Virtual Plant of Basil (*Ocimum Basilicum*) by Using Functional-Structural Plant Model

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**Abstract.** Indonesia is one of the most populated and large country in south-east Asia. Its abundance of natural resources was well known. Supported by its tropical climate, made Indonesia is also among the largest tropical country in the world. However, according to the data, arable land in Indonesia has drastically decreased over the years in line with the rising demand for residency areas. This statistic shows a rather concerning fact that it is possible that even though Indonesia with this richness of natural resources one day would not fulfil its own domestic food needs. Moreover, competitions and hindrances that experienced by the Indonesian farmers might also worsen this limited food supply. In this research, the computational plant model (called virtual model) of the above-land Basil plant (*Ocimum Basilicum P.*) was proposed. The Basil plant that is taken as a research object is specific. It is a plant growing in a hydroponic environment. By using structural and functional plant model (FSPM) and simple mathematical and statistical methods, the constructed model was able to portray the growth pattern of each plant organ morphologically and biologically. The development and growth patterns of each plant organ (i.e., stem, petiole, leaves, etc.) are also depicted in detail and precisely. The model was quite novel. It practically can be exploited by agronomists and researchers to see the potential effort in optimizing the plant’s yield.

1. Introduction

Recently, limited arable land and climate change have been a major problem for every country in providing their domestic food needs. In the case of Indonesia, from 2014 to 2019 arable land for agricultural purposes has been in decline by 4.6% [1]. Worsened by a number of growing populations in need of stable residency, the productive land will also be declining for another upcoming year. Yet along with this limited land problem, farmers in Indonesia also simultaneously facing various challenges in crop production. Crop failure, declining purchasing power for domestic products, market price volatility, high distribution cost, etc. In tackling climate change and limited arable land issues, several other solutions [2] have been proposed regarding these issues including indoor vertical farming [3], farm automation, livestock farming technology, modern greenhouses [4], precision agriculture, block chain, artificial intelligence, soil and water sensors, weather tracking, satellite imaging, pervasive automation, and minichromosomal technology. Above all proposed solutions, this paper is focused more on monitoring how the plant could grow to a certain form. This paper is trying to support those proposed solutions and predict whether those solutions work on a particular plant according to the plant growth and its ideal form by using the plant computational model (PCM). This PCM opens another possibility in assessing whether a certain plant could...
be considered as a good investment, conducting studies about a particular plant based on its morphology, generating plant models for machine learning datasets, or even more.

According to [5], plants grow in various forms in order to adapt to the surrounding environment for their growth. The form of the above adaptation is mentioned in [5] as functional-structural plant modelling (FSPM), where the shape of a plant is based on its internal factors, such as hormones and nutrients distributed within the plant vascular tissue. The previously mentioned environmental aspects such as light, soil, water, nutrients, pests, and pathogens that are absorbed are also included in the FSPM and interact with the function and structure of the plant for efficiency reasons. So, research on the plant structure is virtually needed to be able to simulate the growth of the plant with certain required parameters, in such aspects are the environment that related to the plant growth. Then from the simulation results, it can be implemented on physical plants by applying optimized parameters so that they can increase the growth of the plant to form itself into a more ideal structure [6]. In some cases, the process of growth and development of plants involves some management pattern that is often considered complex, time-consuming, and unintuitive. So, the role of the computational model of a plant has an important role in discovering the process from a better angle. This simulation model can provide a detailed description of the basic mechanisms and parameters of these plants. And finally, it can be seen how they are correlated into a global system that supports the growth of these plants [7].

This PCM research was supplementary to support our other ongoing research related to decision support model (DSM) in determining decisions based on whether cultivating Basil for its virtual plant was profitable and considered as a good investment on its business side. As a stakeholder, they need to cogitate any opportunity given rationally so they could analyse the profit and make their business develop and sustainable as long as possible. Other than investment analysis known as financial aspects, a part of feasibility study which mainly used in assessing the viability of a business in making profits. This study could provide and support those assessments in a better view thus resulting in a more accurate projection. In addition, the model published and its dataset could support other researchers, entrepreneurs, and farmer projects in the agricultural field.

