Circular Economy Model of Indonesian Construction Industry Waste Based on System Dynamics

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***Abstract*— In recent years, circular economy has been widely discussed throughout the world as a solution to the problem of resources efficiency and environmental problems, especially regarding waste. The construction industry is one of the largest waste-producing industries, even 30% of waste on landfills is construction waste. The application of circular economy in the construction industry has many interrelated and dynamic variables that change over time. This study aims to identify the variable of circular economy and analyze the pattern of its relationship using system dynamics method. The variables were obtained from in-depth literature review and interviews, including management performance, low-waste technology, and behavior. From these variables, a causal loop diagram is created. This diagram describes the relationship between variables of circular economy. For model validation, a multi-story building project in Surabaya is used as a case study. This study produces a model that can be used to estimate the volume of construction waste with an accuracy of 86.12%. Scenario simulation results show that worker variables can reduce the volume of waste construction up to 7.91%, higher than other variables.**

Keywords—circular economy, construction waste, waste management, system dynamics

I. INTRODUCTION

In recent years, circular economy has been widely discussed throughout the world as an alternative to the old economic model, namely, “take, make and dispose”, as well as a solution to the problem of resources efficiency and environmental problems. Circular economy is a closed loop system aiming to increase resources efficiency, especially on waste. The circular economy concept is adapted from the principles of 3R (Reduce, Reuse and Recycle), aiming to optimize production, reduce pollution, emissions and waste [1]. The construction industry is one of the largest waste contributors. More than 30% of waste on the landfills are from construction, that is why circular economy is appropriate to be implemented on the construction industry [2]. Studies on circular economy in the construction industry have been carried out across the world. One of them is Malaysia which has developed a strategy to manage construction and demolition waste by implementing the Industrialized Building System (IBS), a well-controlled manufacturing technique. There is also the development of an eco-industrial park where companies work together to utilize their construction wastes. In addition, in some countries a pay-as-you-throw system regulation has been implemented, a waste disposal payment regulation to landfill according to the volume of the waste they produce [3].

In Indonesia, the application of a circular economy has also been carried out in a conventional way, such as reusing unused materials on other projects and selling waste materials to other parties who will later recycle [4]. Some big companies have been unknowingly implementing circular economy concept, e.g. like P.T. Wika reuses materials such as used wood from container or waste from wood shaving [5], P.T. Wika Beton utilizes the sludge from concrete making process for road pavement and dam, and P.T. PP utilizes the waste of steel that has less than 1 meter length and salvage material from demolition as a construction material. The government supported by the constitution (the Law No. 23/2009 and the Law No. 18/2008) has also made a target to reduce up to 30% of waste produced by 2025 [6].

There are many variables in the concept of circular economy in the construction industry. These variables have interrelated relationships with each other. Therefore, it is necessary to make a model that can describe the circular economy in the Indonesian construction industry. The properties of variables in circular economy in the construction industry have similarities with the characteristics of system dynamics. The system dynamics is concerned with making a computer model with complex problem situations, experimenting on the model, and studying the behavior of the model over time [7]. The characteristics of system dynamics include: 1) system dynamics approach a problem while considering the whole system rather than just seeing one individual entity, 2) the dynamic nature of a system are caused by endogenous causes, changes over time occur as a result of the effects of feedback and interaction between variables, although the initial stimulus may be from exogenous causes, and 3) soft variables (such as reputation and morals) are also calculated in system dynamics [8].

The purpose of this study is to identify variables affecting circular economy and analyze the pattern of relationships between variables in a system dynamics model. It is expected that the results of this study can show which variable has a major influence on the implementation of a circular economy especially to reduce construction waste and improve construction waste management. Therefore, the implementation of a circular economy in Indonesia in the future can be improved.

II. LITERATURE REVIEW

Literature review regarding circular economy shows that circular economy is rooted in ecological problems and environmental economics. The main objective of circular economy is to balance environmental conditions and rapid economic development. The form of circular economy is closely related to the principle of 3R (Reduction, Reuse and Recycle). In some European countries, as well as Japan, the United States, Korea and Vietnam, circular economy and 3R are mostly about waste management policies [1].

