Lean Construction: Evaluation of Waste and Carbon Footprint in Construction Project

by Mochamad Agung Wibowo

Lean Construction: Evaluation Of Waste And Carbon Footprint In Construction Project

M A Wibowo[1], M N Sholeh[2] and A W Rizkyawan[1]

[1] Civil Engineering Department, Faculty of Engineering, Diponegoro University, Semarang 50275, Indonesia
[2] Civil and Planning Department, Vocational School, Diponegoro University, Semarang 50275, Indonesia

mnursholeh@lecturer.undip.ac.id

Abstract. Construction projects are large-scale works that are mostly done in open areas. This large and open activity has the potential to produce waste and carbon footprint. Therefore, the purpose of the research is to find out the causes, impact analysis, and possible mitigation of waste and carbon footprint in the construction project. Survey and in-depth interviews with construction projects become research methods. The results showed that the causes of waste were dominated by worker factors while the main causes of waste in the design phase are client requests, DED changes and complexity, and design errors. Meanwhile, carbon footprint occurs because it does not use renewable energy and environmentally friendly materials. The impact of indirect waste is 8.93% of the total workers' budget, while direct waste is 5.64% of the material budget, which is at the contractor's tolerance threshold of 3-6%. The carbon footprint in the production phase still dominates the contribution to the amount of carbon footprint produced when compared to the transportation, fabrication and installation phases.

1. Introduction

Sustainable construction is a comprehensive construction concept that consists of three main aspects: ecological, social and economic aspects [1]. Sustainable construction aims to meet human needs in the present, including its infrastructure network without compromising the ability of the future to continue to be able to build. This concept refers to the 5P guidelines: Progress, People, Planet, Prosperityworker'sand Proficiency [2]. One aspect that has a large impact is the aspect of progress where it is closely related to the productivity of a construction process. Utilization of existing resources in the form of Money, Method, Machine, Man and Material (5M) really needs to be a concern so that it will increase existing productivity and minimize the waste that can occur. In addition, according to Kibert [1], there are 7 principles in sustainable construction, namely reduce, reuse, recycle, protect nature, eliminate toxins, economics, and quality. This principle is used to monitor the construction so that it continues to run without eliminating environmentally-friendly considerations.

Waste generated by construction projects is divided into two, namely direct and indirect waste. Direct waste is defined as material loss due to damage. It cannot be repaired due to misuse or material loss during the construction process [3] while indirect waste is a loss that is not physical [4]. Different

types of waste certainly require different handling. Therefore, currently starting to develop various methods and technologies in an effort to reduce waste. Therefore, currently developing multiple innovations and technologies, one of which is precast technology. Precast is a method of printing components mechanically within a factory by giving hardening time to gain strength before being installed [5]. It can be said that precast is one of the applications of manufacturing concepts where identical products are mass-produced [6]. This technology began to develop in Indonesia and is used in various projects. Kristiana and Pujiandi [7] explained that the use of precast walls could save time from 12 months to 7 months or almost 50% of the implementation time. The construction industry must learn a lot from the manufacturing industry in managing its production so that the amount of waste can be reduced by simultaneously increasing the value obtained [8].

In addition to the large potential of waste, the construction challenge is global warming which results in carbon dioxide (CO_2) rising by buildings and construction processes [9]. This is usually called a carbon footprint. In addition to the large potential of waste, the construction challenge is global warming which results in carbon dioxide (CO_2) rising by buildings and construction processes [10]. This is usually called a carbon footprint. Waste and carbon footprint are very closely related. So the purpose of this research is to analyze the waste and carbon footprint of a construction project. The research review focused on the precast wall to see how the waste and carbon footprint of the use of this technology.

