APPLICATION OF VORONOI DIAGRAM AS TREEHOUSE DESIGN TOOL

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ABSTRACT

This paper aims to study the application of Voronoi diagram to generate the form of treehouse as permanent housing that retains the original trees configuration in the city forest. Design problems arise from the natural pattern of the existing trees configuration inside the research location. The treehouse must be integrated with existing trees configuration and occupy the maximum space between the trees. The development of treehouse design will be utilized with generative method. Then, the data in the form of parameters applied using 3D Voronoi diagram to generate treehouse form that occupy the optimum space between the trees.

Key Words : Treehouse, Voronoi Diagram

1. INTRODUCTION

1.1 Background of Research

The increasing need for residential houses become one of the major causes of deforestation in Balikpapan. The existing trees of city forest must be conserved wahile accomodating the housing needs. Residential treehouse that retains the original trees and make the tree as a point of design development was proposed to solve that problem. Design problems arise from the natural pattern of the existing trees and user's constantly changing activity space requirements.

The most important aspect from design process is the consideration of existing tree configuration in identification and formulation of the spatial patterns that formed between the existing trees. In formulation of the spatial pattern, one of the generative design method, voronoi diagram, was considered as the most suitable method. This methods rely on identifying the nature of processes and principles of self-organization in biological structures and their representation using mathematical models that may apply in architecture. As the result, voronoi diagram elements have meaningful role in shaping some of the contemporary architecture and urban planning. The development of computer technology also has made it possible to create more complicated structures and surfaces inspired by natural forms (Nowak, 2015).

There are several methods commonly used for analysing space, such as Space Syntax, Datascape, and Voronoi Diagram. Space syntax has been used to help architects simulate the effects a designs on the subjects who occupied and make activities in them, either buildings or urban settlements. It can also be applied in a variety of research areas and practical applications including architecture, criminology, IT, urban and human geography, anthropology, and cognitive science (Hiller, 2007). The Datascape method was developed as a response to the need of objectivisation of the architectural design and the option for increased rational evaluation. Datascape is not mere data visualization, it can extrapolates formal spatial realization of the assumptions data behind them. These resulting unexpected forms beyond imagination representation of known geometries and create abstract meaning of the specific datasets (Evans, 2011).

In this paper, voronoi diagram was chosen and will be applied to analyse and generate the form. One criteria can be achieved by voronoi diagram in designing treehouse is the form can fill the maximum occupancy between the trees. The site at MT Haryono street, Balikpapan Utara, Balikpapan, Indonesia (Figure 1) was chosen as research case study.

(a) (b)

Figure 1. (a) Site Geo Location; (b) Existing Site Location (wikimapia.org)

1.2 Aims of The Study

This paper explores emerging geometries of three-dimensional Voronoi polyhedra in terms of their properties as space filling method. This task focuses on how this method can be applied in the context of treehouse design process. Similar to prior approaches, the motivation to become engaged with the Voronoi diagram is its potential for complex unexpected geometries. However, it is unclear whether the Voronoi cell geometry can be controlled sufficiently to generate the form.

2. THEORITICAL REVIEW

2.1 Treehouse

There are several definition of treehouse. The word 'treehouse' and phrase 'tree house' are synonymous. The Oxford English Dictionary defines a tree house as: "A structure built in the branches of a tree for children to play in." A treehouse define as: "A structure built in or around a tree which interacts with, and relies upon, the tree for its support. A treehouse consists of a platform with roof element that define a sheltered space which may be fully enclosed for protection from the surrounding." (Fulton, 2015). Among the treehouse builders, there are several opinion about the amount of ground support permitted for a structure to still be called as a treehouse. Some builders say a treehouse must be fully supported by the tree while others say some ground support is allowed as long as the structure interacts with the tree for most of its support. There are several opinion about treehouse definition and requirements, but it can be concluded if any of the following does not apply, the structure will not be consider to be a treehouse:

1. The treehouse is not fully ground supported, if the tree passes through the structural parts. The treehouse must have interaction with the tree.
2. The tree support must structurally critical. the structure would not stand if the tree was removed.
3. The structure/platform must has roof. It should be a protected from its surrounding.

