Hindawi
Advances in Civil Engineering
Volume 2023, Article ID 2379347, 11 pages
https://doi.org/10.1155/2023/2379347

Research Article

Evaluation of the Implementation of Lean Techniques to Reduce Construction Process Waste in Real Estate Firms in Addis Ababa, Ethiopia

Fitsum Ayfokru,[1] Bahiru Bewket Mitikie ,[1] and Andinet Kebede Tekile [2]

[1]*Department of Civil Engineering, Adama Science and Technology University, P.O. Box 1888, Adama, Ethiopia*
[2]*Department of Water Resources Engineering, Adama Science and Technology University, P.O. Box 1888, Adama, Ethiopia*

Correspondence should be addressed to Andinet Kebede Tekile; andinetm@gmail.com

Received 29 August 2022; Revised 2 February 2023; Accepted 3 February 2023; Published 16 February 2023

Academic Editor: Gladis Camarini

Waste in the construction industry is the loss produced by activities that generate direct or indirect costs but do not add any value. In recent years, waste in the construction industry has been the subject of several research studies around the world; however, it still continues to be a critical issue. Thus, the objective of this study was to develop an analytical hierarchical model for the implementation of lean techniques for the reduction of construction waste in real estate companies in Addis Ababa, Ethiopia. The study was conducted on seven private residential real estate companies which were actively involved in the construction sector at the time, by targeting decision-makers as respondents. Analytical hierarchical process-based questionnaires and face-to-face interviews were conducted for the collection of primary data. Thus, comparison-based surveys and data analyses were used to quantify the relative priorities for a given set of alternatives on a ratio scale based on the judgment of the construction professionals. According to the data analyses, poor material handling, poor site management, and frequent changes in the design were identified to be the three most dominant sources of construction waste. It was found that the real estate companies do not have any waste reduction strategies or practices. Furthermore, the concerned professionals have limited awareness of the lean techniques and their implementation. Based on the findings, the construction companies are recommended to give proper attention to construction waste minimization and a huge task is ahead of the policymakers for lean techniques implementation.

1. Introduction

The construction industry plays a key role in the economic growth of a country. However, it relies heavily on the natural environment for its supply of raw materials, as building construction consumes 40% of the world's raw stones, gravel, and sand, 25% of the virgin wood, 40% of the energy, and 16% of water, annually [1]. On the other hand, one of the common and tough challenges related to the industry is the high rate of waste generation. Luangcharoenrat et al. [2] found that the proportion of construction waste that is landfilled in 13 countries to be between 13 and 60% compared with the total amount of waste. Moreover, the presence of a significant number of waste types within construction activities affects the overall performance and productivity of the industry. Thus, waste within the industry is the center of attention not only from the resource effectiveness point of view but also due to its adverse effect on the environment and productivity.

For a lot of nations, rising levels of waste generation, due to the fast development of towns and cities, are critical issues [3, 4]. The waste created on construction sites results in two cost factors for the builders, which are the cost of the material procurement and that of transporting it and disposing of site waste. Subsequently, waste needs to be characterized as any losses produced by activities that create direct or indirect costs but do not add any value. As a developing nation with rapid population growth and urbanization rates, presently the construction industry in Ethiopia involves a wide variety of buildings, extending from simple houses to high-rise buildings and from schools and hospitals to factories and shopping centers, and extending from highways to hydroelectric and irrigation dams [5].

Real estate development is one of the mega business investments in the country with the transaction of billions of cash in the market. Due to huge current and future housing demands, the actors in the sector are increasing in number [6]. The Ethiopian construction industry is under numerous issues and challenges that the industry is confronting in other developing nations, perhaps with serious severity. Among others, Ethiopia faces challenges of limited resources and environmental impacts related to poor energy and waste management. Construction waste management is a relatively new practice for the Ethiopian construction industry and a study by Tadesse et al. [7] confirmed that 30 to 40% of the project time is wasted in performing nonvalue-adding activities such as overproduction and waiting-related wastes. Generally, Ethiopian construction firms operate under project deliveries delay, cost overruns, quality defects, and low customer satisfaction.

Reducing and managing construction process waste saves the cost of disposal and transport, increases profits, saves time, protects the environment, and creates clean and safe work sites [8]. Different strategies are utilized to reduce construction waste and its impacts. Lean construction, in this respect, is an effective management tool to improve efficiency in the field. An extensive investigation is still underway to adopt lean principles from the manufacturing industry to the construction industry. The process of applying the philosophies used in the manufacturing industry to the construction industry is continuous because lean thinking in construction management is different [9].

Lean thinking (LT) is a concept that construction companies consider to change their way of thinking. It combines philosophies such as waste elimination, continuous improvement, availability of resources, teamwork, and supply chain management cooperatively to ensure success in projects [10]. There are five basic principles of lean construction which help stakeholders to manage their companies and projects flexibly in order to achieve the idea of lean thinking and its benefits; these are, identifying the value of the construction from customer perspectives, recognizing value streams based on the delivery value, removal of waste by various processes which influence the flows within work processes, creation of a system of pull production to ensure that the system does not allow delivery of materials until they are needed by customers and finally, achieving continuous improvement and pursuing perfection [10–12].

When a company starts implementing lean, the description value of its services from the clients' perspective is the first step. This leads to the recognition of waste as everything that adds no value from the clients' viewpoint. Time also has the utmost value to the client. Therefore, these steps will be identified along the value stream through a process called value stream analysis. Value stream analysis is an assessment and planning tool that lean practitioners use to apply lean thinking. It helps to determine inefficiencies in an end-to-end process. It also monitors all the activities being performed by looking through the time aspect. People, materials, and equipment are managed using a chart which tracks down the flow of information along the process flow. The benefits added to the construction industry using value stream analysis are the following: ability to visualize the production flow, foreseeing waste in the system, preventing focus on large improvement opportunities with little impact, creating a framework for designing a complete system, demonstrating the interaction between information and material flow, and developing an implementation plan for future lean activities [13].

