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DEVELOPING A MODEL OF SUSTAINABLE CONSTRUCTION FOR CONDOMINIUM PROJECTS IN DEVELOPING COUNTRIES; CASE OF INDONESIA

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ABSTRACT: Large-scale development of residential projects, including condominiums, is growing rapidly in developing countries. Despite their contribution to economic growth, the condominium also causes adverse environmental impacts. To address the problems, a sustainable construction paradigm has been introduced. Even though sustainable construction has been widely discussed, most studies focused on social and environmental aspects with little consideration for the economic objective of the business. This study aimed to develop a model to achieve three dimensions of sustainable construction for condominium projects. To identify the influencing factors and the interrelationships, a literature review was carried out and followed by a qualitative survey of 25 condominium projects in Surabaya, Indonesia. The variables consisted of resource consumption, waste, regulation, lean construction methods, sustainable materials, organizational capabilities, health and safety performance, resource efficiency, and life cycle cost. For data analysis purposes, a system dynamics approach was applied. The simulations reveal that the current practices are insufficient to achieve sustainable construction. To formulate sustainability policies, scenarios including the implementation of Modular Construction, tax incentives policy and a policy mix were employed. The results indicate that the scenarios could enhance sustainability in condominium projects. It can be concluded that the model can be used as a tool to improve sustainable construction for condominium projects in developing countries.

Keywords: Environmental impacts, Lean construction, Life cycle cost, Sustainable construction.

1. INTRODUCTION

It is predicted that 60% of the world population will live in urban areas, particularly in developing countries, by 2030 [1]. As the population and demands for housing are snowballing, high-rise building seems suitable to solve the land scarcity through the concept of the condominium. Unfortunately, condominium projects as part of the construction sector lead to a rapid increase in environmental impacts attributed to the huge consumption of natural resources such as energy and building materials, and the production of construction waste [2,3]. To address the environmental issues, The World Commission on Environment and Development (WCED) published “Our Common Future”, known as the Brundtland Report which has introduced sustainable development as a new paradigm, defined as development that meets the present demands without compromising the ability of future generations to meet their needs [4]. The concept is based on the balance between economic, environmental, and social aspects of development. As the construction industry plays a significant role in the development, the International Council for Research and Innovation in Building Construction published Agenda 21 for Sustainable Construction in 1999, followed by a special Agenda 21 for Developing countries [5].

The implementation of sustainable construction has encountered difficulties due to the additional costs required to adopt sustainability methods [6]. Coetzee and Brent [7] found that an inhibitor of sustainability practices has been the perception among key decision-makers that the additional costs of sustainable design are too high and therefore, not economically viable. The conflict is experienced mainly by developing countries emphasizing economic growth with little consideration for environmental impacts. In this context, a policy intervention through scenario development is a powerful instrument and should be considered to address the problems by creating motives for the adoption of sustainability practices to enhance sustainability performance in construction [6].

Many studies have reported the adoption of the sustainable constructconceptscept. However, most of the previous studies focused on the environmental perspective. Only limited studies have attempted to explore the problems in achieving the balance of the three sustainability dimensions.

Sadaba [8] discovered that the knowledge gap in the field of sustainability causes this difficulty. The objectives of this study are: 1) to examine the roles of current regulations and construction practices in reducing environmental impacts, and 2) to formulate more effective policies toward sustainable construction for condominium projects as a business entity. These objectives will be attained by developing a dynamics model of sustainable construction which consider influencing factors for sustainable construction, including the role of regulations, the implementations of related construction technology and methods, as well as the application of life cycle costing.

2. RESEARCH SIGNIFICANCE

Some studies have examined the importance of implementing sustainable construction. However, the problem related to extra costs incurred in practice still exists. This study has tried to fill the gap by developing a model to understand the system behavior concerning sustainable construction in condominium projects. The findings of this study will provide an integrated approach to balancing economic growth, social development, and environmental protection, which will be attractive for the interest of the stakeholders.

