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Tree Architecture Model and Tree Health Assessment Using Sonic 3D Tomograph Relationship in Bali Botanical Garden

Siti Fatimah Hanum*, **Ayyu Rahayu, Rajif Iryadi, I Dewa Putu Darma**

Research Center for Plant Conservation, Botanic Garden and Forestry, National Research and Innovation Agency of Republic Indonesia (BRIN), Jl. Raya Jakarta-Bogor Km. 46, Cibinong, Bogor, Indonesia 16911

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Abstract

*The incident of fallen trees or broken branches is dangerous for tourists visiting Bali Botanical Garden. Tree health monitoring in locations with high human activity and near valuable properties is mandatory to minimize the potency of tree failure. Since the stand stability is influenced by biological and physical factors, multiple variables consisting of species characteristics (stem form), tree dimensions (height, diameter, and slenderness coefficient), and tree health were used as parameters of tree health. The aim of this study is to examine the health condition of trees located in XIV.G vak Bali Botanical Garden and to identify the most significant morphological character related to the result of tomograph measurement. A purposive sampling technique was adopted for locations which highly visited. A total of 80 trees were examined as samples to measure tree health. The evaluation used visual observation and tomograph technology. The result showed the most tree defect found were branches covered with epiphyte and moss. However, tomograph examination found only one tree classified at high risk (*Bischofia javanica*) and seven trees classified at medium risk (*Syzygium polyanthum, Syzygium racemosum, Bischofia javanica, Pittosporum mollucanum, Pittosporum* sp. *and Dacrycarpus imbricatus (2 trees). This study suggests the use of tree architecture model as the most significant morphological character on tree samples with medium decay.*

Keyword: *tree health, tree architecture model, tree slenderness coefficient*

**Correspondence author, email*: *sitifatimahhanum2004@yahoo.com*

Introduction

Bali Botanical Garden is the biggest area of botanic gardens in Indonesia. This garden is an ex-situ plant conservation, consisting of more than 23,000 plant specimens varying from tree, shrub, succulent, herb, and climber (Bali Botanical Garden, 2021). There are two types of trees in this garden comprised of collection trees and non-collection trees. A collection tree is a tree that is planted because of its special value, while a non-collection tree is a tree that already exists in the garden or is planted for aesthetic purposes.

The presence of trees in the botanic garden has many functions such as the scientific value that also give an amenity surrounding. However, standing trees with decay inside is often the cause of tree failure. Several research on tree risk assessment at Bali Botanical Garden have already been done (Hanum et al., 2020; 2021; Swari et al., 2022), but the previous publications did not evaluate the influence of tree architecture model on the tree health assessment.

The incident of fallen trees or broken branches is dangerous for visitors and staff. However, the incident is unpredictable (Lazim & Misni, 2016). Thus, tree health monitoring in locations with high human activity and near the valuable property is mandatory for Bali Botanical Garden management to minimize the potency of tree failure. This study aims to examine the health condition of trees located in XIV.G vak Bali Botanical Garden.

Methods

Study area This study was conducted at Bali Botanical Garden in Tabanan Regency, Bali Province, Indonesia from January to May 2021. The sample location is in XIV.G vak with a total area of 11,987 m^2. This location is selected because has a high risk of fallen trees (Figure 1). The altitude is between 1,215–1,325 m asl, soil pH is between 4.9–6.4, soil humidity is between 59–90%; air temperature is between 21.4–26.1 °C; air relative humidity is between 67.5–87%. The canopy tree coverage is between 52–92%.

Identification of targeted tree Sites with the highest frequency of tourist occupancy were the targeted location for this study. In this study, the sample area was XIV.G vak. Eighty trees with a diameter of breast height of more than 40 cm then were identified by species, tree diameter, tree height, canopy coverage and canopy diameter. Each of them was labeled with mikolin label. Each of these trees was checked for visual tree assessment, tree health assessment using a sonic tomograph, tree architecture model and tree slenderness coefficient.

