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EXAMINING THE USE OF VORONOI DIAGRAMS IN ARCHITECTURE ON A STUDENT PROJECT

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Abstract
Inspiration from nature in the design process is a very widely used method. Architects and designers take advantages of aesthetic features and structural systems of the objects found in the nature. Voronoi diagrams also known as Voronoi tessellations emerge at different scales in nature's cell structures, honeycomb and animals fur patterns. Architects and designers use this diagram to obtain a more organic looking design, rather than imitate directly from nature.

The Voronoi diagram is a mathematical formula used in many scientific fields and use of that goes as far as Descartes. The Voronoi diagram is a system that divides the space into sub-spaces in an organic way. The diagram uses points to create cells that surround these points. Points can be placed as spontaneously or can be determined in the direction of a certain data and tessellation can be provided accordingly. Use of Voronoi diagram in fields such as architecture and urban design has increased with the widespread of use of parametric design in architecture. Architects use the Voronoi diagram especially to obtain an organic structure and natural pattern in facade designs. In the academic field, new possibilities that use of the Voronoi diagram can provide for urban design and spatial design are being evaluated.

Use of the Voronoi diagram in architecture and its spatial possibilities were investigated in architectural project course. The subject of the project is to design culture street between two faculty buildings within their campus. The project aimed to design a street with a program consisting of 40 teacher rooms, 10 student club rooms, book sales place and seminar hall. The project theme has enabled this diagram to be used both in the urban space and in the architectural project.

This study mainly focuses on the architectural uses of Voronoi diagrams and to explore new opportunities that this diagram can provide. In this context, entire design process which began with site analysis to space organization and facade design the Voronoi diagram is used will be presented. In this study, the use of Voronoi diagrams in the architectural design process has been evaluated through the experience of architectural project course.
Key Words: *Voronoi Diagram, Space Organization, Parametric Design, Architecture*

1. Introduction

Using computers by designers provides to explore new opportunities in the design process. Parametric design process presents data for architects and designers and also crucial contributions in order to generate alternatives and solutions via parameters. Voronoi diagrams are a parametric design tool that used often in spatial and urban planning in recent years.

Voronoi diagrams and its general characteristics and usage areas in different disciplines were referred within this study in order to understand the usage of Voronoi diagram in spatial and urban planning. Information about usage area of diagram in architecture and urban design and also design process was represented. The usage of diagram in different concepts was exemplified by reviewing and examining of a research project that performs Voronoi diagrams, a well-known building, an urban design project and a competition project.

Finally, student project process and usage of diagram in this process was illustrated and design process was evaluated with examined examples in the conclusion part of the study.

1.1. Definition of Voronoi Diagrams

Voronoi diagrams are widely used in many fields such as anthropology, astronomy, archaeology, biology, cartography, chemistry, computational geometry, crystallography, ecology, forestry, geography, geology, marketing, metallography, meteorology, operations research, physics, physiology, remote sensing, statistics, urban planning and architecture. Voronoi diagrams can be used to understanding the structure of the Universe in astronomy, estimating precipitation process in meteorology, locating public schools in urban planning.[1]

The first use of Voronoi diagram was seen in the disposition of the solar system and its environs written by Descartes in 1644. In 1854, Dr. John Snow used Voronoi diagrams effectively to detect the Broad Street Pump causing the cholera outbreak. Dr. John Snow created zones on the London map according to equal distances between the Broad Street Pump and other pumps, and the death rate from cholera in zone of the Broad Street Pump was much higher.[1]

According to Aurenhammer [2] Voronoi Tessellation is "one of the most fundamental data structures in computational geometry." Voronoi diagrams are an organizational phenomenon creates unique modular structure that various complicated geometries can be used. [3]

Voronoi diagram is a formula that divides space into the regions according to the specified points. Regions are generated by associating each point with the closest points. These points are defined as Voronoi cells. Voronoi diagram consists of Voronoi cell, Voronoi space that surround Voronoi cell, Voronoi vertex and Voronoi foam. [4]

Delaunay Triangulation or Delaunay Tessellation described as dual graph of Voronoi Diagram. [5] (Fig. 1.) Delaunay Triangulation occurs with the joining of the neighboring points that generates Voronoi cells.