Thus, the lean construction aims to complete a project that meets customers' requirements through waste reduction. It involves ways of designing production systems to minimize waste in materials, time, and human effort, with the aim of achieving maximum cost-effective value. It is concerned with a holistic pursuit of concurrent and continuous improvements in the design, construction, activation, maintenance, salvaging, and recycling of building projects. Lean construction promoters helps in identifying the root causes of waste, eliminating those causes with related tools and techniques, and thus encouraging the prevention of waste rather than reactively attempting to overcome the negative effects of loss [12].

Waste is often assumed to be the only physical waste by construction professionals; however, wastes in the industry are also created by nonvalue-adding activities (wastes and wasteful operations) [14]. In comparison with other issues, the effort of the construction management actors to consider nonvalue-adding activities is relatively low, and most of the studies about waste have focused on the consequences, not on the root causes that should be avoided [15]. For performance improvement, waste should be reduced or eliminated. Creating value is the best way to eliminate waste in lean design and construction [16]. Focusing on the value we want to create and systematically creating it is essentially more rewarding and more effective. When one delivers value, waste is eliminated or perhaps not even created in the process [16, 17].

Waste can be categorized according to its source, that is, the stage in which the root causes of waste occur. Waste may result from material manufacturing, design, material supply, and planning processes as well as in the construction stage [18]. Waste is material-related (overordering, overproduction, mishandling, bad storage, manufacturing defects, and theft and vandalism) and time-related (waiting, stoppages, clarifications, variations in information, rework, errors, and interaction between various specialists) [19]. Generally, the most frequent types of waste in construction are the following: waiting (on people, information, and material), corrections (rework), transportation (haulage and soluble handlings), motion, overprocessing (wrong methods), inventory (storage), overproduction (building ahead of time) [12].

Research works show a number of lean tools or techniques which are currently used in the construction industry. The most implemented ones are just-in-time (JIT), the Pull "kanban" system, the 5S process, computer-aided design (CAD), standardization, prefabrication, the last planner system (LPS), value stream mapping (VSM), continuous improvement (Kaizen), target value design (TVD), a waste elimination, clean schedule and work plan, first-run studies (plan, do, check, and act), total production maintenance (TPM), total quality management (TQM), error proofing (Poka-Yoke), Ishikawa diagram, Pareto analysis, daily huddle meetings, failure modes, effects and criticality analysis (FMECA), and five whys [12, 20–22].

Salem et al. [23] and Shaqour [20] placed the benefits of implementing lean construction under the three pillars of sustainability, that is, environmental, economic, and social. The environmental benefits are improved safety control, material reduction, preventing emissions and associated pollution, reduction of energy consumption, and enhanced working environments [12, 22–24]; the economic benefits are due to time and cost reduction, quality improvement, increased productivity, rework minimization, improved prediction of risks, safety, planning and process control, labour cost reduction, and in general an improved life-cycle cost [12, 22, 25–27]; and the possible social benefits are employee and customer satisfaction, minimization of conflicts, improved communication among stakeholders, and improved decision making [12, 23].

The lean construction benefits specifically related to residential buildings and/or real estate projects are reducing total project duration, improving environmental performance, improving the safety of workers, managing uncertainties in supply, continuous improvement in projects, delivery of custom products instantly, delivery of products of service on time and within budget, reduction of direct cost and time in transportation and communication, improved overall equipment effectiveness, and improved employee satisfaction and supplier relationships [22].

Specifically in Ethiopia, Tadesse et al. [7] stated that lean is not yet practiced in the construction industry and only 48% of professionals are aware of the lean concept. Through the efficient reduction of waste and by increasing effectiveness and productivity, the new management tool of lean construction has the potential to benefit Ethiopian construction firms. Analytical hierarchy process (AHP), a hierarchical structure that is a strong and a helpful tool for managing qualitative and quantitative multicriteria elements involved in decision-making behavior, was used to build a model. AHP was chosen for this study because it is a strong yet simple tool. AHP is one of the most inclusive systems considered to make decisions with multiple criteria because this method helps in formulating the problem as a hierarchical structure.

Thus, this study had the aim to build a decision-aiding model which can be used as a tool by construction professionals for the implementation of lean techniques on waste reduction, by considering selected private residential real estate projects in Addis Ababa as the case of the study. To realize the objective, the major sources of wastes, the current practice of reducing wastes, and the assessment of applying lean techniques as alternatives for the reduction of identified sources of waste are used as the operational steps. The study findings can help construction professionals to decide on the selection of lean techniques to be applied to different kinds of sources of waste that are encountered during the construction process.

2. Materials and Methods

The research study was performed in Addis Ababa, the capital city of Ethiopia, where construction is one of the major activities. The real estate-based housing development is especially considered to solve the severe accommodation problem in Addis Ababa, and thus, the business has been popular since the past few decades. This study focused only on private residential real estate companies by using both quantitative and qualitative approaches of descriptive nature, focusing on comparative judgment (prioritization) to develop a model for the implementation of lean techniques on the reduction of construction waste.

During the study, seven companies were actively involved in residential real estate investment in the city. Because the companies were only few in number, so all of them were considered for the study. The companies were managing 16 residential real estate projects and the study purposively targeted decision-makers; namely, construction managers, project managers, as well as site and office engineers.

The questionnaire was designed (Table S1 of the supplementary material) and distributed to make an analytical hierarchy process (AHP) decision-aiding model. To make the AHP model, setting a goal is the first step, which was identified as the implementation of lean techniques to reduce construction waste. For the implementation of lean techniques on waste, the common sources of waste in construction were identified through a literature review [7, 9, 12, 14, 15, 28]. Journals and conference proceedings on the causes of construction waste in high-rise residential buildings and general building works worldwide and in Ethiopia were considered for review.