2. Material and Methods

The Basil plant (Ocimum Basillium P.) was selected as a research object of this research; as it is economical, short lived [8], perfectly fit for plant modelling [9], and has plenty of benefit in respect to this pandemic situation [8]. It defined as short-age plant; thus, for PCM propose, it can be easily studied to model from its seedling until its harvests processes. Another fact about the Basil plant [8], it is stated that from the distillation process of Basil leaves, contains antibacterial substances that could eradicate S. aureus and E. coli with a minimum bactericidal concentration (MBC) of 0.5%v/v and 0.25%v/v respectively. It implies that Basil plants can be used as raw material for non-alcohol hand sanitizer product, so it is hoped that it can replace the use of alcohol-based hand sanitizer which commonly used [8]. With basil-based hand sanitizer, the production cost comparison could be end up cheaper than alcohol-based hand sanitizer. In fact, that this study was arranged during the Covid-19 pandemic, where the impact of the virus have widely impact and claimed the lives of approximately 1.5 million people [10] for the moment when this report was written. Thus, various socializations regarding to the importance of hand hygiene in preventing the chain of spread have become one of the main priorities.

There are various hydroponic technique that could be applied in this research. Among known are wick system, Ebb & flow system, drip system, deep water culture, and nutrient film technique (NFT) [11]. But according to those available technique, this research, the wick system was operated as the hydroponic technique because of its simplicity, accessibility, and due to economical reason. As wick system commonly known for, the system consists of a reservoir to filled with additional nutrient and the water volume was maintained daily. This reservoir then connected to an absorbent medium (rockwool) through a wick (highly absorbent ribbon or rope) which have capillary action. In order to supply the implanted plant in the medium enough water and nutrient to be able to grow.
In its development of PCM generally uses a formal language named the L-System to make the model. The L-System itself was originally popularized by Aristid Lindenmayer [12], in which the study allowed mathematical models to define complex objects by writing some rules. One example is the rules in graphing the snowflake curve in [13]. This formal language discovery was enough to grab many researchers’ attention, because it was based on abstract automata and formal language theory. So, that the abstract growth process in a plant can be translated into a grammatical form that is easier to understand [14]. Then the application of the L-System could further refined with the support of computer graphics introduced by [15], where previously the L-System which applied this formal language only had the ability to produce very rigid and less natural growth patterns (fractals). Meanwhile, the research conducted by Smith has the ability to produce more natural and complex growth patterns (grafts) by allowing irregular growth structures, but still applying the concept formal language same as the L-System.

For the platform used, the researchers used the Growth-Grammar-Related Interactive Modelling Platform (GroIMP) as software for plant modelling platform. This modelling software has been widely used in implementing model that its growth pattern could be translated in the basis of growth grammar [16]. It is suitable for various plant modelling purposes including rice varieties [6], Wheat [17], Norway Spruce Trees [14], Apple tree [18], and etc. Along as the research progresses, we also found another growth simulator software such as SIBYLA [14,19]. But SIBYLA was mostly meant specifically for matured trees that wildly grows in the forest, which contradict to our research object that could only depicted as a short-lived cultivated crop. Other plant modelling software also has been found named ADEL. But, most of the research about ADEL modelling software only available in generating wheat [20] and maize [21] plant even though this modelling software similarly implementing L-System as its formal language. Documentation
related to ADEL software development was also remain unfound by authors and possibly have an enclosed community. As this research was implementing L-System for its main growth grammar concept, the GroIMP fulfilled those criteria as a software built upon the L-System concept as its formal language [14]. The GroIMP also has a plenty of features that continuously being used in other research and abundance resource of documentation and source code of growth algorithm for any plant structure. [16].

