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Computational Modelling of Tectona Grandis for Economic Investment Decision

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Abstract: Teak trees (Tectona grandis) are well-known for their quality and benefits, and they are in high demand among people worldwide. The high demand for teak trees raises the price of teak trees and creates opportunities to invest in teak trees. This research aims to develop a computational model of teak trees developed using the Functional-Structural Plant Modeling (FSPM) method and Growth-grammar interactive modelling platform (GroIMP) software to visualize teak tree growth over a 20-year period. The model not only considers morphological aspects such as stem height, stem diameter, and leaf size, but also important economic factors for investment decision-making. The simulated teak tree model grows up to 1000 trees in 1 hectare of land with an average selling price of IDR 1,032,500 per tree. Investment metrics such as Break-Even Point (BEP) and Return On Investment (ROI) are used in this study to assess the profitability of teak tree investments. With a minimum total cost of IDR 183,470,000 for 20 years, the model indicates that the BEP is achieved when planting 128 trees. Furthermore, by planting 1000 trees, the ROI can reach a remarkable 462.76% of the total investment cost.

Keywords: *Plant computational modelling, Functional structural plant modelling, Growth-grammar interactive modelling platform, Investment Decision, Tectona Grandis*

1. Introduction

The Teak tree, scientifically known as Tectona Grandis, is a widely recognized tree species originating from Southeast Asia and thriving in several countries within this region [1]. Teak trees can reach heights of 40-70 meters with a trunk diameter of up to 2 meters. Their leaves are elongated with pointed tips and long petioles [2]. Teak is renowned as a primary source of raw material for the timber industry due to its high market value and the exceptional quality and benefits of Teak wood, attributed to its remarkable durability and the beauty of the fibers it produces [3].

The wood from teak trees can be used for construction materials and furniture, such as tables, chairs, doors, windows, frames, cabinets, carved crafts, and many other purposes. This has led to a situation where the demand for teak wood, both domestically and internationally, exceeds the supply from teak plantations [4]. The high market demand has resulted in a crisis of teak wood raw materials, causing the price of teak wood to increase significantly in the market [5].

Therefore, teak cultivation offers promising opportunities for farmers seeking long-term investments in teak trees. Teak cultivation serves as a vital source of income for teak farmers, contributing to the improvement of their household earnings. To support this endeavor, a computational teak tree model and financial metrics are essential in investment decision-making for predicting teak tree sale prices, thus maximizing the profit of teak farmers.

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Plant Computational Modeling (PCM), also known as virtual plant or tree modeling, is a component of ecoinformatics or environmental informatics that integrates agricultural science, botany, computer science, and statistics. PCM generates models aimed at understanding the mechanisms of tree growth and development, as well as predicting how trees respond to environmental changes [6]. PCM employs the Functional-Structural Plant Modeling (FSPM) method, which combines structural, physiological, and statistical models to construct a computational plant model [7]. These models are built based on datasets of plant growth and development measurements.

FSPM (Functional-Structural Plant Modeling) is the aspect of a plant's structural and functional characteristics that enables it to adapt to its surrounding environment for the sake of its growth and survival [8]. FSPM can be implemented using the Growth Grammar-Related Interactive Modeling Platform (GroIMP) software. GroIMP is a software tool used for constructing three-dimensional (3D) virtual computational tree models. The GroIMP modeling platform can be executed using the Extended L-System (XL) programming language, which is an extension of the Java object-oriented programming language.

In this research, the researcher will develop a three-dimensional virtual PCM model of teak trees to determine the strategic decision of whether teak tree cultivation is profitable and can be considered for business investment. With the existence of these models, it can provide information on the annual growth and development of teak trees, up to the age of 20 years in this study, along with an overview of investment analysis that can be beneficial for stakeholders interested in expanding their agricultural ventures. Furthermore, the published model and its dataset can support other researchers, entrepreneurs, and farmers in various agricultural projects.

