

2021

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Randa Ismail Taha Abdel Mageed Negm

Associate Prof., Department of Decoration, Faculty of Fine Arts, Alexandria University, Egypt,
randa.taha@pua.edu.eg

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Recommended Citation

Negm, Randa Ismail Taha Abdel Mageed (2021) "The Concept of "Voronoi Diagram" and its impact on the formation of Scenic Design," *International Design Journal*: Vol. 11 : Iss. 2 , Article 14.

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The Concept of "Voronoi Diagram" and its impact on the formation of Scenic Design

DR. Randa Ismail Taha Abdel Mageed Negm

Associate Prof., Department of Decoration, Faculty of Fine Arts, Alexandria University, Egypt,
randa.taha@pua.edu.eg

Abstract:

Science and mathematics developed with great leaps that affected the world, and as a result, new trends and concepts appeared based on the development of mathematics and computers. One of these concepts is the "Voronoi diagram". The new concept emerged as an important mathematical principle in the field of architecture, and the development of computer algorithms affected the concept of the Voronoi diagram significantly. The Voronoi diagram is one of the most common structural network systems in nature, due to its abundance in nature through plant and animal shapes, ground cracks, tree branches, and lines Blood vessels in humans, animal fur patterns, and beeswax tablets. Its use dates back to the year 1644 AD when Rene Descartes used it in describing the partition of space by means of the stars. And Johann Gustav in 1850 AD, while studying mathematical quadratic equations, the term "Voronoi diagram", taken from the name of the Russian mathematician Georgi Voronoy. Voronoi diagram varies in shapes and patterns and ranges from random to structured form. Architects and designers used the aesthetic features and structural systems of the Voronoy diagram inspired by nature and applied them to their various projects and designs; The research presents the idea of Voronoy diagram, their characteristics, and the different types of structures, which range from organization to randomness and their multiple uses in architecture. The research dealt with several practical examples that the architects were inspired by the diagram of Voronoi. The research also dealt with the application of the concept of Voronoi to furniture units through various design examples. The research proposes the idea of taking advantage of the different forms of the Voronoy diagram and how to benefit from them in designing different theatrical scenes suitable for sci-fi and fantasy performances, celebrations, fashion shows and other theatrical performances. use the application of "aesthetics of the concept of Voronoi" in designing Theatrical scenes range from simplification to complexity in design, and finally, at the end of the article, the results of the study.

Keywords:

Voronoi diagram
Scenic design
Architectural concept
Aesthetics.

Paper received on the 20th of November 2020, accepted 11th of January 2021, Published 1st of March 2021

Introduction:

The world witnessed a great development on the technical level that cast a shadow over computer science, and modern mathematical concepts appeared. All this development affected all different sciences and provided solutions to many problems through advanced mathematical concepts, one of the most important of these concepts are the "Voronoi Diagram". As an important mathematical principle in the field of architecture, with the development of computational algorithms (12), modern design engineering has interestingly helped the development of very complex spatial systems, inspired by patterns inspired by the natural world, including the concept of "Voronoi Diagram "".(16) The "Voronoi Diagram" system is one of the most widespread network systems in nature, due to its abundance in the forms of plants and animals, "in the crevices of the ground, branches of leaves and blood vessels in humans,

honeycombs, and animal fur patterns(3)," Its shape is between randomness and regularity, and as a result of its complex aesthetic compositions, architects and designers have benefited from the aesthetic features and structural systems of them in designing their architectural projects as a new source of inspiration (13).

Methodology:

The research will be based on:

- The descriptive and analytical approach: through the study of the Voronoi diagram, its pioneers and its basic features in architecture.
- Experimental approach: deals with the innovative aspect of designing complex theatrical scenes inspired by Voronoi diagram.

Hypotheses:

- The researcher assumes that the Voronoi diagram can be used to design different

theatrical scenes suitable for fictional, fantasy, and ceremonial performances, fashion shows, and other theatrical performances.