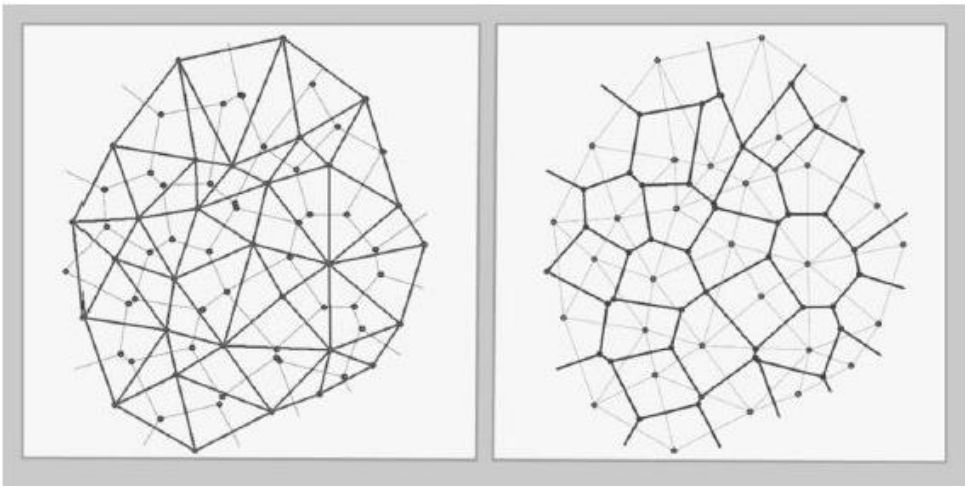


Fig. 1. Delaunay triangulation and Voronoi diagrams [5]

2. Use Of Voronoi Diagrams In Architecture

2.1. Redevelopment of the Glorieta Juan Carlos I

Esc Studio won the competition for the Redevelopment of the Glorieta Juan Carlos I with a proposal by using software that implements Voronoi diagrams for spatial planning. (Fig. 2.) The software was used throughout public consultations so that people participated in the design process with their proposals. The software was used throughout public consultations. With this software participation of people provided to design process by sharing their opinions. Voronoi diagram was used to divide the square into circulation areas and activity places. These circulation areas connect directly the city and center of square while preserving existing vegetation. Activity places were formed by a step up of the Voronoi cells. The use of children and elderly people has been considered when designing the activity places. These places enable to perform various activities. [6]

The ESC studio also proposed sustainable climate systems with their project. Air conditioning units supported by photovoltaic cells, lighting and fog units can reduce temperature of the square in summer. [6]

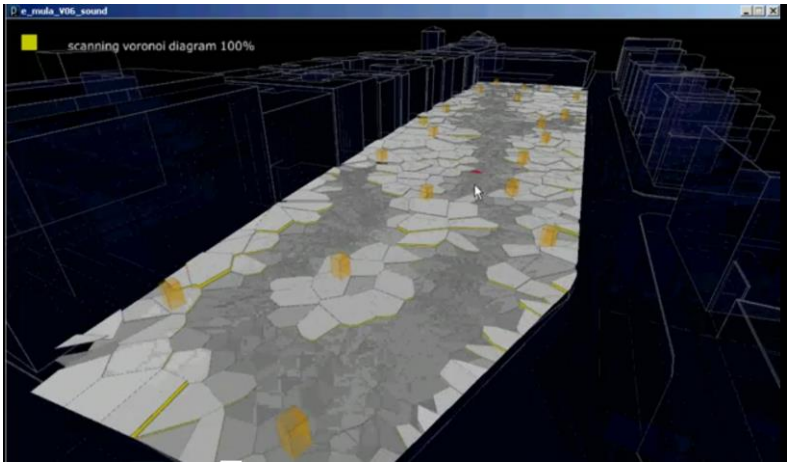


Fig. 2. Esc Studio's proposal[6]

2.2. National Kaohsiung Performing Arts Center

In the proposal of Zaha Hadid, it was aimed to build an open green connection considering the locally precious trees, historical buildings, boundaries in the site. Depending on these data, point distributions were generated. A pattern was obtained according to point distribution by using Voronoi diagrams. (Fig. 3.) In this way, It will be able to maintain the current situation of the site and provide strong public connections with the surrounding green areas. [7]

The building was designed by expanding the pattern created in the ground and the Voronoi pattern can be seen on all of the design from landscape to the structural details. Voronoi diagrams were shown in the roof and canopy form, in the all components of façade system and ventilation systems in the roof. [7]

