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Sustainable Transformation in the Construction Industry: Reducing Environmental Impact and Enhancing Cost Performance through Waste Utilization and Lean Construction

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ABSTRACT

This research aims to improve cost performance and reduce environmental damage in the construction industry in Indonesia through the implementation of value engineering and lean construction methods. Through a case study on high-rise building construction, the research findings reveal that utilizing concrete waste as a substitute for formwork and applying lean construction practices can achieve cost savings of 55.83% compared to the initial plans. Furthermore, this approach provides additional benefits such as increased construction efficiency, utilization of more sustainable resources, and enhanced corporate reputation in terms of environmentally-friendly practices. The results of this research contribute to achieving zero waste in the construction industry, improving cost performance, and actively participating in global environmental conservation efforts. Moreover, the study has the potential to enhance the sustainability of the construction industry in Indonesia and provide long-term positive benefits.

1. Introduction

The construction industry has a central role in economic development, this is supported by the rapid globalization and urbanization which results in the need for well-structured space and community facilities. The construction of high-rise buildings has become the right solution to meet space requirements, but the need for their rapid growth has also resulted in serious environmental damage due to the use of natural materials such as sand and budget constraints to achieve cost efficiency targets. Previous studies have indicated that construction waste accounts for 10%-20% [1] of the total materials brought to project sites, while sand and gravel extraction [2] poses a threat to aquatic ecosystems. Additionally, only 30% of projects are completed within budget, with 34% falling below the budget and 36% exceeding it[3].The

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context of this ongoing research, the need for sustainable transformation in the construction industry is increasingly urgent to reduce the impact of environmental damage and increase cost efficiency. This research aims to bridge the interests between environmental and economic goals in industrial construction with a focus on waste utilization, application of value engineering and the principles of Lean Construction. This research will identify the main challenges in integrating waste utilization in this case using value engineering and lean approaches, which propose effective approaches to reduce environmental impact and improve cost performance.The purpose is to find sustainable solutions that reduce waste, minimize environmental impact, and enhance cost efficiency in high-rise building construction, aligning with the principles of sustainable urban development[4].

This research will identify the main problems faced by the construction industry in achieving a sustainable transformation. The focus of this research will focus on reducing the environmental impact of extracting natural material needs, construction waste and opportunities to increase cost efficiency through the application of value engineering and lean construction principles. Although this research has a clear focus on the integration of waste and Lean Constructions, the limitations of the problem will limit the scope of certain aspects of this sustainable transformation. The approach used in this study will involve literature analysis and case studies of foundation concrete waste.

2. Research Method

2.1. Value Engineering

Value Engineering (VE) was born in the United States (USA) in World War II. So that it is not a new concept, this method has long been developed and applied to advanced industries and projects in the world[5]. So that the results of the achievement from its application cannot be doubted[6]. Value Engineering defined as "a systematic process used by multidisciplinary teams to increase project value through an analysis of its functions"[7]. Al-Yousefi (2007) notes that Value Engineering is a team effort that aims to analyze the function and quality of a project to produce practical cost-effective alternatives that meet end-user requirements [8]. The concept that is often used in value engineering is Fast Diagram[9].