2. Related Works

Many researchers have conducted various studies in the field of PCM using the FSPM approach along with the GroIMP method. This methodology combines structural, physiological, and statistical models to create computational plant models, using the XL programming language, which evolved from the L-system [9]. As an example, one study focused on fine-tuning a rice model to account for light influence, incorporating leaf growth parameters and leaf angles for two rice varieties. The outcome of this research successfully simulates above-ground native rice plants during their vegetative stage [10].

Another plant modeling used FSPM and GroIMP to estimate plant growth, determine the amount of vitamins each plant contains, model the investment value of Bok Choy plant sales by Utama and Wibowo [11], and foresee the financial investment in hydroponically grown green amaranth by Jabar et al [12]. Additionally, Chi et al. developed a 3D digitalization model to simulate leaf arrangement, known as phyllotaxy, particularly in mangrove species [13]. FSPM and GroIMP have also been employed in assessing the development of canopy structures in Norwegian spruce cypress trees (Picea abies Karst.) and creating more realistic models of biomass production [14]. Furthermore, these methods also have been applied to investigate water and sugar transport in an apple branch along with the functional elements of xylem and phloem in each organ [15].

3. Research Method

The research process consists of four stages, namely: (1) Preliminary Study, (2) Data Collection, (3) Model Development, and (4) Model Verifying & Validating. Each stage involves the use of specific methods and produces specific outputs. Figure 1 illustrates the research stages to be undertaken to achieve the research objectives using UML Activity Diagram methodology

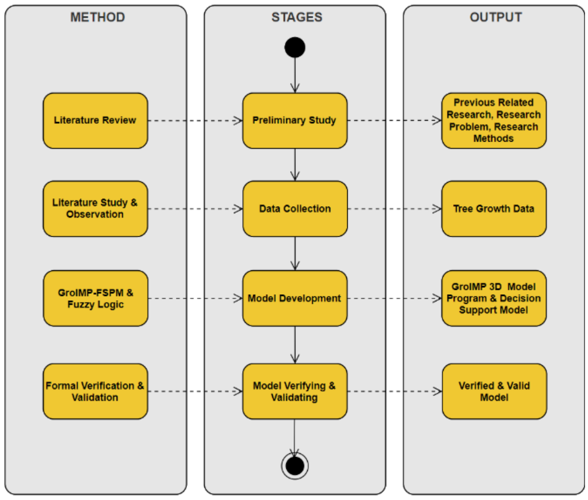

Fig. 1. Research Stages

3.1. Preliminary Study

The first stage in this research is the Preliminary Study, which involves an examination of various previous studies with similar research topics. This stage aims to gather information about theories and methods that can be applied to this research and to prevent duplication or plagiarism with existing research. The method used in this stage is a literature review.

The literature review is conducted by searching for information from various sources such as academic journals related to forestry and agroforestry, books, and other relevant sources like ResearchGate, Google Scholar, Science Direct, and IEEE Xplore. This is done to ensure that this research can provide new contributions.

3.2. Data Collection

Data Collection is the second stage of this research. Observational and literature study methods are employed in this phase. The data under investigation consists of teak trees (Tectona grandis) collected from various sources. This includes annual stem height growth and tree diameter, located in the Saradan Forest Management Unit, Perum Perhutani Unit II, East Java, with a planting spacing of 3 x 1 meters from Ginoga et al [16] and the length and width of leaves were obtained from Sumiati [17].

To support the research data on teak trees, direct field observations were also conducted in the Sindang Asih Teak Forest located in Tangerang. Through brief interviews with local people in the teak forest, it was discovered that all the teak trees in the forest were approximately 20 years old. Figure 2 provides a view of 20-year-old teak trees in the Sindang Asih Teak Forest. The observed parts of the teak tree are those that can be measured, such as stem diameter, length, and leaf width. However, height data for the trees were not available due to measurement equipment limitations and data unavailability during the observation process. Diameter and leaf measurements were conducted using a simple tool, a measuring tape.