2. Material and Methods

2.1. Research design

The purpose of this study is to analyze the waste and carbon footprint on the precast wall. The precast wall was chosen because it is widely used in various buildings. The design of this study began with the study of literature and continued with the collection of data. A case study was conducted at one of the mall projects in Indonesia. The contractor is a state-owned company in Indonesia. The research design concept is as follows:
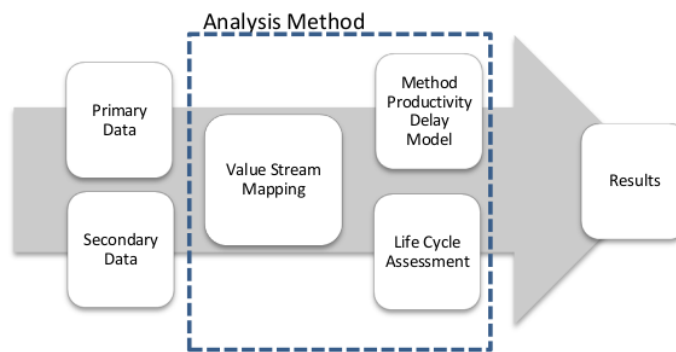

Figure 1.The research design

2.2. Research analysis

Understanding a problem requires a method or way to process data. In this study, three methods were used to analyze the data that had been obtained. The three methods are Method Productivity Delay Model (MPDM), Value Stream Mapping (VSM) and Life Cycle Assessment (LCA). Method Productivity Delay Model is a method used to combine studies of time and productivity measurements. MPDM relies on the ability of field observers to collect cycle time data for an operation. From this measurement, the production cycle time will be obtained which will be processed in such a way through the MPDM method so that productivity in the form of overall productivity and

ideal productivity in units/hour. In addition, this method also helps researchers find the location and amount of waste.

Value Stream Mapping is used to map processes to an operation. There are 3 things that will be identified in Value Stream Mapping that can help researchers in understanding the waste that occurs [12]. These 3 things are Non-Value Added Activity (NVA), Non-Value Added Activity but Necessary (NVAN), and Value Added Activity (VA). Various instruments and indicators have been developed to help assess environmental impacts caused by carbon dioxide emissions, namely Life Cycle Assessment (LCA), Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Environmental Risk Assessment (ERA), Cost-Benefit Analysis (CBA), Material Flow Analysis (MFA), Ecological Footprint and Carbon Footprint [13]. This research focuses on the Life Cycle Assessment method for assessing carbon dioxide emissions generated by the wall precast.

3.   Results and discussion

3.1. Waste analysis

The discussion starts with the visualization of Value Stream Mapping, as shown in Figure 1. VSM is used to monitor how the process of precast wall works from start to finish. In the figure below, it communicates between the contractor and several suppliers and owners. The workflow of the precast wall is reinforcement, installation of mold, casting, demolition of mold, storage, transportation, and installation. This VSM makes it easy for contractors or suppliers to monitor how the information and workflow of precast wall work.
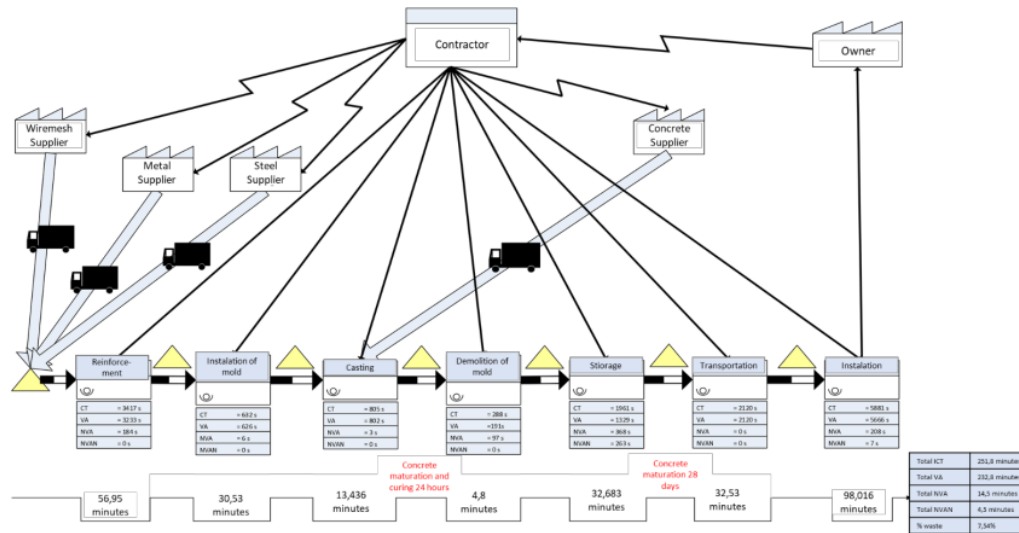
Figure 2. Value stream mapping of wall precast