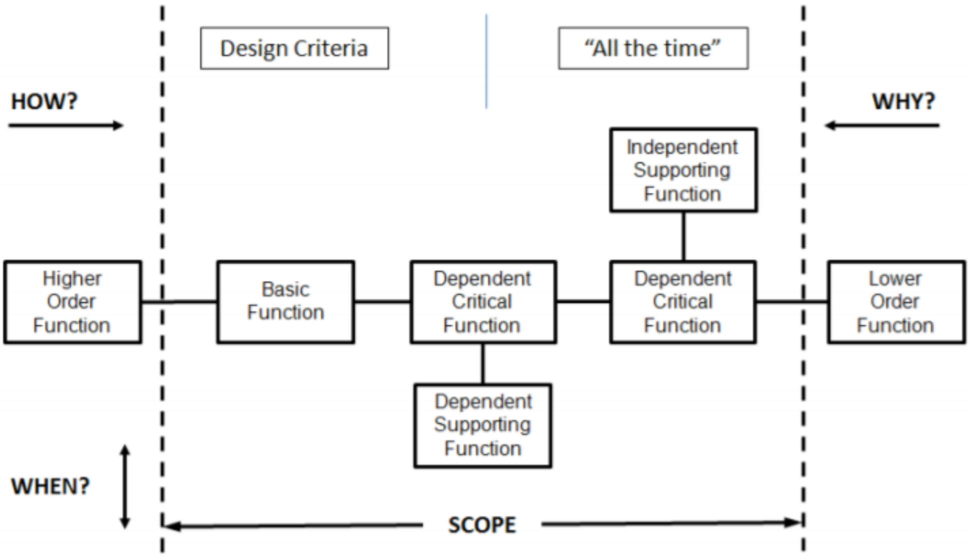

Figure 1. Fast Diagram

FAST diagram is done to see the identification of basic functions and complementary functions. The way this diagram works starts with determining the main function and how to achieve it (how), and will explain why this is done (why). This diagram also performs the

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division between the scope of design and scope of construction to achieve the analysis made. The FAST diagram explains the concept of thinking in the design phase and construction phase. In the design phase explain how to do to solve the problems that will arise. While during the construction period, it was explained how to solve the problems that arise.

2.2. Lean Construction

The main focus of the Lean concept is cut waste value-adding Increasing globalization and urbanization have led to an increase in the need for space and the public order of society[10]. The solution to these needs is a high-rise building. However, this increase has caused a number of problems, is a waste generated during construction, damage to the environment due to the use of natural materials and over budget. Lean is a management philosophy, which focuses on identifying waste and utilizing its tools and principles to minimize or eliminate waste. Lean construction application to reduce waste is the Last Planner System method.

The main of the Last Planner is to keep work away from uncontrolled uncertainty through active identification of constraints (constraint analysis). Last Planner helps the project team create a systemic view (Last planer book) [11].