A study on identification and assessment of factors that affect waste management performance in construction projects has been already carried out. The results of these studies indicate that out of the 59 variables, the 5 most influential variables are manpower, materials and equipment, construction methods, management practice and industry policy [9]. In addition, a study on waste management systems model using system dynamics has also been done before. This model is made to evaluate waste management strategies. Waste management performance is assessed by the amount of waste produced. The variables used are waste management budget, effectiveness of waste management, waste collection factors and waste generation factors. From the study, it is found that the effectiveness and budget of waste management has an effect on the amount of waste produced [10].

A model of cost-benefit analysis of construction waste management has been made and the simulation results show that the increase of cost of construction waste disposal in landfills will reduce construction waste. However, if it is too high, the environmental cost will increase due to increasing illegal disposal of construction waste. This indicates that the higher cost of waste disposal must be balanced with better enforcement of regulations, so that illegal construction waste disposal does not increase [11].

The amount of construction waste can be estimated by knowing some data, namely, the economic age of the building and the area of the building. Whereas, to estimate the type of construction waste can be known from the main material types used by the building, such as bricks, steel, reinforced concrete, reinforced concrete steel and wood [12].

A study on reuse of building materials in the concept of sustainable construction in Indonesia shows that many types of construction waste materials can be reused or reprocessed materials such as wood and iron. Regulations related to used materials have existed in several regions, such as in Makassar City and Bangka Regency, but there are no national regulations governing them [13].

This study uses dynamic system method. System dynamics are models that can help understand the structure and behavior of a system that has non-linear relationships and feedback [14]. There are three basic processes of system dynamics model creation, namely: 1) creating the model, 2) validating the model, and 3) analyzing the scenario [15].

Some studies use system dynamics regarding construction waste, some of which discuss the effects of construction workers' behavior on reducing construction waste. The results of these studies show that organizational management has a major influence on reducing construction waste, meaning that construction waste can be reduced to 34.58% by changing these parameters. Variables other than organizational management which have a big influence are personal factors, organizational culture and attitudes [16]. Another study using system dynamics is a model of environmental benefits assessment from reducing construction waste; the results of the study concluded that good waste reduction management can reduce up to 40.63% waste production and waste reduction can provide environmental benefits including reducing gas emissions greenhouse of 12,623.30 kg [17].

III. METHODOLOGY

A. *Model Construction Based on System Dynamics*

From the literature review, there are some variables found in the circular economy in the construction industry. In addition, relationships between variables are also obtained so that causal loop diagrams can be created by first making loops and relationships between several variables, which will later be combined into one.

From Cha et al. [9], we can make a diagram of variables that can affect waste management quality. Waste management performance is influenced directly by manpower, materials and equipment, construction methods, management practice and industry policy. The diagram is shown in Fig. 1.

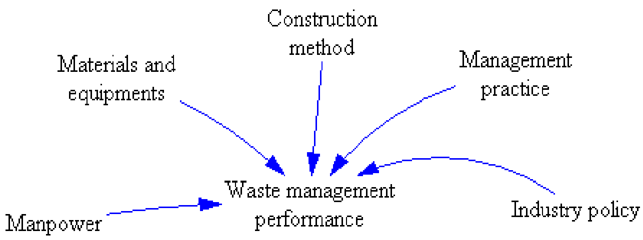

Fig. 1. Waste management performance diagram

Benefit-cost of waste management is affected by the amount of total cost of waste management and total benefits of waste management. Both cost and benefits are influenced by other variables, as well. The diagram is shown in Fig. 2 [11].