The survey was conducted based on a comparison of the identified sources as a criterion that relies upon AHP for its methodology. The survey objective was to quantify relative priorities for a given source of construction waste and lean techniques as an alternative on a ratio scale, based on the judgment of the construction professionals. A pairwise comparison matrix was constructed for all elements within the same level and each of the lower levels with one matrix for each element in the level immediately above.

Common sources of construction waste identified were set to be compared with each other to build the decision-aiding model. After the comparison was performed, for each compared source of construction waste, there were two suggested lean techniques which were also identified through a literature review as an alternative for waste minimization (Table S2 of the supplementary material). So, the respondents were asked to compare the two alternatives and to decide which one could be more applicable.

Each decision-maker entered his/her desired amount for each member and then individual judgments (of each respondent) were converted into group judgments (for each one of the paired comparisons) using their geometrical average. The scale ranging from one to nine, where one

Table 1: The fundamental pairwise comparison scale [31].

Scale	Ranking	Explanation
1	Equally important	Both criteria or alternatives contribute to the objective equally
3	Moderately important	Moderate preference is given to one criterion or alternative over the other
5	Strictly important	Strict preference is given to one criterion or alternative over the other
7	Very strictly important	Very strict preference is given to one criterion or alternative over the other
9	Extremely important	The highest preference is given to one criterion or alternative over the other
2, 4, 6 &8	Mid values	

denoted that the two elements were the same or were equally important and number nine implied that an element was extremely more important than the other one in a pairwise matrix, was used. The pairwise scale and the importance value attributed to each number.

On the other hand, a face-to-face interview (given in the supplementary material) was used as a tool to assess the companies' practice on waste reduction. The interview was meant to supplement the questionnaire and to enhance the reliability of the data obtained by the questionnaire. Several issues were raised to understand the waste reduction strategies and if the company had its own system of waste management scheme. Seventy-seven interviews were conducted from March 01 to April 30 in the year 2021 with all construction professionals who responded to the questionnaire survey within the real estate companies.

The AHP procedure engaged a variety of options in the decision and is capable to apply sensitivity analysis on the subsequent criteria and benchmarks. Also, it makes judgments and calculations easier because of paired comparisons. Moreover, it demonstrates the compatibility and incompatibility of decisions, which are the reward of multicriteria decision-making [29]. The simplest form used to structure a decision problem is a hierarchy consisting of the following three levels: the goal of the decision at the top level, followed by a level consisting of the criteria by which the alternatives, located in the third level, will be evaluated [30]. And this shows the relations between the objectives, evaluation criteria, subcriteria, and alternatives in a ranked way. After structuring the hierarchy, the relative importance of decision criteria is assessed by comparing the decision alternatives to each criterion, and finally, the overall priority for each decision alternative and the overall ranking of the decision alternatives are determined [31]. Thus, the steps used in AHP are as follows:

Step 1: The issue and goal of decision-making are brought hierarchically into the scene of the related decision elements. Decision-making elements are decision indicators and decision choices [29]. In using the AHP to model a problem, one needs a hierarchic or a network structure to represent that problem as well as pairwise comparisons to establish relations within the structure. In the discrete case, these comparisons lead to control matrices [30]. Thus, the first step is defining the decision problem and identification of the criteria and alternatives.

Step 2: The structural hierarchy is established.

Step 3: Pairwise comparison matrix is formed. The pairwise comparison is conducted based on the answers of either a decision-maker or an expert, who evaluates the importance of each criterion per decision objective(s) by using a scale ranging from 1 to 9 (Table 1).

The pairwise comparison matrix which is called matrix A is extracted from the data collected from the respondents. $A = [a_{ij}]$ represents the expert's preference (Ai versus Aj for all i, $j = 1, 2, 3, \ldots, n$). Relative measurement wi, $i = 1, \ldots, n$, of each of n elements is a ratio scale of values assigned to that element and derived by comparing it in pairs with the others. In paired comparisons, two elements i and j are compared with respect to a property they have in common. The smaller i is used as the unit and the larger j is estimated as a multiple of that unit in the form $(w_i/w_j)/1$ where the ratio w_i/w_j is taken from a fundamental scale of absolute values [30].

Step 4: Eigenvalue and Eigenvector are derived. The values in the comparison matrix are normalized and the Eigenvector is obtained by calculating the average of each line in the normalized comparison matrix. These averages provide an idea of the priorities of the options compared to each other. The Eigen matrix is calculated by multiplying the Eigenvector and the comparison matrix.

(a) The value in each column of the pairwise matrix are summed as $C_{ij} = \sum_{i=1}^{n} c_{ij}$
(b) Each element in the matrix is divided by its column total to generate a normalized pairwise matrix X_{ij} represented as

$$X_{ij} = \frac{c_{ij}}{\sum_{i=1}^{n} c_{ij}} \left\{ \begin{matrix} W11 & W12 & W13 \\ W21 & W22 & W23 \\ W31 & W32 & W33 \end{matrix} \right\}. \quad (1)$$

(c) The sum of the normalized column of the matrix is divided by the number of criteria used (n) to generate a weighted matrix (priority vector), W_{ij} which is represented as

$$W_{ij} = \frac{\sum_{i=1}^{n} w_{ij}}{n} \left\{ \begin{matrix} W11 \\ W21 \\ W31 \end{matrix} \right\}. \quad (2)$$

Table 2: Random consistency index values [29].