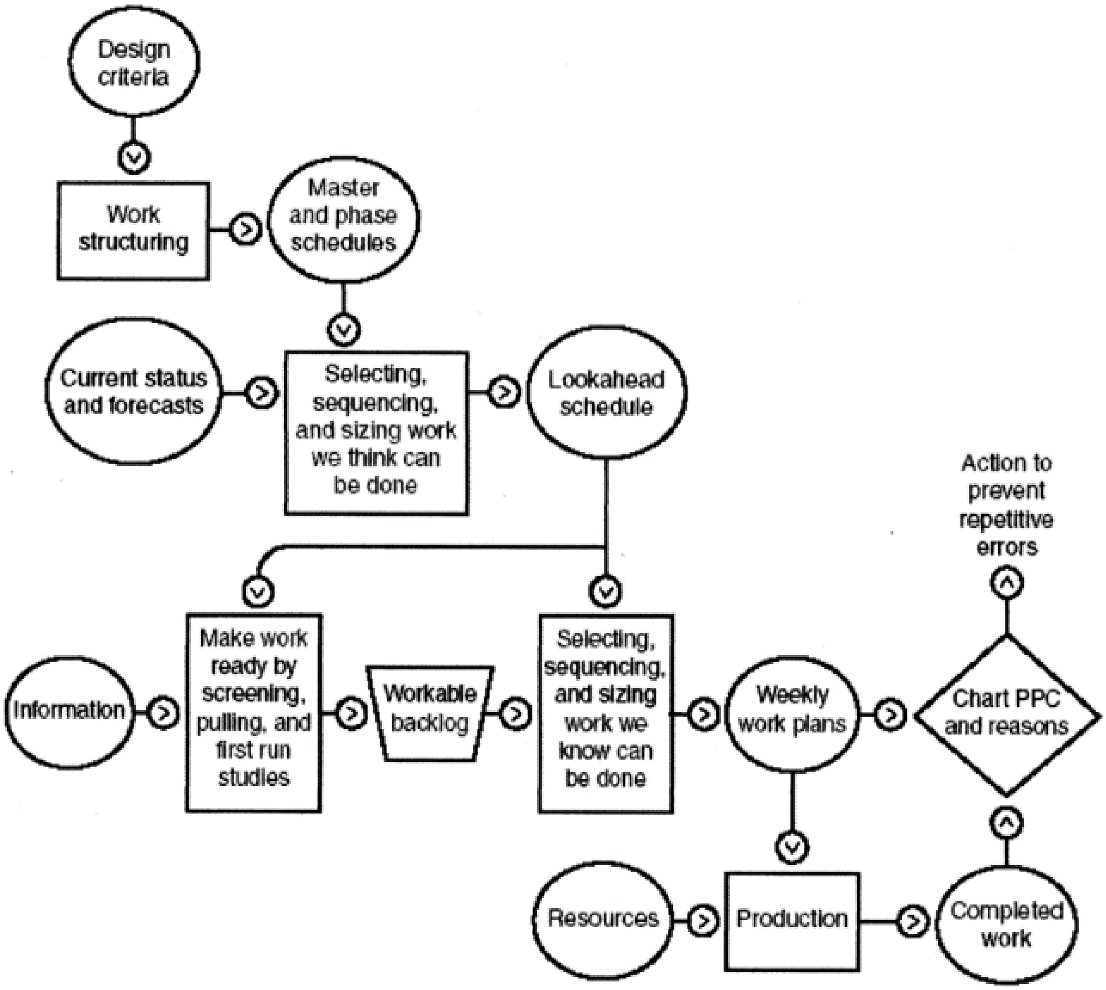

Figure 2. Last Planner System Methodology

The results of the last planner are usually evaluated by questioning whether there is a difference between "SHOULD" and "CAN". Erratic resource dispatch such as information advice and unpredictable completion of job requirements validates the approximate equation of “WILL” to “SHOULD”, and rapidly results in planning delays that govern actual production.

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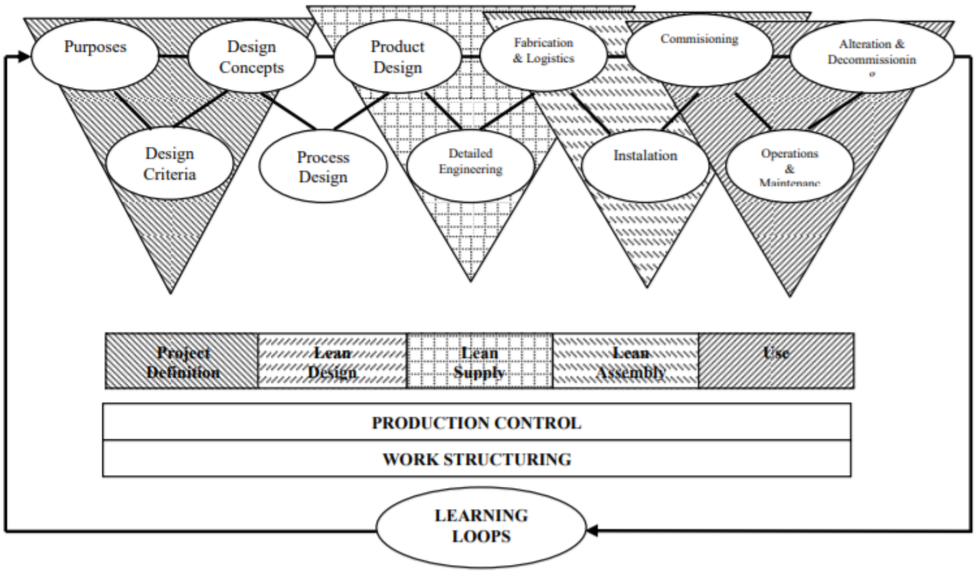

Figure 3. Lean Project Delivery System

The Last Planner System invented by Ballard when implementing Lean Production for the construction industry is a system that focuses on flow (Flow View). The flow of work starts with a complete design result. Furthermore, the work will be determined from the aims of the design.

2.3. High Rise Building

High rise building structures generally consist of a lower structure and an upper structure. Lower structure is a foundation, upper structure is a building structure that is above ground level, such as columns, beams, plates, stairs[12]. The foundation is a very important part of the structure of the building and always costs a lot of money to do it.

Generally, deep foundation formwork of concrete brick is made of cement, water, coarse gravel and sand, where the amount of natural materials is limited. Sand and gravel represent the highest volume of raw materials used on earth after water. Its use greatly exceeds the natural renewal rate. In addition, the amount being mined is increasing exponentially, mainly as a result of the economic growth in Asia. The negative effects on the environment occur all over the world. Damage was more severe in small river catchments. The same applies to threats to ecosystem forms from marine extraction[13].

