IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 18 October 2023, accepted 11 November 2023, date of publication 1 December 2023,
date of current version 13 December 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3338719

RESEARCH ARTICLE

An Object Driven Model of Above-Land Merkus Pine Tree for Quantifying the Commercial Contribution With Functional-Structural Plant Modeling

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This work was supported by the Indonesian Ministry of Education and Culture (KEMENDIKBUD RISTEK) and Bina Nusantara University through the Fundamental Research Project under Grant 179/E5/PG.02.00.PL/2023, Grant 1402/LL3/AL.04/2023, and Grant 149/VR.RTT/VII/2023.

ABSTRACT The Merkus Pine tree is awfully prevalent in Indonesia, especially for its role in reforestation efforts. Beyond its academic significance, it carries economic importance for local communities and the nation at large. This study aims to establish an object-oriented model of the Merkus Pine tree, concentrating on its above-ground attributes. This object-oriented model-developing approach is integrated with the functional-structural plant modelling (FSPM) technique. The constructed model, referred to as an object-driven model, has achieved a verification and validation value of 1.00. This model enables the simulation of the Merkus Pine tree's growth and development, encompassing both its physical structure and economic contribution. The simulation outcomes highlight that a single Merkus Pine tree, upon reaching fifteen years of maturity, can yield an economic contribution of approximately IDR 47,980.04. Also, the developed virtual model of the Merkus Pine tree can be operated as a green lab to analyze its growth and development being interconnected to other aspects; e.g. environment, politic, and culture.

INDEX TERMS Merkus pine tree, economic contribution, object-oriented approach, functional-structural plant modeling.

I. INTRODUCTION

The Merkus Pine tree (Pinus Merkusii Jungh. Et De Vriese) is a well-known tree in Indonesia, primarily utilized for Indonesian reforestation programs. Its habitat provides unique ecosystem types [1]. The Merkus Pine's root system helps stabilize soil, preventing erosion on slopes and hillsides. This is crucial for maintaining soil fertility, preventing landslides, and preserving water quality in nearby water bodies. In addition, it also contributes economically. its economic significance lies in its contribution to various industries, recreation, and potential for generating sustainable income for communities.

The associate editor coordinating the review of this manuscript and approving it for publication was Claudia Raibulet.

Based on a botanical perspective, it falls under the Pinaceae family and Pinus genus [2]. The Merkus Pine stands as the singular representative of the Pinus genus capable of thriving in tropical climates, naturally flourishing along the southern equator. Its indigenous habitat extends across Southeast Asia, including Indonesia, with a notable presence on Sumatera island [3].

As a captivating subject of study, the Merkus Pine has attracted the attention of numerous researchers. Among these scholars, [4] did an investigation involving the compilation of a dataset pertaining to the stem length and diameter of the Merkus Pine. This comprehensive dataset comprises 1,542 pairs of height and diameter measurements, serving as the foundation for developing and assessing various models. Also, [5] conducted an evaluation on 3,425 pine trees located in Zambia, encompassing both Merkus and Michoacana

Pines. Their aim was to examine the applicability of the established general h-d model to these specific species, create mixed-effect h-d allometric models that offer optimal alignment, and analyze the impact of stand attributes and climatic conditions on the predictive accuracy of the h-d models.

Furthermore, [6] analyzed the characteristics of microenvironmental factors (e.g. radiation, humidity, and temperature) within the Merkus Pine forest located in the UB Forest Area. This study encompassed on-site observations employing the purposive sampling method. The collected data encompassed both primary (microclimate) and secondary (topography) information. Then, [7] determined the soil chemical properties (i.e. pH, C-organic, N-total, P-available, K-total and CEC) of the Merkus Pine stand. The research was executed in Watutau Village, Lore Peore Sub-district, Poso District, Central Sulawesi.

In this context, the research is focused on creating a virtual model for the Merkus Pine tree with the objectives of simulating tree morphological growth and development, as well as calculating its economic contributions. The primary methods employed in this study involve the utilization of functional-structural plant modelling (FSPM) and an object-oriented approach. FSPM is leveraged to intricately represent the tree's morphology, employing mathematical and statistical considerations. Simultaneously, an object-oriented approach serves as the foundational model development method.

The final virtual Pine tree model serves as an ecological laboratory (green lab), functioning as an academic simulation platform aimed at overseeing the development of Pine trees within specific geographical confines and under defined environmental conditions, all without the need for real-world implementation. Undoubtedly, this green-lab leads to cost and risk reduction in the supervision of reforestation endeavours. The modelling encompasses a spectrum of reforestation management considerations, spanning ecological, societal, cultural, and assorted dimensions. The study's findings are effectively presented within the confines of this paper, which is structured into five distinct sections: introduction, related literature, research methodology, results and discussions, and conclusions and future prospects.

II. RELATED WORKS

Many studies have been conducted already by researchers, specifically in the field of plant computational models. One very close research is research done by [8]. Reference [8] constructed a virtual Scots Pine tree model for quantifying the significance of geometrical traits for light absorption. The model simulation and sensitivity analysis were done in GroIMP and PYGMALION respectively.

In addition, [9] developed a model measuring the annual and seasonal effects of weather inputs on plant production. Weather variables for this model included seasonal effects of accumulated degree days, total precipitation, average temperature, season length, past year's precipitation, and last year's plant production. Then, [10], which continued by [11], developed a 3D plant model for analyzing the growth and yield of sweet pepper plants with different stem densities under supplemental lighting and estimating the canopy light profile and photosynthesis using ray-tracing simulation.

Furthermore, [12] introduced an innovative algorithmic model for plant classification employing 3D modelling via a spotting platform, along with a structural methodology to comprehend plant motion. Reference [13] constructed a three-dimensional representation of a cotton plant to simulate air circulation, utilizing computational fluid dynamics in conjunction with machine learning techniques. Reference [14] established a dynamic 3D simulation model to assess the leaf area index of soybean plants, facilitating a nuanced understanding of their growth dynamics. Then, [15] also modelled a virtual plant via FSPM and operated to support making a decision of agricultural investment.

In addition, [16] operated FSPM to model the trees' ability in light capture, particularly for mixed-species forests. The model considered the interplay between structure, physiology and the environment in 3D and scale from organ-specific characteristics to tree and community performance. Reference [17] developed a plant model providing a unified description of the optimal plant geometrical structure by combining FSPM and particle swarm optimization algorithm, specifically for extracting the features. To provide a comprehensive overview of the related works performed, TABLE 1 offers a comparative analysis of the relevant studies.