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54	1.56	1.58	1.59

Step 5: Determination of consistency ratio. The accuracy and consistency of a survey is a significant aspect of research, referring to the validity and reliability of data. For this study, the first face validity measure was conducted by having academicians who understand the topic to go through the questionnaire to evaluate the content, and based on their evaluation and comments the questionnaire was revised. After that, a pilot survey was conducted on the projects where 16 questionnaires were distributed to be filled by project managers and engineers. By checking if the questionnaires were filled correctly, the data were collected and checked for its reliability by consistency ratio.

For the validation of comparison, the consistency of the pairwise matrix (CI) was checked by

$$\mathrm{CI} = \frac{(\lambda_{\max} - n)}{n - 1}, \quad (3)$$

where $\lambda_{\max}$ presents the maximum Eigenvalue and n is the matrix size.

The consistency ratio (CR) is calculated by using the following formula:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \quad (4)$$

where RI is the random consistency index obtained from a randomly generated pairwise comparison, for which Table 2 is used. The consistency ratio should be smaller than 0.10, otherwise the calculation is considered inconsistent.

Based on the results of the study, an AHP decision tree is built with prioritized sources of construction waste and their respective lean techniques. The overall steps of the study are shown in Figure 1.

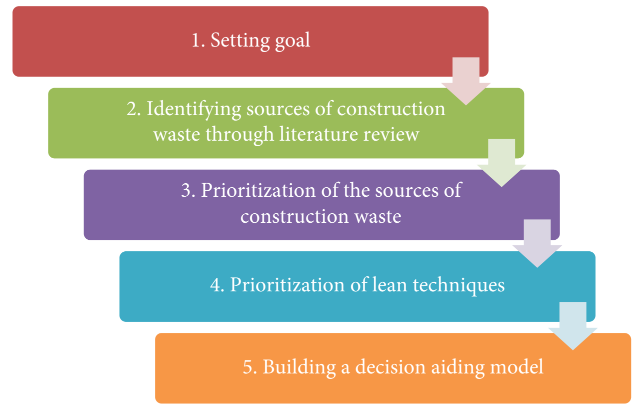

Figure 1: Steps used in the study.

3. Results and Discussion

A total number of 77 questionnaires were distributed and 66 survey papers were returned, with an 85.71% response rate. The designed questionnaire was distributed to construction professionals; namely, construction managers, project managers, office engineers, site engineers, and supervisors, in the real estate sector based on the data provided by the Ministry of Housing and Urban Development of Ethiopia. Table 3 presents the detail. The professionals have at least a first-degree educational background. Besides, 37.84% of them have 1–5 years of experience in the construction industry, 48.65% of them with 6–10 years of experience, and the remaining 13.5% have an experience of more than 10 years.

Before working on the approach of reducing waste, the waste handling practices of the companies, their waste reduction technique in place, if any, and the awareness of the professionals about lean construction and lean techniques were assessed by using face-to-face interviews. Based on the survey, 53 (80.3%) of the professionals had no awareness of lean techniques and their application in the construction industry, and the rest had only limited familiarity with lean techniques but they did not have the experience to implement them to minimize waste. Moreover, the interview revealed that all the companies had no waste reduction system at all. In agreement with this result, a study by Yibeltal [5] showed that all contacted companies in Bahir Dar city (Ethiopia) did not have a construction waste management strategy in their firms. This implies that proper attention is not given to construction waste reduction by both the professionals and the firms in the industry.

4. Prioritization of Sources of Construction Waste

The sources of construction waste, which were identified through literature review (Table 4), were set to be compared with each other by construction professionals. The identified sources were eight in number and then they turned into a questionnaire which consisted of 36 paired comparison questions, for each criterion to be prioritized.

According to Saaty [32], to make comparisons, one needs a scale of numbers that indicates as to how important or dominant an element is over another concerning the criterion for which they were compared. The matrix was arranged and a score range of 1 to 9 was selected and allocated, where a maximum score implies that the row is more important than the column. The diagonal of the matrix was allocated at a score of 1. Going on columnwise, the value in the corresponding column just below the diagonal is reciprocal of the scores in the corresponding row. Likewise, all the columns were calculated and added to arrive at the total. Finally, after judgments have been made on the impact of all the elements and priorities have been computed for the hierarchy as a whole, to evaluate the result of the questionnaire, an 8 by 8

Table 3: Response rate of questionnaires.

Respondent	Distributed	Successfully responded	Incomplete response	Incorrect response	Not returned
Construction manager	7	4	1		2
Project manager	16	12		2	2
Office engineer	22	19	1	2	
Site engineer	16	15		1	
Consultant	16	16			
Total	77	66	2	5	4
Return rate (%)	100	85.71	2.59	6.49	5.19

Table 4: Sources of waste.

Criteria	Code
Poor material handling and storage	*C*1
Excess inventory	*C*2
Poor site management	*C*3
Frequent changes in design	*C*4
Poor planning	*C*5
Rework	*C*6
Overproduction	*C*7
Delay (waiting)	*C*8

Table 5: Comparison matrix.

Criteria	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8
*C*1	1	7	3	3	3	5	5	3
*C*2	1/7	1	1/5	1/5	1/5	1/3	1/3	1/5
*C*3	1/3	5	1	1	3	3	5	1
*C*4	1/3	5	1	1	3	3	3	1
*C*5	1/3	5	1/3	1/3	1	3	3	1
*C*6	1/5	3	1/3	1/3	1/3	1	1	1
*C*7	1/5	3	1/5	1/3	1/3	1	1	1/3
*C*8	1/3	5	1	1	1	1	3	1
Sum	2.876	34.0	7.067	7.200	11.867	17.333	21.333	8.533

Table 6: Normalized pairwise matrix and weighted matrix.