Table 1. Waste in Construction

Material	Mean	Median	Coefficient of Variability	Coefficient	Min	Max	Number of Site
	(%)	(%)	(%)	(%)	(%)	(%)	
Steel reinforcement	10.3	10.6	39.5	32.5	4.0	17	12
Premixed Concrete	9.5	8.6	56.8	49.7	2.4	23.3	35
Cement	73.7	45.2	84.6	109.3	6.4	247	41
Sand	47.5	40.7	71.9	67.6	6.8	118	24
Crushed stone	31.3	37.1	61.7	48.4	8.7	56.1	5

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Lime	48	32.8	78.3	100.5	6.4	247	11
Premixed mortar	59.8	32.6	116.0	143.2	5.3	207.4	8
Soil (mortar constituent)	182.2	173.9	30.2	35.0	133.9	247.1	4
Ceramic blocks	18	13.8	75.8	76.6	2.0	60.7	53
Concrete blocks	11.3	7.7	98.4	95.8	1.2	43.3	30
Normal bricks	52.2	78.0	74.2	45.7	4.2	82.6	5
Ceramic tiles	15.6	144	74.1	63.0	1.8	49.7	18
Electrical pipes	15.4	15.1	17.1	17.3	12.9	18.1	3
Electrical wires	25	26.7	42.6	40.3	13.9	40.3	3
Hydraulic and sew age pipes	19.9	14.8	84.4	71.8	7.6	56.5	7
Gypsum plaster	45.1	29.5	151.2	223.3	-13.9	119.7	3
Paints	15.3	14.6	43.0	44.6	8.2	23.7	4
Carpet	14.0	14.0					1

Source : Formoso et al. (2002)

According to Formoso et al. (2002), very high levels of waste are assumed to exist in construction. Studies in various countries have confirmed that waste represents a relatively large percentage of production costs although it is difficult to measure all waste systematically in construction [1].In the table of waste generated in the construction above, Premixed Concrete Cement Sand material is an important part of construction work which contributes a lot to construction waste. Cement Premixed Concrete contributes an average of 9.5%, Cement 73.3% and Sand material an average of 47.5%. Referring to the facts above, it is necessary to use the waste.

3. Description and Technical

3.1. Pareto Distribution Analysis

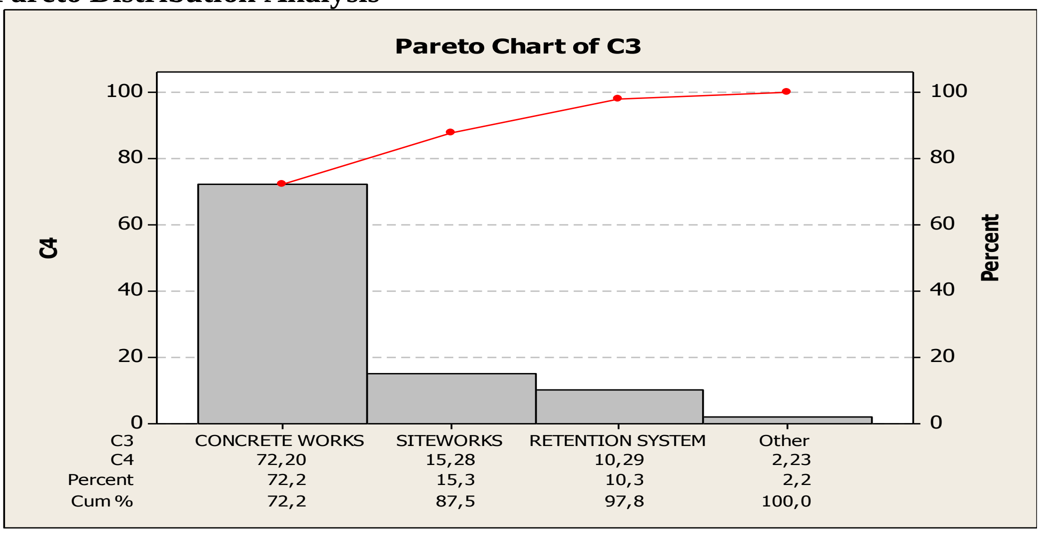

Figure 4. Pareto Chart

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Foundation work explained through Pareto analysis by sorting the largest to the smallest work costs, then adding the cumulative total cost of the foundation work. So that from the total project cost it is known that the concrete work object which has a large weight need carried out in the next stage.