TABLE 1. Related works comparison.

Works	Object	Findings	Limitations
[8]	Scots Pine	Considering the geometrical traits for light absorption	Did not cover applied impact
[9]	Seasonal plants	Measuring the annual and seasonal effects of weather inputs on plant production	Did not correlate to economical impact
[10] [11]	Sweet Pepper	Photosynthesis model	Did not cover applied impact
[12]	Tomato varieties	Plant classification model	Did not cover economic factors
[13]	Cotton plants	Air circulation model	Did not cover applied economic aspects
[14]	Soybean plants	Canopy area index assessment model	Did not cover applied economic aspects
[15]	Bok Choy plants	Plant model for agriculture investment	Only covered the model above land plant
[16]	Mixed-species forests	The model sun-light captured by trees	Did not convert the light capturing to economic value
[17]	Virtual plants	Plant model providing a unified description of the optimal plant geometrical structure	Lack of realisation of the real phenomenon.

Drawing from several prior works, there has been a noticeable absence of discussions regarding a tree model built on the foundation of object analysis and design. In the current study, an object-oriented approach is adopted to present a clear and comprehensible blueprint for the model's core design and development. Additionally, the FSPM method is employed to create a virtual representation of the morphological aspects of Pine trees. Furthermore, the developed model delves into the prediction of economic contributions. Notably, the model can accurately forecast the annual economic contribution of a single Merkus Pine tree, though this represents only one facet of our investigation. Other dimensions, such as the environmental perspective, are not addressed yet.

III. RESEARCH METHODOLOGY

The activity diagram in Figure 1 illustrates the stages of the research, following a framework adapted from the general model design approach [18]. Five study main stages are conducted: (1) Preliminary Studying, (2) Data Collecting and Analyzing, (3) Model Analyzing and Designing, (4) Model Constructing, and (5) Model Verifying and Validating. In the first stage, the "Preliminary Studying" was conducted to gain a deeper understanding of the research subject and explore various theoretical foundations related to the study. This involved a thorough literature review using desk-based methods, accessing online libraries (e.g. sciencedirect.com), to gather up-to-date literature on virtual tree modelling, Merkus Pine, reforestation management, and its commercial contribution. Additionally, a field trip to the Mangunan Pine Forest in Bantul City (the province of Central Java, Indonesia) was performed to observe and get practical insights and technical understanding of the morphology of Merkus Pine trees.

The second stage, "Data Collecting and Analyzing", involved gathering primary and secondary data for modelling. Collecting morphological data of the Merkus Pine tree required visiting the Mangunan Pine Forest and also looking for several secondary data from kinds of literature (e.g. [3] and [4]); mainly, the secondary data coming from [3] who talked about the analysis of Markus Pine trees in Linge sub-district area, in Aceh Province (Indonesia). Here, the collected data were used to create a mature dataset and to construct the virtual tree model.

The third stage, "Model Analyzing and Designing", utilized the FSPM method [19] to analyze the growth and development model of the Pinus Merkus tree. The object-oriented method [20] was also employed, where each organ of the tree was considered as an independent object with unique behaviour. The outcome of this stage was the initial design of the morphology, growth, and development model of the Merkus Pine tree.

The "Model Constructing" stage was performed then, where the FSPM method operated, to build the model. This was carried out on the Growth Grammar-related Interactive Modeling Platform (GroIMP). The virtual model of the Merkus Pine tree based on object-oriented conception, which could be utilized to calculate the economic contribution, was constructed academically. Here, the economic value is Pinewood price. It is calculated in every year (until the fifteenth year) of virtual Pine model simulation; with market price assumption coming from [21] as one of the references for Indonesian price seekers of the latest goods.

Finally, the constructed model was verified and validated through stages "Model Verifying and Validating". In this stage, the formal methods of verification and validation [22] were operated. The model gets a value of 1.00 for both verification and validation values. It means that the constructed model is academically and practically true. The references used throughout this process were carefully selected and linked to the specific aspects (sub-models) to be verified and validated, which necessitated in-depth literature research.

IV. RESULT AND DISCUSSION

Based on the concept of object orientation, as a model development method, the principle of the actual physical object is used to illustrate the tree's organs; besides the tree itself as the mother object. Here, an above-land Markus Pine tree naturally has four kinds of organs: stem, branch, leaf, and fruit. The study well-thought-out the under-land tree organs (i.e. tree root).

Conceptually, in this study, the object is a logical individual/entity being different from each other [23]. The class represents a collection of objects which share the same features, constraints, and definitions. Then attributes are basic types of declaring a data property belongs to the object/class. They are a required component of the object/class [24]. There are three kinds of relationship between objects: one-level relationship; aggregation, to depict the relationship of object's parts; and generalization, to show the relationship of object's inheritance.

The diagram usually operated to show the interconnected objects (i.e. business and method objects) in the designed model is a class diagram. Thus, using such a diagram, the constructed model is scientifically configured via a drafted class diagram in Figure 2. The drafted class diagram itself is a class diagram configuring the object's connections without describing their attributes and operations. Consequently, according to Figure 2, the main objects of the developed model are "AboveLandMerkusPine" (as a business object) with other aggregative objects (i.e. "Stem", "Branch", "Leaf", and "Fruit") and a method object "FSPM" which has two generative objects "Math" and "Statistics". The composition sounds like an above-land Merkus Pine tree consisting of one or more stems. A stem consists of one or more branches. A branch consists of one or more leaves and fruits.

Moreover, the detailed class diagram of the constructed model is figured in Figure 3. It is a completed construction of objects' relationships in the model. All objects are determined entirely via the attributes and operations that describe each object exclusively. Surely, all attributes (characteristics) and operations (behaviours) are considered in the constructed model. For example, the object of "Stem" has five attributes