3. LITERATURE REVIEW

3.1 Sustainable Construction Paradigm

Sustainable construction is defined as “creating and operating a healthy built environment based on resource efficiency and ecological design” [9]. This term explicitly addresses social, economic, and ecological issues of development concerning community development. Furthermore, the International Council for Research and Innovation in Building Construction (CIB) formulated the Principles of Sustainable Construction as a guideline: reducing resource consumption, reusing resources, using recyclable resources, protecting nature, eliminating toxicity, and applying life cycle costing [9]. These principles are essential for determining suitable methods and policies to improve sustainable construction.

3.2 Lean Construction Method

Sustainable construction directly relates to the efficiency of transforming natural resources into social needs [10]. In line with the objective, the lean construction concept has been introduced to reduce all types of waste, time, and effort, and to get the maximum value of resources [11]. To implement the strategy, principles of lean construction were identified. It includes reduction of non-value adding activities, increase output value, variability and cycle time reduction, steps minimization as well as continuous control and improvement of the whole process. The strategies and practices of lean construction expressed in the principles aim to positively impact on social, economic, and environmental dimensions of the project sustainability. Several construction methods contain lean construction principles, such as Building Information Modelling (BIM), prefabricated (precast) construction, and Quality Management [10]. In this study, BIM, quality management, and precast construction method were selected to represent lean construction principles as influencing factors as those practices have been widely implemented in many developing countries.

3.3 Sustainable Materials Selection

Material selection plays a vital role in construction sustainability. Incorrect material will adversely impact the environment [12]. In this study, concrete has been considered a potential sustainable material for some reasons. First, concrete is a critical element of condominium projects, which offers many advantages such as durability, longevity, and heat storage capability. Second, concrete consumes a considerable amount of energy and raw materials in the forms of cement and steel. Third, out of the global greenhouse gas emission, 27% comes from non-metallic minerals, mainly cement, and 30% comes from steel [13]. By altering unsustainable components with more environmentally friendly materials, concrete is the potential to improve construction sustainability.

3.4 Environmental Regulation

Government regulation is the prime driver towards reducing the negative impacts of urban development on the environment. There are two types of regulations: standard and code. Measures are classified as mandatory and voluntary. Most developed countries have been imposing mandatory standards while developing countries are still engaged with voluntary-based standards [14]. However, its effectiveness relies on enforcement and monitoring rather than the clauses. A study reported that regulation enforcement is still challenging for most developing countries [15].

3.5 Sustainable Construction Indicators

The indicators of sustainable construction selected for this study were obtained from literature reviews and from the owner’s perspectives, selected based on the important roles in the context of a condominiuprojectsct to represent the three aspects of sustainable construction [16] (Table 1). The construction industry is responsible for about 40% of the energy consumption and 30% of the global greenhouse gas emission, mainly during the building operation. If the demand for energy consumption is fulfilled by unacceptable environmental damage, material efficiency will be the answer [17].

Table 1 Sustainable construction indicators

Aspects	Indicators
Social	Health and safety
	Customer satisfaction
Economic	Cost efficiency
	Life cycle cost
	Project duration
Environment	Material efficiency
	Energy efficiency

3.5.1 Material Efficiency and energy efficiency as the environmental indicators

Material efficiency denotes the efficient use of natural materials in creating products and services with fewer resources and environmental impacts. As greenhouse gas emission has been among the most significant problems that directly contribute, material efficiency can be used as an environmental indicator [16]. Energy efficiency refers to using less energy to produce the amount of service or products. It has significant contributions to climate protection which leads to life cycle cost savings [18], hence it can be considered as the indicator of sustainable construction.

3.5.2 Health and Safety as the social indicator

Despite the government interventions and project stakeholders' efforts to improve health and safety performance, workplace accidents remain social and economic problems. The protection of workers against disease and injury arising from employment is a fundamental element of social justice and constitutes a social dimension of sustainable development [19]. Therefore, the design process should involve health and safety performance to improve sustainability [20].

3.5.3 Life Cycle Cost (LCC) as the economic indicator

The condominium is a long-lasting built space; thus, early decisions in the project life cycle have long-term consequences. However, most investors consider the investment cost more important than the operating cost and maintenance cresultinglted from the decision made in the early stage of development, which leads to environmental degradation. Life cycle cost is a technique that enables a comparative cost assessment to a specific time that considers initial and future operating costs [21]. It consists of the investment costs and operating costs such as energy, utilities, maintenance, and irregular expenses. The adoption of LCC is the otential to generate a solution to achieve the economic aspect of sustainability [22].