3.2. Function Analysis

The function analysis phase, the first activity carried out is to find functions randomly (random) and then group them, and find each type of function. The function part / process consists of an active verb and a measurable noun[14].

Table 2. Analysis of Functions in Foundation Work

No	Job description	Verb	Noun	Function
A	Procurement of Foundation Formwork materials	Shifting Material	Procurement	Primer
B	Installation of Foundation Formwork	Installation	Install it	Primer

Source: (donomartono1999)

From table 2 it can be explained as follows:

- Functional analysis only describes the work items to be analyzed by VE and the functional definitions of verbs and nouns. Apart from being used in the information stage, function analysis will also be used in the analysis stage. - A, B are the components of the work items to be analyzed function.
- In the function column there are columns for verbs, nouns and functions which are function aids rather than components. For the verb is the help of the verb function on the component. For nouns are auxiliary noun functions rather than components. For Function is an aid function type rather than a component. P is a primary/principal function, while S is a secondary function.

3.3. Creative Phase

The creative phase of Value Engineering, the objective is to generate a wide range of alternatives that effectively fulfill the primary or main function. This involves the generation of ideas and brainstorming sessions to expand the pool of potential alternatives that can be considered[15]. The emphasis is on encouraging creativity and exploring innovative solutions that can address the project's requirements in a cost-effective manner. By promoting a collaborative and open-minded approach, the creative phase aims to foster a rich and diverse set of alternatives that can be evaluated and selected for further analysis and implementation. This phase plays a critical role in unlocking new possibilities and unlocking the full potential of Value Engineering in driving value enhancement and cost optimization in construction projects.

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Table 3. Type of formwork based on the materials used

Types of Formwork	Material Quality	Making	Shape Function
Conventional	Multiplex	Fabrication & Manufacturing	Sheet
Knockdown	Iron plate	Fabrication & Manufacturing	Modul
Fiber Glass	Fiber	Fabrication & Manufacturing	Modul
Concrete brick	Sand & Cement Mix	Manufacturing	Rectangle
Waste Concrete	Waste Concrete	Waste	Irregular

Source : (Hutabarat,1995)

From table 3 it can be explained about the type of formwork, the quality of the material, the method of manufacture and the form. Where from the results of the creative stages of this type of formwork it is concluded that the concrete waste has the same quality as the existing concrete/utilization of dilapidated waste which has an irregular shape.

Table 4. Method and Time of Foundation Formwork Work

Types of Formwork	Method of Implementation	Execution time	Information
Conventional	Material Procurement, Manufacturing & Execution	Wasting time to procure materials	The existence of Formwork Material Cost
Knockdown	Material Procurement, Manufacturing & Execution	Wasting time to procure materials	The existence of Formwork Material Cost
Fiber Glass	Material Procurement, Manufacturing & Execution	Wasting time to procure materials	The existence of Formwork Material Cost
Concrete brick	Material Procurement, Manufacturing & Execution	Wasting time to procure materials	The existence of Formwork Material Cost
Waste Concrete	Execution	The implementation is faster because the material is already available	Zero Cost Formwork Material

Source : (Hutabarat,1995).

From table 4 it can be explained about the method, time and costs incurred due to the use of formwork materials. Where from the results of the creative stages of selecting the type of formwork, it is concluded that concrete waste has a faster time from the procurement side with no material purchase costs incurred.

The foundation functions arranged in a FAST (Function Analysis System Technique)[16].