In order to have a better illustration for the generated GroIMP model to work, we provided a model based on unified modelling language (UML); e.g. class and activity diagrams. This class diagram is a construction model of an object where we do not have sufficient knowledge about the characteristics and knowledge that involves direct observation is difficult to do or can be said to be impossible to do. This model is broadly a process of building an illustration about how the object being constructed in this study [22]. The selection of class diagrams as a modeling method is because it is specifically adjusted for the software modelling that being used during the construction of the GroIMP model. Class diagram is also often considered as high-level configuration on the involvement of entities / objects in the developed model.

As can be seen in Figure 3, the class diagram model to be develop consists of 3 main classes, namely Basil, SkyLight, and Nutrition. Where in the Basil class there are 6 other sub-classes, namely Seed, MainStem, Cotyledon, MainLeaf, ChildNode, and ChildLeaf. In the Weather class, it is devoted to knowing the influence of the weather or in other words exposure to sunlight that is around the environment of the research object.

![Figure 3. Model of PCM structure using Class Diagram](image)

To know how the process of DSM using method fuzzy logic can produce decisions based on the model that has been made. For an overview of the algorithm, this model is made using the activity diagram so that process activities can be more clearly displayed on the system and can assist in understanding the overall process. The activity diagram of this algorithm model can be seen in Figure 4. It can be seen in Figure 4 that the first time the modelling process to produce this strategic decision began. It was done by the virtual
model development of this Basil plant (*Ocimum Basilicum P.*) until it harvests; where the virtual modelling simulates the plant growth from seedling to harvesting period within the GroIMP software, as explained earlier in this chapter. After the growth simulation has been generated perfectly, then the data that affects the basil plant growth pattern will be gathered collectively. The data type that affects the plant growth pattern was illustrated using class diagram in Figure 3.

![Diagram](image)

**Figure 3.** An Algorithm Model of Plant Growth for PCM using Activity Diagram

### 3. Results and Discussions

As mentioned in hydroponic paragraphs in section 2, this research was conducted using wick system as the cultivation hydroponics technique. And had also mentioned previously in class diagram in section 2, that this generated model will consists of 6 main sub-classes for its plant model. Those sub-classes are Seed, MainStem, Cotyledon, MainLeaf, ChildNode, and ChildLeaf. The dataset was documented daily within 60 days’ periods which is a common planting period for Basil Plant.

As described previously in class diagram section, that the plant model will be constructed upon 6 class with several parameters to support trend line equation in visualizing its growth. This rule-based process was running recursively according to a given day that was formerly initiated as 60 days. This paper will
only cover the overall algorithm, whereas the bending corner, angle and other algorithm related to its growth is not included in this paper due to the page limitation. The full code will publicly available soon and we will inform as this paper published. For the overall concept of the XL programming in this study depicted in the Pseudocode Code 1.

Pseudocode Code 1. The Whole concept of XL Programming in the Study

```plaintext
// Seed
Seed(age, angle, level), (day < seedStop) ==> Seed(age, angle, level);

// Seed => RootStem
Seed(age, angle, level), (day == rootStemStart) ==> Seed(age, angle, level)
RootStem(age, angle, level);

// RootStem => Cotyledon => MainStem
RootStem(age, angle, level), (day == seedStop) ==> RootStem(age, angle, level)
[ Angle(-) Cotyledon(age, angle, level)
  Angle(+) Cotyledon(age, angle, level) ]
MainStem();

// MainStem => MainLeaf => ChildNode => ChildLeaf => MainStem
MainStem(age, angle, level), (day == mainStemStart) ==> MainStem(age, angle, level)
[ Pivot(+) MainStem(age, angle, level)
  [ Angle(-) MainLeaf(age, angle, level)
    [ Angle(-) ChildNode(age, angle, level) ChildLeaf(age, angle, level) ]
    [ Angle(+) ChildNode(age, angle, level) ChildLeaf(age, angle, level) ]
  ]
  [ Angle(+) MainLeaf(age, angle, level)
    [ Angle(-) ChildNode(age, angle, level) ChildLeaf(age, angle, level) ]
    [ Angle(+) ChildNode(age, angle, level) ChildLeaf(age, angle, level) ]
  ]
];

// ChildNode => ChildLeaf => ChildNode
ChildNode(age, angle, level), (age == childNodeStop) ==> ChildNode(age, angle, level)
[ Pivot(+) ChildNode(age, angle, level)
  [ Angle(-) ChildLeaf(age, angle, level)
    [ Angle(-) ChildLeaf(age, angle, level) ]
    [ Angle(+) ChildLeaf(age, angle, level) ]
  ]
];
```