2.2 Tree Architecture

Tree architecture is the result of growth by the apical meristem tissue (main bark) that will form a pattern on the tree branching and continued with the same loop. Certain tree species will have certain patterns also in the growth of branching form certain models (Tomlinson, 1986).

The shapes of trees that are in the same group of biology, tend to naturally similar in shape and architectural patterns (Tomlinson, 1986). The models of tree architecture comprises 23 models (figure 2) for the types of trees and other forest vegetation encountered as a model in forest trees in tropical areas. Further explanation, tree architecture is an abstraction of a genetic tree by a plant since the start of growth, tree architecture is different understanding of the pattern of growth, habitus and forms a header. Tree architecture is the shape of the end product of a pattern of behavior apical meristem growth, size or habitus is not a differentiating factor for tree with herbs may have an end result similar growth patterns of behavior (Halle and Oldeman, 1978).

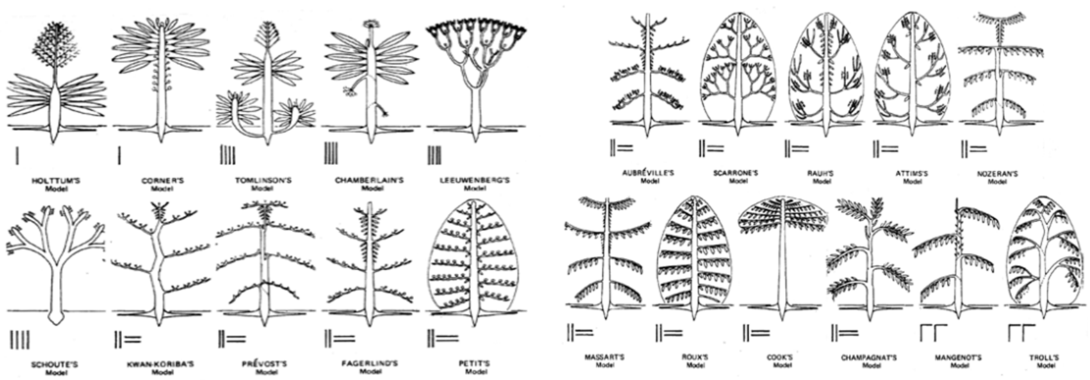
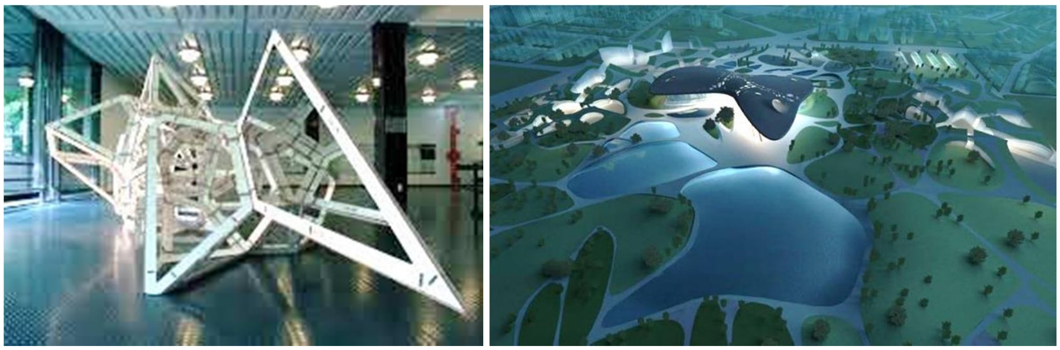


Figure 2. Tree Architecture Models (Halle and Oldeman, 1978)

2.3 Voronoi Diagram

There are already several research regarding exploration of the Voronoi diagram under specific consideration of its geometrical properties rather than its cell topology. The Voronoi structure has been used as a tool for form finding, M-any is a research project in Zurich which explores the formal spectrum of emergent geometries of a parametrical Voronoi structure (Figure 3a). Process control parameters, are related to topological aspects of the cells in the first place. This geometry is rarely limited, but sometimes have unexpected results as well. The work of these researchers is like the work of architects such as Toyo Ito, Fuller or Frei Otto, that is inspired by formation principles, geometries, spatial effect and constructions in nature (Friedrich, 2008). Other project known is Kaohsiung National Centre for the Performing Arts. The building was designed by Zaha Hadid in a competition. She used Voronoi diagram to analyze the relationship between the environment and site data. Visitors access points are controlled using data on the site such as trees, monuments and borders. The area around points, which is created by the analysis of the relationship between space and the site, is connected to the main flow of human traffic, so that it becomes a tool for space traffic control (Figure 3b). Deformation of visual data and canopie, roofs and facades designs is derived from the Voronoi diagram (Park et al., 2008).