Statement of the problem:

This study attempts to answer the following questions:

- Can we benefit from employing the new Concept "Voronoi diagram", in forming theatrical scenography?
- What can be provided by the new trend of "Voronoi diagram" for visual visions in scenic design?

Objectives:

- Study aesthetics and visual values of the trend of "Voronoi diagrams", and the need to clarify the possibility of using the trend of "Voronoi diagrams" and utilizing it in the design of visual compositions that can be used in the formation of innovative theatrical scenes.

Significance

- Achieving new design and plastic entrances in the field of theatrical stage design.
- Opening new horizons for experimentation in the pursuit of new creative solutions in the design of the theatrical landscape, inspired by the various forms of the Voronoi diagram."
- Presenting a new aesthetic vision to create designs inspired by Voronoi diagram".

Definition of the term "Voronoi diagram":

Voronoi diagrams are commonly used in many fields such as anthropology, astronomy, biology, cartography, computational geometry, urban planning, and architecture And etc. Voronoi diagrams can be used to explain the structure of the Universe in astronomy, to estimate the precipitation process in meteorology(11).

Basically the Voronoi diagram is a mathematical theory focused on the division of space into a set of areas or cells that are close and adjacent to each other.(8)

According to Aurenhamme, Voronoi diagrams are an organizational phenomenon that generates a special modular structure that can be used in several complicated geometries. (5)The Voronoi diagram is a formula that divides space into regions by the defined points. Regions are created by associating the closest points to each

point(7)The Voronoi diagram consists of the Voronoi cell, the Voronoi space surrounding the Voronoi cell, the Voronoi vertex, and the Voronoi edge(foam) . In another definition Voronoi diagrams is a method of interpolation of spatial data into polygons around each point in such a way that each position in the region surrounding a given point is closer to it than to any other point. This system was developed more than 100 years ago by professor Georgy Voronoi and used in many science disciplines around the world fig(1-2).

The first use of the Voronoi diagram was for arranging the solar system and its surroundings, published by Descartes in 1644. In 1854, Dr. John Snow used Voronoi diagrams successfully to discover the large street pump that caused the outbreak of cholera. Dr. John Snow created areas on a map of London with the same distances between the broad street pump and other pumps, and the cholera mortality rate in the Broad Street pump area was much higher.(2) Voronoi geometry simulates arrangements found in nature and can be seen in nature in 2D and 3D shapes such as beehives, soap bubbles, sponges, crystals, etc(12).

The components of the Voronoi diagram is:

The Voronoi diagram consists of the following set of elements:

- 1-**The site:** the point from which the Voronoi diagram is created.
- 2 – **Edge:** a vertical line or a straight line connecting two centers.
- 3 – **The node:** is the point where the edges of the polygons cross.
- 4 – **cell:** region inside convex polygons with no holes or intrusion.
- 5 – **Voronoi boundary:** these are convex polygons that contain Voronoi space. (6)fig (3).

Types of Voronoi diagram:

The types of the Voronoi diagram differ according to the grid of points generated, how they are distributed and are divided into three types:

- 1-**Regular Voronoi diagram:** in which the dots are equally distributed over a square, hexagonal, or spiral grid.
- 2 – **Random Voronoi diagram:** points are randomly distributed.
- 3-**The Clustered Voronoi diagram :** in which the points are grouped into groups. (10)

