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LEAN CONSTRUCTION DESIGN APPLICATION AS A RESIDENTIAL CONSTRUCTION PROJECT COST MANAGEMENT

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ABSTRACT

This study aims at identifying waste factors from inefficient construction project operations. It intends to design lean construction tools that minimize time wastage for housing construction projects at PT XYZ. The results are expected to produce recommendations for responses to waste factors in housing construction projects. The recommendations could aid in further implementing construction project management with a lean approach. PT XYZ is a subcontractor whose services dominate small and medium-scale residential construction projects. Project completion time is a significant factor in determining project success. Data in this qualitative study were obtained by distributing questionnaires and conducting in-depth interviews with several respondents. The results showed that four activities were considered time-wasting factors in housing construction projects. The Last Planner System could generate time savings for three of 120 calendar days. Additionally, the company's readiness to implement lean construction principles was indicated by a score of 3.5 out of 5. This showed that the principles have been stated in every project but are rarely applied.

Keywords: Lean Construction, Last Planner System, Residential Construction, Time Management, Waste.

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1. INTRODUCTION

The increase in company losses in the Building and Construction Sector during the Covid-19 pandemic concerns many people. The parties involved in implementing construction projects are the owners, main contractors, and subcontractors. In general, the community is affected by the losses suffered by construction service companies (Larasati *et al*., 2021). Due to the impact of this pandemic on the national economy, the construction sector's performance recorded negative growth of -3.26% in 2020 from 5.76% in 2019. This is according to the 2020 Constant Price GDP data regarding business fields (Badan Pusat Statistik, 2021).

Subcontractor companies are construction implementers seeking ways to ensure their continued operations. PT XYZ is a construction service company founded in 2016, providing design services for new houses or buildings, renovation, and interior design. Housing projects are the most dominant regarding service needs, accounting for almost 40% of all construction projects at PT XYZ. The company's 2020 annual report shows that the net profit after tax decreased by 18% from the previous year. The decrease was due to a lower income and increased construction services business line operating expenses. Furthermore, a preliminary interview with the company's owner found that several projects were delayed in completing the target set in the contract. This resulted in increased expenses, reducing the income from working on a project.

PT XYZ has several housing development contracts of various sizes and types. One housing project undertaken in 2018 experienced a more than three months delay in completion. The project also suffered a cost overrun of more than 56 million rupiahs compared to the Budget Plan Report (RAB). In 2019, PT XYZ worked on an office renovation project and experienced a delay of more than two months. The delay caused cost overruns of more than 14 million rupiahs compared to the RAB Report. This shows that completion time significantly influences the project success assessment and the contract's sustainability with the project owner. Therefore, PT XYZ aims to improve time management to minimize time wastage in construction projects and maintain the company's business continuity.

Lean thinking is a method of managing construction projects in the manufacturing sector. Its objective is to redefine performance against three perfection dimensions, including (1) unique special products, (2) delivered instantly, with (3) no in-store storage. According to Howell & Ballard (2010), the concept is ideal for maximizing value and minimizing waste. Lean Manufacturing is also known as lean, whose main philosophy is that any expenditure of resources that do not create customer value is a waste and must be eliminated (Atkinson *et al*., 2011). Value is any action or process for which customers are willing to pay.

Lean construction shows increasing improvements in several studies from many countries. For instance, applying lean principles in construction improves the cost structure (Salem *et al*., 2006), productivity (Agbulos *et al*., 2006; Al-Sudairi, 2007; Kung *et al*., 2008), delivery time, reliability of plans (Ballard, 2000; Cho & Ballard,

2011; Liu *et al*., 2011), quality (Leonard, 2006), the relationship between work partners (Miller *et al*., 2002; Salem *et al*., 2006), and job satisfaction (Nahmens *et al*., 2012).