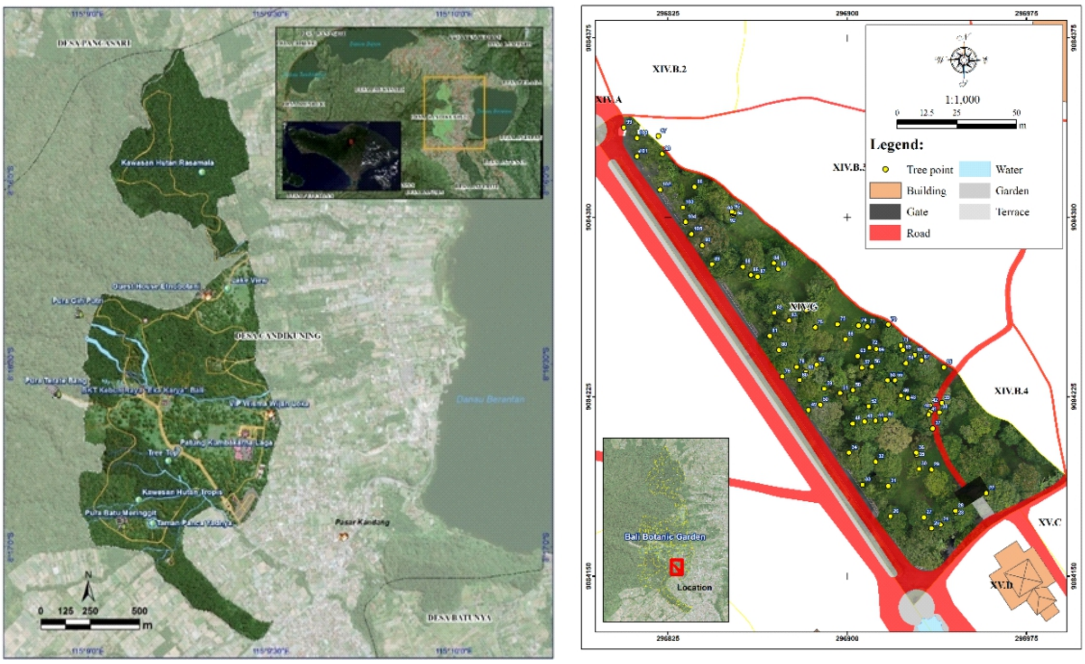

Figure 1 The map of research location (red color) in Bali, Indonesia. Spatial distribution of targeted species at Bali Botanical Garden (yellow dot).

Visual tree assessment The visual inspection was done by walking surrounding the tree at 360° to check the tree condition from the top to the bottom. Visual observation of tree trunk condition was also done by looking at the outermost trunk of the sample tree, especially to see whether there were any symptoms or signs of deterioration. Visual inspection was conducted following the modified tree risk assessment form from International Society of Arboriculture (ISA). The information collected by visual observation consists of tree information, target assessment, site factor, tree health and species profile, load factors and tree defects.

Tree health assessment using sonic tomograph Sonic tomograph is a non-destructive technology to measure the inside condition of a tree. The step to use the ArborSonic 3D Acoustic Tomograph tools was initiated by placing eight sensors perpendicular to the trunk at an equal distance in counterclockwise order, then connecting the sensors to the amplifier boxes. After that connect the battery box on any end of the line then connect to a unit of laptop. Each sensor was tapped with a steel hammer to generate sound waves. Furthermore, the software will display the internal sound-velocity distribution of the tree.

Interpretation of tree's condition based on a sonic tomograph The tomogram with green color means a good condition, yellow and red color mean decayed condition while blue color mean hollow condition. Determination of tree level damage using ArborSonic was performed based on Helmanto et al. (2018) who classified it as a high risk if the percentage of decay wood is above 60%, moderate risk if the percentage of wood decay is between 30–60% and low risk is the percentage of wood decay is below 30%.

Determination of tree architecture model The determination of tree architecture model of tree samples was carried out using 23 tropical tree architecture models based on Halle et al. (1978). The tree architecture model has an important role in transformation and translocation of rainfall in each tree (Arrijani & Lombok, 2006).

Determination of the slenderness coefficient Tree slenderness coefficient (TSC) is a good indicator of the wind-throw stability of trees (Wang et al., 1998; Ezenwenyi & Chukwu, 2017; Oladoye et al., 2020). This coefficient is obtained from a ratio between height (h) and the diameter of the tree at breast height (dbh) (Adeyemi & Adesoye, 2016).

Tree decay model from tree canopy, tree architecture model and tree slenderness coefficient The multinomial logistic regression analysis with R was used to get information on the model and the contribution of each independent variable input as shown in Equation *[1]* (Wirabuana et al., 2021).

$$Y = a + b(X1) + c(X2) + d(X3) \qquad [1]$$

note: a, b, c, d = constanta (intercept)

Dependent variable is decay class (Y) and the independent variables used are architecture model (X1), the canopy (X2), and tree slenderneess coefficient (X3) which have been standardized in the previous data range. Class of tree decay has 3 classes (low, medium and high). Architecture models have 5 classes (Figure 13), tree canopy has 4 classes (based on range diameter with interval 3.4 m for each class) and TSC has 3 classes (low, medium, high).

Determination of tree damage Analysis of tree damage was carried out by collecting parts of decaying standing trees then collected and sent to the Biomaterials Research Center-BRIN. The result of this analysis was to determine the cause of damage.