Criteria	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	Criteria weight
*C*1	0.35	0.21	0.42	0.42	0.25	0.29	0.23	0.35	**0.318**
*C*2	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.02	**0.0257**
*C*3	0.12	0.15	0.14	0.14	0.25	0.17	0.23	0.12	**0.1679**
*C*4	0.12	0.15	0.14	0.14	0.25	0.17	0.14	0.12	**0.1564**
*C*5	0.12	0.15	0.05	0.05	0.08	0.17	0.14	0.12	**0.1057**
*C*6	0.07	0.09	0.05	0.05	0.03	0.06	0.05	0.12	**0.0604**
*C*7	0.07	0.09	0.03	0.05	0.03	0.06	0.05	0.04	**0.0485**
*C*8	0.12	0.15	0.14	0.14	0.08	0.06	0.14	0.12	**0.1170**
Sum	1	1	1	1	1	1	1	1	

comparison matrix was created. A basic, but very reasonable, assumption is that if attribute *A* is more important than attribute *B* and it is rated at 9, then *B* must be less important than *A* and it is valued at 1/9. The matrix was established by making rows and columns having the same parameters. The weight of each criterion is shown in Table 5.

After obtaining the pairwise judgments (Table 5), the next step was the computation of a vector of priorities or weighting of elements in the matrix. In terms of matrix algebra, this consists of calculating the priority vector (eigenvector) of the matrix by adding the members of each column to find the total. To normalize each column to a sum of 1.0 or 100%, elements of the column were divided by the total of the column and were added up. To compute the priorities, scores were normalized first (Table 6). The sum of the normalized column of the matrix was divided by the number of criteria used (n) to generate a weighted matrix or priority vector (last column of Table 6).

Table 7: Calculation for λ_{max}.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	Weighted sum value	Ratio
C1	0.318	0.1799	0.5037	0.4692	0.3171	0.302	0.2425	0.351	2.6834	8.438
C2	0.4452	0.0257	0.03358	0.03128	0.02114	0.0199	0.016	0.0234	0.6162	7.271
C3	0.1049	0.1285	0.1679	0.1564	0.3171	0.1812	0.2425	0.1170	1.4155	8.430
C4	0.1049	0.1285	0.1679	0.1564	0.3171	0.1812	0.1455	0.1170	1.3185	8.430
C5	0.1049	0.1285	0.0554	0.0516	0.1057	0.1812	0.1455	0.1170	0.8898	8.418
C6	0.0636	0.0771	0.0554	0.0516	0.0348	0.0604	0.0485	0.1170	0.5600	9.271
C7	0.0636	0.0771	0.03358	0.0516	0.0348	0.0604	0.0485	0.0386	0.4082	8.416
C8	0.1049	0.1285	0.1679	0.1564	0.1057	0.0604	0.1455	0.1170	1.1427	9.766
Criteria weight	0.318	0.0257	0.1679	0.1564	0.1057	0.0604	0.0485	0.1170	Sum of ratio	68.44

Table 8: Criteria weight.

Criteria	Code	Weights (%)	Rank
Poor material handling and storage	C1	31.8	1
Poor site management	C3	16.8	2
Frequent changes in design	C4	15.6	3
Delay (waiting)	C8	11.7	4
Poor planning	C5	10.6	5
Rework	C6	6.0	6
Overproduction	C7	4.9	7
Excess inventory	C2	2.6	8

To accept the criteria weight determined above, the consistency of the data needs to be checked. Consistency is associated with the internal coherence of the decision-maker when the judgment is considered in the pairwise comparison matrices. It is the most important measurement of the results from the pairwise comparison in the AHP. A true consistency ratio is calculated by dividing the consistency index for the set of judgments by the index for the corresponding random matrix.

Lambda Max (λ_{max}) is the maximum eigenvalue of the matrix and it is needed to calculate the consistency index (CI). The ratio column in Table 7 represents the finding of λ_{max} by dividing all the elements of the weighted sum matrix by the priority vector for each criterion.

Thus, λ_{max}, which is the sum of the ratio divided by n, becomes 8.555. This, in turn, gives a consistency index of 0.093. Therefore, using the random index (RI) of 1.41 for $n = 8$, a consistency ratio of 0.056 was found, which is acceptable as it is less than 0.10. The consistency ratio verifies that the comparison is consistent and reliable enough to use the criteria weight for rating. Based on this, Table 8 represents the eight criteria which were compared with each other and their rating accordingly.

Poor material handling, poor site management, and frequent change in order prioritized to be the top three sources of waste. After prioritizing the sources of waste, the next step was to find the mechanisms of reducing them to the least amount possible. To achieve this, some lean techniques were identified through a literature review. Under each factor of waste, two lean techniques were used to be prioritized for implementation. A brief description of the lean techniques is given in the supplementary materials.

5. Prioritization of Lean Techniques as Alternative for Waste Reduction

5.1. Poor Material Handling and Storage. This was found to be the most dominant source of waste with a 31.8% priority rate. It was also found to be a major source of construction waste by different researchers, elsewhere [28, 33]. Just-in-time and the 5S process were the lean techniques set to be compared as an alternative for the reduction of waste due to poor material handling and storage. 58.3% of the professionals preferred just-in-time to be more applicable compared to the 5S process (Figure 2). Just-in-time in construction is used to eliminate waste by receiving goods only as they are needed for production processes. The 5S is a technique that results in a workplace that is clean, uncluttered, safe, and well-organized to help reduce waste and optimize productivity. Thus, it can reduce wastage caused by poor material handling.

5.2. Poor Site Management. Poor site management was given a rate of 16.8% compared to the other factors. It was ranked to be the first-factor causing construction waste by Nagapan et al. [34]. The two lean techniques compared for the implementation of reducing wastage related to poor site management were plan-do-check-act and daily huddle meetings, with a preference of 60.32 and 39.67% by the professionals, respectively. A daily huddle meeting was also presented as the most used lean technique by Ogunbiyi et al. [35]. Daily huddle meeting with diverse professionals at the site helps to improve communication and workflow. And the plan-do-check-act technique aims to improve processes occurring in a company and it helps eliminate recurring mistakes.