Luangcharoenrat *et al*. (2019) identified the factors contributing to construction waste in the industrial sector in Thailand. The study grouped 28 causes of waste into design and documentation, materials and procurement, construction methods and planning, and human resources. The results showed that design changes, negligent work attitudes and behavior, ineffective planning and scheduling, and material storage had the highest impact on waste occurrence in construction projects in each category. Furthermore, Kololu & Camerling (2017) investigated the necessity of lean methods for the contractors, supervisors, and suppliers involved in construction projects. The results indicated the need to implement lean methods by optimizing the construction work in company projects. Rybkowski *et al*. (2020) introduced and developed lean design and programs as a training technique after examining trade associations, businesses, consultants, and project owners. The findings indicated that small construction companies, design firms, and consultants could implement lean construction using a semi-structured approach.

This study was conducted in a construction company that have not implemented a lean construction approach as cost management in their projects. The stages in this study include design, data collection, and analysis. The study questions are: 1). What are the waste factors in the construction project? 2). How is the design of applying lean construction in a construction project? 3). How is the company's management readiness to implement lean construction?

This qualitative case study analyzed construction project activities that may result in value-added waste. The analysis was based on the company's current SOP and assessed PT XYZ's readiness to apply lean principles in residential construction projects. This study was expected to produce recommendations for responses to waste factors in the company's residential construction projects. The waste factor identification results would be used to shape the design of the appropriate lean construction tool to minimize time wastage.

2. LITERATURE REVIEW

2.1. LEAN THINKING

Lean is a philosophy and methodology of management that utilizes various tools and techniques to improve quality and reduce waste (Waterman & McCue, 2012). Management needs to take a systematic approach to how they view their organization. This system consists of processes that provide outputs (products and services) to internal and external customers. Examination of this process will enable management to identify which lean tools appropriate for the implementation (Radnor & Boaden, 2008).

Lean Thinking in the book (Womack & Jones, 1997) is described as a theoretical framework and principles related to lean production. The five main principles of Lean Thinking summarized by (Womack & Jones, 1997) are:

1. Value: Value can only be determined by the end customer, whereas the customer is all downstream operations. In multi-party construction, the owner as a construction client can rarely be the sole end customer (Jørgensen & Emmitt, 2008).
2. Value Stream: Analyze the three types of actions along with the value stream; the first activity that creates value; second, activities that do not create value but are unavoidable with current production technologies and assets; third, activities that do not create value and are determined to be avoided.
3. Flow: Once the company has reduced or eliminated waste and variation from one process and streamlined the flow of value, the next step is to make the remaining process steps "flow". The goal of this principle is for the product to move from concept to customer without interruption or delay.
4. Pull: This principle is closely related to the "pull" system developed by Toyota Production System. End users draw production in such a way that only fits their needs.
5. Pursue of Perfection: This principle implies "Total elimination of "waste" so that all activities along the value stream create value" The lean concept associated with perfection is called kaizen, which means continuous improvement in the West. By applying the previous four principles organizations gain and discover more of the hidden waste that can be eliminated.

2.2. LEAN CONSTRUCTION

The success of lean principles in manufacturing and the benefits arising from their use are the motivations for adopting lean principles in construction (Gao & Low, 2014). Lean first appeared in the construction industry a few years after its full acceptance in the Western manufacturing industry. Several authors have attempted to explain the lean construction perspective. According to (Koskela, 1992), lean on its initial discussion mentioned the potential of a "new production philosophy" in the construction industry. Then (Koskela, 2000) synthesized three different perspectives on the construction process, which formed the foundation for what is now known as lean construction. A simple definition given by (Koskela *et al*., 2007) is that lean construction is designing a production system to minimize the waste of materials, time, and effort to produce the maximum value.

The Lean Construction Institute (LCI) defines lean construction as a production-based management approach to project delivery that is typically useful on complex, uncertain, and past projects. Lean construction strives for the same goals as lean production, to eliminate waste and maximize value (Koskela *et al*., 2007). On the other

hand, LCI implies that the industrial approach in manufacturing is directly applicable to construction.