Results and Discussion

Characterisation of targeted trees The observed tree sample was 80 trees consisting of 12 species namely *gintungan* (*Bischofia javanica* Blume, 55 trees), *suren* (*Toona sureni* (Blume) Merr., 1 tree), *jambu anum* (*Syzygium racemosum* DC., 1 tree), *salam* (*S. polyanthum* (Wight) Walp, 4 trees), *merameke* (*Pittosporum mollucanum* Miq., 2 trees), *ketapang* (*Terminalia catappa* L., 1 tree), *Terminalia* sp. (2 trees), *P. pullifolium* Burkill (5 trees), *Pittosporum* sp. (1 tree), and *jamuju* (*Dacrycarpus imbricatus* (Blume) de Laub, 7 trees). Most of the trees have tree diameters between 31–60 cm and heights between 21–30 m (Figure 2).

Visual assessment result Most of the sample trees have symmetries crown models. However, tree defects mostly found on sample trees are branches covered with epiphyte, moss and liana (Figure 3). Visual tree defects were easily known from the outside such as holes in the bottom of the trunk or little holes in the bark (Figure 4). Cavity was found in *S. polyanthum* and *S. racemosum* (Table 1).

In order to understand the cause of the hole in the sample tree especially in *S. polyanthum*, we sent the sample of wood decay to the Characterization Laboratory Cibinong-Integrated Bioproduct laboratory. The result showed that wood decay at *S. polyanthum* was caused by soil termites (Figure 5). Termites tend to live in a place with soils that are fine-textured and moist (Sileshi et al., 2010). The soil conditions in the study plots were rather rough, but the moist soil conditions due to frequent flooding caused the area around tree roots to have the potential to become termite nests. This condition was exacerbated by the absence of organic matter or litter on the surface as termite food, causing termites to eventually eat the weathered parts of the tree.

The tomogram of the trunk Based on the result of ArborSonic 3D Acoustic examination, there was one tree with high risk and seven trees with medium risk (Figure 6.). Tree with high risk is *B. javanica* because the wood decay was about 62% while trees with medium risk which has wood decay 30–60% were *S. polyanthum*, *S. racemosum*, *B. javanica*, *P. mollucanum*, *Pittosporum* sp. and *D. imbricatus* (2 tree) (Figure 7). Suddenly, on December 2022, *S. racemosum* has fallen because of a breakage on the bottom of the trunk (Figure 8). The bottom of this tree shows a hollow inside the trunk. The hollow inside the trunk was allegedly caused by stem borer since *S. polyanthum* also showed a similar defect (Hanum et al., 2021).

Based on Nunes et al. (2010) the main factor influences stand stability comprised of biological and physical factors. Physical factors are mainly associated with the wind

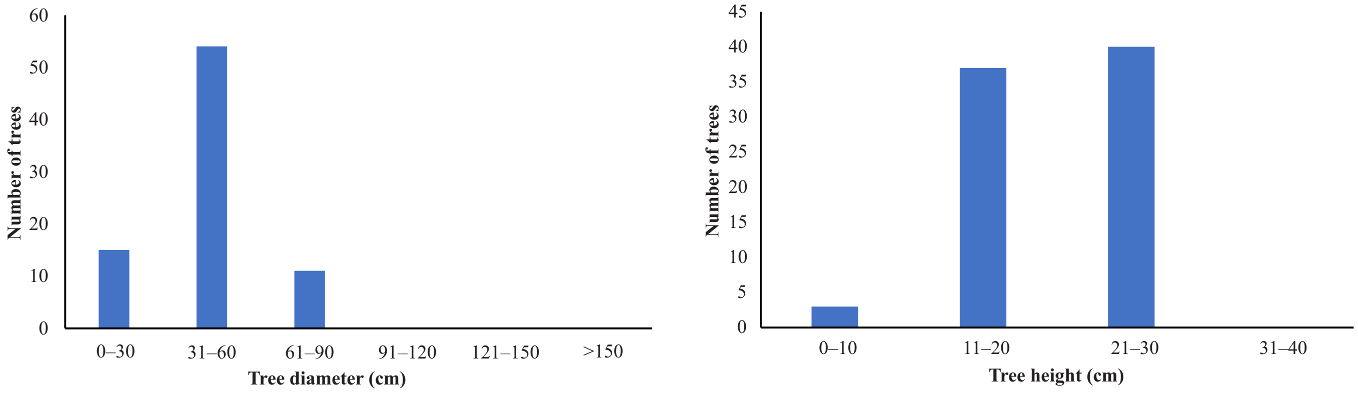

Figure 2 Tree diameter (left) and tree height of sample tree (right).