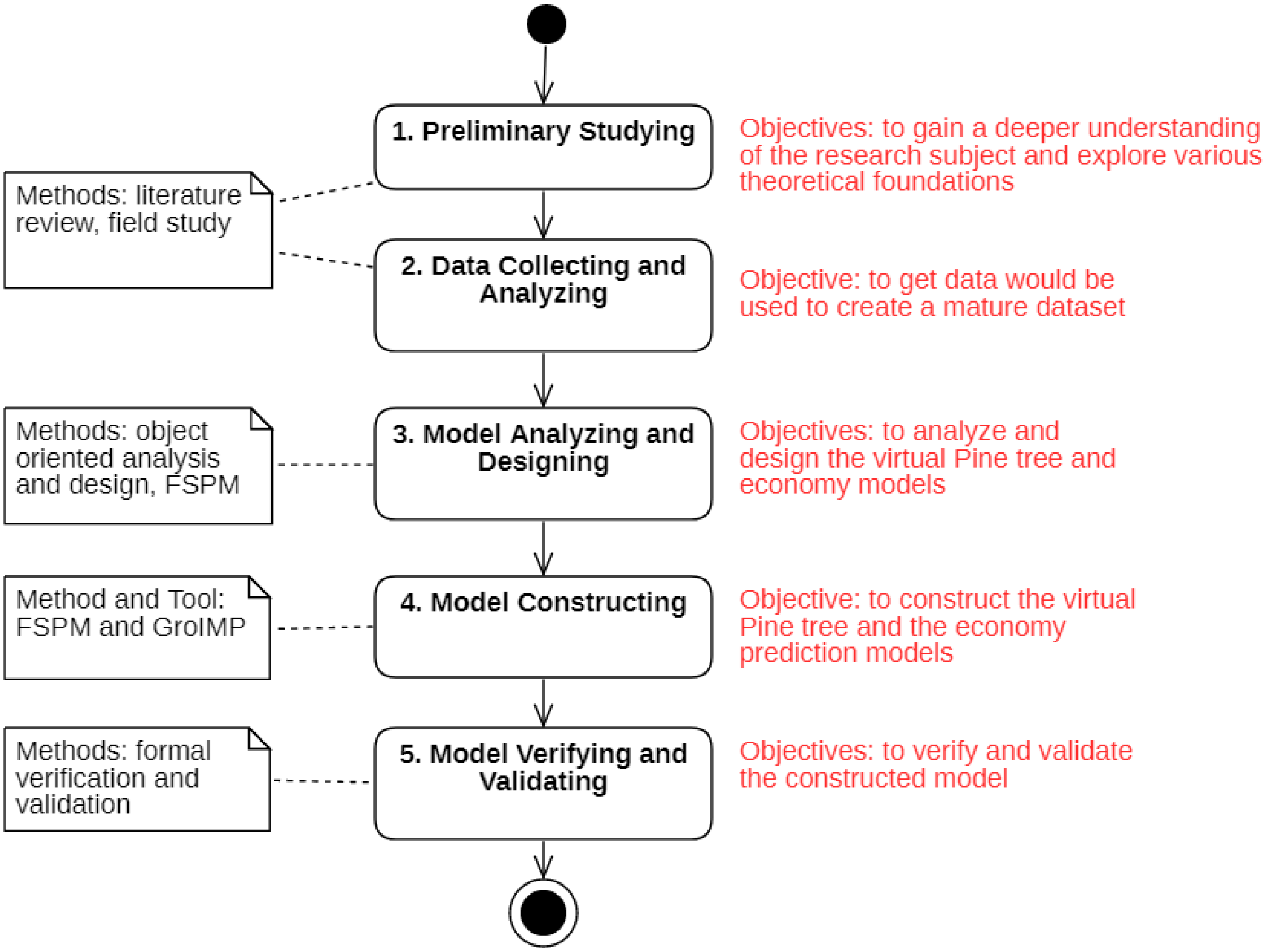

FIGURE 1. The research stages.

and two operations. The mentioned attributes consist of "stemTexture" (stem texture), represented using picture data type; "stemDia" (stem diameter), measured in float data type; "stemLen" (stem length), also in float data type; "stemDiaInc" (stem diameter increment), utilizing float data type, and "stemLenInc" (stem length increment), also utilizing float data type. Then, can be seen in Figure 4, is an example of each picture for (A) leaf, (B) stem, and (C) fruit operated to practically control the attributes "leaf-Texture", "stemTexture", and "fruitTexture" respectively via GroIMP model language. In this case, the business objects also have two similar operations: "grow()" and "develop". The operation "grow()" is used to describe the object's behaviour of upward growth and the operation "develop" is operated to depict the object's behaviour of development.

Furthermore, the other business objects are "Branch", "Leaf", and "Fruit". The object "Branch" has six attributes and two operations. These attributes are "branchTexture" (branch texture) with picture data type, "branchDia" (branch diameter) with float data type, "branchLen" (branch length) with float data type, "branchDiaInc" (branch diameter increment value) with float data type, "branchLenInc" (branch length increment value) with float data type, and "branchAngle" (branch angle value to grow) with float data type. Similarly, the objects "Leaf" and "Fruit" have six similar attributes as well.

In addition, the model algorithm is depicted in Figure 5 using the activity diagram. There are eight main activities until the model can calculate the economic contribution of one Pine tree. The virtual tree growth and development are modelled yearly. The growth and development depend on the increment value of each tree organ; where the model also can measure the new diameter and length every year. The stem length and diameter increments are defined randomly. Besides those increment values, the branch angles are also randomized. They all are determined by 0.84±0.17m, 0.01±0.01m, and 65 ± 55^o respectively. The decision notation appears to check does the *yearCount* reaches 15 or not; it means the tree grows and develops until its age is more

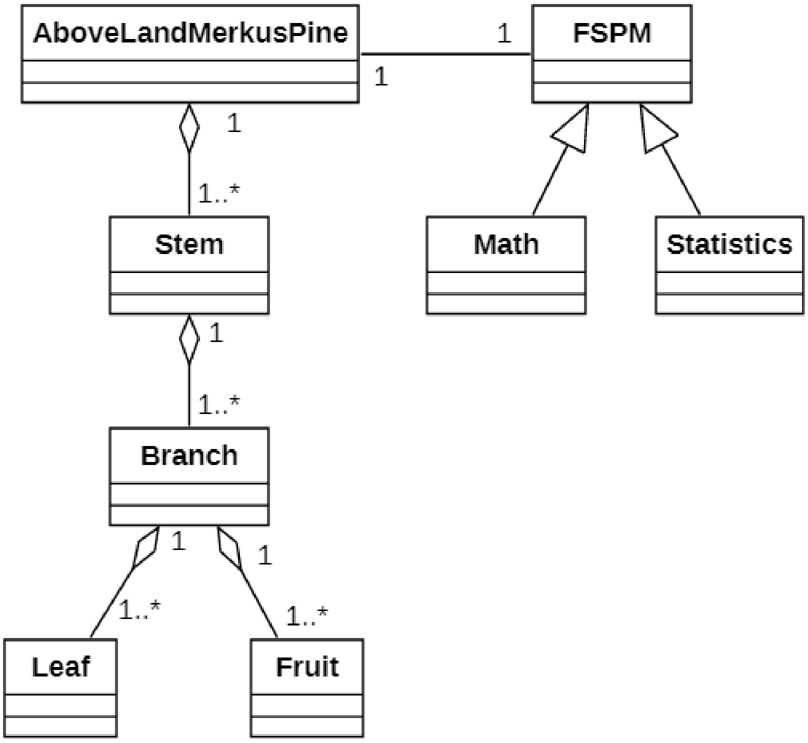

FIGURE 2. The drafted class diagram for the constructed model.