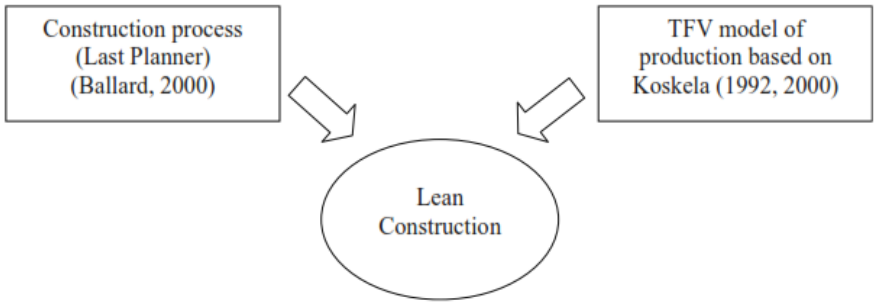

Figure 1. Two Core Interpretations of Lean Construction

An alternative interpretation of the lean construction concept is illustrated in Figure 1. This school of thought addresses the application of lean production methods to construction. The most famous is the Last Planner approach to planning and managing the construction process (Ballard & Howell, 1998). The goal is to create a reliable workflow by having the project team including all affected parties create a phased plan for the work segment. The process involves discussions with site staff and planning to ensure that work does not wait for workers and workers do not wait to work.

Diekmann *et al* (2004) modified lean manufacturing principles to adapt to lean construction principles based on a greater degree of discretionary behavior and uncertainty in the industry. In manufacturing, the production system is defined and controlled by the production line configuration. In contrast, in construction, the production system is determined by the project manager and individual workers. The principles of lean construction in the same literature are developed for each sub-principle used to assess lean behavior or application in construction. The principle of lean construction by (Diekmann *et al*., 2004) was adopted from lean production in the manufacturing industry. The same literature also informed the differences between lean manufacturing and construction principles. In assessing the application of lean construction principles to construction projects, the assessment components used are obtained from lean assessment tools. The application of lean construction principles by (Salem *et al*., 2005) is carried out by measuring the application of these principles on the scale 1-5.

2.3. WASTE

Construction projects involve various activities, namely planning, implementing, and delivering. Activities in general in construction projects must create value for the project owner. Inefficiency in project activities is classified as one of the following three types, namely, inefficiency due to waste (non-value added activities/NVA),

inefficiency due to work that does not directly contribute value (non-value added but necessary activities/NVAR), and inefficiency due to poorly designed work processes (value-added activities/ineffective VA) (Diekmann *et al*., 2004). According to the lean construction concept, waste is identified into seven types of waste. The definition of each waste is explained according to the following table.

Table 1. Type of Waste in Construction Project

Type of Waste	Description
Over-production	More products that produced than the design planned at the engineering stage.
Defect	Defects in the construction product result in additional work that is not planned. The additional work can be reworking a construction product or repairing the construction product.
Transportation	Waste occurs by the location of work and the location of inefficient material sources. Materials move from one process to another
Waiting	Waiting is a waste of work time. The work team must wait to do their duties until the previous work process is complete. Waiting time can be caused due to delays in previous work or because work productivity is not the same.
Inventory	Inventory relates to the storage of unnecessary raw materials. Storage of raw materials has a risk of damage or loss when the raw materials are in the warehouse or stockyard.
Motion	The waste that occurs is a movement of either workers or tools that do not change the product shape. This movement does not add value to a work product.
Over-processing	Over-processing waste occurs by unnecessary operations have been carried out by contractors. Unnecessary operations are more processes than the customer (owner) wants.

2.4. APPLICATION OF LEAN CONSTRUCTION IN WASTE REDUCTION

1. Last Planner System
   Ballard (2000) shows that the Last Planner System (LPS) is a technique that shapes workflows and maps project variability. The last planner is the person or group responsible for operational planning. Some of his responsibilities include establishing a product design structure to facilitate workflow improvement and control of production units, also the completion of individual tasks at the operational level. The LPS application itself has a sequence in its implementation, namely master schedule, reverse phase schedules (RPS), six-week lookahead, weekly work plan (WWP), and percent plan complete (PPC).
2. Increased Visualization
   Increased Visualization, is another lean tool that provides key information to the workforce through the placement of different signs. Workers can remember elements such as workflow, performance, and determining actions if they can visualize them (Moser & Santos, 2003). In construction, visual efforts focus on safety, scheduling, and quality assurance issues.
3. Tool-Box Meeting
   Two-way communication is the key to the daily meeting process to achieve employee engagement. With awareness of the project team and problem-

solving involving workers together with training provided by management, employee satisfaction (meaningful work, self-esteem, sense of growth) will increase. As part of the improvement cycle (Scrum Concepts), there is a short daily start-up meeting where team members quickly provide the status of what they had done at the previous day's meeting, especially if a problem might be preventing the completion of the task.