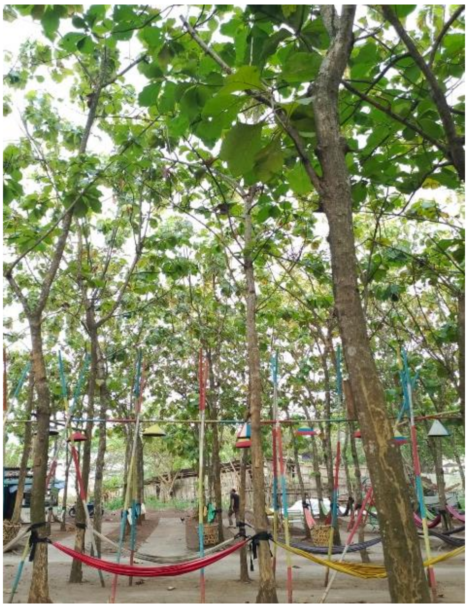

Fig. 2. Sindang Asih teak forest

The purpose of the direct observations was to validate that the measurements of stem diameter, length, and leaf width of 20-year-old teak trees are consistent with the data obtained from the literature study, and to supplement missing data such as stem texture, soil, and leaf texture. The texture of each of these components will be used as shaders in the teak tree modeling process to make the model have a shape and color that closely resembles a real teak tree. Subsequently, all observation documentation processes were carried out using a camera to capture images as demonstrated in Figure 3 when measuring stem diameter and Figure 4 when measuring leaf length and width with a tape measure. All collected teak tree data were analyzed carefully and selected meticulously to ensure their relevance and high quality.

Fig. 3. Measuring the diameter of the teak trunk

Fig. 4. Measuring the length and width of the leaf

3.3. Model Development

The third stage of this research is Model Development. Based on previously collected data, the teak tree computational model was developed into a 3D visual representation using GroIMP software with the FSPM method and the object-oriented XL programming language. The model built takes into account various factors, such as growth rate, size, age of the tree, and the economic contribution of teak wood. The annual growth of teak trees is simulated up to a specified limit of 20 years. The output results in the form of information on each factor from the calculation model will be printed every year on the groimp platform and can be saved in the form of CSV data which can be used for simulations and further research. Finally, a teak tree investment decision making model was built using financial metrics such as Break-Even Point (BEP) and Return On Investment (ROI)

3.4. Model Verification and Validation

The fourth stage of this research involves model verification and validation using the formal validation and verification method [18]. The results from the developed computational model are validated to assess the degree of accuracy of the model and confirm its correctness based on the data used. This verification is carried out by checking the calculations or formulas employed during model construction and comparing them with existing theories. Furthermore, validation is also conducted by comparing the model with real-world field data. This is done to ensure and demonstrate that the model accurately represents the growth and development of teak trees

4. Results and Discussion

4.1. Model Components

All the components of the model used in this research are depicted through a class diagram, which can be seen in Figure 5. The class diagram provides a visual overview of the model's structure, class descriptions, and the relationships between the classes involved. In the virtual teak tree class diagram, there are four defined classes. The main class, Teak Tree, plays the central role and includes three sub-classes: Leaf, Stem, and Soil. Each of these sub-classes has specific functions related to the teak tree, such as leaf analysis, stem growth, and planting area.