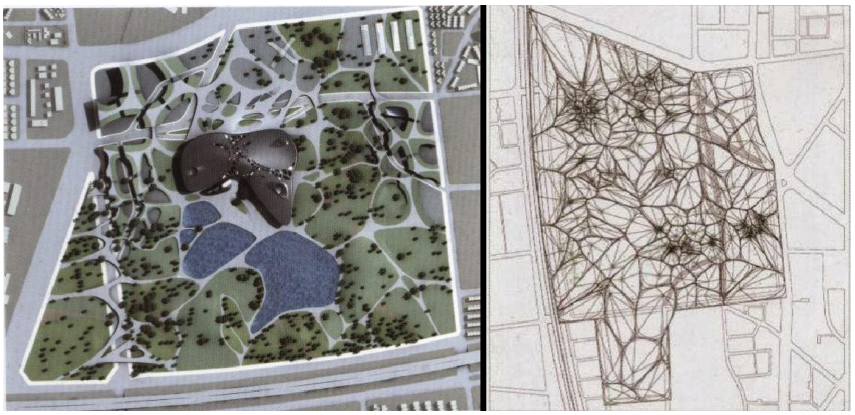


Fig.3. Site plan and Voronoi pattern [8]

2.3. Net Lab

NetLab is a research project focused on exploring the possibilities of parametric design architecture. Especially, the project examines how to construct a space from cell structures, according to the determined parameters such as user requirements, various scale and social systems. For this purpose, software which

contains representational tool, modeling tool, contextualizing tool, customizing tool and design tool was developed from Voronoi algorithms. [9]

Initially, x,y and z-coordinates of points was defined in the software. These coordinates obtained through analysis of site, user data and program input. The points located at different z-coordinates, represent people in different levels. The areas of the spaces, the number of people and program were defined in the software; volumes, structural networks and surfaces were emerged as a result. The software allows to editing the result product, changing parameters and making adjustments. [9]

Horizontal surfaces are created by using algorithmic adjustments by joining points close together. Circulation among the cells placed according to the hierarchy parameter was formed by offsetting cells, deleting cells, adding curves to cells. The different sized grids formed between cells can be used both as internal walls and façade system. [9]

2.4. Water Cube

Beijing National Aquatics Center also called Water Cube was designed for a competition for Beijing 2008 Olympic Games. The consortium formed by PTW Architects has won the competition with their project proposal, which combines the bubble form which symbolizes water and symbolism of square that important in China culture. [10]

The outer shell of the building is designed based on natural structure of the soap bubbles. (Fig. 4) The entire shell consists of 4000 bubbles. The outer shell of the building is designed based on natural structure of the soap bubbles. These bubbles keeps inside the energy receives from the sun. Thus it makes enormous contributions to energy efficiency by using natural light for heating the interior space. [10]

Weaire-Phelan foam tessellation was used to generate the soap foam structure. Weaire-Phelan foam is a volume creation, division system based on Voronoi pattern. [11]

Fig. 4. Watercube [10]

3. Case Study: Design Process Of A Student Project

The project is a design for a culture street in the space between the buildings in the campus of KTO Karatay University. The objective of the project is to design 40 lecturer rooms, 10 student club rooms, book store and seminar hall with the street concept .

A design experiment of Voronoi diagrams was performed within the architectural project course with a student. Although the student did not have a skill to using parametric design tools, the project was conducted because of his decisive attitude for performing a design with diagrams.

Firstly, the student could find a website via internet browser to form Voronoi cells with javascript applet. [11] There is a divided pattern with predefined Voronoi diagram on the website. This pattern can be regenerated with a click. In the Figure 5, the predefined pattern and divisions occurred by clicking are presented. In this manner, divided cells transform into a pattern that occurs a street texture by becoming more different than undivided.