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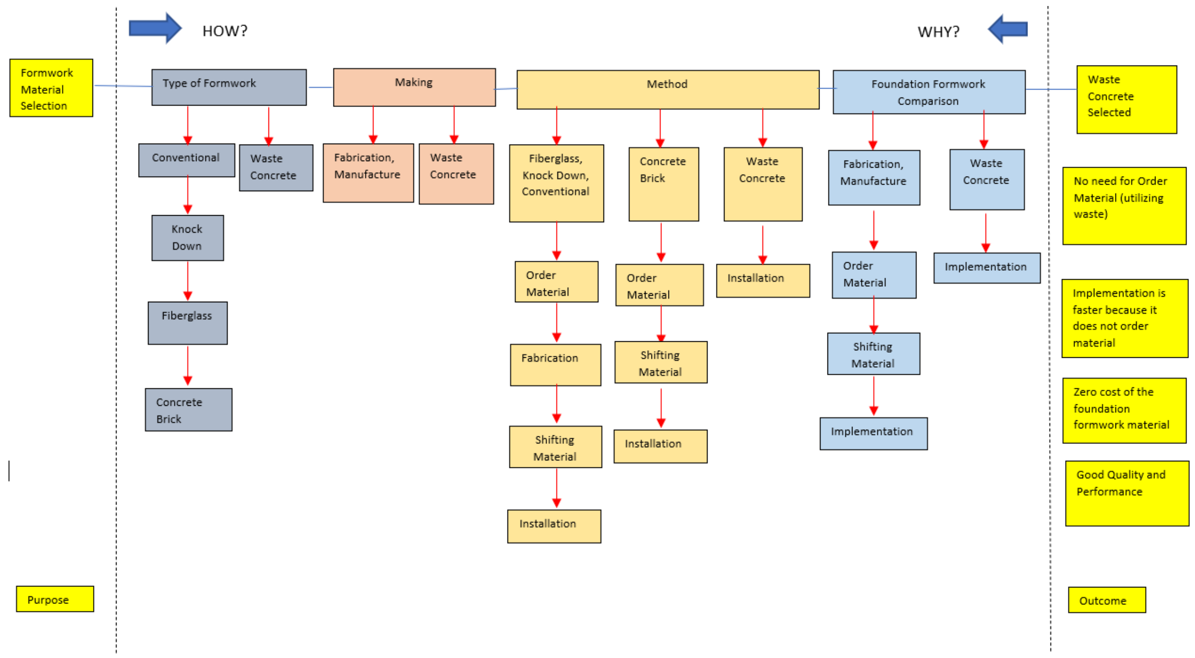

Figure 5. Function Analysist Diagram

The Results of fast diagram found alternative waste concrete used as an alternative to concrete brick formwork without reducing its value and function to optimize the value[17].

3.4. Evaluation

Ranking the advantages and disadvantages of selecting formwork material:

Table 5. Type of formwork based on the materials used

Selected Creative Ideas	Advantage	Loss
Waste Concrete	**The quality** is stronger because it from the remains of soldier pile concrete **Speed** because it does not need time to materials **The supply of materials** reduces environmental pollution due to the use of natural materials **Cost** There is no cost to buy formwork material	The fulfillment of foundation formwork needs depends on waste concrete

Source : (Hutabarat,1995).

From the several tables on the creative stages above, it can be concluded in table 5, that concrete waste from soldierpile has several advantages:

1. Quality is stronger because it is made of remnants of soldier pile concrete
2. Speed because it does not require time for procurement of materials
3. Material supplies reduce pollution environment due to the use of natural materials
4. Cost There is no cost for purchasing formwork materials

However, it has drawbacks in terms of fulfilling the amount of foundation formwork needs depending on concrete waste.

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3.5. Recommendation

In this stage of Value Engineering, the results include the identification and selection of alternative materials for the foundation formwork[18] Ma et al., 2018, specifically by utilizing waste concrete as a replacement[19]. This innovative approach not only addresses the issue of waste management but also presents a sustainable solution by repurposing materials that would otherwise be discarded. Furthermore, the study extends its focus to explore the potential use of waste concrete as a substitute for concrete bricks, contributing to the reduction of raw material consumption and further minimizing environmental impact. Additionally, the implementation of Lean Construction practices is emphasized, aiming to streamline construction processes, eliminate waste, and enhance overall project efficiency. By integrating Value Engineering with Lean Construction principles, this research aims to achieve cost savings, promote sustainable practices, and optimize resource utilization in the construction industry. The following is an overview of the implementation of lean construction with the last planner system.