5.3. Frequent Change in Design. This waste criterion was put third by the professionals with a 15.6% priority rate. However, Fadiya et al. [28] and Nagapan et al. [34] reported frequent changes in design to be the most dominant source of construction waste in their studies. According to the survey result, in real estate projects, change in design mainly occurs due to the owner's request for the modification of the design. Setting lean techniques to be implemented for frequent change in design might not work because it involves avoiding design errors. However, if the change in design is

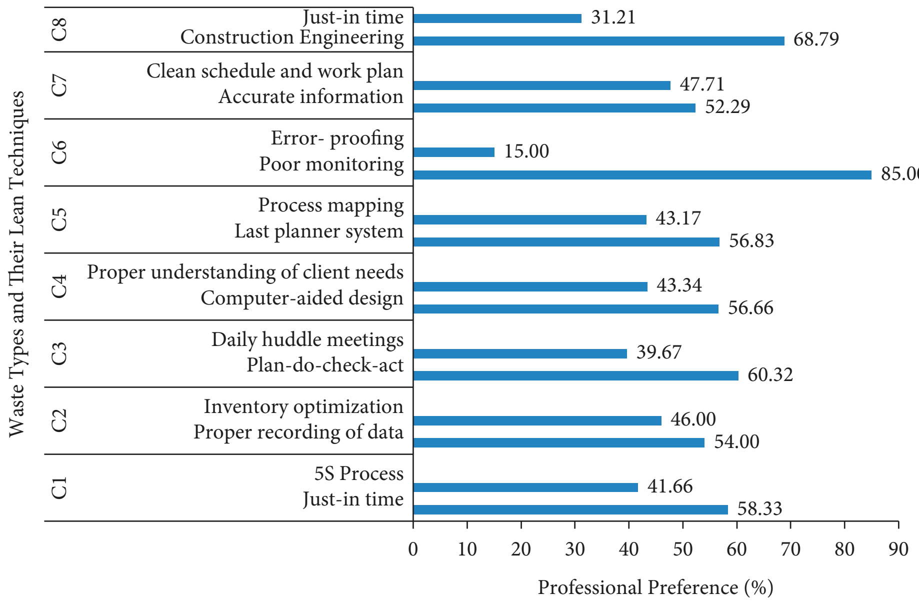

Figure 2: Professionals' preference of the construction waste reduction alternative lean techniques.

requested because there is an error in the design, two lean techniques can be set as an alternative. Computer-aided design was prioritized at the rate of 56.66% and proper understanding of client requirements at 43.3%. Sarhan et al. [12] stated CAD to be the most commonly used design tool by many construction professionals. Besides, using building information modeling (BIM) can reduce waste to a recognizable amount by detecting an error in design.

5.4. Delay (Waiting). Waiting for a delivery of material or the completion of the preceding activity was the fourth level listed source of waste, with an 11.7% rating. Sarhan et al. [12] showed waiting to be a common type of waste in construction projects in Saudi Arabia. Concurrent engineering was rated 68.79% to be a more implementable lean technique to minimize waste related to waiting, compared to the just-in-time technique. Concurrent engineering eliminates a lot of delay by identifying activities that can overlap and be integrated. On the other hand, just-in-time can eliminate waiting time mainly by timely delivering construction materials.

5.5. Poor Planning. Even though poor planning was shown to be one of the most dominant sources of construction waste by Khanh and Kim [9], in this study it was placed fifth with a 10.6% priority rate. The corresponding two lean techniques compared for waste reduction were the last planner system and process mapping, with rates of 56.83 and 43.17%, respectively. Abo-Zaid and Othman [33] reported the last planner system to be the most common lean tool used in Egypt. If the planned sequences are not convenient and needed replanning, one of the best-known lean techniques is the last planner system [12]. It is an important tool for the construction management process and to monitor planning efficiency by assisting the smooth workflow variations, reducing the uncertainties plaguing construction processes, and for developing foresight. The process mapping implementation helps to develop the road map to tackle improvement areas to bridge the gap between the existing state and the proposed state of different construction activities.

5.6. Rework. Rework is required when the completed work does not comply with the actual contract and in this study, it was rated as poor following the poor planning as a source of waste. However, a study by Bekr [18] ranked rework second. Compared to error-proofing, proper monitoring was the strongly favored lean technique alternative for waste reduction, with 85% preference. Error proofing can be implemented to reduce construction waste by avoiding simple human error in the workplace and by identifying activities that are prone to errors.

5.7. Overproduction. Overproduction is the fabrication of products before their need or producing excess in amount. Using accurate information was marginally chosen (52.29%) as the lean technique of reducing waste compared to having a clear schedule and work plan.

5.8. Excess Inventory. Excess inventory as a source of construction waste has got the least priority rate. The companies check on the material purchase request which is sent from the sites and before approving the request, engineers at the office check the amount of material requested to reduce excess inventory. The two lean techniques set for the reduction of excess inventory are the proper recording of data and inventory optimization. 54% of the professionals preferred implementing proper recording of data to reduce waste. Both lean techniques help us to know the materials which are already at the site and the materials to be purchased to execute a certain construction activity. This avoids purchasing excess amounts because excess inventory tides up companies' capital, and also longer storage of material leads to loss and deterioration of the construction materials. It is also a means by which construction companies and suppliers can keep a track of materials, workforce, and equipment.

Generally, the hierarchical approach can serve as a tool to decide on identifying sources of construction wastes and which lean technique to use to reduce them. The first level of the hierarchy is about the objective of the model which is the implementation of lean techniques for construction waste reduction. The second level of the hierarchy represents the major sources of construction waste and their priority rate, compared to each other. Controllable waste associated with management activities and flows are the most important factors in reducing process waste [36]. The third level represents lean techniques for the implementation and their respective rate, to pinpoint the more applicable and effective one. The decision-maker can easily identify the appropriate lean techniques for the different sources of construction waste commonly encountered in the industry.