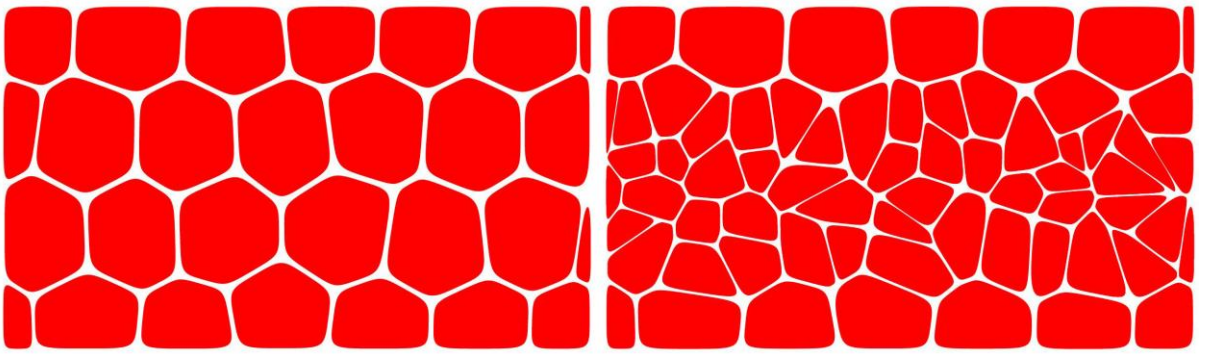
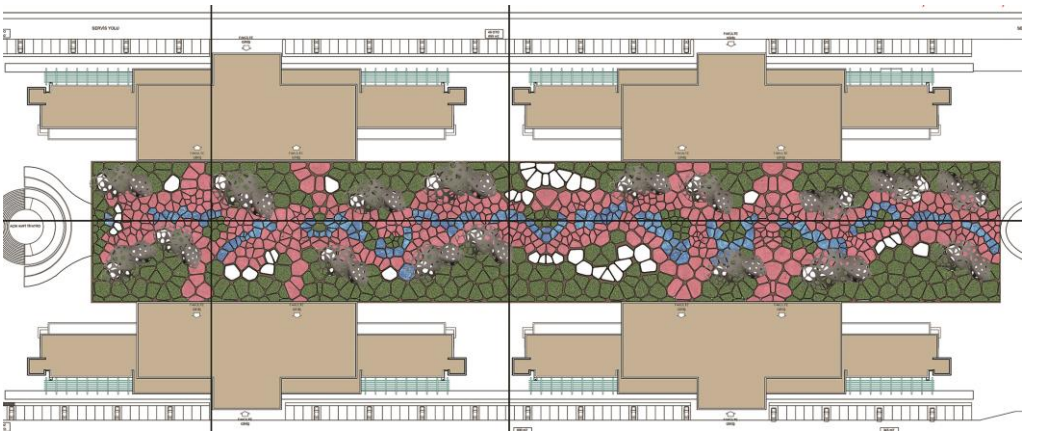


Fig.5. Predefined and modified pattern [12]

At the end of this process, a street texture was occurred with Voronoi cells. Architectural and urban planning is comprised of points that are obtained from environment data of Voronoi cells within the usage of this diagram. However, the student followed a different way in this point. He occurred these pattern via website and save as a image. Then he imported this image into architectural drawing program and he draw Voronoi pattern over the image. He had to perform too many experiments to equalize size of cells to the size in the program.

Street texture produced with the pattern created in the website. Voronoi cells were designed as hard ground, water features and grass depending on space. (Fig. 7) The sitting elements and buildings were formed by elevating the cells. Spaces bigger than Voronoi cells were occurred by compounding Voronoi cells.

Lecturer rooms that have single area were formed as raising ground texture. Generated organic form did not affect the usage of space adversely. However, the same fact was not discussed for seminar hall, which was



shaped by compounding and raising Voronoi cells. The pattern occurred by Voronoi diagrams was used for also in the façades. Some areas were covered by eaves and holes were poked on the eaves through Voronoi diagrams.

Fig.7. Site plan of student project

4. Conclusion

Voronoi diagrams are confronted as a parametric design tool, which is used often by architects and urban planners in the recent years. The usage of the pattern that is organic and non-droning and formed by Voronoi diagrams, occurs a great effect on this diagram. Besides, this diagram provides many advantages for architecture because of its opportunities by coding points and coordinates that obtained from space, requirements or program and then doing space planning. Also, tridimensional structures can be designed not only two- dimensional structure. In this context, it was proved with a NetLab research project that volumetric design can be shaped by using this diagram. Cellular structure system, which is designed as tridimensional, on Water Cube facade and roof allowed to use energy effectively with appropriate lining material and cultural refers.

This student project design process was conducted different from parametric design processes. However, similarities between final product and designs formed by algorithms were presented. Ground pattern is not based on certain parameters unlike examined projects. Voronoi diagrams provide flexible and alternative production opportunity for space arrangement, despite of occurring as randomly.

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