This plant modelling simulation was built for the Basil Plant. It was managed to simulate the growth of this Basil plant respectively for a given days and achieved a quite similar value to onsite documentation that had gathered. As can be seen in Figure 5, which on the upper part of the figure represents the documentation of our dataset; and the lower layer of the figure represents the simulation using GroIMP software. On other our ongoing project, we attempted to arrange the research to focus more on the dynamic of bending corner and angle while maintaining the standard deviation. This so-called "bending" effect on each sub-stem happened either affected by gravitational activity or acclimation to changing light conditions. And this event often happened either because the stem was too thin and appears to have some teardrops.
perch on its cotyledon or the source of light was pointed in an opposite direction. The bending equation used will be described in detail in the next sub-section along with other calculated parameters related to its growth.

Figure 5. Comparison of the model (virtual plant) and gathered image dataset respectively with 10 days interval

The method in creating the growth formula for this model is rather simple but quite effective and providing an accurate graph line according to the data points. The excel "Trend line Equation" tools providing us formula that finds a line that fits into each data points. The selection on trend line type is based on the accuracy of the generated model while using the equation. After some empirically study, finally the best possible equation with the smallest possible deviation value was concluded [22]. Formula for deviation value is described in Equation 1. The description of all plant organs’ mathematical equations is presented in Table 1.

\[
\sigma = \frac{|N_{\text{model}} - N_{\text{reference}}|}{N_{\text{reference}}}
\]  

(1)

Table 1. Trend line Equation of each plant components based on deviation values

| Class      | Component | Trend line Type | Trend line Equation         | Deviation (\(\sigma\)) at Harvest day (day = 60) |
|------------|-----------|----------------|-----------------------------|-----------------------------------------------|
| Seed       | Length    | -              | constant value              | 0.0000                                        |
|            | Width     | -              | constant value              | 0.0000                                        |
| Cotyledon  | Length    | Linear         | \(y = 0.2377x + 2.2933\)    | 0.0048                                        |
|            | Width     | Linear         | \(y = 0.2873x + 1.0291\)    | 0.0620                                        |
| Internode  | Linear    | Linear         | \(y = 0.0446x - 0.0238\)    | 0.0733                                        |
| Internode  | Width     | Linear         | \(y = 0.0179x + 0.0205\)    | 0.1560                                        |
| Angle      | Linear    | Linear         | \(y = 2.4654x + 46.937\)    | 0.0000                                        |
4. Conclusion
This collaboration between FSPM and GroIMP is a technique and modelling platform software that we utilized to build our model decision, respectively. By using Basil plants (Ocimum Basillium P.) as our research object which contains antibacterial substances that potentially replace commonly used alcohol hand-sanitizer, which for some minors had a sensitive skin when in contact with alcohol-based hand sanitizer. For future study, we also have an undergoing research that could answer whether harvesting a basil plant on a given scale was a good investment rather than other option related to agricultural sectors. With 23 parameters gathered upon our own dataset documented in a daily basis. The model achieved an accuracy ranging from 0.00 – 0.48 with a visualization that looks similar to the images we had gathered as you can see in Figure 5. Some possible improvements in this study including a better granularity in its deviation, if possible the model could have a better deviation result in a daily basis assessment. A more dynamic and reliable trend line that could maintain accuracy above 60 days might provide a superb PCM accuracy. The acclimation to changing light positions was not included in the study on bending mechanism. It is an opportunity to be enriched in the next study. Furthermore, the developed model could provide a better projection for farmers and stakeholders before working directly on site to prevent further investments loss. And especially among academics, the constructed model could give researchers insights into how the plants work or how it was possible that this L-System could give a more clarity on plant modelling.