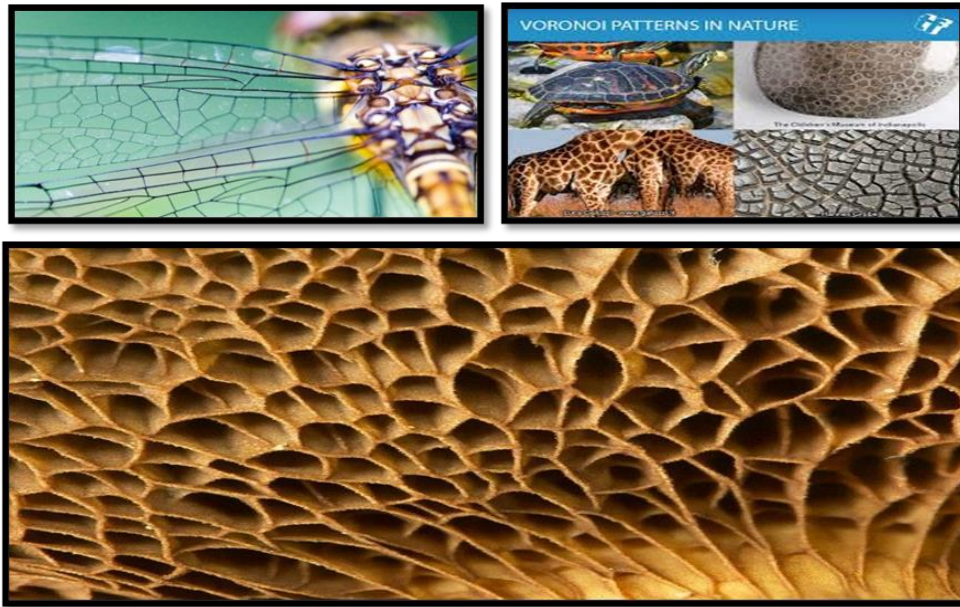


Figure (1) Different models of the Voronoi diagram in nature.

(1b) To the right is a close-up of an insect's wing showing the Voronoi diagram.

Michele Yamazaki (2017) Vectorize Voronoi Texture Tutorial retrieved from toolfarm.com on 15/1/2021

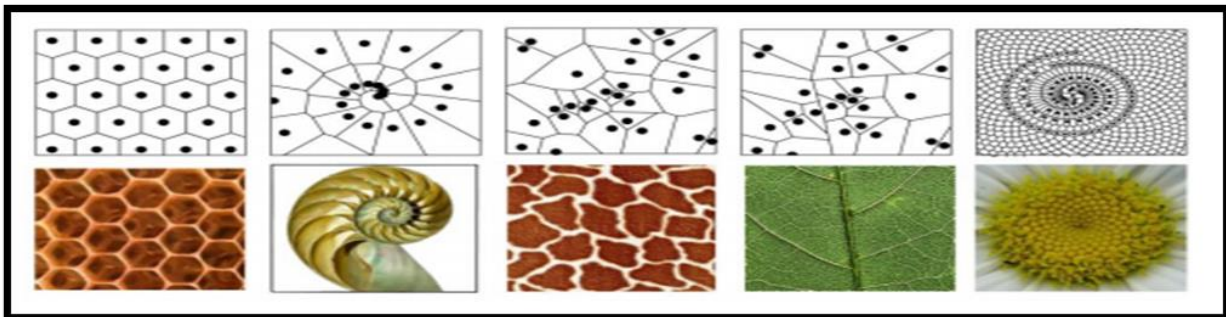


Fig. (2) above, a diagram of the form of the Voronoi diagram and below, Different models of the Voronoi in nature

Sarah Merhej (2017) Voronoi diagrams retrieved from shamra-academia.com 10/1/2021

Steps to create a Voronoi diagram:

- 1- Define a set of generated points.
- 2- Connect these lines with straight lines.
- 3- Define the points that refer to the middle of the previous lines.
- 4- Draw vertical lines on the previous lines from their midpoints (averages).
- 5- Averages intersect with each other to form a new grid known as the "Voronoi diagram".