(a) (b)

Figure 3. (a) M-any: Parametric design based on the Voronoi diagram (Friedrich, 2008); (b) Existing Site Location (archilovers.com)

The Voronoi diagram is a graph that consist from cells created by the edges and nodes of the Voronoi diagram an equidistant point from at least three centers. The diagram built up from segments and half lines which constitute and perpendicular the edges of Voronoi areas for each of the centers (Tomaszjaniak, 2011). The Voronoi area is defined for each center as a set of points on the plain which are closest to a given center. The Voronoi diagram is defined for a given set of n points as plain divided into n areas in such a manner that each point in any cell is closer to a specific point from a set of n points than the remaining n-1 points. In two-dimensional space, the Voronoi cells are convex polygons, in three-dimensional space they form convex polyhedral (Nowak, 2015). Voronoi tessellation defined as one of the most fundamental data structures in computational geometry, that is used for modeling natural phenomena and study of their mathematics, especially geometry, combinatorial and stochastic properties and their calculation representative. Also suggests various methods for clustering multidimensional data (Park and Jun, 2008).

The main reason voronoi diagram was used in this paper is that the voronoi diagram enables dividing a multi-dimensional space into subspaces. Its application is defining equivalent geometric areas by defining different vectors/line as the center of sub-spaces. Any other vector in the space can be related to the most closely center vector which divides the whole space into sub-spaces effectively, the result is an best choice for splitting spaces. In the application to form a treehouse, it is important t mixímize the space that can be generated.

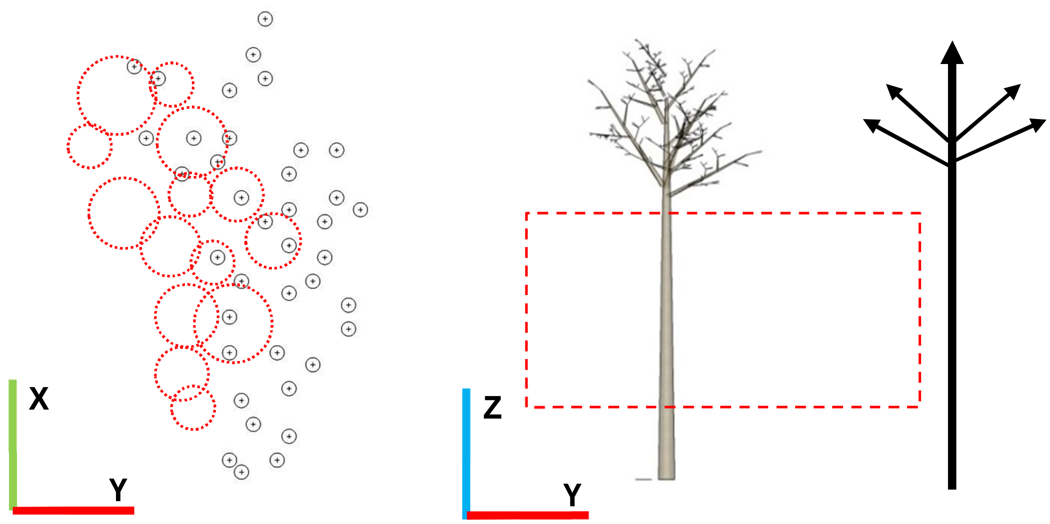
3. METHODOLOGY

The treehouse generative method that utilize by voronoi diagram was applied at the points of the existing trees on the location to generate tha maximum space occupancy. The software used in this paper is using Trial version of Rhinoceros and Grasshopper Plugin, developed by Robert McNeel & Associates . Each point is connected using voronoi diagram to locate geometric patterns between the trees. This imaginary connecting lines are useful for determining the occupicable area which coud be applied to the design. After finding the patterns, the design develop by seeking the most appropriate and optimum geometric form. The basic shape developed into an advanced form more complex shapes by combining the basic geometric shapes and adapted to the broad needs minimal space occupancy. The effective range of a viewable area of the Voronoi cells are formed and the distances between these sites nearby. Making the Voronoi diagram with a mix of search methods and testing distance Voronoi point Voronoi diagram using circles so that the right can be established.