References
[1] Pertanian S J K 2019 Statistik Lahan Pertanian Tahun 2014 - 2018 (Jakarta)
[2] Manida M and Ganesha M K 2021 New Agriculture Technology in Modern Farming - Plug and Play Tech Center International Journal of Management Research and Social Science (IJMRSS) 8 109
[3] Shamshiri R R, Kalantari F, Ting K C, Thorp K R, Hameed I A, Weltzie n C, Ahmad D and Shad Z 2018 Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture International Journal of Agricultural and Biological Engineering 11 1–22
[4] Viviano F 2017 This tiny country feeds the World National Geographic
[5] Renton M 2013 Aristotle and adding an evolutionary perspective to models of plant architecture in changing environments Frontiers in Plant Science 4

[6] Utama D N 2015 The Optimization of the 3-d Structure of Plants, Using Functional-Structural Plant Models. Case Study of Rice (Oryza sativa L.) in Indonesia Environmental Informatics (PEI) of the Georg-August University School of Science (GAUSS)

[7] Prusinkiewicz P and Runions A 2012 Computational models of plant development and form New Phytologist 193 549–69

[8] Cahyani N M E 2014 Daun Kemangi (Ocinum Cannum) Sebagai Alternatif Pembuatan Handsanitizer KEMAS: Jurnal Kesehatan Masyarakat 9 136–42

[9] Peter K V. 2012 Handbook of herbs and spices

[10] Anon Template:COVID-19 pandemic data Wikipedia

[11] Sharma N, Acharya S, Kumar K, Singh N and Chaurasia O P 2018 Hydroponics as an advanced technique for vegetable production: An overview Journal of Soil and Water Conservation 17 364

[12] Lindenmayer A 1968 Mathematical models for cellular interactions in development I. Filaments with one-sided inputs Journal of Theoretical Biology 18 280–99

[13] Prusinkiewicz P and Lindenmayer A 1992 The Algorithmic Beauty of Plants (Przemyslaw Prusinkiewicz and Aristid Lindenmayer) vol 34 (Regina, Canada: Springer-Verlag)

[14] Fabrika M, Scheer L, Sedmák R, Kurth W and Schön M 2019 Crown architecture and structural development of young Norway spruce trees (Picea abies Karst.): A basis for more realistic growth modelling BioResources 14 908–21

[15] Smith A R 1984 Plants, fractals, and formal languages Computer Graphics (ACM) 18 1–10

[16] Anon 1994 Grogra.de Documentation Georg-August University

[17] Zhu J, van der Werf W, Anten N P R, Vos J and Evers J B 2015 The contribution of phenotypic plasticity to complementary light capture in plant mixtures New Phytologist 207 1213–22

[18] Merklein J, Poirier-Pocovi M, Buck-Sorlin G H, Kurth W and Long Q 2019 A dynamic model of xylem and phloem flux in an apple branch Proceedings - 2018 6th International Symposium on Plant Growth Modeling, Simulation, Visualization and Applications, PMA 2018 (Institute of Electrical and Electronics Engineers Inc.) pp 50–5

[19] Ondřej Š and Jiří S 2010 The Sibyla model and development of beech forests affected by air pollution Central European Journal of Biology 5 371–83

[20] Fournier C, Andrieu B, Ljutovac S, Saint-Jean S and Saint-Jean S 2017 ADEL-Wheat: a 3D Architectural Model of wheat development

[21] Fournier C and Andrieu B 1999 ADEL-maize: An L-system based model for the integration of growth processes from the organ to the canopy. Application to regulation of morphogenesis by light availability Article Agronomie 19 313–27

[22] Hartanto M and Utama D N 2020 Intelligent decision support model for recommending restaurant ed S Tomasiello Cogent Engineering 7 1763888