4. First Run Studies
   According to (Mossman, 2013), first-run studies (FRS) are integral concept to Last Planner System. FRS is used to study a process to know what can be improved, which is safer to do, more quickly completed, and completed with the required quality. FRS is based on the PDCA (Plan-Do-Check-Act) cycle. Cycles show that this is done for repetitive things, but that is not the only purpose of forming cycles. So FRS can be used for something that will be repeated, time-critical, safety-critical, or where quality can be a problem.
5. The 5s Process
   Lean construction sees project construction as a flow of activities that must generate value for the customer (dos Santos *et al*., 1998). To manage project flow, it is necessary to visualize the activities to be carried out and make the process transparent. Workplace visuals attempt to increase process transparency. These efforts are summarized in the Five S (Hirano, 1996; Kobayashi, 2018): Seiri (concise; sort), Seiton (tidy; straighten), Seiso (clean; shine), Seiketsu (take care; standardize), and Shitsuke (diligent; sustain).

3. METHODS

This qualitative case study used primary and secondary data obtained through interviews and observations, as well as from work contract documents and orders for PT XYZ's projects. The analysis unit was a residential construction project which started in 2020 and was divided into several development clusters. Observations of the project clusters were conducted from February to June 2022. The residential projects are located in three regions within the Greater Jakarta area.

This study began by collecting the variables causing waste in construction projects from books, journals, and previous studies. The data were collected using interviews and observations to determine the process of implementing a construction project at PT XYZ. The observations and interview results showed the factors of waste in construction projects based on the seven waste categories in the literature review chapter. This study used five respondents, each with a different purpose for obtaining information, as shown in Table 2.

Table 2. List of Respondents

Code	Job Position	Information Purpose
Respondent 1	Technical Director	To determine the flow of the construction project process at PT XYZ and the sources of time-wasting factors in the PT XYZ construction project.
Respondent 2	Project Manager	To group activities in construction projects into 3 types of activities (VA, NVA & NVAR)
Respondent 3	Project Manager	To group activities in construction projects into 3 types of activities (VA, NVA & NVAR)
Respondent 4	Project Manager	To group activities in construction projects into 3 types of activities (VA, NVA & NVAR)
Respondent 5	CEO	To identify the barriers of applying lean construction principles on the PT XYZ construction project.

Each respondent in Table 2 has a distinct objective for obtaining information, as stated in the column information purposes. Interviews were only conducted with respondents 1 and 5. The Technical Director was selected as an interviewee because they were actively involved in implementing and monitoring projects. The implementation started from the auction process to handing over the project to the owner. Furthermore, the President Director was selected as an interview respondent due to the engagement in corporate culture changes, work procedures, and performance improvements. This is also because of a role own in overcoming challenges in construction project management.

Interviews were semi-structured using the questions shown in Appendices 1 and 3. The two respondents were interviewed to discuss their experiences and expectations of the study object. The interviews were held on April 26, May 24, and June 18, 2022, and lasted 45 to 150 minutes. Respondents 1 and 5 were interviewed at the PT XYZ project site and the company office, respectively.

Written questions were distributed directly at the project site to respondents 1, 2, 3, and 4 to answer question 1. The questions were about the activities of the construction project under study. The activities were divided into three based on Diekmann *et al*. (2004). Appendix 1 shows the list of written questions. A Work Breakdown Structure (WBS) was used to know each activity when implementing a construction project. The next stage was confirmation to respondent 1 through interviews on the recapitulation of answers to the written questions. Appendix 2 shows the list of interview questions for respondent 1.