From the Value Stream Mapping method and the Method Productivity Delay Model can be mapped the activities of value-added activity, non-value added activity and non-value added activity with the average results. In detail, MPDM can calculate the duration of work for each activity. In the table below the duration is calculated in units of seconds as follows:

Table 1. The activities and delay of wall precast

Activity	Duration (seconds)	%
Value added activity	13969	92,46
Non-value added activity	868	5,76
Non Value Added Activity but Necessary	269	1,78
Total cycle time	15106	100

The table above explains that in the precast wall work, there are several delays along with their duration. The highest delay is the value-added activity with 13969 seconds or 92,46 % of total cycle time. The productivity level of each job is calculated into two categories, namely Ideal Productivity (IP) and Overall Productivity (OP) with the following results:

Table 2. The productivity level of wall precast

Work or activity	IP (units/hour)	OP (units/hour)
Clearing work	1,221	1,152
Print installation work	4,556	4,520
Casting work	4,486	4,470
Demolition works	18,653	12,379
Storage work	2,170	1,471
Transportation	1,719	1,719
Installation work	0,636	0,613

The table above explains that demolition works are the highest delay in precast wall work with ideal productivity of 18,653 units/hour and overall productivity of 12,379 units/hour. While the lowest delay is the installation work with ideal productivity of 0,636 units/hour and overall productivity of 0,613 units/hour. These results indicate that with precast technology, wall mounting becomes more effective and efficient because the delay time is very low.

The next stage of analysis is about the level of waste. Waste levels that occur in precast wall work are divided into two groups, namely direct waste and indirect waste. This amount of waste will have an impact on project costs. Direct waste in this project is in the form of materials that have been ordered but not used in the project. The volume of material that becomes direct wast is as follows:

Table 3. The producing waste and wastage level of wall precast work

Waste type	Producing waste	Wastage level (%)
Concrete f'c 30	12 m^3	0,61
Wiremesh	1655,85 kg	1,04
10 mm plate	9,77 pieces of waste (volume: 2,1 m x 2,4 m x 10 mm)	1,73
8 mm plate	8,73 pieces of waste (volume: 2,1 m x 2,4 m x 8 mm)	1,29
Elbows 100,100.10	5,23 sticks (length: 6 m)	0,39
Reinforcement D10	105,9 kg	0,06
Reinforcement D13	902,85kg	0,51
Dynabolt	0	0
The total wastage level		5,64

The total wastage level generated is 5.64%. This waste has an impact on the material budget of Rp. 85.927.944,12. The majority of direct waste comes from refining materials, with a wastage level of 5.03%. While the indirect cost of this project comes from activities that do not provide added value in the form of NVA (Non-Value Adding Activity) and NVAN (Non-Value Adding Activity but Necessary). The percentage of indirect waste is 7.54%. Workers' cost with overall productivity generates a worker wage of Rp 1.378.845.569,84. Worker cost with ideal productivity produces a worker's wage rate of Rp. 1,269,266,265.86. The difference between both calculations is the cost caused by the waste that occurs that is equal to Rp 109.579.303,97 or 8.63% of worker cost.

3.2. Carbon footprint analysis

The carbon emissions generated in the precast wall work include the stages of production, transportation, fabrication, and installation in this research review project are:

- At the production phase of the precast wall of this project construction project, carbon emissions were produced in 197,976 $tonCO_2^e$ concrete material, 131,018 $tonCO_2^e$ wire mesh material, 10 mm plate material 29,554 $tonCO_2$, 8 mm plate material 21,016 $tonCO_2^e$, elbow 100,100.10 material 22,556 tonnes $tonCO_2^e$, D10 reinforcement material 3,953 $tonCO_2^e$, reinforcing material D13 amounted to 9,161 tons of CO_2^e and dynabolt material amounted to 1,478 tons of CO_2^e.