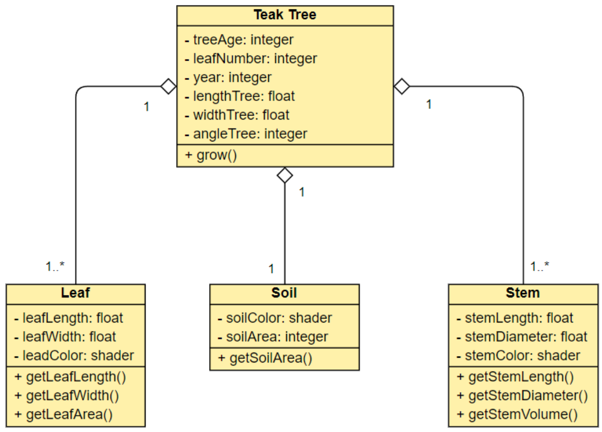

Fig. 5. Class diagram for model components

4.2. Model Algorithm

The flow of the teak tree model algorithm process which is described using the UML Activity Diagram method can be seen in Figure 6. The model creation process begins with setting the growth age of the teak tree, namely 20 years. The value of growing years can be determined freely, depending on the age that will be analyzed in the research. Next, the process of determining variable values for tree components such as stems and leaves is carried out. In addition, the value of stem and leaf increase was also determined randomly using a range of minimum and maximum values. This growth value was obtained from the dataset collected in the previous subsection. After all the variables have been set, the model will run the grow function until the age limit for the growth of the teak tree, which is 20 times. During each grow process, the model will calculate the size of the stem and leaves and also calculate the stem volume and leaf area. After reaching the specified age limit, the model will calculate the economic value of the teak tree when it is 20 years old and all data information related to the teak tree will be exported to CSV.

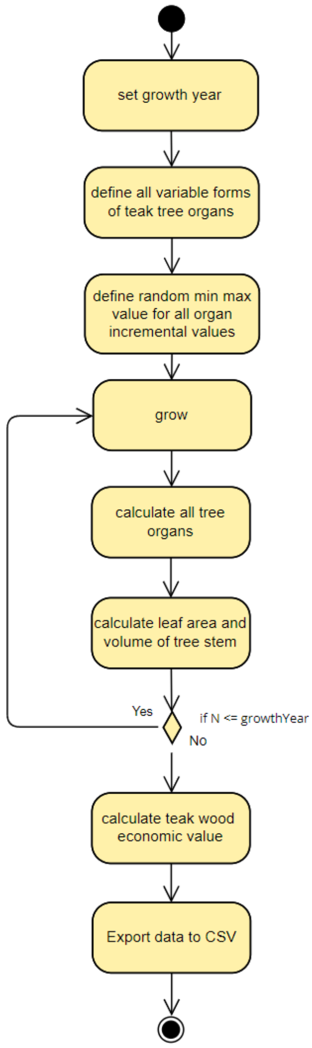

Fig. 6. Algorithm process flow for building models

4.3. Virtual Teak Tree Model

This model was developed using the Functional-Structural Plant Modeling (FSPM) method, utilizing the GroIMP application and the XL programming language. Figure 7 presents a visualization of a virtual model of a teak tree without texture, while Figure 8 depicts a visualization of a virtual model of a teak tree with shader textures derived from real teak trees at the data collection stage in the Sindang Asih teak forest. Each model is constructed based on the morphology of teak trees up to the age of 20 years, including tree components such as the stem and leaves. All these tree components are calculated within GroIMP using fundamental statistical and mathematical concepts to simulate their growth each year.

Fig. 7. Virtual model of teak tree without texture

Fig. 8. Virtual model of teak tree with texture

The growth and development of each teak tree organ is modeled in GroIMP mathematically every year using random increase values with a range of minimum and maximum values for teak tree growth from the dataset obtained. By using random values, the size of each teak tree model produced will have a different size. The units used for the added value of each tree organ are meters. The increase in height and diameter of teak tree trunks was randomly generated with values of 0.805 ± 0.295 m and 0.0092 ± 0.002 m, respectively. Meanwhile, the length and width of teak leaves were randomly generated with values of 2.2 ± 1.55 m and 1.475 ± 0.975 m, respectively.

Furthermore, we can see the trend of the results of the growth of each tree organ in the model using the linear trend line equation formula. This trend was taken from data on the average growth of 10 teak tree models each year which were developed on the GroIMP platform. Figure 9 and 10 depict the average annual increase in tree height and trunk diameter, while Figure 11 depicts the average annual increase in leaf length and width. Trends in tree height and diameter are presented through equations (1) and (2), where THt represents tree height in year t, while TDt represents trunk diameter in year t. In addition, trends in leaf length and width are formulated in equations (4) and (5), where LLt represents the leaf length in year t. and LWt represents the leaf width in year t.