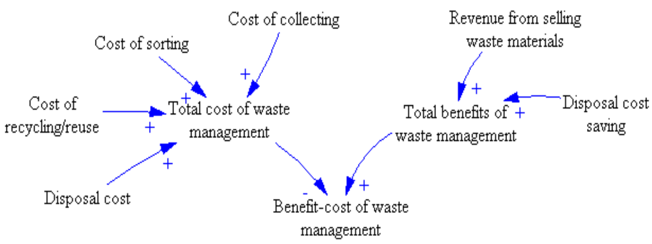

Fig. 2. Benefit-cost of waste management diagram

Ding (2016) and Oriola (2014) have already made two causal loop diagrams, but the causal loop was made in consideration of how construction waste management works in their countries. This research used their causal loop diagram as a base causal loop as shown in Fig. 3 and Fig. 4.

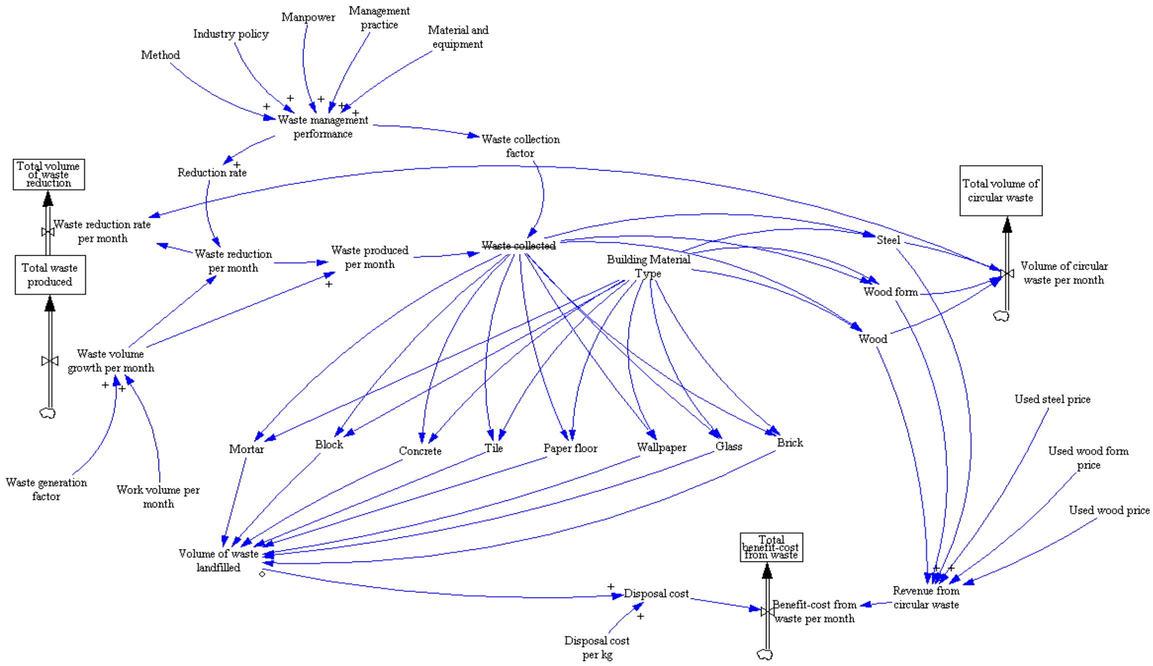

Fig. 6. Stock and flow diagram

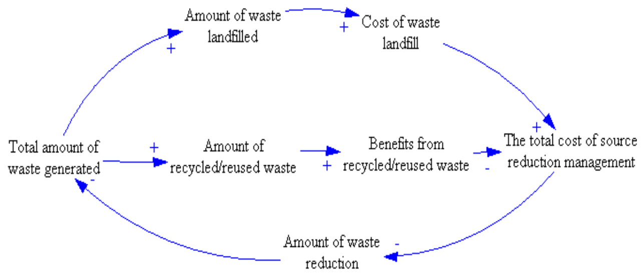

Fig. 3. Causal loop from Ding (2016) research

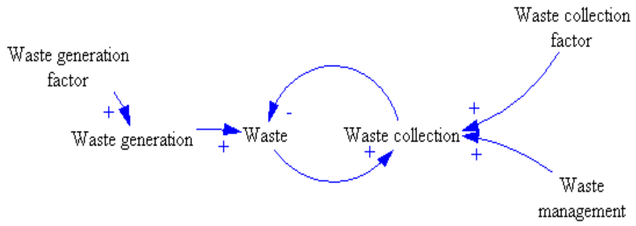

Fig. 4. Causal loop from Oriola (2014) research

From those four diagrams, a causal loop diagram was made and which will be used as a guide for making stock and flow diagrams as shown in Fig. 5.