Question 2 was related to the findings in question 1 regarding the time-wasting factor in the PT XYZ construction project. The interview question 1 results were used to decide the company's appropriate lean construction tool to minimize time wastage. To answer question 3, all respondents at the project site were given written questions about applying lean construction principles. Appendix 3 shows the questions containing an assessment component of lean construction principles in construction projects. The component used lean assessment tools by Diekmann *et al*. (2004). The written question answer data were tabulated to confirm the responses from respondent 5 using an interview. The interview was conducted to determine the obstructions in

lean construction principles at PT XYZ. The list of questions for respondent 5 is shown in appendix 4.

4. ORGANIZATION PROFILE

PT XYZ is a company engaged in civil construction, planning, mechanical and electrical implementation, and freight transportation services. It was established on February 16, 2016, and registered as a limited company on January 24, 2017. This is based on the Letter of Approval from the Minister of Justice Number AHU-0009295.AH.01.11 of 2017. The company has experience in handling planning and designing projects for residential houses, offices, shops, and other public buildings. PT XYZ has 4 types of service businesses, including:

1. Construction work services: Building construction projects.
2. Integrated construction services: Planning, designing, supervising, and building construction projects.
3. Consulting services: Planning, designing building designs, and supervising construction works.
4. Freight transportation services: Providing and renting goods vehicles of various goods transport vehicles.

5. RESULTS AND DISCUSSION

The written questions in Appendix 1 were distributed to respondents 1 and 4 to answer the first study question. Data were recapitulated based on categorizing activities on the project being studied. The conclusion was drawn from acquiring the highest scores for each activity in the NVA, VA, and NVAR categories. The list of activities in the written questions was obtained by applying the Work Breakdown Structure (WBS) to PT XYZ's initial plan for project completion. The description of activities with WBS determined the activities in each work phase.

The result showed that 17 of 63 activities were categorized as non-value-added by respondents 1-4 because they are time-wasting. This time wastage was analyzed further to determine the right lean construction tool to minimize the time wastage. Observations showed that these activities require various work processes, as indicated in Table 3.

Table 3. Processing Time on Non-Value-Added Activities (NVA)

ID WBS	Activity	Actual (Days)
A1.1	Make sales orders	1

A1.2	Create and issue survey orders	1
A5.2	**Studying material specifications**	**2**
A5.3	**Submit a production plan and purchase plan**	**3**
A6.1	Make a supplier checklist	1
A6.2	Coordination with suppliers	2
A7.4	Update the storage list in the storage	1
B6.2	Wall formwork checking	2
B6.4	Wall iron check	3
B10.4	Roofing iron check	2
A7.5	Loading & Transport of materials to the site	2
B1.4	Dispose of the excavated soil for the disposal	6
B2.2	Checking the installed foundation formwork	2
B3.3	Curing process & waiting for formwork to be removed	12
B10.6	Curing process & waiting for formwork to be removed	6
A7.2	**Unloading material to storage**	**1**
A7.3	**Material arrangement in storage (FIFO)**	**1**

Further analysis found that four activities in bold in Table 3 were correctly categorized as non-value-added while 13 were incorrectly considered non-value-added. This is based on Diekmann *et al*. (2004), where the category of NVA activities or pure waste sources requires time, resources, and space. However, these activities do not add value to the products or services provided to customers. Diekmann *et al*. (2004) also found that waste comes from non-value-added activities and could also be caused by inefficiency. This is because work does not directly contribute to value or inefficiency due to poorly designed processes or ineffective VA activities. Therefore, further analysis showed that the 17 activities contradicting the NVA category are a time-waste factor.

In answering the second question, further analysis was conducted to determine the waste factor in the activities in Table 3 using the categories in Igwe *et al*. (2020). The analysis aimed to determine the right lean construction tool to minimize waste in construction projects. The results showed that the factor of overprocessing, transportation and waiting causes waste in these activities. Furthermore, respondent 1 was interviewed to determine the three waste factors in the construction project since the company's establishment. The results showed that the three waste factors are caused by unreliable scheduling and work planning. Appendix 2 shows the list of interview questions.