4. ANALYSIS AND DISCUSSION

4.1 Existing Tree Characteristics

Based on the observations, the tree that occupied all regions in site, relatively homogeneous and mostly consists of Meranti Trees (*Shorea bracteolata Deyr*). Meranti tree species can be classified into 'Massart Model' growth pattern. From the study, there are some limitations from the X axis and Y axis (Figure 4). The distribution pattern of tree resulted areas that formed differently in different place.



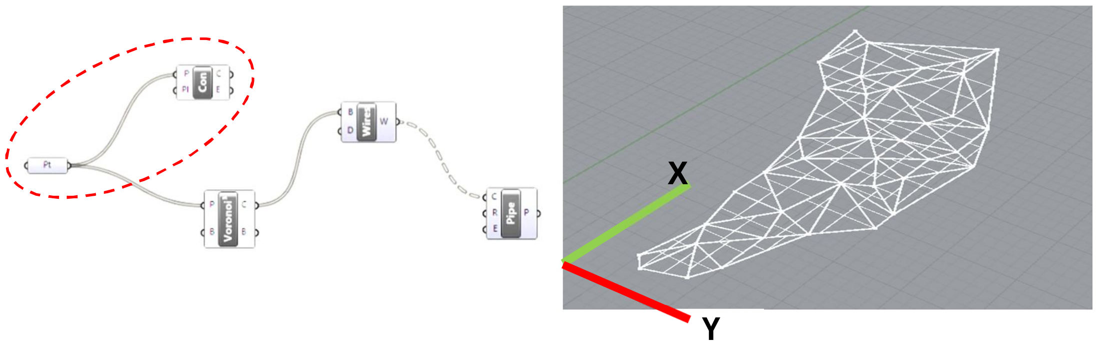
(a) (b)

Figure 4. (a) Imaginary Space between tree coniguration in X,Y axis; (b) Growth Pattern and Space avaliable in Z axis

The analysis of existing trees observation shows the most potential for the development of space units maximum is vertically due to the growth of tree trunks monopodial continuously and does not intervene the space between the tree vertically.

4.2 Tree Configuration

This phase includes the identification of the space that formed inside the existing position of the trees, advantages and disadvantages, and the tendency of the area of a triangle inside the pattern. The form of triangulation synthesized to be the set of parameter for determining the position of a point (Figure 5b). This point will be generated to form a Voronoi cell, so that the basic form of this will be developed into a treehouse space.



(a) (b)

Figure 5. (a) Delaunay Triangulation algorithm; (b) Generated triangulation of existing tree configuration

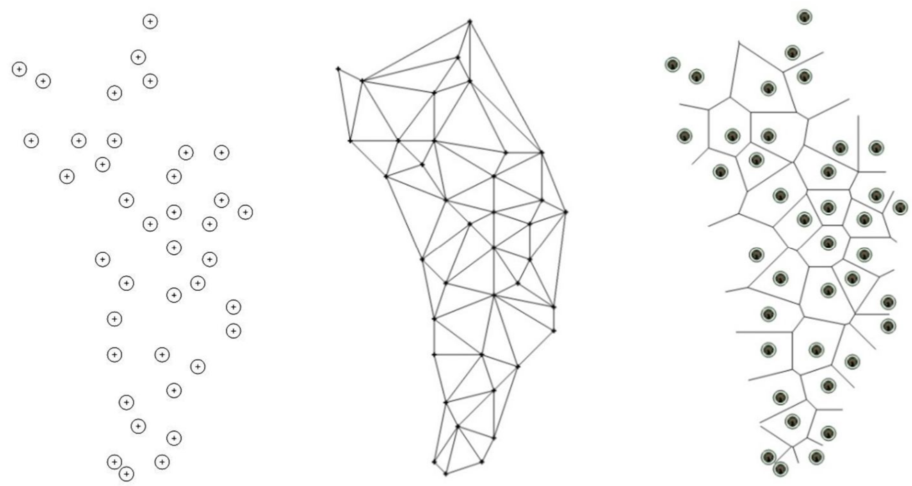
According to the results of triangulation points trees, found a range of parameters and formulation of existing patterns of trees:

- Each point of the tree in the middle of the trees has 4 to 6 points connections.
- Each point linked and separated by distance of 2 meters up to 8.5 meters.
- Area of triangle formed inside the pattern varies from 2.5 m2 to 16.5 m2

From the observation result, it shows that most of the space that formed between the trees has meet the minimum requirements for minimum housing as regulated by Ministry for Public Housing in Indonesia (Fitriani, 2007). Some space that doesn't meet the minimum requiements must be separated in elevation to make the appropriate minimum space for accomodating housing activities.

4.3 Voronoi Application

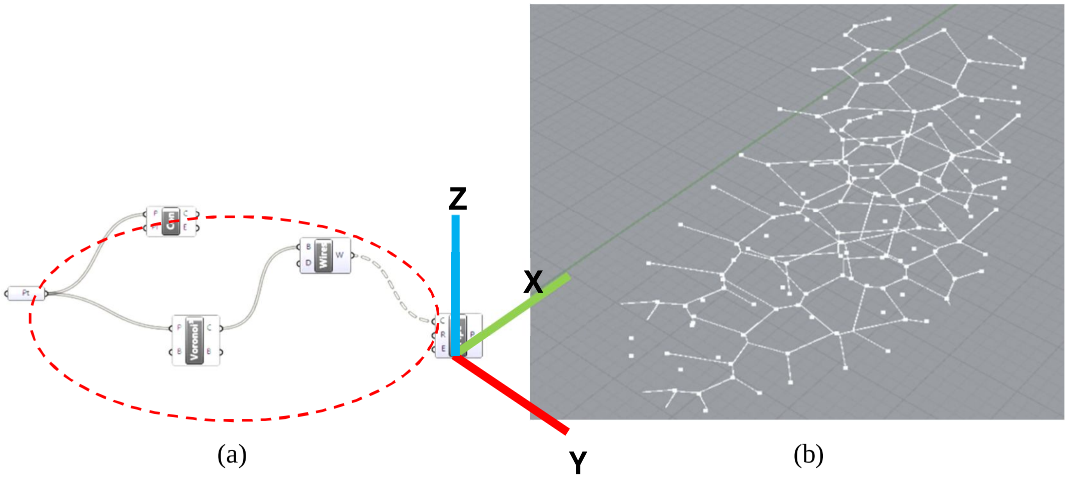
First, the sets of point of the existing configuration must be applied (Figure 6a). Second, Delaunay Triangulation applied to study the space and distance between the trees to get which area between the trees can or can not engaging spaces for house activities. These step resulting the set of rule and parameter to control the generation of voronoi diagram (Figure 6b). Voronoi diagram get the patterns and pathways found in between the trees. The Voronoi diagram can be a reference to develop treehouse space between the lines. According to the needs placing residential space, a Voronoi diagram is used to find the effective range of the area around the tree and becoming residential units (Figure 6c).



(a) (b) (c)

Figure 6. (a) Existing Tree Coordinates; (b) Triangulation Result; (c) Voronoi Diagram 2D

From the generated voronoi 2D diagram, each vertex has occupy the exact place in the center of each trees. The tree coordinate located as parameter to generate voronoi diagram. The points that occur will be elevated by placing the point of the top and bottom coordinate of each tree. At the point that filling the space, the two-dimensional voronoi point shifted into the Z axis to form 3 dimensional space (Figure 7b). Based on the pattern of two-dimensional Voronoi which has been formed, it was found that a Voronoi point of intersection of the respective maing Voronoi lines and adjustable height with a number of different points (Figure 7a).



(a) (b)

Figure 7. (a) Voronoi 2d Algorithm and (b) generated points of tree configuration using voronoi diagram and separated in two elevation

After all these steps, we can predict that voronoi 3D diagram will occupy the optimum space between the trees and expected the achievement of criteria in this study. However, as i already mention earlier, it still can not be expected how and what shape it will occur after the application of Voronoi diagram.