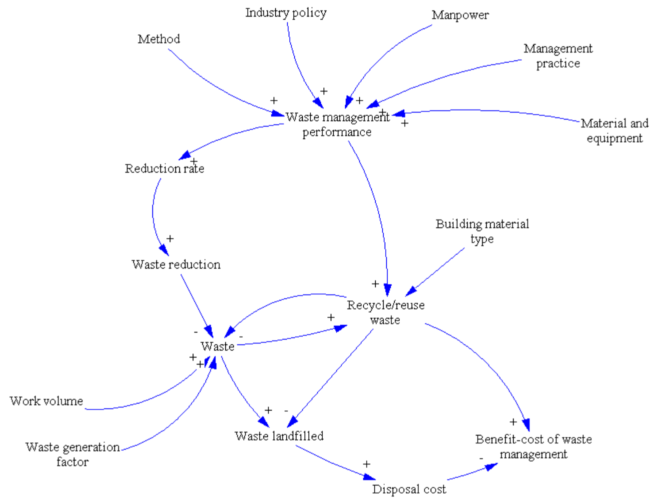

Fig. 5. Proposed causal loop diagram

B. Data Collection

After the causal loop diagram has been made, it is necessary to do in-depth interviews with the expert to validate the variables, the relationship of variables and the causal loop diagram. The experts chosen in this study were Project Managers and QHSE staff since they understand waste management in construction industry. Data obtained from the interview results were processed. In addition to validating, the expert can also add new variables which will later be used for structural simulations. Structural simulation is a model simulation that was done by adding new variables that were not present in the previous model.

C. Scenario Simulation

There are two types of scenarios in dynamic system simulations, namely structural scenario and parameter scenario. Structural scenario is a scenario that adds a new variable to determine the behavior of the model. Meanwhile, the parameter scenario is a change in the value of the existing variable parameters in the model to determine the behavior of the model due to an increase in the parameter value of a variable. In this research, parameter scenario was simulated by changing the value of five variables that affecting waste management performance, namely manpower, materials and equipment, construction methods, management practice and industry policy. The five simulated scenarios are listed in Table I.

TABLE I. SCENARIO TABLE

Scenario	Explanation
Scenario 1	Increasing the value of Method variable into 100% or 1, while the other variables are constant.
Scenario 2	Increasing the value of Industry Policy variable into 100% or 1, while the other variables are constant.
Scenario 3	Increasing the value of Manpower variable into 100% or 1, while the other variables are constant.
Scenario 4	Increasing the value of Management Practice variable into 100% or 1, while the other variables are constant.
Scenario 5	Increasing the value of Material and Equipment variable into 100% or 1, while the other variables are constant.

D. Model Validation

After creating causal loop diagrams, stock and flow diagrams are created using the assistance of the Vensim program. The formulations used in stock and flow diagrams are obtained from previous studies and the results of interviews with experts. The forms of stock and flow diagrams can be seen in Fig. 6. After all the formulations were entered in the model simulation test program, simulation was conducted one by entering data input from all variables. After simulation, it is necessary to have model validation to show that the modeling that has been made is valid and in accordance with the actual conditions. Some of the model tests performed are model structure test, limit adequacy test, model parameter test, extreme condition test and model behavior test.

- Structure verification test.

  This test is conducted to find out whether the structure of the model that has been made is consistent and relevant to the system we want to model. All information made on this model such as variables and relationships between variables is obtained from the literature review and in-depth interview with the experts. Therefore, the structure of the model is logical and can represent the actual system in the industry.