6. Conclusion

Based on the findings of this study, the real estate companies did not have any waste reduction strategy or practices, showing the sensitivity even big-size construction firms in Ethiopia give to construction waste. Moreover, significantly large proportions of the professionals in the industry have no awareness of lean techniques and those having awareness do not know how to implement the techniques for construction waste reduction. The study applied lean theory through the analytical hierarchical process approach, by applying alternatives of lean techniques to support achieving the optimum goal and as a tool for the reduction of construction waste.

The sources of waste are prioritized as poor material handling and storage, poor site management, frequent changes in design, waiting, poor planning, rework, overproduction, and excess inventory. Corresponding to the prioritized list of source of waste, the preferred lean techniques are just-in-time, plan-do-check-act, CAD, construction engineering, last planner system, poor monitoring, accurate information, and proper data recording, respectively. The study showed that poor material handling, poor site management, and frequent change are the top three sources of construction waste with a priority rate of 31.8%, 16.8%, and 15.6%, respectively.

The familiarity gained about waste and lean techniques from this research could be combined into training techniques for leaders in the construction industry to ensure successful project completion. By using the preferred lean techniques the companies can reduce construction waste effectively. The construction companies are expected to give due attention to material and site management because these are the major sources of construction waste. Generally, the concerned professionals need to pay attention not only to physical waste but also to nonphysical waste (waiting time, unnecessary movement, and others) and they need to update themselves on the state-of-the-arts.

This study showed that the analytical hierarchical process (AHP) decision support model can effectively be applied for prioritization of the causes of construction waste and to assign correspondingly appropriate lean techniques to achieve the aim of minimizing construction waste. The application of AHP can also be made to analyse complex situations in other construction management activities and to make sound decisions. Future study is needed to compare and contrast AHP and other multicriteria decision-making methods to reduce uncertainties and to get optimized solutions under various decision-making scenarios. Finally, as this study was limited to only private residential real estate companies which are found in Addis Ababa, similar studies may be conducted in other big cities of the country addressing other construction industry infrastructures.

Data Availability

The data generated or analysed during this study are included in the manuscript.

Disclosure

The manuscript was prepared from a thesis which was presented in partial fulfillment of the requirement for the Degree of Masters in Civil Engineering with specialization in Construction Engineering and Management, ASTU, Ethiopia.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Fitsum Ayfokru developed the methodology, performed the investigation, collected the data, performed formal analysis, and wrote the original draft. Bahiru Bewuket Mitikie conceptualized the study, performed supervision, and reviewed and edited the manuscript. Andinet Kebede Tekile edited the language and technical contents, prepared tables and graph, and prepared the manuscript.

Acknowledgments

The authors would like to acknowledge the support from the University. The authors are also grateful to all the organizations who provided the opportunity to collect the data and the individuals who sacrificed their time in filling the survey and provided the necessary materials and supported this research. This research project was funded by Adama Science and Technology University (ASTU)ASTU/SM-R/352/21), Adama, Ethiopia.

Supplementary Materials

The survey questionnaires used for the research are given as supplementary material under Table S1 and brief description of the lean technique alternatives used in this research are also given as supplementary material under Table S2. The interview questions are also included in the supplementary file. (*Supplementary Materials*)

References

[1] S. O. Ametepey and S. K. Ansah, "Impacts of construction activities on the environment: the case of Ghana," *Journal of Environment and Earth Science*, vol. 5, no. 3, pp. 18–27, 2015.

[2] C. Luangcharoenrat, S. Intrachooto, V. Peansupap, and W. Sutthinarakorn, "Factors influencing construction waste generation in building construction: Thailand's perspective," *Sustainability*, vol. 11, no. 13, p. 3638, 2019.

[3] J. Solis-guzman, M. Marrero, M. V. Montes-delgado, and A. Ramirez-de-arellano, "A Spanish model for quantification and management of construction waste," *Waste Management*, vol. 29, no. 9, pp. 2542–2548, 2009.

[4] N. Wahi, C. Joseph, R. Tawie, and R. Ikau, "Critical review on construction waste control practices: legislative and waste management perspective," *Procedia - Social and Behavioral Sciences*, vol. 224, pp. 276–283, 2016.

[5] A. Yibeltal, "A study on sustainable construction waste management practices: the case of building construction projects in Bahir Dar City,Ethiopia," MSc Thesis, Bahir Dar University, Bahir Dar, Ethiopia, 2020.

[6] Y. Selam, "Experience and prospects of private residential real estate development in alleviating housing problems in Addis Ababa," M.Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia, 2016.

[7] A. Tadesse, D. Zakaria, L. Zoubeir, and V. A. Gonzalez, "Characterization of waste in Ethiopian building construction projects," in *Proceedings of the 26th annual conference of the International Group for Lean Construction (IGLC)*, pp. 797–806, Chennai, India, July 2018.

[8] S. Tafesse, "Material waste minimization techniques in building construction projects," *Ethiopian Journal of Science and Technology*, vol. 14, no. 1, pp. 1–19, 2021.

[9] H. D. Khanh and S. Y. Kim, "Identifying causes for waste factors in high-rise building projects: a survey in Vietnam," *KSCE Journal of Civil Engineering*, vol. 18, no. 4, pp. 865–874, 2014.

[10] O. A. Oguntona, C. O. Aigbavboa, and G. N. Mulongo, *An Assessment of Lean Construction Practices in the Construction Industry*, Springer International Publishing AG,part of Springer Nature, Berlin, Germany, 2019.

[11] J. P. Womack and D. T. Jones, "Lean thinking: banish waste and create wealth in your corporation," *Journal of the Operational Research Society*, vol. 48, no. 11, p. 1148, 1997.