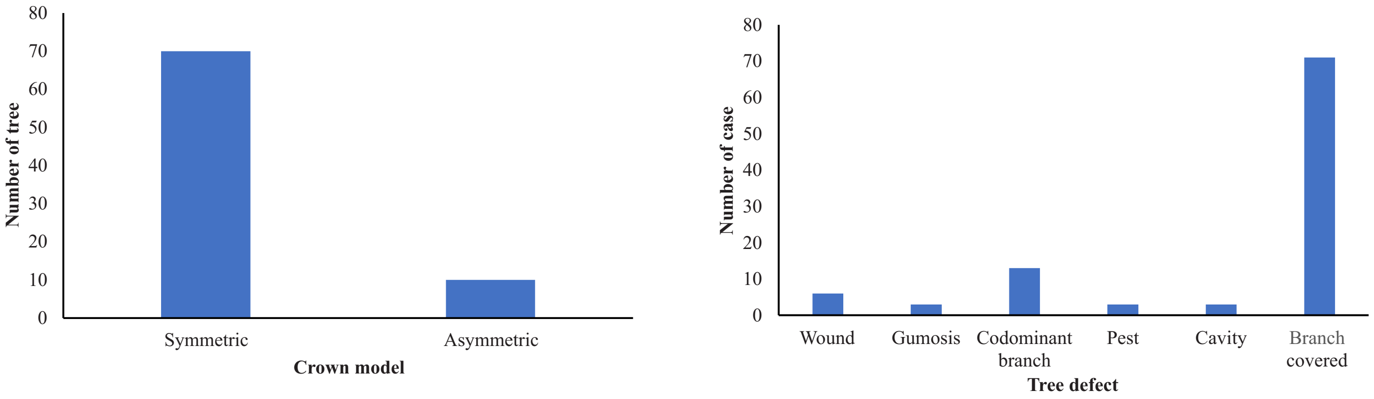

Figure 3 Crown model of sample tree (left) and tree defect found on sample tree (right).

Figure 4 Visual defect in sample tree.

Table 1 Visual condition of high and medium risk tree based on ArborSonik Acoustic 3D Tomograph

Species name	Sample number	Visual condition
Syzygium polyanthum	1	Hole in bottom of the trunk
Syzygium racemosum	15	Hole in bottom of the trunk
Bischofia javanica	25	Hole in bark
Bischofia javanica	36	Decay on the bottom of the trunk
Pittosporum mollucanum	71	Health
Pittosporum sp.	73	Previous history, the tree was codominant, but only left one.
Dacrycarpus imbricatus	78	No destruction found on the trunk
Dacrycarpus imbricatus	79	No destruction found on the trunk

Figure 5 Destruction at *Syzygium polyanthum* trunk.

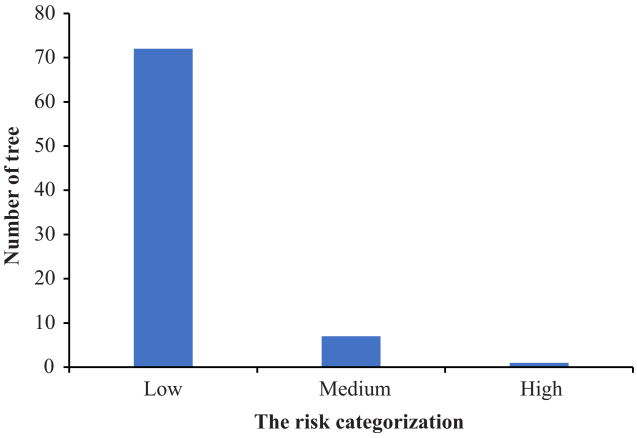

Figure 6 The level of tree risk based on Arborsonic.

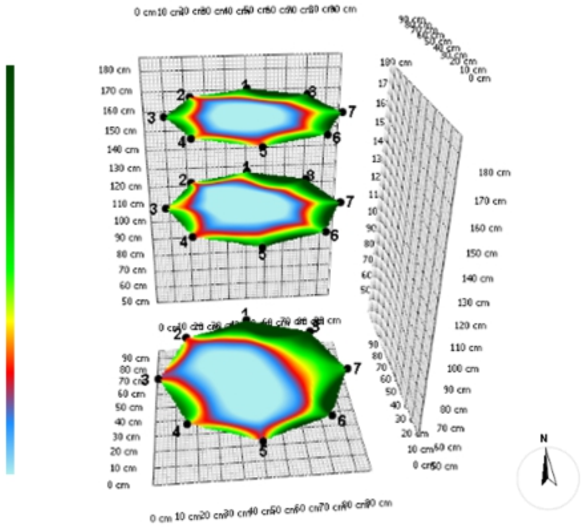

Figure 7 The result of arborsonic examination on *Bischofia javanica*.