4 METHODOLOGY

This study examined the problems of environmental impacts caused by human activities in developing condominium projects and designed a model to address the issue. It started with a preliminary list of contributing factors to sustainable construction selected from the literature review, followed by a qualitative survey through a questionnaire distributed to the selected condominium projects in Surabaya and Jakarta, Indonesia as a developing country. This aims to collect experts' perceptions of the influencing factors which will be used as model variables and the relationships among them. Numerical data of environmental impacts during the construction and operational phase as well as the components of life cycle costs were also collected. Data were further analyzed using the system dynamics approach to propose a dynamic hypothesis and to develop a model of sustainable construction for condominium projects. In this regard, Ventura Simulation was adopted to explore the system's dynamic behavior and the interaction among the system variables. There are four steps involved in the model development: articulating the problems to be addressed, formulating the dynamic hypothesis, constructing a model to represent the system, formulating simulations to test the model output, and designing scenarios to formulate better policies.

4.1 Problem Articulation

Problem articulation is vital for determining the model boundary and selecting the significant variables. Sterman [23] stated that a clear problem definition makes the modeling process purposeful and generates a successful model. Based on a reference model representing the changes of specific variables over time and expressing the problems to be addressed, the articulation is created. In this study, the problems associated with condominium projects are a huge amount of energy and material consumption and waste generation that will generate negative impacts on the environment. The second problem is how to conserve the environment while fulfilling the economic objective of the project. The problems would be explained through the dynabehavioriour of the influencing factors.

4.2 Preliminary List of Influencing Factors

Based on the problem definition supported by an intensive literature review, a preliminary list of important factors was identified. It consisted of environmental impacts (material and energy consumption and construction waste), lean construction (BIM, precast method, quality management), sustainable materials, building regulation,ion and sustainable construction indicators (health and safety performance, project duration, material, and energy efficiency, LCC).

4.3 Design of Questionnaire

A two-section questionnaire was designed to collect qualitative and quantitative data, using the influencing factors obtained from the literature review. Part 1 of the questionnaire explained the purpose of the study and the demographic data of respondents. In the second part, respondents were requested to choose the factors using a Likert scale, ranging from strongly disagree to strongly agree.

4.4 Data Collection

Data were collected from twenty-five condominium projects constructed between 2016-2020 in Surabaya which were selected using purposive sampling, from which 32 experts from the projects, including engineers, developers, and property management consultants joined the survey as respondents. Out of the total participants, 75% are undergraduate, and 60% are managers. 42% of the respondents had more than 20 years of working experience in high-rise projects. All projects implemented a certain level of sustainable construction methods as part of building permit requirements. Respondents' perceptions of the influencing factors of sustainable construction were obtained and used as variables to design a model hypothesis. Quantitative data regarding material and energy consumption, waste generation, construct,tion, and operational costs covering construction and operational phases were also collected for analysis purposes.

4.5 Model Variables

Based on the survey results, the research variables were determined as follows:

a. Environmental regulation.
b. Environmental impacts: energy and material consumption, waste.
c. Construction methods: BIM, quality management, precast construction, sustainable materials.
d. Sustainable construction indicators: material and energy efficiency (environment), health and safety (social), life cycle cost (economic).

Since the survey result shows that the project duration has insignificant values, these factors were excluded as an influencing factor.

5. MODEL DEVELOPMENT

During this phase, a dynamic hypothesis was established to reflect the current condition of sustainable construction in a condominiuprojectsct. Three mapping instruments were used to establish the hypothesis: The subsystem diagram, Model boundary chart, and Causal loop diagram (CLD).

5.1 Sub-system Diagram

The system consisted of several subsystems, where each subsystem was controlled by variables in specific criteria (Fig. 1). Take, for example, the environmental impacts caused by the projects encourage the government to impose environmental regulations. As the regulation is mandatory for building construction, the organization should respond by implementing selected construction methods to comply with. In turn, the practices will reduce environmental impacts. The interactions among variables are reflected in the CLD.