5. RESULT

5.1 Voronoi Spatial Form

This tree house form (Figure 8) is the result of Voronoi algorithm with two ponts in the Z axis parameters based on altitude set by applying a standard height of from the study. In this configuration, the space formed by Voronoi cells divided vertically and horizontally, to optimize the volume and quantity of voronoi cells.

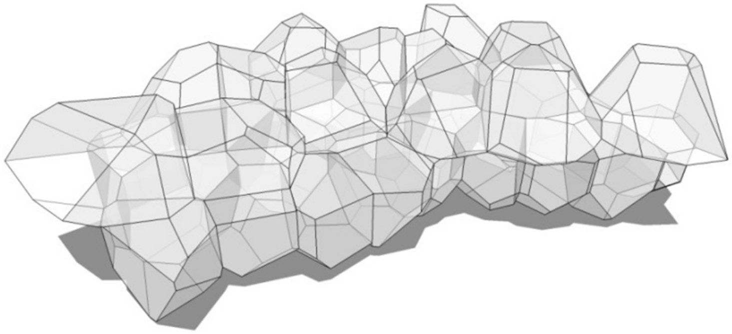
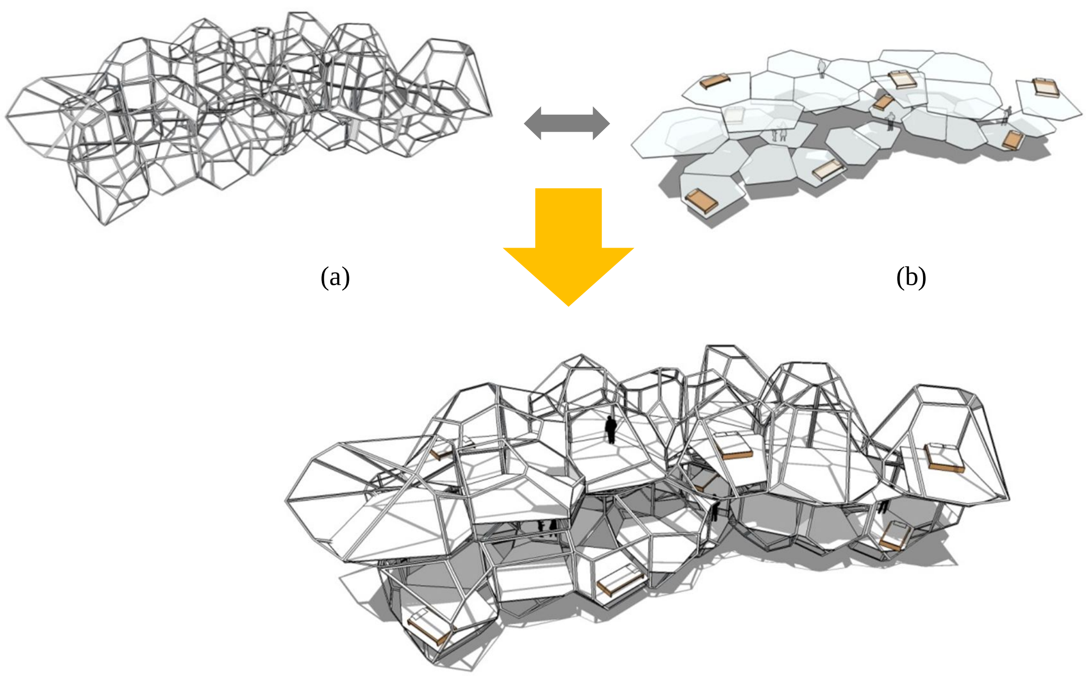