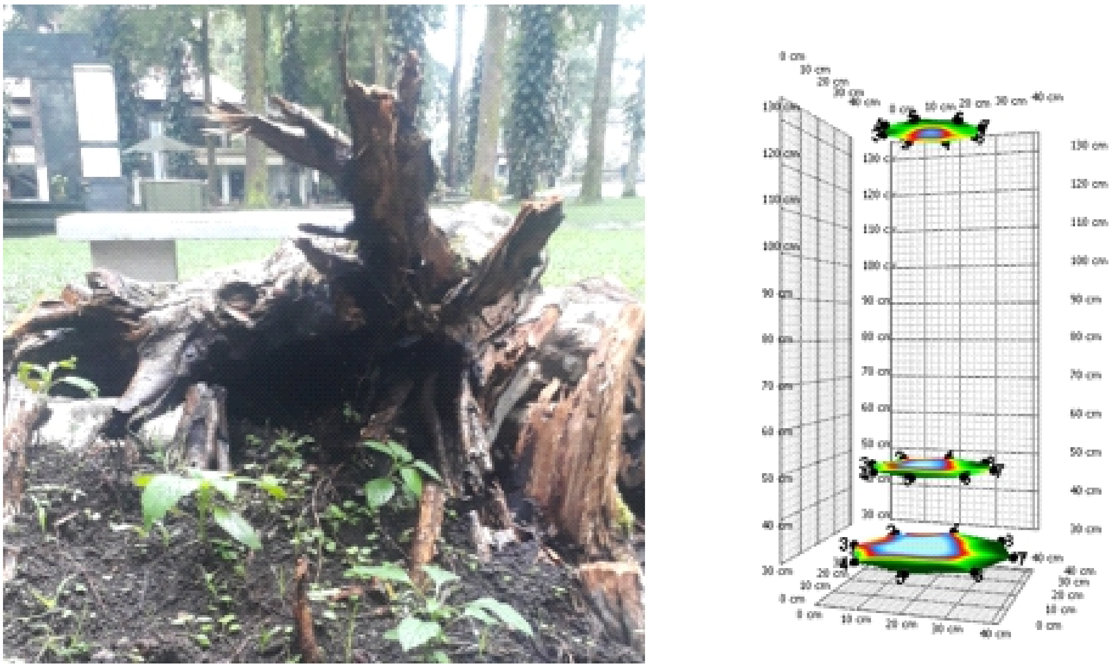

Figure 8 The hollow inside bottom trunk of *Syzygium racemosum* (left). The tomogram result of *Syzygium racemosum* (right).

components (direction, speed and duration), the topography and the site properties (soil depth, structure and drainage). Biological factors consist of the species characteristics (root anchorage, crown architecture, stem form and strength as well as the mechanical properties of the wood), tree dimensions (height, diameter, crown ratio and slenderness coefficient), tree vigour and health, and tree aggregation (stand density).

Correlation between morphological characters with the risk from arborsonic examination Tree morphological character has no significant relation with the result of arborsonic examination (Table 2.). The tree's morphological character consists of canopy, crown wide, and height tree.

Correlation between tree architecture character with the risk from arborsonic examination Tree architecture model of sample tree was determined based on the key to architectural models of tropical trees written by Halle at al. (1978), consists of scarrone, massart, aubreville, fagerlind, and theoretical I (Table 3). This model is based on the tree

Table 2 Correlation between morphological characters with the result of arborsonic examination

Morphological character	Correlation result (R^2)
Canopy coverage (%)	-0.05, *p*-value = 0.64
Crown wide (cm)	-0.087, *p*-value = 0.445
Height tree (m)	-0.17, *p*-value = 0.13

Table 3 Tree architecture model of sample trees

Class tree architecture	Sample tree
Rauh	55
Massart	5
Aubreville	12
Fagerlind	1
Theoretical I	7
Total	80

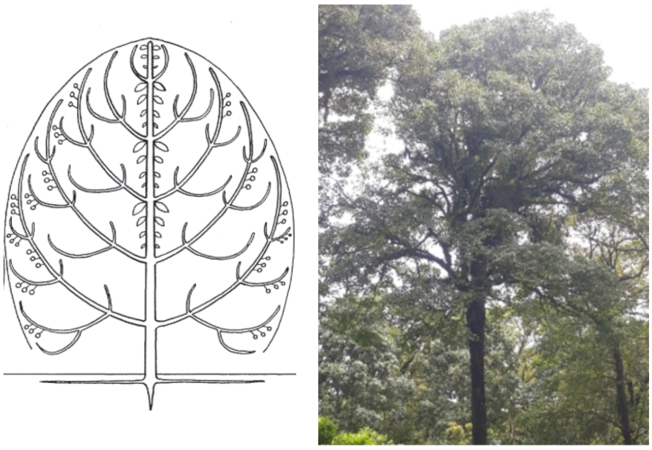

Figure 9 Sketch of *rauh* tree architectural model based on Halle et al. (1978) (left), An example of *Bischofia javanica* (right).

branch system.

B. javanica was the dominant tree sample (55 specimens) which has rauh architectural tree model (Figure 9). The rauh model has stems branched (polyaxial), vegetative axes all orthotropic, inflorescences lateral, branches monopodial, and trunk with rhythmic growth in height (Halle et al., 1978). This architecture model allows for a lot of stem flow to occur and little water escapes from the crown. This type of tree has a high interception potential (Hadinoto & Suhesti, 2018).