than 15 years. Indeed, in-between randomized values come from empirical data. Those values are determined with equations (1) and (2); where val_{rand} is a randomized value, val_{med} symbolizes a median value of data, val_{min} presents a min value of data, and val_{max} denotes a max value of data.

$$val_{med} = \frac{val_{max} - val_{min}}{2} \tag{1}$$

$$val_{rand} = val_{med} \pm (val_{max} - val_{med}) \tag{2}$$

After 15 years of growth and development, all data of diameter and length (specifically of stem) are reached. The data are used to calculate the stem volume and the economic contribution of one tree. The stem volume is simply calculated via the formula of the partial cone [25], in equation (3); where the SV symbolizes a stem volume, the R_y illustrates a radius of the yth year tree base stem, the r_y signifies a radius of the yth year tree peak stem, and h_y portrays a height of yth year tree stem. The r_y itself is calculated via equation (4); where c depicts a peak stem diameter coefficient with value 0.0007.

$$SV_y = \frac{\pi h_y}{3}(R^2 + Rr + r^2) \tag{3}$$

$$r_y = ch_y \tag{4}$$

Precisely, the determination of economic contribution value follows a straightforward rule-based approach. The economic worth is notably influenced by the diameter measurement of the base stem of each tree (based on empirical real market data). A larger stem diameter results in a correspondingly higher economic value for the tree. The simple algorithmic pseudocode of this rule-based approach is illustrated in Listing 1.

```
Begin
    IF (stemDia <= 0.10m) THEN
        (ecoVal = IDR 0.00 / m3)
    ELSE IF ((stemDia > 0.10m) AND
        (stemDia <= 0.13m)) THEN (ecoVal
        = IDR 550,000.00 / m3)
    ELSE IF ((stemDia > 0.13m) AND
        (stemDia <= 0.19m)) THEN (ecoVal
        = IDR 750,000.00 / m3)
    ELSE IF ((stemDia > 0.19m) AND
        (stemDia <= 0.28m)) THEN (ecoVal
        = IDR 1,000,000.00 / m3)
    ELSE (ecoVal = IDR 1,100,000.00 / m3)
End
```

LISTING 1. The pseudocode of rule in determining the economic value.

Likewise, for describing the data exchange among objects, the sequence diagram is used. Figure 6 is a sequence diagram for the constructed model's growth and development activities. The object "Stem" delivers the randomized values of "stemLenInc" and "stemDiaInc" to the object FSPM.

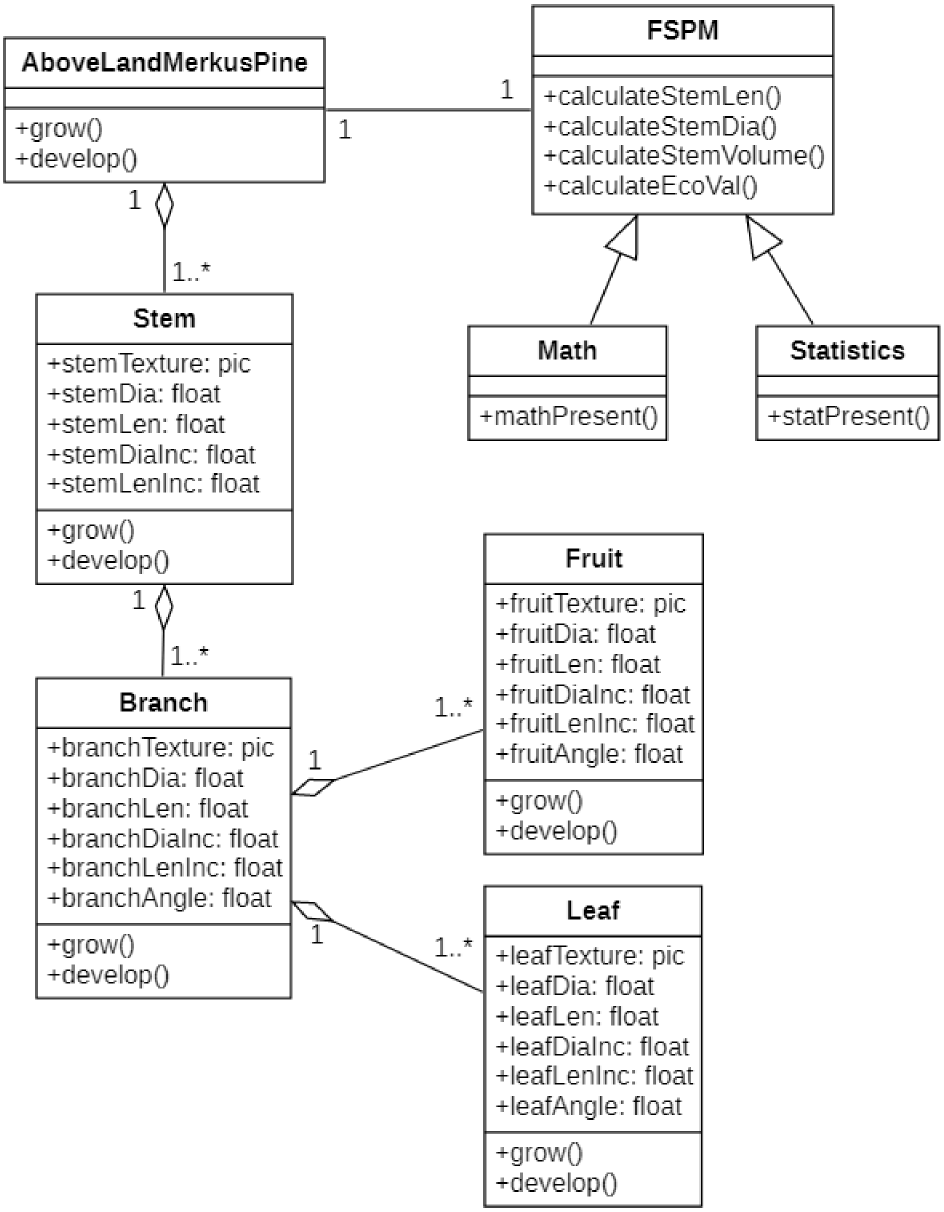

FIGURE 3. The completed class diagram for the constructed model.