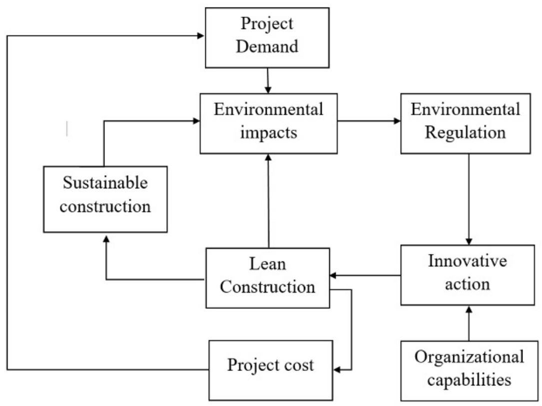

Fig.1 Sub-system diagram

5.2 Model Boundary

A model boundary chart was established based on the variables obtained from the literature review and validated by the qualitative survey. It explained the model's scope by classifying the variables into internal and external (Table 2).

5.3 Causal Loop Diagram (CLD)

In this step, a dynamic hypothesis comprised variables and the interrelationships were defined and represented by a CLD, which described the implementation of current practices and regulations to achieve sustainable construction in condominium projects (Fig. 2). The system's structure provided a feedback mechanism and generated subsystems with different polarities, where the positive sign means reinforcement (R), and the negative sign is balancing (B). Consider loop B1 as an example. The increase in energy consumption triggers the need for regulation to control the negative impact. To achieve the objectives, the regulation requires organizations to impose a quality standard during the design and construction phases. Eventually, the method will reduce energy consumption.

Table 2 Model boundary chart

Internal factors	Reference	External Factors	Reference
Quality management	[9]	Material durability and price	[12]
Sustainable material	[12]	Training, safety equipment	[20]
Health and safety	[20]	GDP growth	[24]
Population	[24]	Birth rate, mortality, migration rate	[24]
Condominium project growth	[25]	Constructability, competitiveness	[30]
Material consumption	[26]	Regulation	[31]
Energy consumption	[27]	Utility cost	[32]
Waste generation	[28]		
BIM	[29]		
Precast construction	[30]		
Material efficiency	[31]		
Energy efficiency	[31]		
Project cost (LCC, investment)	[32]		