S. polyanthum and *S. racemosum* have the massart architectural tree model (Hallé et al., 1978; Arijani & Lombok, 2006; Ekowati et al., 2017) that have branch stem polyaxial with no equivalent vegetative axis, homogeneous (differentiated on the orthotropic axis)(Figure 10). The trees of this model consist of 5 trees. This branching is acrotonic stem form not modular construction with lateral inflorescence, branching pattern common monopodium, stem growth and branch is rhythmic. The plagiotropic branches have not been caused by apposition, monopodial or sympodial due to substitution. This tree architecture model allows for a lot of crown flow to occur and little water from the stem (Hadinoto & Suhesti, 2018).

D. imbricatus has the theoretical I tree model (Figure11) that has the characteristics of a branched, polyaxial or tree with several different axes, with a vegetative axis that is not equivalent to a homogeneous, heterogeneous or mixed form but always has a clear distinction between stems and branches (Arijani & Lombok, 2006). The stem and branching's growth are continuous and have plagiotropic branching due to apposition.

Toona sureni has the fagerlind model (Figure 12). This model has branching trunk characteristics, polyaxial, unequal vegetative axis, vegetative axes heterogenous (differentiated into orthotropic and plagiotropic axes or complexes of axes), acrotonic branching, terminal inflorescence, monopodial growth in height rhythmic (Halle et al., 1978; Sharma et al., 2016).

Aubrevile model has characteristics of a stem branch, vegetative axes heterogenous, acrotonic branching, lateral inflorescences, trunk with an orthotropic monopodium, trunk with rhythmic growth and branches plagiotropic by apposition (Halle et al., 1978). *Terminalia* sp., *Pittosporum* sp. and *P. pullifolium* have indicated this model (Figure 13).

The tree architecture model signs branch type. A total of 80 trees have been classified into five tree architecture classes (Figure 14). This variable is nominal data so it would be descriptive information about the tree architecture character data. Model 2 (massart model), Model 5 (theoretical I), and Model 3 (aubreville) are relatively more contribute to making medium decay to the trees. However, model 2 has indicated more decay because the Myrtaceae family has susceptible to insect or stem borer.

Tree slenderness coefficient (TSC) The result of tree slenderness coefficient (Figure 15) showed that trees with a high tree slenderness coefficient (TSC>80) were six trees comprised of *B. javanica* (2 trees), *P. pullifolium* (2 trees), *D. imbricatus*, and *P. mollucanum*. Trees with medium slenderness coefficient (70<TSC<80) consist of *B. javanica*, *P. pullifolium* (2 trees), and *D. imbricatus*. This result is

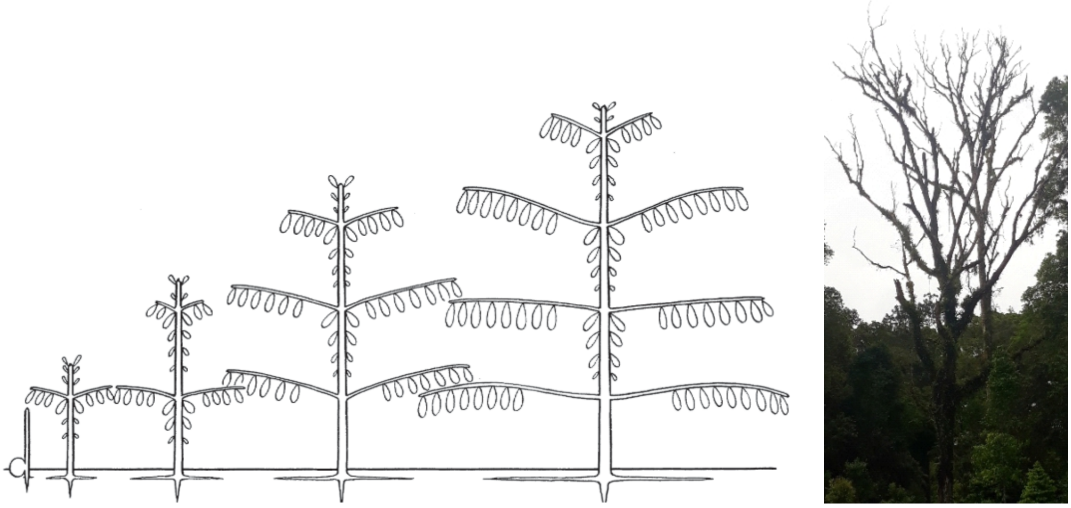

Figure 10 Sketch of massart tree architectural model based on Halle et al. (1978) (left), An example of *Syzygium polyanthum* (right).