The application of lean construction tools was simulated in one housing project at PT XYZ. The project period is 19 weeks or 120 days, from February 14 to June 25, 2022. Implementing lean construction tools should be simulated and designed as a corrective action against activities that cause time wastage. Moreover, the traditional scheduling used by PT XYZ should be structured through a scheduling change process.

Salazar *et al*. (2020) stated that the Last Planner System is a planning and control system based on the lean production philosophy to improve planning reliability and performance.

This study used the internal LPS concept (Larsson & Ratnayake, 2021), where work is defined based on what is achieved through several stages in the LPS. The stages include master, phase, look-ahead, and weekly planning.

a) Master Planning

The initial stage in making the Last Planner System design is forming a master schedule. It is used by workers to determine the schedule and planning for project implementation. The Residential Project at PT XYZ uses traditional scheduling from previous projects adjusted in the case of a different scope of work. In LPS tools, the master schedule is developed with the reverse scheduling technique. Milestones and start dates are set by working backward from the project completion date.

b) Phase Planning

The Last Planner System includes weekly periodic meetings to measure the percentage achievement of the work planned. This study was simulated by forming an LPS application design for three weeks, from April 18 to May 14, 2022. Unlike the traditional scheduling system in LPS, the schedule was divided into different phases grouped on set milestones as a goal. There were seven milestones in which the scheduler's PIC called the parties working during the study period.

c) Look-ahead Planning

The pull technique is emphasized in LPS, where the team starts with the final goal to be achieved before withdrawing the phase and the activities in the scheduling. In the meeting to determine the look-ahead planning, each party involved described their work. This makes it possible to know which jobs are possible obstacles that delay the milestone's completion. The parties involved write their respective activities for three weeks into sticky notes posted on the look-ahead board. There are ten components in the sticky notes form. The components contain the name of the subcontractor or foreman, ID/WBS No., PIC, Duration, Work, Start Shift (Morning, Afternoon, Night), Zone, Needs/Predecessor, and Constraints. The parties in the specified phase fill in these components according to their respective information and work. The sticky notes format used in designing the LPS application is shown in Figure 2.

Figure 2. Sticky Notes Look-ahead Plan

After implementers have posted their respective schedules on the look-ahead board, the PIC scheduler planner reviews and adjust the described work to minimize waiting time. Observations at this stage showed the possibility of minimizing time wastage. The LPS application design is associated with time-wasting activities during the simulation period. Four activities in Table 2 could be minimized in processing time with ID WBS, B6.2, B10.4, B3.3, and B10.6.

Table 4. Processing Time on Non-Value-Added Activities (NVA)

ID WBS	Activity	Before (Days)	After (Days)	Diff (Days)
B6.2	Wall formwork checking	2	2	0
B6.4	Wall iron check	3	2	1
B3.3	Curing process & waiting for formwork to be removed	12	10	2
B10.6	Curing process & waiting for formwork to be removed	6	5	1

Table 4 shows a difference of 4 days in processing time savings in the activities of codes B3.3, B6.4, and B10.6. The observations and simulations showed that this time saving could be performed after coordination between the Formwork Foreman and the Construction Foreman to eliminate waiting time between each worker. This LPS design is also not limited to residual construction. Therefore, it could be applied to PT XYZ's future construction projects.

d) Weekly Work Plan

Activities were scheduled towards milestones and look-ahead planning in the next three weeks and the first working week. The next step was scheduling weekly work planning for the first week of April 23, 2022. Activities in this stage specify the work to be performed in week two from April 18 to 24, 2022. This aims to make the workflow more predictable when the parties involved reliably plan and

execute the work. The parties monitor work progress in the field, calculate the weekly Percent Plan Complete (PPC), and record variances or obstacles during the construction implementation. A second-week planning evaluation was conducted, led by the LPS planner. These regular meetings also synchronize actions as a commitment of the parties involved in planning.

The respondents answered the questions regarding applying lean construction principles in PT XYZ's construction project. The results showed that the five main principles of lean construction, culture & people, and waste elimination had a lower value than the average assessment. Figure 3 summarizes the results of the questions in an average spider-web diagram.