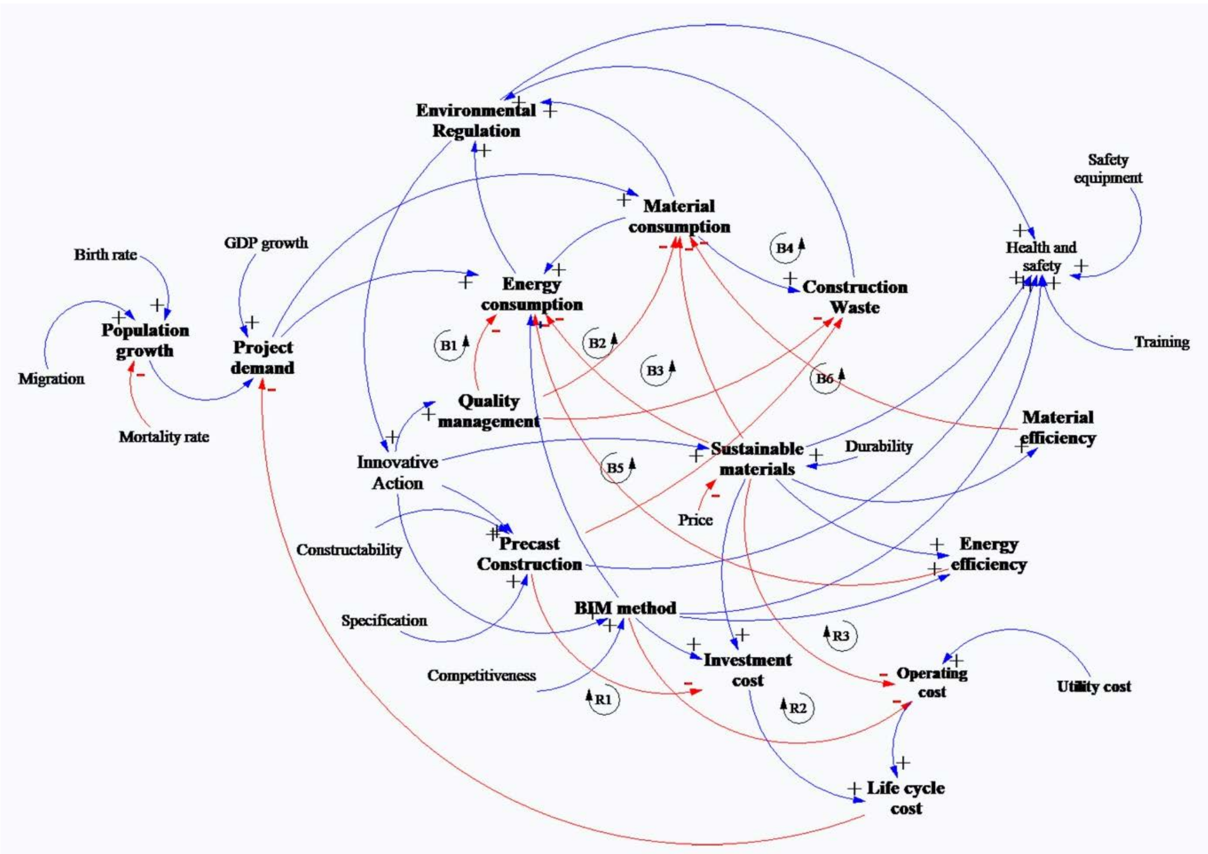

Fig. 2 Causal loop diagram

5.4 Stock Flow Diagram (SFD)

In this stage, all selected variables of the CLD were classified as stock and rate. If the variable unit were rate or discharge or velocity, the variable would be classified as rate or flow. Conversely, if the variable unit were accumulating and changing over time, the variable could be classified as stock or level. This classification is important to develop the stock and flow diagram that would represent the actual system. Qualitative data were converted to quantitative data to make it compatible with SFD for further analysis using Ventura Simulation software. The proposed base model of sustainable construction is shown in Fig.3.