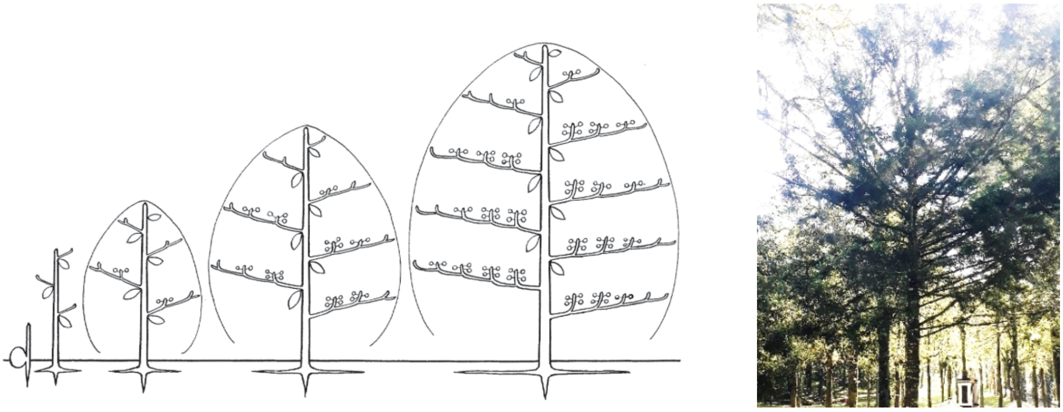

Figure 11 Sketch of theoretical I tree architectural model based on Halle et al. (1978) (left), An example of *D. imbricatus* (right).

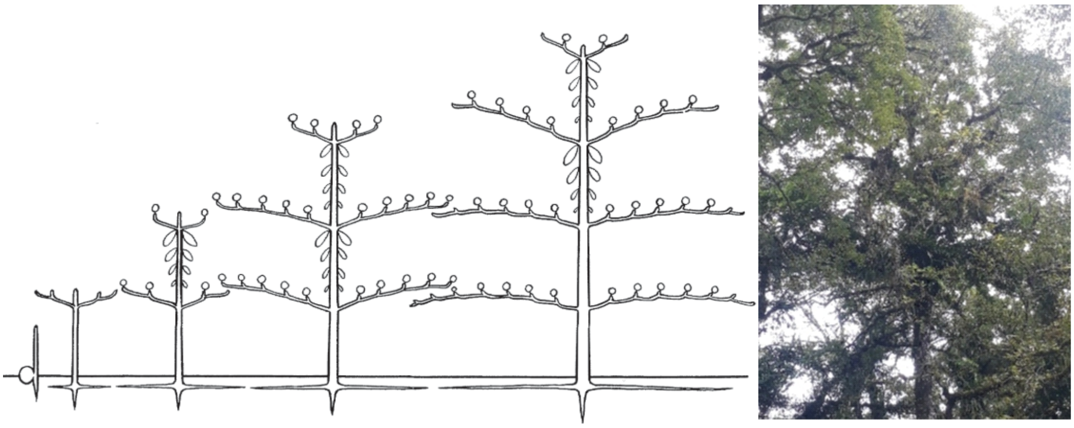

Figure 12 Sketch of fagerlind tree architectural model based on Halle et al. (1978) (left), An example of *Toona sureni* (right).

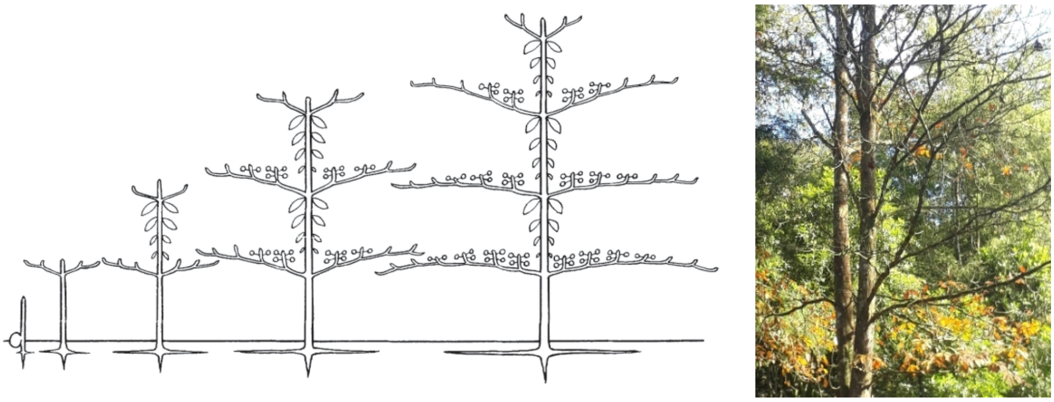

Figure 13 Sketch of aubreville tree architectural model based on Halle et al. (1978) (left), An example of *Terminalia* sp. (right).