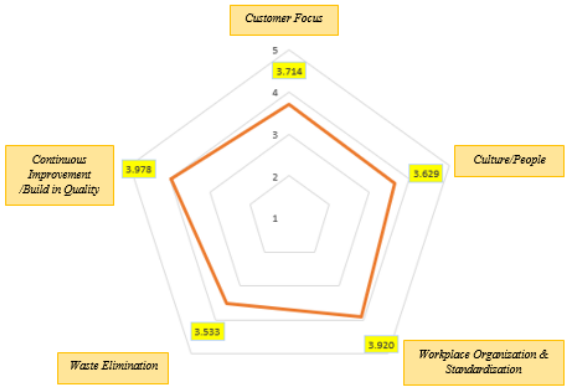

Figure 3. Spider-Web Diagram Application of Lean Construction Principles

Figure 3 is a Spider-Web diagram showing the respondents' assessments of the data recapitulation of written questions on applying lean construction principles at PT XYZ. The principle of Build in Quality gave the highest value of the five main principles, meaning it is often applied to projects. The waste elimination principle gave the lowest result of 3.524, meaning it is rarely applied due to certain obstacles. Each principle visualized in Figure 3 provides an overview of the data in the written question but does not show the relationship between variables.

Eight variables in the assessment component have the lowest value, meaning the sub-principles of lean construction are rarely applied to the PT XYZ construction project due to certain obstacles. Subsequent interviews with respondent 5 found obstacles to applying lean construction principles, as in Table 4.

Table 4. Obstacles to Implementing Lean Construction Principles

Code	Obstacles to Applying Lean Construction Principles
Main Principles	*Customer Focus*

X2	Define value from the customer's perspective, not individual participants' perspective
X7	Use target costing/value engineering
Main Principles	*Waste Elimination*
X25	Practice JIT delivery
X28	Balance crews, synchronize flows
X31	Use production planning, detailed crew instructions
X32	Implement last planner/reliable production scheduling/short interval production scheduling
X41	Reduce difficult setup/changeovers
X43	Reduce scrap

The answers to questions given to respondents 1-5 showed the PT XYZ management's incapacity to overcome the obstacles to applying lean construction principles. Efforts to eliminate waste must be applied to every project to save costs. Furthermore, interviews conducted with respondent 5 indicated that these obstacles had not been anticipated. This means PT XYZ is not ready to apply lean construction principles in its projects. Moreover, the company's readiness to apply lean construction principles relates to the second study question. Several obstacles were also identified to implementing the LPS design.

6. CONCLUSION AND RECOMMENDATION

This study examined the waste factors, the design of the lean construction tools, and the company's readiness to apply them in its projects. The results could be summarized in the following points:

1. The three of seven waste factors often occurring in construction projects at PT XYZ are overprocessing, waiting, and transportation. The written question results and the analysis showed that 17 and four activities were categorized as non-value added, respectively. However, these activities are time-wasting in PT XYZ's residential construction project.
2. The design of lean construction tools is estimated to overcome the waste problem at PT XYZ. The lean construction tool designed is the Last Planner System, comprising Master, Phase, Look-ahead, and Weekly Work Planning. The LPS simulation could save project completion time by 4 of 120 calendar days. This could be achieved by coordinating between parties involved in the construction to ensure that no workers wait for other work to be completed, especially checking formwork and ironing.
3. Evaluating the application of lean construction principles in PT XYZ's construction project showed an average of 3.7734 on the five main principles tested on a scale of 1 to 5. This shows that the value of "Towards Lean" implies that lean construction principles are rarely applied to every construction

project. The lowest application assessment is on the principles of waste elimination and culture or people, each with obstacles in its application.