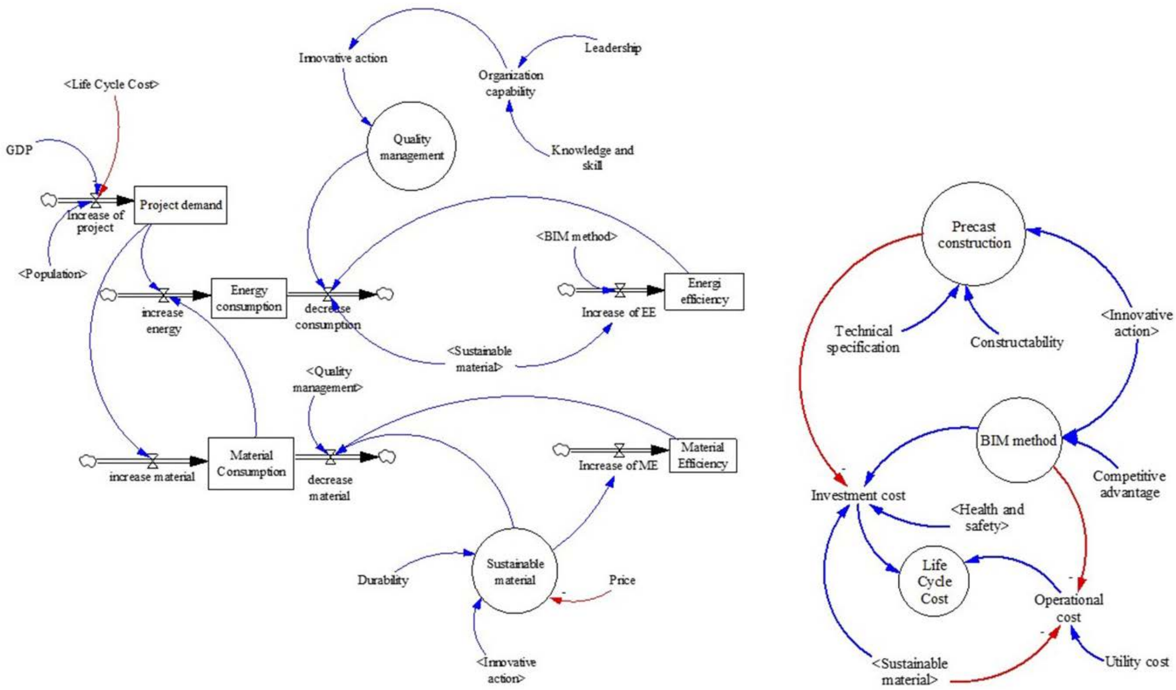

Fig. 3 Base model

6. SIMULATION RESULTS

Before conducting quantitative analysis, qualitative values of each variable were checked to make sure that the weights are normally distributed. The data obtained from the questionnaire showed a normal distribution to be applicable for further analysis of the stock variables. The model of sustainable construction was simulated within the period of 18 months from 2016 to 2020,onn a quarterly time scale. In this paper, material consumption and LCC were chosen among the variables to show the dynamics of environmental impact and sustainability indicators. The results indicated an increase in material consumption, despite the implementation of regulation, quality standards, and the use of sustainable materials (Fig. 4). A similar pattern was also attributed to energy consumption and waste generation. Although the environmental regulation had been integrated into the building permit, the expected positive outcomes were insignificant. This is because the regulations are limited to the site impacts of the construction with little consideration for the entire process [33]. This finding was consistent with the report from previous studies [15]. The result also showed that the practices of construction methods had no significant contribution to sustainability in the projects because of the extra cost to adopt the practices that might risk the economic objective. The LCC simulation result also found that the impact of regulation and sustainability methods were not effective to reduce the LCC as it was still increasing up to 12% so the economic aspect of sustainability was not achieved (Fig. 5).

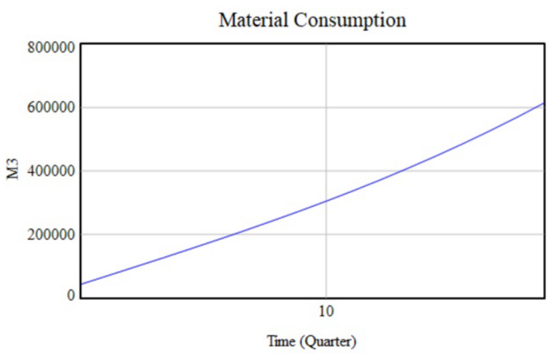

Fig. 4 Simulation result of material consumption

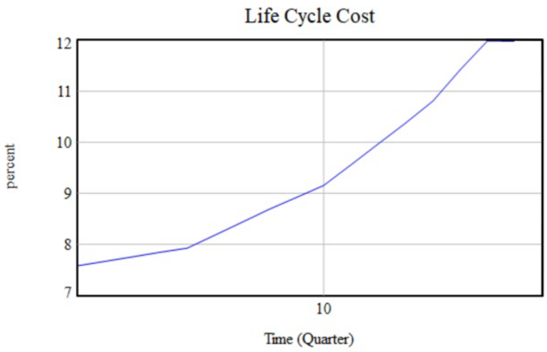

Fig. 5 Simulation result of LCC

7. SCENARIO IMPLEMENTATION

Considering that the base model simulation results showed unfavorable performance of sustainable construction in the selected condominium projects, the scenario technique was utilized. SThe scenario technique is a strategic toolanalyzelyse various potential future developments. It is beneficial in exploring possibilities and improvements to obtain better social problem results [34]. The strategies were designed by applying new methods or policies as variables taken from previous literature works, considering their significant contributions to solving the problem. In this study, the scenarios were developed to simulate how structural changes in the system would improve the achievement of three dimensions of sustainable construction in condominiprojectsect.

- Scenario 1: This scenario aims to simulate the impact of the modular precast construction method on material consumption, material efficiency, and LCC.
- Scenario 2: This scenario is concerned with the role of a tax incentive to enhance material efficiency and decrease LCC through the use of sustainable materials.
- Scenario 3: A combination of S1 and S2. It is designed to examine the effect of a mixed policy on material efficiency and the LCC.

The scenarios were simulated within five year period starting from 2021 to 2025, which corresponds to the period of base model simulation.