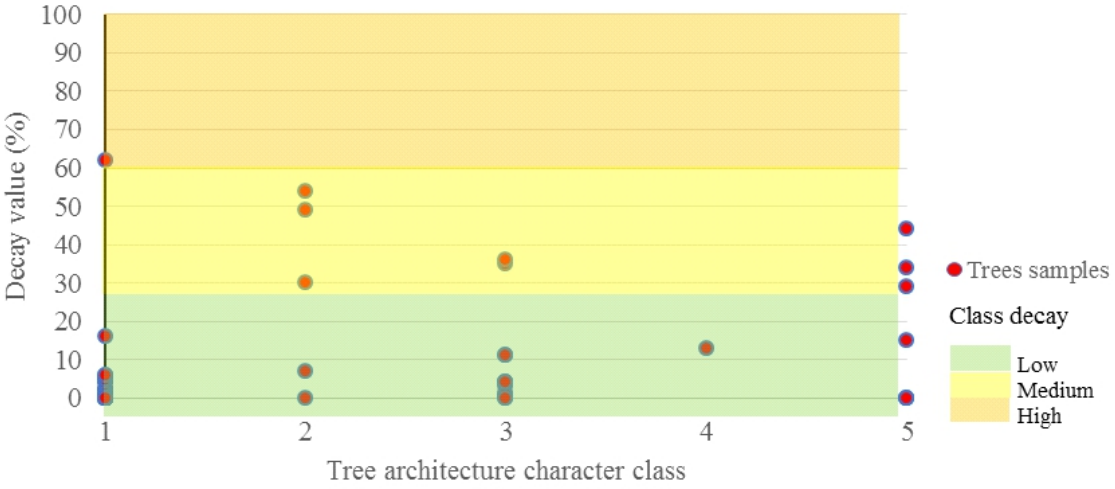

Figure 14 Graph the distribution trees diagnostic based on class tree architecture, where: 1 = rauh model, 2 = massart model, 3 = aubreville model, 4 = fagerlind model, and 5 = theoretical I model.

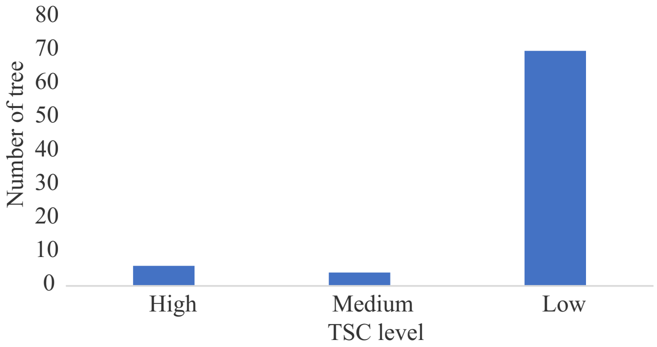

Figure 15 Tree slenderness coefficient result.

similar to Hanum et al., (2021) which showed *B. javanica* also has a higher TSC value at Bali Botanic Garden with a sample location wider compared to this research. This tree is also found frequently to get stem breakage. This is probably because of the character of plagiotropic branch which is covered with epiphyte and mosses and has a high interception potential. *B. javanica* was used as reforestation species in Bali Botanic Garden location a long time ago (Siringo-ringo et al., 2019). Tree slenderness coefficient is an indicator to examine the stability of the tree and evaluate the mechanical properties of stem wood (Zhang et al., 2020). Tree slenderness coefficient has a straight relationship with the risk of stem breakage or tree fall due to wind or snow (Nunes et al., 2010).

Tree canopy, tree architecture model and tree slenderness coefficient contribute to tree decay model Results model showed two matemathic models that have the medium model (g1) and the high model matemathics (g2).

Table 4 Validation of the model using Wald test statistics

Category decay	Intercept	X1	X2	X3
Medium	-2.811905	2.60647681*	0.0745330	-0.2794858
High	0.391250	-0.03356049	-0.3269757	-0.1109451

Note: X1 = the architecture model, X2 = the canopy, X3 = tree slenderness coefficient

Table 5 Validation of the model using Sig.

Category decay	Intercept	X1	X2	X3
Medium	0.004924911	0.009147902*	0.9405863	0.7798720
High	0.695612438	0.973227629	0.7436863	0.9116599

Notes: * = significant correlation, X1 = the architecture model, X2 = the canopy, X3 = tree slenderness coefficient

$\text{Logit (g1)} = -3.747189 + 0.6938735X1 + 0.03863522X2 \quad 0.1965858X3$

$\text{Logit (g2)} = 53.120657 - 9.0844064X1 \quad 44.39402735X2 \quad 2.3761310X3$

The model was validated using the Wald and significance (Tabel 4 and Tabel 5). The Wald value on variable > 1.96 (Tabel 4) and Sig. value < 0.05 (Tabel 5) indicated having a high contribution to each model. From this model, only tree architecture model variable (X1) has a significant contribution to the model of logit (g1) or the mathematical model of medium decay but not in a high decay.

Conclusion

There were 80 trees assessed using arborsonic in Bali Botanical Garden. Only one tree was classified as high risk (*Bischofia javanica*) and seven trees were classified as medium risk (*S. polyanthum*, *S. racemosum*, *B. javanica*, *P. mollucanum, Pittosporum* sp., and *D. imbricatus*). The tree architecture model was the most significant morphological character on tree samples with medium decay.

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