Recommendations for PT XYZ from the results of this study in an effort to minimize waste and cost overruns on construction projects in accordance with the research questions to be answered in this study are as follows :

1. Regarding the factors of waste that occur in the implementation of construction projects at PT XYZ, the efforts that the company can make to minimize waste are to carry out detailed and detailed scheduling and work planning in each phase of work. Furthermore, in the discussion section, it is recommended that PT XYZ apply the lean construction tool design, Last Planner System to form a reliable schedule and planning, one of the main milestones is by forming a Master Schedule.
2. The design of the lean construction tool implementation, Last Planner System is considered appropriate to minimize waste, the main cause of which comes from unreliable scheduling. PT XYZ needs to assign PIC as "planner" and needs to conduct comprehensive training for workers involved in scheduling so that LPS can be consistently applied to every construction project undertaken by PT XYZ.
3. In terms of PT XYZ's readiness to apply lean construction principles. Currently it is considered not ready to apply the principles of lean construction. Supported by the results of written questions in the research and observations made at this time there has been no corrective action taken or handling the risk of the possibility of these obstacles occurring. However, based on the literature analysis, PT XYZ as an effort to adopt the lean principles early can start with identification of waste in the project, action against waste, workplace standardization, developing a lean culture, engaging clients/owners with lean transformation and continuously improvise.

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APPENDICES

Appendix 1. List of Written Questions 1

A. Activity Category

The following are activities that have been compiled with a Work Breakdown Structure (WBS) from housing project work to be categorized into these activities which are divided into three types of activities, namely:

a) Value added activities (VA/Value Added): work that directly contributes to the final form of the product and the customer is willing to pay
b) Non-Value Added Activities (NVA/Non-Value Added): Work that does not add value to the final product directly or indirectly is considered waste that must be eliminated
c) Necessary but Non-Value Added but Required (NVAR/Non-Value Added but Required) activities: activities that must be carried out to enable value added (VA) activities to be completed but do not directly contribute to the final shape of the product.

The following is a table of WBS that must be identified for the categorization of activities (Give a check in the column provided below)

ID.WBS	Activity	Type of Activity		
		VA	NVA	NVAR
A	**Initial Work**			
A1	**Bidding**			
A1.1	Make sales orders			
A1.2	Create and issue survey orders			
A1.3	Conduct site survey			
A1.4	Preparing RAB			
…	…			
B16.1	Additional work/change			

Appendix 2. List of Interview Questions (Respondent 1)

No	Questions
1	What determines the following activities in the NVA category?
2	The grouping of these activities in the following waste factors. What are the main causes of the wastage factor?
3	What actions have been taken to address waste if these factors occur?

Appendix 3. List of Written Questions 2

B. Application of lean construction principles

The following are the assessment components in lean principles. On every project that you have ever been involved in, give an assessment of how far the implementation of the component is on the following scale:

1	2	3	4	5
None	**Low**	**Moderate**	**High**	**Very High**

Information:

1 = Never stated and applied to all projects that have been done
2 = Only stated but never applied to all projects that have been done
3 = It has been stated on every project but rarely applied to the projects being worked on
4 = as been stated on every project and is often applied to the projects being worked on
5 = Has been stated and applied to all projects that have been done

No	Description	Score					Clear?	
		1	2	3	4	5	Y	N
Customer Focus								
1	Project objectives and customer (owner) needs are understood by all parties involved							
2	Value addition is defined in terms of the whole project by all teams							
3	Teams are formed to develop strategies to achieve project objectives							
…	…							
54	KPI measurement and reporting is carried out in the same format throughout the supply chain so as to							

	provide consistency and comparability							

Appendix 4. List of Interview Questions (Respondent 5)

No	Questions
1	What are the barriers to applying the principle of "Setting value from the customer's point of view"?
2	What are the barriers to applying the principle of "Using target costing and value engineering"?
3	What are the barriers to implementing the "JIT delivery practice" principle?
4	What are the barriers to applying the principle of "Worker balance, flow synchronization"?
5	What are the barriers to applying the principle of "Use production planning, detailed worker instructions"?
6	What are the barriers to implementing the principle of "Implementing a reliable last planner system/production scheduling"?
7	What are the barriers to applying the principle of "Easing complex setup activities and reducing changeovers between jobs"?
8	What are the barriers to applying the principle of "Reducing waste material"?