Figure 8. Voronoi Bubbles Result

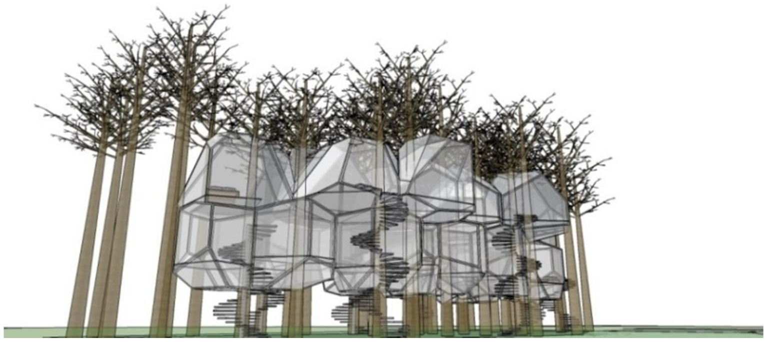
5.2 Treehouse Design Development

The voronoi application has formed an optimally space that occupy the space between the existing trees. The result of 3 dimensional voronoi cells will be developed to become the space to form the treehouse. The edges of voronoi bubbles will be generated to form the space structure (Figure 9a), so that the space inside the bubble can optimally used as activity container inside the treehouse (Figure 9c). From the structural result, the patform was made from the widest area that can be made horizontally.



(a) (b)

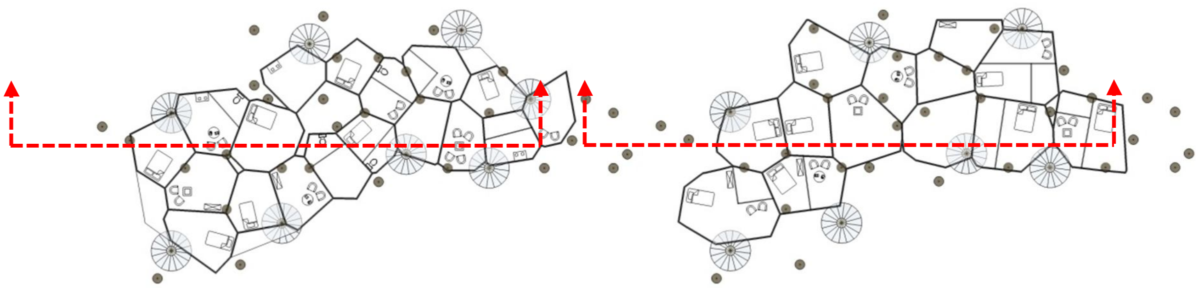
(c)



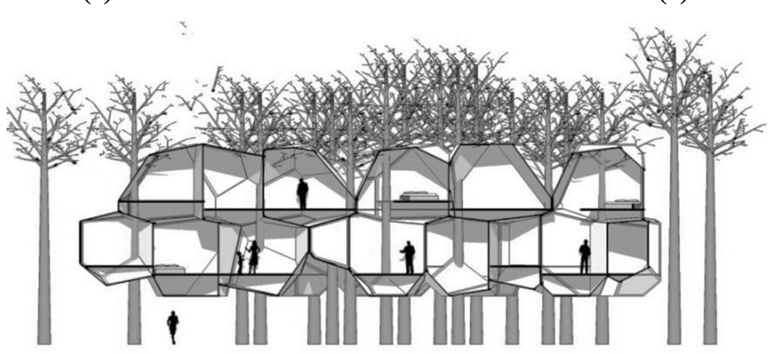
(d)

Figure 9. (a) Treehouse Space Frame; (b) Treehouse Platform; (c) Axonometry of Treehouse; (d) Treehouse's schematic view Treehouse; (d) Treehouse's schematic view

Further design development shows that the space formed by voronoi bubbles can contain the requirements for a housing space and activity. Each of voronoi diagram may varies in shape and area depend on the tree location and elevation (Figure 10c). From the user's activity, the voronoi cell divided to accomodate the romm requirement. The spiral stair was proposed to become user's acces to enter te treehouse. The layout shows every tree located in each unit perimeter and indicating the maximum space occupation,



(a) (b)



(c)

Figure 10. (a) Section Plan from +3.00 Elevation; (b) Section Plan from +6.50 Elevation; (c) Treehouse's Section View

6. CONCLUSION

Design integration with nature is an important aspect from design consideration. It is particularly important to design based on the formation of existing tree configuration and understand the processes occured form the nature and formulate them appropriately in order to apply these models into architecture. The space between the trees can be formulated and identified using voronoi diagram. The result generated from voronoi bubbles automatically fill the optimal space between the trees. Voronoi diagram implementation in the design development of treehouse, in particular the structural forms and structural elements, allows for an optimal design and a variety of spatial forms.

7. ACKNOWLEDGEMENT

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