$$TH_t = 0{,}8291t + 0{,}0488 \quad (1)$$

$$TD_t = 0{,}0092t - 0{,}0067 \quad (2)$$

$$LL_t = 0{,}022t + 0{,}0021 \quad (3)$$

$$LW_t = 0{,}0147t - 0{,}0008 \quad (4)$$

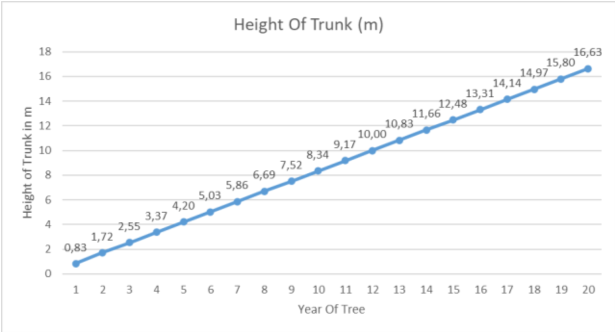

Fig. 9. Average stem height each year

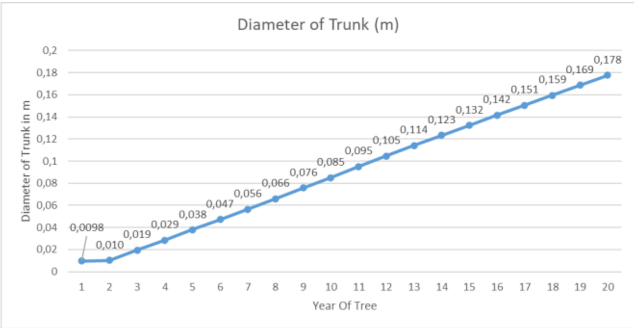

Fig. 10. Average trunk diameter each year

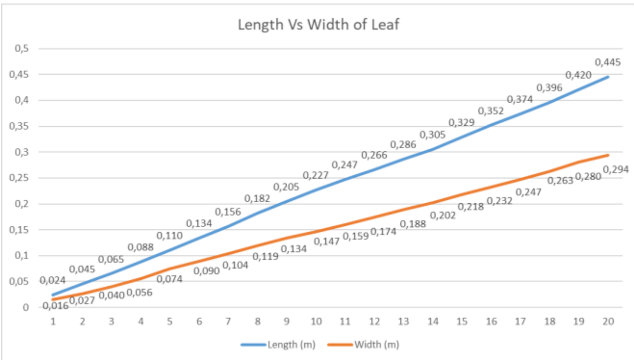

Fig. 11. Average length and width of leaves each year

In addition, this model can also determine stem volume and leaf area using previously calculated data from each part of the tree. Leaf area calculations assume a rectangular leaf shape. so the formula for calculating leaf area is the same as the formula for calculating the area of a square, namely the length of the leaf multiplied by the width of the leaf. For bar volume, equation (6) is used to calculate bar volume in year t. Figure 12 depicts the development of tree trunk volume each year, while Figure 13 displays the total leaf area each year. The annual trend of stem volume can be calculated using equation (7), while the total leaf area for each year can be calculated using equation (8), which represents the leaf area in year t.