- At the transportation phase of this development project, carbon emission was produced on dynabolt material of 275,963 $kgCO_2^e$, steel plate and elbow of 648,051 $kgCO_2^e$, reinforcing material of 635,736 $kgCO_2^e$, wire mesh material of 646,512 $kgCO_2^e$ and precast wall of 934,364 $kgCO_2^e$.

- At the manufacturing phase of this development project, carbon emissions were generated from the use of welding transformer fabrication equipment at 309,96 $kgCO_2^e$, a blender at 1285,783 kgCO2e, concrete vibrator at 160,884 $kgCO_2^e$, cutting wheel 205,6 kgCO2e and mobile tools crane amounting to 9205,2 $kgCO_2^e$.

- At the installation phase of this development project, carbon emissions from the use of tower crane installation tools amounted to 12464 $kgCO_2^e$ and welding transformer equipment amounted to 230,42 $kgCO_2^e$.

The results of carbon emission analysis based on literature studies conducted as a validation of the results of this research analysis are at the production and fabrication phase of this development project, carbon emissions of 218,575 $tonCO_2^e$ were generated. At the transportation phase of this project, Bali development project produced carbon emissions of 90,935 tons CO_2^e. At the installation phase of this development project, carbon emissions of 3,283 tonCO2e were generated.
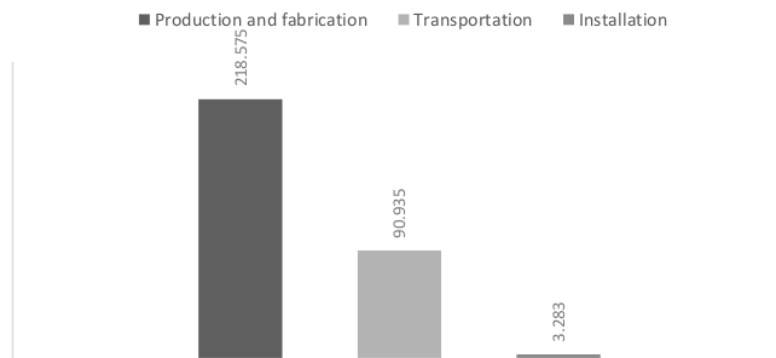

Figure 3. Carbon footprint analysis results ($tonCo_2^e$)

Then the total carbon emissions resulting from the analysis of this project development project amounted to 443,501 tonCO$_2$^{e} (94% production phase, 2% transportation stage, 1% manufacturing stage and 3% installation stage). Total carbon emissions generated based on literature studies as a validation of the results of the study amounted to 312,794 tonCO$_2$^{e} (70% production and manufacturing phase, 29% transportation phase and 1% installation phase). To overcome the carbon footprint generated from the analysis of this development project, 16 trembesi types of trees are needed, and 11 trees are based on the analysis of literature studies [14]. However, the case study project cannot be planted due to the limited land available. The time needed for the trembesi tree to grow perfectly is far longer than the life span of the project so that it cannot directly overcome the carbon footprint generated by the project construction phase, but it can cope with the carbon footprint generated by the operational phase of the building.

4. Conclusion

Precast wall work is basically applied to facilitate the work, but the implementation still encountered obstacles or waste. The research said that the biggest waste in the precast wall is demolition work and the lowest is the installation work. This is consistent with the hypothesis that precast technology does not take up much time for installation. While the carbon footprint analysis stated that the production and fabrication phases are a huge source of carbon footprint compared to other phases. The contractor needs to carry out more stringent supervision in the field and conduct project management more thoroughly. More detailed material planning can minimize reinforcement waste (one of the dominant direct waste factors) so that the volume of waste in the material can be reduced. Optimizing the use of BIM and implementing risk management can be several ways that can be taken. To reduce the carbon footprint produced, it is expected that the contractor will calculate the carbon footprint generated from the tools used, also perform routine maintenance and periodic checks on fabrication equipment and precast wall installations. In addition, substitution with more environmentally friendly material needs to be done for future projects (example: geopolymer concrete).

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