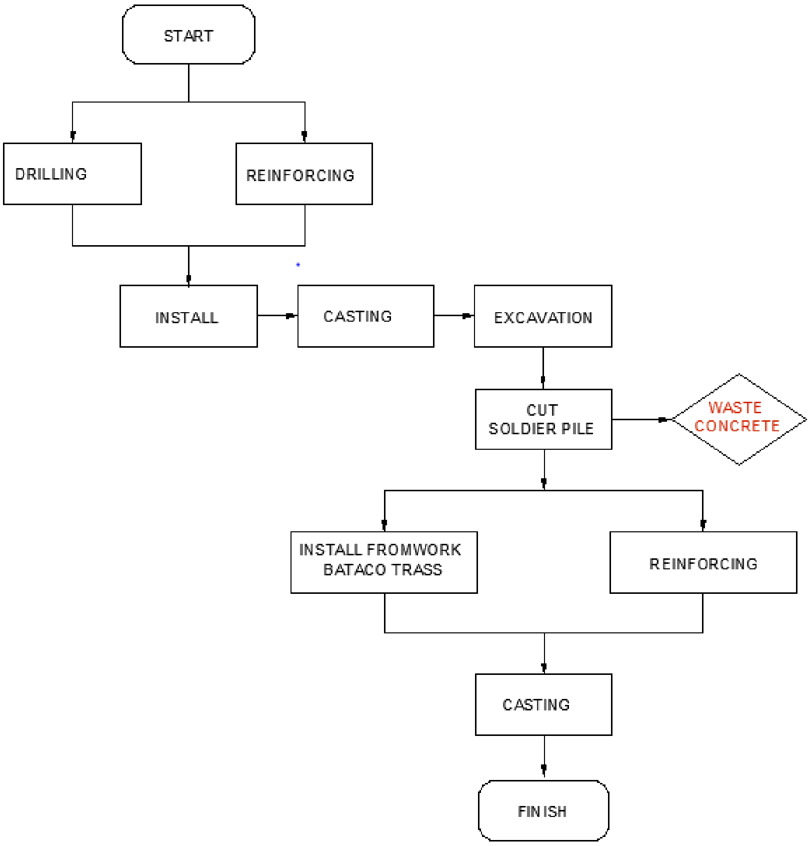

Figure 6. Waste Producing Analysis Flow Chart Last Planner System
Source: (The Last Planner Production System workbook, 2007).

The diagram of figure 6 explains the workflow of the borepile foundation where during the borepile breaking process it produces concrete waste which will later be used as a substitute for adobe formwork.

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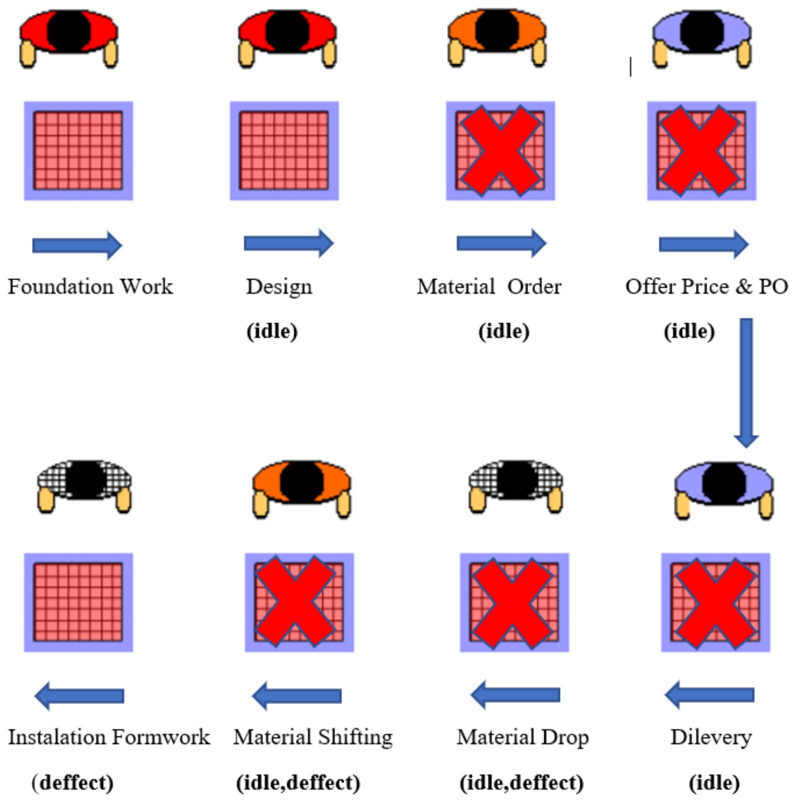

Figure 7. Lean Construction Formwork Production Process
Source: (The Last Planner Production System workbook, 2007).