Those values are operated by the object method FSPM to make the tree's stem grow and develop randomly. So do other objects (i.e. "Leaf" and "Fruit"). They also transfer the increment values to the FSPM object. In every counter value added (in every year tree's growth and development), the object method FSPM gives four types of data: stem length, stem diameter, stem volume, and economic value. Then, the 3D illustration of four types of virtual 15-year-old Pine trees in horizontal and vertical views is exhibited in Figures 7 and 8 respectively.

Figures 9 to 11 respectively depict the graphs of the simulated height, diameter (base stem diameter), and volume trend of ten Pine trees' main stems from the first until the fifteenth year of age. The Pine tree's main stem grows and develops linearly; however, the volume increases sloping exponentially. The averages of the main stem's height, diameter, and volume in the fifteenth year are 12.67±0.81m, 13.05±2.69cm, and 0.07±0.03m3 respectively. Then, the mathematical expression of each trend is represented in equations (5) until (7).

Equation (5) represents the median linear mathematical expression for the trend in main stem height over the years, with an R-squared (R^2) value of 0.99. Here, H_i denotes the main stem height for the ith year. Similarly, equation (6)

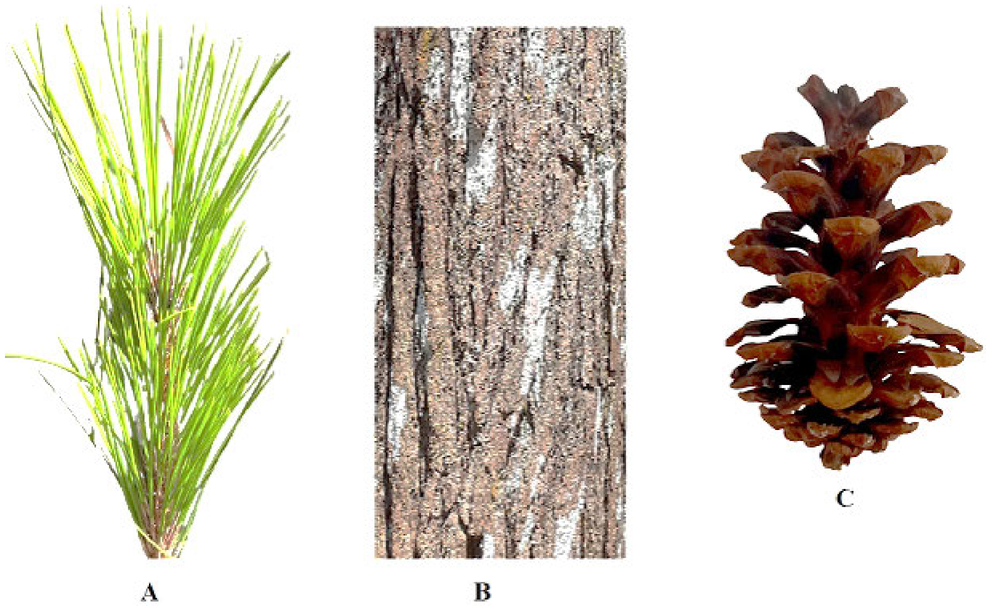

FIGURE 4. The example of pictures (A) leaf, (B) stem, and (C) fruit functioned to mold the leaf, stem, and fruit textures respectively.

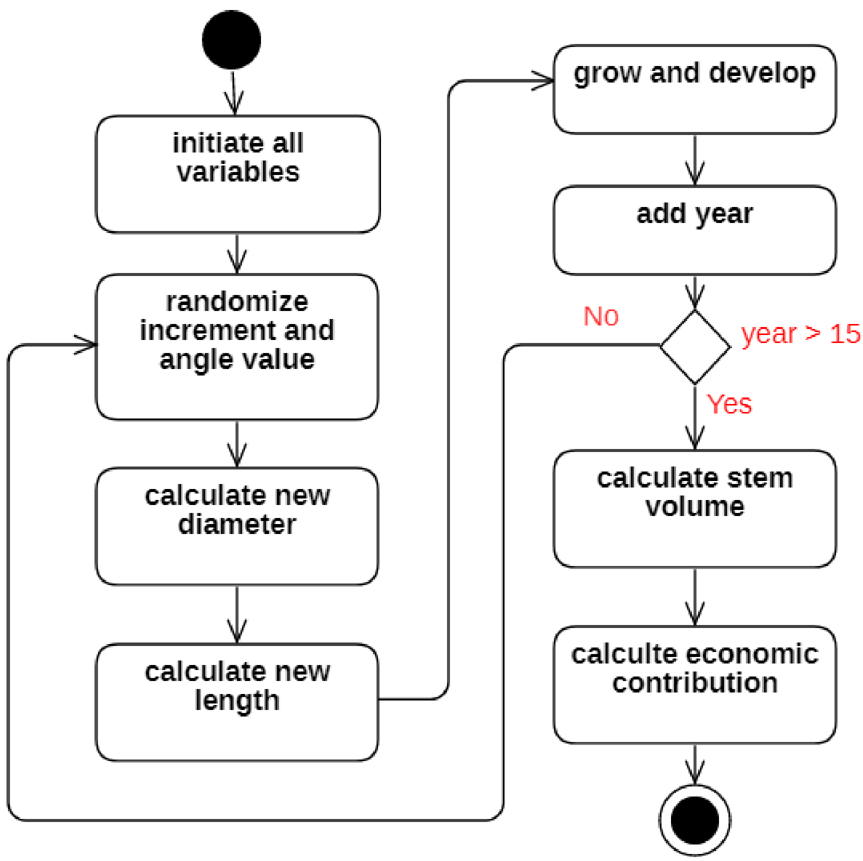

FIGURE 5. The activity diagram for the constructed model algorithm.

represents the median linear mathematical statement for the trend in main stem diameter over the years, also with an R^2 value of 0.99. Here, D_j represents the main stem diameter for the jth year (where the diameter itself is twice the