$$TV_t = \pi \frac{TD_t^{\ 2}}{4} . TH_t \quad (6)$$

$$TV_t = 0{,}0202t - 0{,}0997 \quad (7)$$

$$LA_t = 0{,}0068t - 0{,}0246 \quad (8)$$

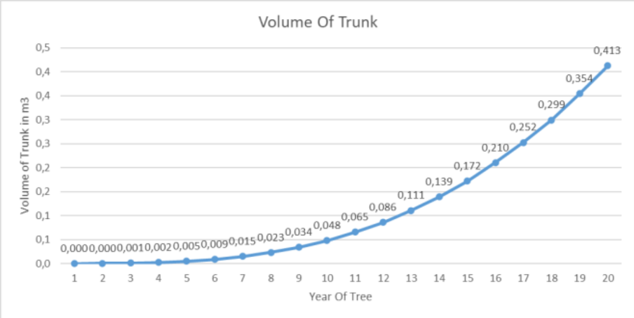

Fig. 12. Average Volume of Trunk

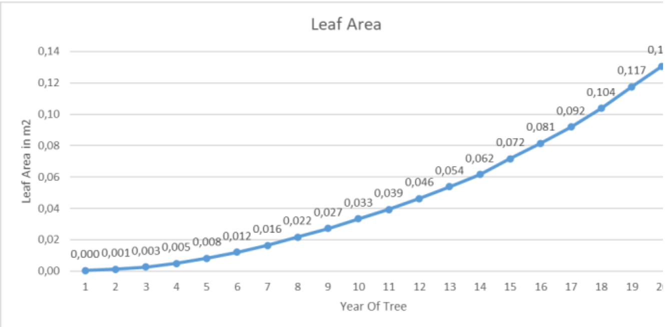

Fig. 13. Average annual leaf area

Visualization of tree trunks without leaves is also carried out to observe the development and morphological structure of teak tree trunks and branches every 5 years, as depicted in Figure 14. Furthermore, the teak tree model was also visualized in a larger number of 25 teak trees as seen in Figure 15. This teak tree model is planted on land with a spacing of 3 meters. The soil used is also textured so that the color resembles the color of the original soil.

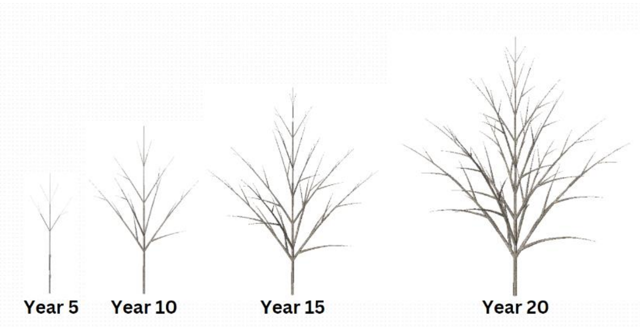

Fig. 14. Virtual model of teak tree trunk every 5 years.

Fig. 15. Multi tree model of 25 teak trees

4.4. Economic Investment Decision

Teak tree models that are developed until they are 20 years old have an average diameter of between 16-19 cm so that this teak wood is classified as class A1 teak [19]. The price of A1 class teak wood on the market is sold for IDR 2,500,000 per m3 [20]. With an average tree volume in the model of 0.413 m3, the income obtained from one tree can be calculated by multiplying the average model volume by the market price of A1 class teak wood to obtain a selling price of around IDR 1,032,500 per tree. Certainly, this becomes particularly intriguing when cultivating teak trees in significant quantities, as one hectare of land can accommodate approximately 1000 teak trees. For more detailed calculations, investment metrics such as break-even point (BEP) and Return of Investment (ROI) are used to calculate teak tree investment analysis by considering the costs incurred. The BEP metric is calculated in rupiah units using equation (9) where FC is fixed cost, VC is variable cost, and TR is total revenue. Next, ROI is calculated using equation (10) where TC is the total cost.

$$\text{BEP in Rupiah} = \frac{FC}{1\text{-}(\frac{VC}{TR})} \quad (9)$$

$$\text{ROI} = \frac{TR\text{-}TC}{TC} \text{ x } 100\% \quad (10)$$

Each of these metrics is used for different conditions in investing. The first condition is using BEP, where the costs incurred for investing in teak trees with a total of 1000 trees for 20 years are fixed costs consisting of renting 1 hectare of land for 20 years and equipment for planting teak trees around IDR 125,070,000. Then the variable costs consist of seeds, fertilizer, pesticides and day labor costs for planting, maintenance, thinning and harvesting around IDR 58,400,000 so that the total investment or costs incurred for 1000 teak trees in 1 hectare of land costs around IDR 183,470,000. In this condition, BEP is also calculated with varying numbers of trees ranging from 25 to 1000 trees with different total income and costs for each number of trees as depicted in the graph in Figure 16. In this graph, BEP is reached when 128 trees are planted, with a total cost and total revenue of IDR 132,160,000. Therefore, if the number of trees planted exceeds 128, the investment in teak trees will begin to generate a profit.