7.1 Scenario 1

The modular precast construction method is an advanced 3D-based printing construction method used to construct modular buildings. According to Yunus, Hamid, and Noor [30], this method offers many advantages such as increasing productivity and efficient use of material, improving onsite health and safety, and reducing construction waste by up to 50%. Therefore, the purpose of this structural scenario was to minimize waste and reduce material consumption which could improve material efficiency and reduce construction cost (Fig. 6). In this model, the variable increased the value of precast construction.

7.2 Scenario 2

This structural scenario was designed by introducing a tax reduction policy as an economic incentive to enhance the consumption of sustainable materials over the construction and operation phase of the project by reducing the value-added tax of the material price (Fig. 6). It is a fiscal instrument to reduce costs or business risks to attract investors in specific sectors [26]. A fiscal device is a progressive government policy that directly reduces cost and increases resource efficiency [35]. In this model, a tax incentive was designed to reduce the project's investment cost.

7.3 Scenario 3

Scenario 3 aims to obtain a better outcome by combining the role of modular precast construction for modular buildings and tax incentive policy. The policy mix is a potential instrument to deliver more effective resource savings than an individual policy [36]. It is expected that this scenario would generate considerable balance in achieving the social and environmental aspects of sustainable construction without sacrificing the economic objective of a condominium project.

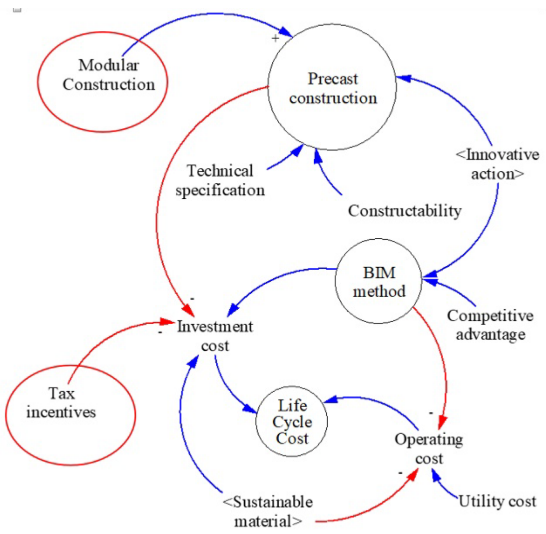

Fig. 6 Scenarios

The simulation results of material consumption and life cycle cost variables after applying three scenarios on the base model with a quarterly interval are shown in Fig. 7 and Fig. 8. To some extent, the outcomes indicate that the strategies can potentially reduce material consumption and LCC.