The diagram of figure 7 describes the workflow of foundation begeting where there are elements of several work items, namely the procurement of formwork materials, procurement of goods, delivery, material reduction and shunting of material so that the elimination results in cost efficiency as a substitute for adobe formwork.

Figure 8. Soldier Pile Foundation

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Figure 9. Lean Concept Applications Waste Concrete to Increase Value

4. Results and Discussions

The cost of the selected alternative from the previous stage is calculated, followed by a comparison of the cost with the initial design of the project[18]. This analysis involves evaluating the cost of implementing the alternative design in contrast to the estimated cost associated with the initial design. By directly comparing these costs, the research aims to assess the extent to which the alternative design can significantly reduce project expenses. This evaluation provides valuable insights into the potential cost savings that can be achieved through the implementation of the alternative design.

Table 6. Budget Plan. Foundation Formwork

A	Install Concrete brick1: 5 T = 17 Cm		Coefficient.	Price (IDR)	amount (IDR)
1	Concrete Brick 35 x 17 x 8 cm	Pcs	30,0000	2.658	79.733
2	Concrete sand	M3	0,0797	250.589	19.972
3	Gray cement	Bag	0,3640	78.467	28.562
4	Installing Concrete brick	M2	1,0000	22.148	22.148
	Sub Total				150.415
B	Material requirements				
1	Concrete brick 35 x 17 x 8 cm	m2	3.596,00	79.733	286.719.149
2	Shifting Material				15.823.000
	Sub Total				302.002.149
C	Total cost foundation formwork				
1	Concrete brick 35 x 17 x 8 cm	m2	3.596,00	150.415	540.891.578
	Sub Total				540.891.578

Source: (Bill of Quantity Project, 2019).

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In Table 6, which is sourced from the budget plan for the foundation formwork work using bricks, it explains that there is a cost burden on material procurement of 286,719,149 (IDR) with a total of all foundation formwork costs of 540,891,578 (IDR).

Table 7. Total Cost foundation formwork with concrete waste From Budget Plan

No	Total Cost				
1	Concrete brick 35 X 17 X 8 Cm	m2	3.596,00	(70.682)	(254.172.429)
		Sub Total			(254.172.429)

Source: (Budget Plan Project, 2019).

In table 7, which is sourced from the budget plan for the foundation formwork work using waste concrete, it explains that there is a cost elimination in the procurement of materials amounting to 254,172,429 (IDR) which gives a cost efficiency value to the work.

Table 8. Proposed Foundation Formwork from Budget Plan

Criteria	Initial Plan (Existing)	Value Engineering & Lean Alternatives
Foundation Type	Concrete brick	Waste Concrete
Cost	540.891.578	(254.172.429)
Savings	**302.002.149**	**55,83%**

Source: (Budget Plan Project, 2019).

In table 8, which is sourced from the planned foundation formwork work cost budget using waste concrete, it explains that there are cost efficiency results in material procurement of 254,172,429 (IDR) which gives a cost efficiency value of 55.83% for the foundation formwork work.

5. Conclusion and Suggestion

5.1. Conclusion

The application of Value Engineering and Lean Construction has yielded significant cost efficiency, with a remarkable 55.83% reduction compared to the initial project plan costs[21]. This outcome highlights the effectiveness of these methods in optimizing construction processes[22]. Furthermore, this research emphasizes the importance of developing additional strategies to address other construction wastes. By implementing Value Engineering and Lean Construction approaches, construction industry stakeholders can unlock further opportunities for waste reduction and cost optimization, contributing to more sustainable and efficient construction practices[23].

5.2. Suggestion

This study recommends several actions for the construction industry in Indonesia. Firstly, exploring innovative methods for managing different types of construction waste should be prioritized, going beyond concrete waste and focusing on recycling and repurposing techniques. Secondly, promoting the adoption of Value Engineering and Lean Construction principles through awareness campaigns, training programs, and collaborations will drive cost reduction and sustainability[24]. Additionally, establishing guidelines and regulations supporting sustainable practices and waste management is crucial. Lastly, fostering research collaboration among academia, industry, and government institutions is necessary for

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advancing sustainable construction techniques and materials[25]. Implementing these recommendations will lead to a more sustainable and cost-efficient construction industry, reducing waste, mitigating environmental impact, and improving overall project outcomes[26].

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