- Boundary-adequacy test

  This test is conducted for three purposes, namely: 1) is the model endogenous? 2) Does the behavior of the model change extreme? 3) If the model limits are expanded, does the system policy recommendations change? All variables in the proposed model have been observed, and it can be concluded that all variables have an effect on research to reduce construction waste and improve construction waste management.

- Parameter verification test

  The purpose of this test is to check the parameter value whether it is consistent and relevant to the system we want to make. All parameter values of the proposed model are taken from the review literature and in-depth interviews and all parameters have a theoretical basis. Therefore, all parameter values are relevant to the system.

- Extreme condition test

  This test looks at model behavior by giving an extreme value to one of the variables to verify that: 1) each equation

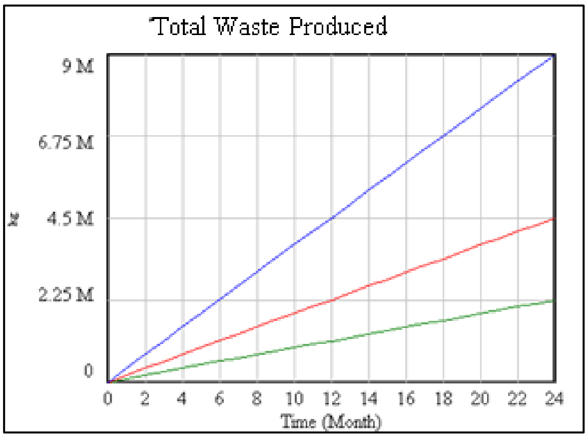

Fig. 7. Extreme condition test

  makes sense even when it is given extreme inputs, and 2) the model can be used even in the extreme conditions. For example, by looking at the relationship between work volume per month (VPB) and the total waste produced (TL). VPB is changed from 0 m2/month, 5000 m2/month, 10000 m2/month and 20000 m2/month. When the VPB value is 0 m2/month, the TL value is also 0 kg. When the VPB value increases, the TL value also increases as seen in Fig. 7. These results indicate that the model behaves consistently. In addition, other variables are also checked in the same way.

- Model Behavior Test

  This test was conducted by comparing the result of the simulation with the actual result on the field. Two multi-story building in Surabaya were used as a comparative test. The first building produced 3,044.98 kg of steel waste on the 11^{th} month of the project. Meanwhile, by using simulation, the amount of steel waste produced on the 11^{th} month of the project is 2,604.615 kg.

$$Percentage\ differences = \frac{|3{,}044-2{,}604|}{2{,}604} = 16.91\%$$

$$Model\ accuracy = 1 - 16.91\% = 83.09\%$$

  On the second building test, the project produced 216,832 kg of waste landfilled on the 14^{th} month of the project. Meanwhile, by using simulation, it produced 195,505.1 kg of waste landfilled.

$$Percentages\ differences = \frac{|195{,}505.1-216{,}832|}{216{,}832} = 10.85\%$$

$$Model\ accuracy = 1 - 10.85\% = 89.15\%$$

$$Average\ model\ accuracy = \frac{83.09\% + 89.15\%}{2}$$

$$= 86.12\%$$

IV. RESULT & ANALYSIS

A. Base Simulation

Case studies were carried out in a multi-story building in Surabaya. The selected project was a residential building project with an area of 0.56 ha, 42 floors and the duration of the project was 32 months. Waste generation index in this study was 19.5 kg/m2. The simulation results show that the total construction waste produced in the 32th month was 4,039,572 kg, while the total of circular waste was 122,763.9 kg.

B. Scenario Simulation and Analysis

The five planned scenarios were simulated. With these scenarios, practitioners were able to choose the most appropriate way to reduce construction waste. The five scenarios are compared and the results are as shown in Table II.