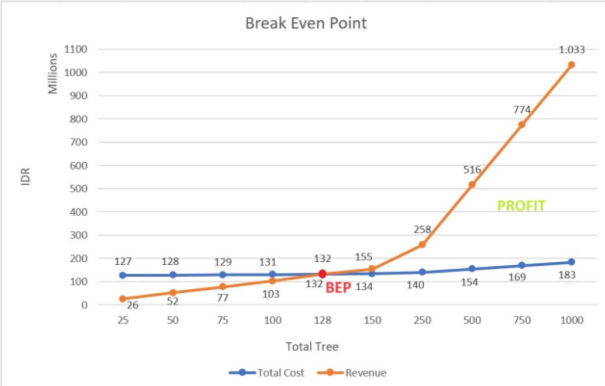

Fig. 16. Break Even Point (BEP)

Finally, the second condition utilizes ROI metrics with the total costs are multiplied by 2 to 3 times from the first condition. This is done to assess whether the costs incurred beyond the initial conditions are still profitable or not. Consequently, it can be assumed that the costs outlined in the first condition represent the minimum expenses associated with teak tree investments. This approach is adopted due to the potential variation in costs incurred by individuals investing in teak trees, which can be influenced by factors such as land and equipment usage, additional expenses, and other related costs.

Figure 17 illustrates the ROI (Return on Investment) graph for a 20-year teak tree investment, considering three different investment cost scenarios ranging from a minimum total investment of approximately IDR 183,470,000 to three times that amount, around IDR 550,410,000. The graph clearly demonstrates that, under these varying cost conditions, profitability can still be achieved when planting of 500 teak trees per hectare. This finding is particularly compelling for teak tree investment, as it shows that with an investment cost of around 550 million, planting 1000 teak trees over a 20-year period can yield profits equivalent to 87.59% of the total investment. Meanwhile, with a minimum total investment cost of around 183 million, planting 1000 teak trees over a period of 20 years can generate profits equivalent to 462.76% of the total costs invested.

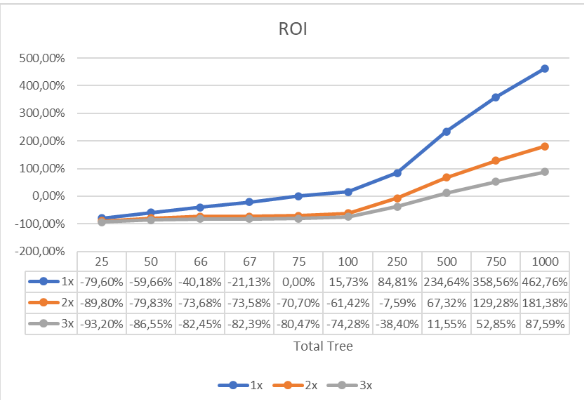

Fig. 17. Return Of Investment (ROI)

4.5. Model Verification And Validation

The model built has been verified and validated with a verification value of 1.00, indicating its academic and practical accuracy and validity. Various mathematical formulas within the model, such as stem volume calculations, leaf area calculations, and investment metric calculations, have been carefully verified. A comprehensive verification summary can be found in Table 1.

First, the equation (6) is used as a formula for calculating the trunk volume. The equation is a formula for officially calculating the cylinder volume that comes from Hardjana [21]. In GroIMP, the modeling platform used in the study, the formula is coded as "float volumeStem = 3.14 * (totalDiameter/2) * (totalDiameter/2) * totalHeight;". The other one is a formula used to measure the leaf area. It is rectangular area calculation as the Teak leaf has rectangular structure expectedly where the area is width times length, and the formula is coming from Syahbana [22]. The formula is coded in GroIMP as "float widthAllLeaf = widthAllLeaf * lengthAllLeaf;".