[12] J. G. Sarhan, B. Xia, S. Fawzia, and A. Karim, "Lean construction implementation in the Saudi Arabian construction industry," *Construction Economics and Building*, vol. 17, no. 1, pp. 46–69, 2017.

[13] O. Salem, J. Solomon, A. Genaidy, and M. Luegring, "Site implementation and assessment of lean construction techniques," *Lean Construction Journal*, vol. 2, no. 2, pp. 1–21, 2005.

[14] S. A. Abbasian-Hosseini, A. Nikakhtar, K. Y. Wong, and A. Zavichi, "Implementing lean construction theory to construction processes' waste management," in *Proceedings of the International Conference on Sustainable Design and Construction (ICSDC)*, pp. 414–420, Kansas City, Missouri, March 2011.

[15] D. D. Viana, C. T. Formoso, B. T. Kalsaas, I. D. Tommelein, and C. L. Pasquire, "Waste in construction: a systematic literature review on empirical studies," in *Proceedings of the 20th Annual Conference of the International Group for Lean Construction*, San Diego, CA, USA, July 2012.

[16] A. Mossman, "Creating value: a sufficient way to eliminate waste in lean design and lean production," *Lean Construction Journal*, pp. 13–23, 2009.

[17] S. Wandahl and E. Bejder, "Value-based management in the supply chain of construction projects," in *Proceedings of the 11th Annual Meeting of the International Group for Lean Construction*, Blacksburg, VA, USA, November 2003.

[18] G. A. Bekr, "Study of the causes and magnitude of wastage of materials on construction sites in Jordan," *Journal of Construction Engineering*, vol. 2014, Article ID 283298, 6 pages, 2014.

[19] G. L. Garas, A. R. Anis, and A. El Gammal, "Materials waste in the Egyptian construction industry," in *Proceedings of the IGLC-9*, Singapore, Singapore, August 2001.

[20] E. N. Shaqour, "The impact of adopting lean construction in Egypt: level of knowledge, application, and benefits," *Ain Shams Engineering Journal*, vol. 13, no. 2, Article ID 101551, 2022.

[21] M. S. Bajjou and A. Chafi, "Lean construction implementation in the Moroccan construction industry: awareness, benefits and barriers," *Journal of Engineering,Design and Technology*, vol. 16, no. 4, pp. 533–556, 2018.

[22] I. Maradzano, S. Matope, and R. A. Dondofema, "Application of lean principles in the South African construction industry," *South African Journal of Industrial Engineering*, vol. 30, no. 3, pp. 210–223, 2019.

[23] O. Salem, S. Pirzadeh, S. Ghorai, and A. Abdel-Rahim, "Reducing environmental, economic, and social impacts of work-zones by implementing lean construction techniques," in *Proceedings of the 22nd Annual Conference of the International Group for Lean Construction*, pp. 145–155, Oslo, Norway, June 2014.

[24] S. Ghosh, S. Bhattacharjee, P. Pishdad-Bozorgi, and R. Ganapathy, "A case study to examine environmental benefits of lean construction," in *Proceedings of the 22nd Annual Conference of the International Group for Lean Construction*, pp. 133–144, Oslo, Norway, June 2014.

[25] A. Reinbold, "Benefits of lean construction for affordable housing," MSc Thesis, University of Applied Sciences, Berlin, Germany, 2017.

[26] D. Ivina, N. O. E. Olsson, I. D. Tommelein, and E. Daniel, "Lean construction principles and railway maintenance planning," in *Proceedings of the 28th Annual Conference of the International Group for Lean Construction (IGLC28)*, California, CA, USA, July 2020.

[27] R. H. Ansah and S. Sorooshian, "Effect of lean tools to control external environment risks of construction projects," *Sustainable Cities and Society*, vol. 32, pp. 348–356, 2017.

[28] O. O. Fadiya, P. Georgakis, and E. Chinyio, "Quantitative analysis of the sources of construction waste," *Journal of Construction Engineering*, vol. 2014, Article ID 651060, 9 pages, 2014.

[29] H. Taherdoost, "Decision making using the Analytic Hierarchy Process (AHP); a step by step approach," *International Journal of Economics & Management Systems*, vol. 2, pp. 244–246, 2017.

[30] T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts and Applications of the Analytic Hierarchy Process*, Springer Science+Business Media, New York, NY, USA, 2 edition, 2012.

[31] I. Temiz and G. Calis, "Selection of construction equipment by using multi-criteria decision making methods," *Procedia Engineering*, vol. 196, pp. 286–293, 2017.

[32] T. L. Saaty, "Decision making with the analytic hierarchy process," *International Journal of Services Sciences*, vol. 1, no. 1, pp. 83–98, 2008.

[33] M. A. Abo-zaid and A. A. E. Othman, "Lean construction for reducing construction waste in the Egyptian construction industry," in *Proceedings of the 2nd International Conference on Sustainable Construction and Project Management - sustainable infrastructure and transportation for future cities*, Aswan, Egypt, December 2018.

[34] S. Nagapan, I. A. Rahman, A. Asmi, A. H. Memon, and R. M. Zin, "Identifying causes of construction Waste–case of central region of Peninsula Malaysia," *International Journal of Integrated Engineering*, vol. 4, no. 2, pp. 22–28, 2012.

[35] O. Ogunbiyi, J. S. Goulding, and A. Oladapo, "An empirical study of the impact of lean construction techniques on sustainable construction in the UK," *Construction Innovation*, vol. 14, no. 1, pp. 88–107, 2014.

[36] Y. E. Abdelrazig, "Using lean techniques to reduce waste and improve performance in municipal construction project delivery," MSc Thesis, The University of Texas at Arlington, Arlington, TX, USA, 2015.