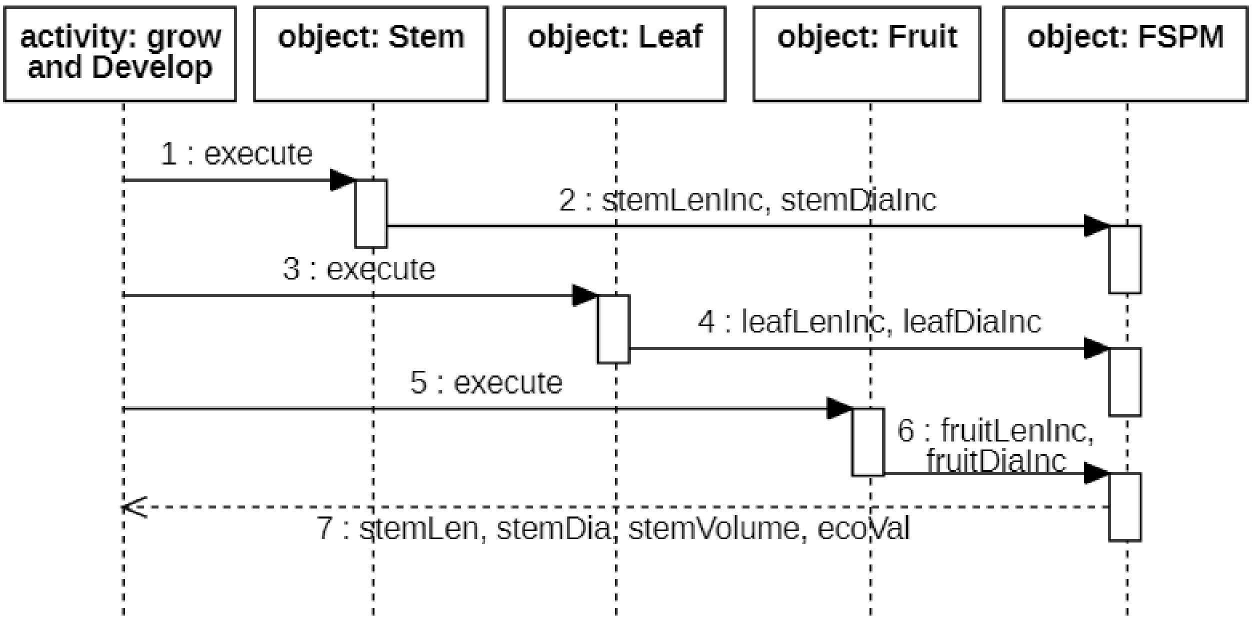

FIGURE 6. The sequence diagram for the constructed model.

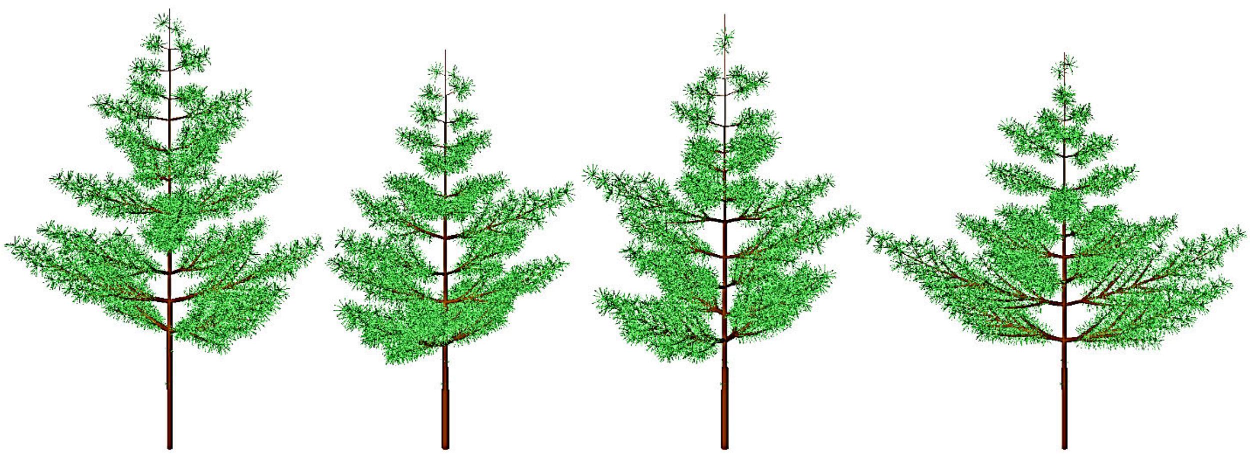

FIGURE 7. Four 3d-illustrations of virtual 15-year-old pine trees in a horizontal view.

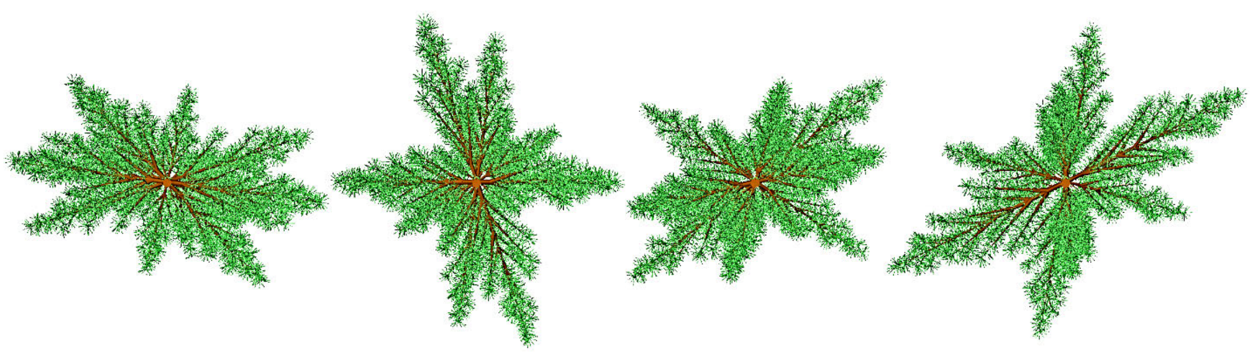

FIGURE 8. Four 3d-illustrations of virtual 15-year-old pine trees in a vertical view.

radius). Then, equation (7) conveys the median quadratic math statement for the trend in main stem volume over the years, with an R^2 value of 0.99 as well. In this case, V_k signifies the main stem volume for the kth year. Here, the

