bottom erected on the lift. It helps the sub-contractor to push it to send a signal for the worker in the station. The worker in the station receives a signal on the screen explaining the material type required with its quantity and to which workplace it should be delivered. After each mixing operation, the worker cleans the mixer and the workstation (Fig 3d) to keep it clean and organized.

Fig. 3 Illustrations of the centralized mixing; a) scope of the station; b) Kanban tool; c) the ready-mix mortar; d) cleaning the mixer

Results and Discussion

This section summarizes the qualitative assessment for the centralized mixing and supply of bulk materials. It reflects several benefits in terms of quality, safety, a clean workplace, and reducing non-value-adding activities. These benefits are summarized as follows.

1- Eliminating the non-value-adding activities: This is satisfied by providing the subcontractors with ready-mixed material and enabling them to devote their time to value-adding-activities.

2- Keeping the construction site clean and in order: This helps to reduce accidents resulting from slips and trips which in turn improve safety issues in the construction site.
3- Eliminating the non-value-adding activities required for cleaning: workers to clean the construction site, delivering the waste using the crane to a specific location in the site, bringing trucks to deliver these wastes to a landfill and paying for dumping the wastes.
4- Improving the mix properties and characteristics: A worker in the mixing station for all sub-contractors will mix according to the ratios specified in the standards and specifications and this will standardize work, which is a lean goal.
5- Improving the mix quality: This is satisfied by avoiding mixing two materials with different characteristics, which cause quality problems. For example, plaster cracks result from mixing mortar in the same container where gypsum materials were mixed. Gypsum swells when it absorbs water, so the remaining gypsum particles in the mixing container causes the plaster to be cracked and dislocated.
6- Supporting control and monitoring of materials: The presence of materials in a specific location helps in identifying and recognizing the consumption of each material daily. Also, it helps in keeping the material safe from weather effects and theft.
7- Eliminating material waste: This is satisfied by mixing in the exact quantity required by the sub-contractor. Traditionally, the sub-contractor mixes the material in a random quantity, so at the end of the day, the surplus material will be wasted. However, applying the centralized mixing concept helps in delivering the right quantity to the sub-contractor which means at the end of the day the material waste will be close to zero. In this way, we achieve pull flow, which in turn can reduce the mixing of excess materials.

Conclusion

The implementation of centralized mixing and supply of bulk materials as a lean construction concept demonstrates that lean principles play an important role in reducing the different types of wastes and energy due to eliminating certain energy-consuming operations in the construction industry. The construction sites that implemented centralized mixing showed an improvement in different areas. Non-value-adding activities were reduced by improving individual sub-contractors' operations. Also, it removed the need for workers to clean the construction site and transport those wastes to landfills. Safety issues improved by reducing the probability of slips and trips since the construction site is clean and organized. The quality of the mixing improved in two ways. First, the mixing ratios are controlled by the worker in the mixing station, and this maintains the lean standardization concept. Second, three separate mixing vessels (Fig.3a) were used for mortar, gypsum and glue, which avoided contamination and reduced the quality defects. Having a dedicated location at the construction site gives the ability to identify the daily consumption of material, and it helps in keeping the material in a safe place from weather conditions and theft. Finally, the centralized mixing station can potentially address environmental waste control through reducing the amount of wasted materials and their transportation to a landfill which can be translated to carbon footprint and GHG. This paper shows the first stage of this research, a qualitative assessment of the impact of centralized mixing and supply of bulk materials station. A second stage that quantifies the mixing stage and material waste reduction is ongoing.

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