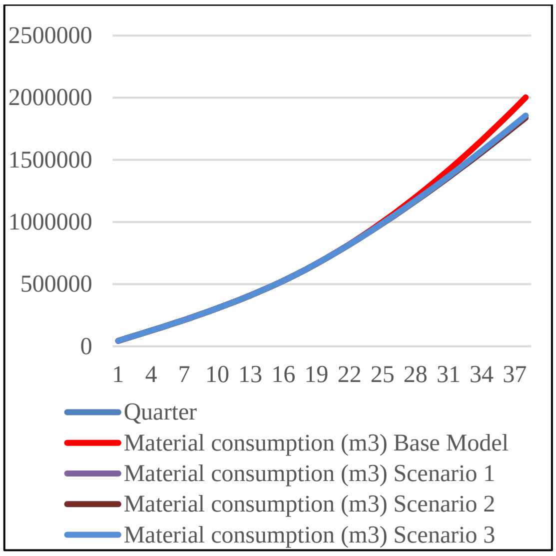

Fig. 7 Simulation result of material consumption

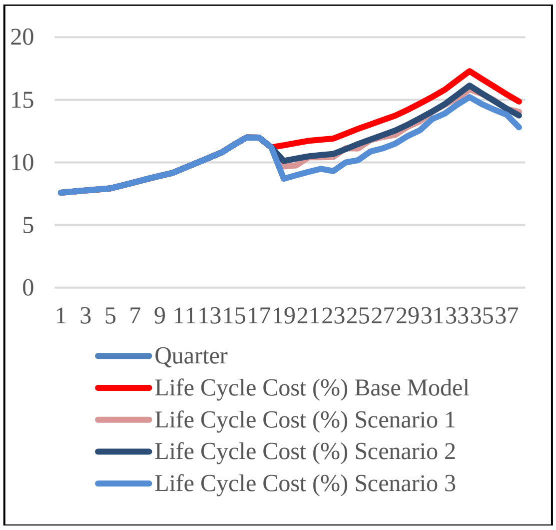

Fig. 8 Simulation result of the LCC

8. RESULTS AND DISCUSSION

The first objective of this study is to examine the current regulations and construction practices' contribution to reducing the environmental impacts of the projects. From the simulation of the base model, it is evident that the effects of lean construction and the utilization of sustainable materials as well as the implementation of existing regulations are insufficient to reduce the environmental impacts because the material consumption still increases up to 2.8 times higher. Similarly, the economic indicator indicates that the LCC also rises about 4%. To enhance the sustainability achievement, three scenarios were employed. It included the introduction of the 3D volumetric precast method for modular construction, the tax incentive implementation, and mixed policy combining the two scenarios. The simulations show that the practice of the 3D volumetric precast method will reduce material consumption by up to 7% in the next five years. Meanwhile, the LCC decreases by 0.8%. The simulation of tax policy as the second scenario indicates that the tax incentive can lower material consumption by 8% within the simulation period. Similarly, this policy positively impacts the LCC as the cost decreases by 1.1%. Furthermore, the simulation of the third scenario combining 3D volumetric precast and the tax policy shows that the material consumption decreases by 8.4% while the LCC is 2% lower after 5 year period.

The results reveal that scenario 2 and scenario 3 generate an additional 1.4 % reduction in material consumption than scenario 1 (Fig. 7). This finding shows that tax incentive is an effective instrument to reduce non-renewable construction materials used during construction and operational phases, by reducing material costs aiming to promote sustainable materials. This result also confirms the previous report [14]. On the other hand, the impact of the modular precast method in reducing natural resource consumption is less than the tax policy. This is because the effect of the construction method is limited to cement-related consumption during the construction phase only.

The simulation results of the economic indicator indicate that the mixed policies can only reduce LCC up to 2% after five years of implementation (Fig. 8). This result demonstrates that implementing modular precast construction and tax incentive policies will reduce environmental impacts by considerable value but not significant in achieving an economic objective. This outcome is different from a previous study which discovered that the cost of implementing sustainable practices in the built environment was much less than that most decision-makers believe [7]. This is probably due to the lack of documented qualitative data on the selected projects and the limitation of the system dynamics model proposed in this study.

In line with the second objective of this study, the simulation suggests that the mixed policy consisting of modular construction application and tax incentive results in the optimum environmental impact reduction as well as reduces the investment cost. Therefore, the mixed policy is the most effective strategy to improve sustainable construction performance in condominium projects. The results also demonstrate the ability of the model to provide various possibilities in designing effective strategies and policies to enhance sustainability in condominium construction.

9. CONCLUSIONS

The application of the modular precast construction method, tax incentives, and the combination of the two variables is the potential to reduce material consumption, improve material efficiency, and decrease life cycle costs on different scales within the observed period. The results also explain that the optimum outcome in improving the balance of environmental, social, and economic performance can be achieved by combining suitable sustainable construction methods and fiscal policy. However, the use of the modular precast method requires deep consideration due to the market feasibility. On the other hand, implementing a tax policy might result in a potential loss of national gross income. Therefore, a comprehensive analysis should be conducted before formulating the strategies for the future.

The dynamic model in this paper was developed based on qualitative and quantitative data obtained from selected projects in Surabaya and Jakarta. While the research findings are considered representative as the survey has included a wide range of the project stakeholders such as developers, designers as well as property managers in Indonesia, it can be concluded that the model can be used as a reference to formulate a better policy to improve the performance of the three dimensions of sustainable construction in condominium projects with some necessary adjustments to suit the different political and economic condition of the respective developing country. To improve the study results, future research should include alternative methods and strategies as the policy interventions, supported by sophisticated quantitative documentation on resource consumption, resource efficiency, and the costs obtained from the planning to operation phase.

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