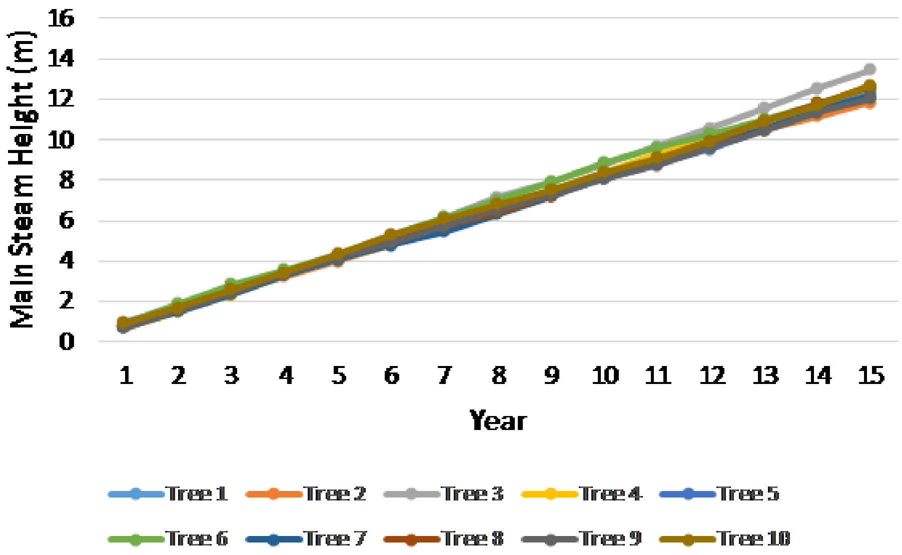

FIGURE 9. The simulated length/height trend of ten pine trees' main stem.

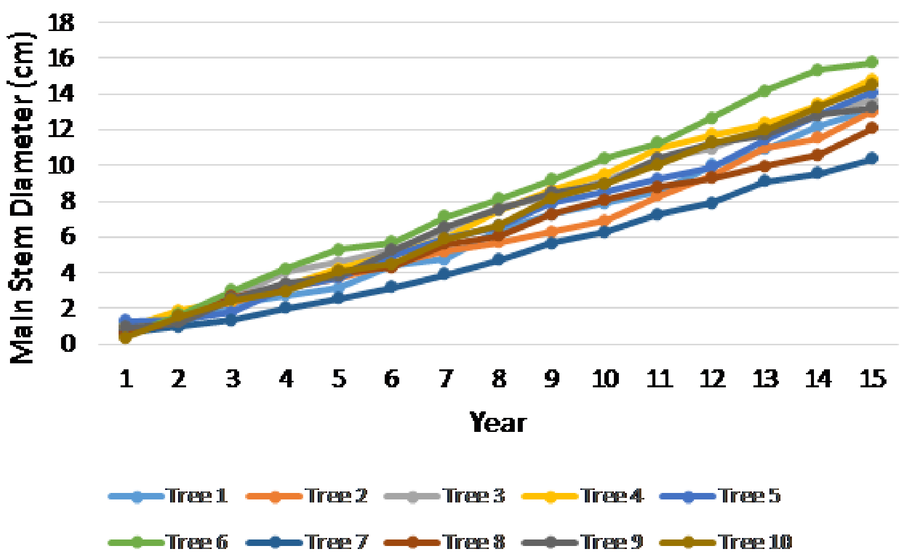

FIGURE 10. The simulated diameter trend of ten pine trees' main base stem.

main stem volume is measured via equation (3).

$$H_i = 0.8227i - 0.0133 \tag{5}$$

$$D_j = 0.9253j - 0.4888 \tag{6}$$

$$V_k = 0.0005k^2 - 0.0033k + 0.0053 \tag{7}$$

Figure 12 depicts the simulated trend of economic value (in IDR) per year for individual Pine trees. On average, the economic value begins to appear in the sixth year. In the sixth year, each Pine tree generates approximately IDR 1,661.75 of economic value, while the highest average value reaches around IDR 47,980.04 in the fifteenth year. The trend's median is modelled using a quadratic mathematical expression with an R^2 value of 0.93, as presented in equation (8), where EV_l indicates the economic value of Pine trees for the lth year.

$$EV_l = 514.25l^2 - 5503.8l + 10363 \tag{8}$$

Furthermore, for evaluating the constructed model, verification and validation approaches are used. Table 2 presents the verification value of the constructed model. In the verification process, there are three kinds of selected model parts verified academically: calculation of main stem volume, calculation of economic contribution, and randomization of

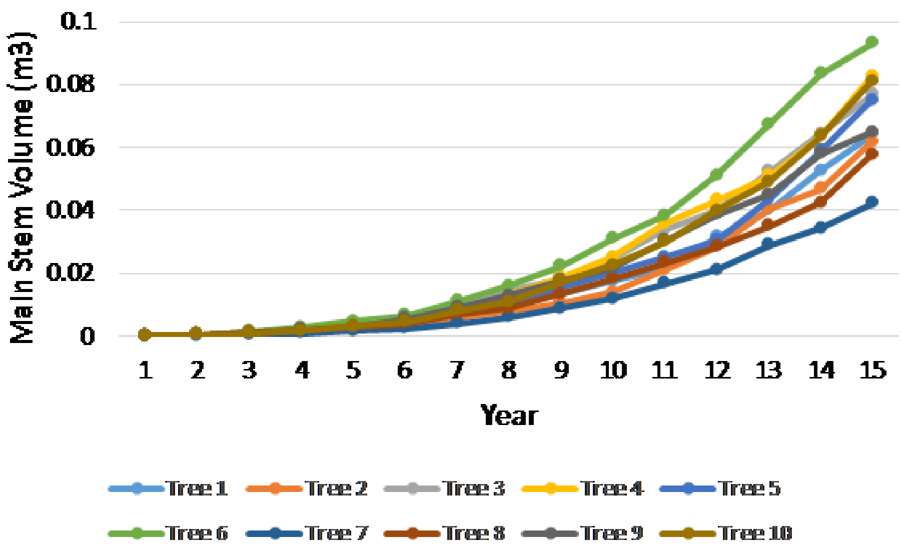

FIGURE 11. The simulated volume trend of ten pine trees' main stem.