Table 1. Model verification result

Model Elements	**In Reference**	**In Model**	**Trueness**	**Verification Value**
Stem Volume	V = 1/4 x π x d^2 x t or V = πr^2 x t	3.14 * (totalDiameter/2) * (totalDiameter/2) * totalHeight	V	1.00
Leaf Area	L = length x width	widthAllLeaf * lengthAllLeaf	V	1.00
Break Even Point (BEP) in Rupiah	BEP = $\frac{FC}{1-(\frac{VC}{TR})}$	fixCost / 1 – (varCost/ totalRevenue)	V	1.00
Return Of Investment (ROI)	ROI = $\frac{TR-TC}{TC} x\ 100$	((totalRevenue – totalCost) / totalCost) * 100	V	1.00
			Verification value	1.00

The next formula is to calculate the investment value.

First, equation (9) is used as a formula to calculate the Break Even Point (BEP) metric which comes from Mamondol [23]. In GroIMP, the modeling platform used in this research, the formula is coded "float BEP = fixCost / 1 – (varCost/ totalRevenue) ;". Finally, the formula in equation (10) is used to calculate the Return of Investment (ROI) metric that comes from Herlin et al. [24]. In GroIMP, the modeling platform used in this research, the formula is coded "float BEP = ((totalRevenue – totalCost) / totalCost) * 100;". All of these formulas between reference code and model code have the same connotation. Thus, the model element is considered to perform an academically correct formula resulting in a verification score of 1.00.

Furthermore, the model also achieves a validation value of 1.00, signifying that the data employed in the model are accurate and practically valid. The complete validation of the model can be found in Table 2. The model can produce teak tree growth data, such as an average leaf length of 0,445 m in the 20th year. According to actual data, the range for leaf length is between 0.440±0.310 m. This implies that the value of the single leaf length produced by the model is valid, with a validation value of 1.00.

Another example is the average trunk height in the 20th year, which is determined to be 16.62 m by the model. Real data indicates that the range for trunk height is 16.1±5.9 m. This demonstrates that the value of trunk height generated by the model is valid, with a validation value of 1.00.

As a final example, the model indicates that the average trunk volume in the 20th year is 0.412 m². According to actual data, the range for trunk volume is between 0.516±0.350 m3. This indicates that the value of leaf area produced by the model is valid, with a validation value of 1.00.

Table 2. Model validation result

Model Elements	**Value in Model**	**Value in Real**	**Trueness**	**Validation Value**
Trunk Height in 20th year	16.62 m	16.1±5.9m	V	1.00
Trunk diameter in 20th year	0.177 m	0.184±0.04 m	V	1.00
Trunk volume in 20th year	0.412 m3	0.516±0.350m3	V	1.00
Leaf length in 20th year	0.445 m	0.440±0.310 m	V	1.00
Leaf width in 20th year	0.294 m	0.295±0.195 m	V	1.00
Leaf area in 20th year	0.130 m2	0.190±0.177m2	V	1.00
			Validation value	1.00

5. Conclusion

This research has successfully developed virtual teak tree models using investment analysis metrics, including ROI and BEP, to predict the economic value, which is essential for making informed investment decisions in teak trees. The FSPM-GroIMP method was employed to construct a model that visually simulates the morphological growth of teak trees over a 20-year period. This visualization encompasses calculations for stem diameter, stem height, stem volume, leaf length, leaf width, and leaf area on an annual basis. The model has achieved a verification and validation score of 1.00, signifying its academic and practical accuracy. This study offers valuable insights for teak entrepreneurs and novice teak tree investors. By providing predictions of economic value through the model, it can offer guidance and information for optimizing investment decisions in teak trees to maximize profits.

Furthermore, the resulting model can also assist agronomists, forestry experts, and environmental researchers in examining teak tree growth morphology within computer-simulated ecosystems that are academically malleable. Future research directions may involve a more comprehensive exploration of all aspects of teak tree organ behavior and their correlation with ecological factors, such as the impact of rainfall, temperature, planting location, and weather conditions on teak tree trunks. Furthermore, extending the dataset to include more than 20 years can provide teak wood of greater quality and get a higher price at sale, expanding the range of data regarding teak tree investment and teak tree sizes.

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