TABLE II. SCENARIO SIMULATION RESULTS

Scenario	Total Volume of Waste Produced (Kg)	Waste Volume Decreased Percentages
Base Simulation	4,039,572	0%
Scenario 1	3,847,937	4.74%
Scenario 2	3,860,182	4.44%
Scenario 3	3,720,009	7.91%
Scenario 4	3,816,774	5.52%
Scenario 5	3,839,032	4.96%

V. CONCLUSION

The system dynamic model in this study is in accordance with the conditions in the field, proven from in-depth interviews with experts as well as the results of several tests. The proposed model can be used to predict the volume of construction waste with 86.12% of accuracy. From the results of the scenario simulation, it can be concluded that the Manpower variables has the biggest influence on construction waste generation.

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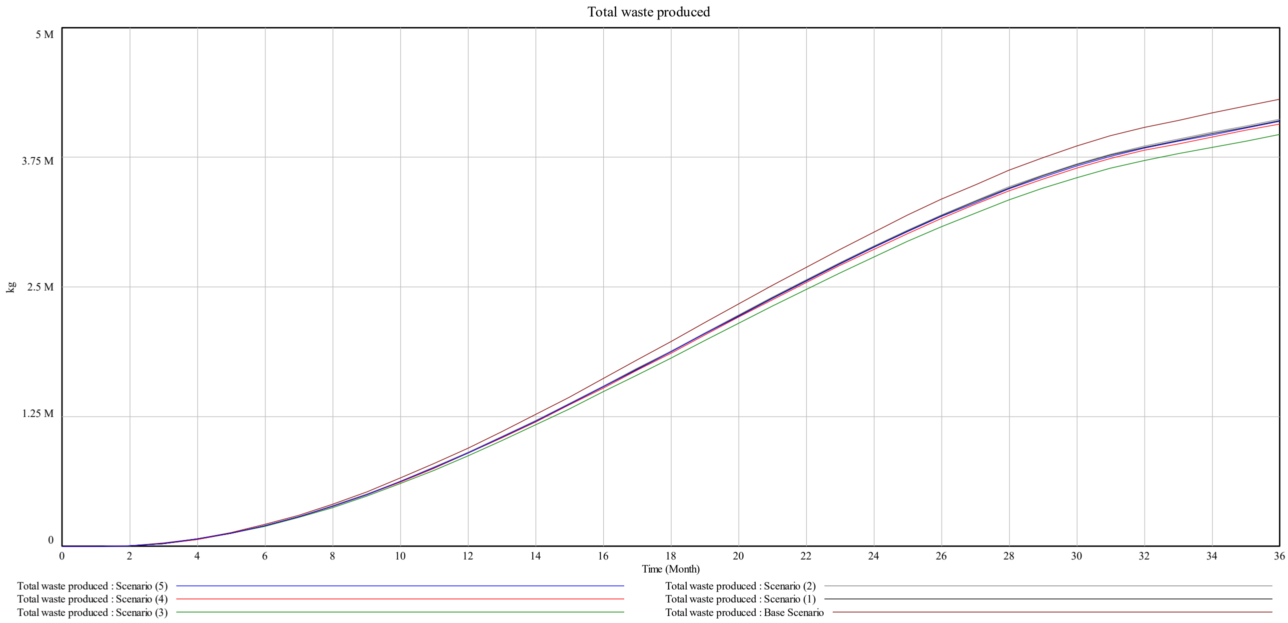

Fig. 8. Scenario simulation results

The results of the scenario simulation shown in Fig. 8 and Table II indicate that scenario 3 or increasing Manpower value parameter to 100% or 1 can decrease waste produced up to 7.91%. Scenario 4 or increasing Management Practice value parameter to 100% or 1 can decrease waste produced up to 5.52%. Scenario 5 or increasing Material and Equipment value parameter to 100% or 1 can decrease waste produced up to 4.96%. Scenario 1 or increasing Method value parameter to 100% or 1 can decrease waste produced up to 4.74%. Scenario 2 or increasing Industry Policy value parameter to 100% or 1 can decrease waste produced up to 4.44%. It can be concluded that Manpower variables has the biggest influence on construction waste generation.

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