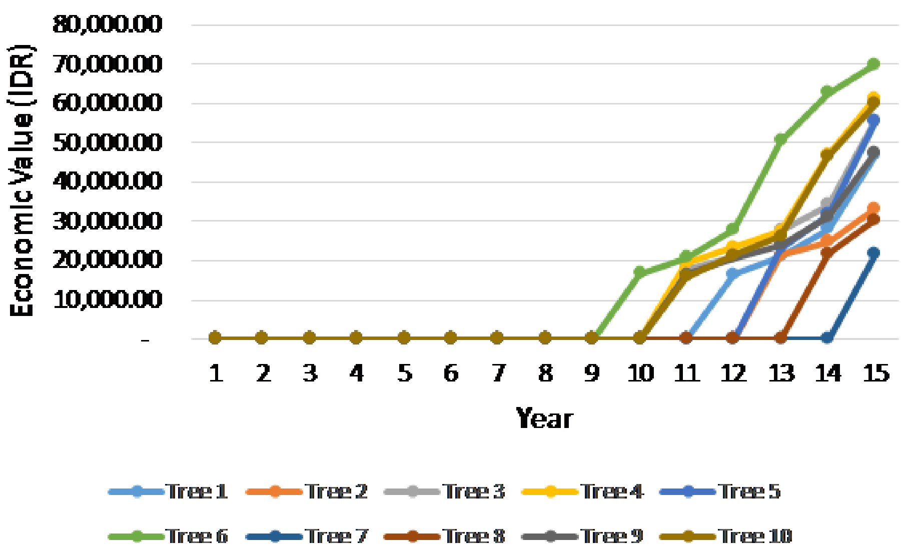

FIGURE 12. The simulated economic value trend of ten pine trees.

three vital variables. The formula for calculating the main stem volume value is in equation (3) coming from [25]. The formula is represented in code Listing 2; where the *assStemDia* represents an assumed stem diameter. They have similar mining and get the same value when manually executed (with the same inputs). Thus, the model part of the main stem volume calculation is evaluated as a verified part and gets a verification value of 1.00.

Moreover, for determining an economic value for each 1m3 main stem volume, Listing 1 represents the data and information coming from [21] (Table 3). After analysis, they have a similar meaning. It means, the part of the model for determining economic contribution value is verified and it gets a verification value of 1.00. And, for randomizing the tree growth, development, and angle are represented in code Listing 3. They are fitted with the fundamental model platform GroIMP coding [19]. Also, these randomizing processes (one of the model parts verified) are scientifically verified and get a verification value of 1.00.

```
stemVolume = ((3.14 * stemLen) / 3) *
(((stemDia / 2)*(stemDia / 2)) +
(stemDia / 2 * assStemDia / 2) +
((assStemDia / 2) * (assStemDia / 2)));
```

LISTING 2. The model code of formula for calculating main stem volume.

TABLE 2. The constructed model verification value.

No.	Model Parts	Ref.	Model	Evaluation	Ve. Value
1.	Formula for calculating main stem value	[25]	Code 2	Fulfilled	1.00
2.	Rule for determining the economic contribution value	[21]	Code 1	Fulfilled	1.00
3.	Code for randomizing three variables (stemLenInc, stemDiaInc, and branchAngle)	[19]	Code 3	Fulfilled	1.00

```
stemDia:i[diameter]+=random(0.00,0.02);
stemHeight:realGrowHeight+=random(0.67,
    1.00);
RH(random(10,120));
```

LISTING 3. The model code for randomizing three variables stemLenInc.

TABLE 3. Economic price of 1m3 main pine stem.

No.	Diameter	Price
1.	0.00 – 0.10m	IDR 0.00
2.	0.10 – 0.13m	IDR 550,000.00
3.	0.13 – 0.19m	IDR 750,000.00
4.	0.19 – 0.28m	IDR 1,000,000.00
5.	> 0.28m	IDR 1,100,000.00

Table 4 shows that the constructed model is practically true with a validation value is 1.00. It means all parameter value operated in the model (in average value) is 100% in the range of real value represented by [2]. Two chosen parameters compared to the real are the height and diameter of the main stem. For example, the model has an average tree height in the fifteenth year of 12.45m, which is in the range of real data (12.50±2.50m); thus the validation of such parameter is fulfilled. So does the parameter main stem diameter, it has a validation value of 1.0 (fulfilled). The model has an average diameter value of 13.45cm, it fits with the real value (14.65±9.24cm).

TABLE 4. The constructed model validation value.

No.	Parameter	Real	Model	Evaluation	Va. Value
1.	Main stem length/height	12.50±2.50m	12.45m	Fulfilled	1.00
2.	Main stem diameter	14.65±9.24cm	13.45cm	Fulfilled	1.00

Indeed, utilizing the same approach (FSPM) and modelling framework (GroIMP), [8] formulated a virtual model of a Pine tree to assess the importance of light absorption. However, it's important to note that their investigation focused on the Scots Pine, as opposed to the Merkus Pine tree addressed in this study. In contrast, the model proposed in this research not only captures the morphological aspects of Merkus Pine tree growth and development but also introduces the capability to forecast the individual tree's economic contributions. This particular aspect, distinguishing our study, remained unmentioned in the works of both [13] and [14]. Then, among all the aforementioned studies, none explicitly elucidates the aspect of model design; however, in this study, comprehensive detailing of the model design aspect (specifically, the utilization of an object-oriented approach) is provided. The summary of the research gap that can be fulfilled by this research is mentioned in Table 5.

TABLE 5. The previous research's gap fulfilled by the study.

Studies	Research Gap Fulfilled
[8]	In contrast to [8], this study took a unique approach by utilizing Merkus Pine as the research subject
[13] [14]	Unlike [13] and [14], this research provides a comprehensive exploration of the model design element, with a specific focus on the implementation of an object-oriented approach

V. CONCLUSION AND FURTHER WORKS

An object-driven virtual model of the above land Merkus Pine tree was successfully developed. The model consists of eight objects with two types of main objects: "AboveLandMerkusPine" and "FSPM". The model can morphologically simulate the Merkus Pine tree growth and development year by year over 15 years and simulate its economic contribution; where one single Merkus Pine tree can contribute approximately IDR 47,980.04 at the end of the fifteenth year. Also, the model was claimed as an academically and practically true model, because based on the verification and validation process, the model gives perfect value.

However, there are several things that can be done in further work. The detailed virtual design should be explored more. Several parameters such as shadowing, lighting, branch number, distance of ground and the first branch, etc. should be considered in the model. As well, the model can be enriched to be able to predict the environmental contribution.

ACKNOWLEDGMENT

The authors unwavering encouragement and resources have been instrumental in the realization of this endeavour. They acknowledge their pivotal role in fostering an environment conducive to the pursuit of knowledge and innovation. They sincere appreciation goes to BINUS University and DIKTI for their visionary guidance and collaboration throughout this research journey.

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