Inspiration from nature in the design process is a very commonly used tool. Designers can take advantage of the aesthetic characteristics and structure of the objects contained in nature. The Voronoi diagram is a structure that divides space into sub-spaces in an organic way. The Voronoi diagram can be used to construct various scenic designs appropriate fig (4).(8)

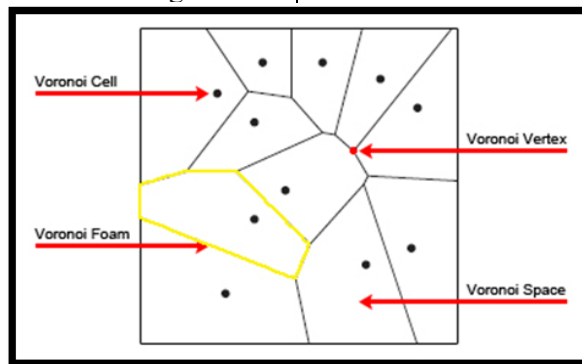


Fig. (3) left and right The components of the Voronoi diagram

Ana Kuzle (2020) Voronoi diagrams retrieved from jwilson.coe.uga.edu on 101/1/2021

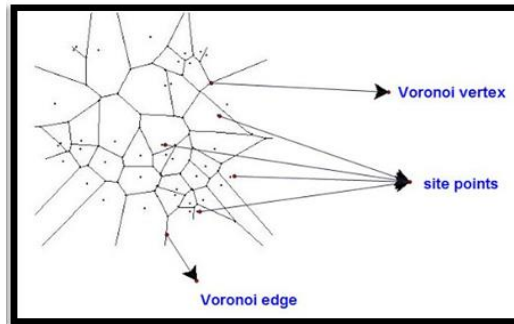
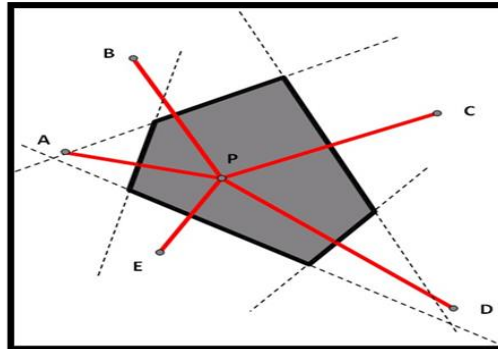


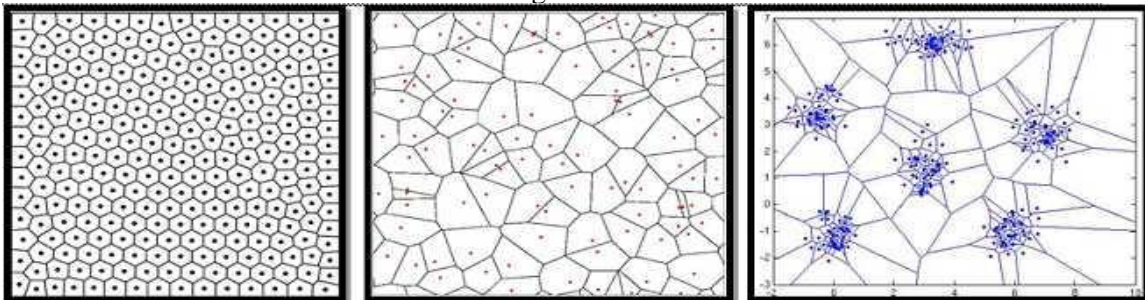
Fig. (3b)left and right The components of the Voronoi diagram

Ana Kuzle (2020) Voronoi diagrams retrieved from jwilson.coe.uga.edu on 10/1/2021



(3b) a Graphic representation of Voronoi polygons

Wojciech Pokojski & Paulina Pokojska (2018) Voronoi diagrams – inventor, method, applications retrieved from researchgate.net on 10/1/2021



(a)

(b)

(c)

Fig (4) types of Voronoi: Regular , Random and The Clustered Voronoi diagram

(a)Regular Voronoi

Yuki Saka(2007) Latinized, improved LHS, and CVT point sets in hypercubes retrieved from researchgate.net on 10/1/2021

(b)Random Voronoi

Md Abul Hayat & Shah Mahdi Hasan(2015) Downlink OFDMA Network Analysis with Stochastic Geometry Models retrieved from researchgate.net on 10/1/2021

(c)Clustered Voronoi

H. Koivistoinen and others(2006) A Voronoi Diagram Approach to Autonomous Clustering retrieved from .semanticscholar.org on 10/1/2021

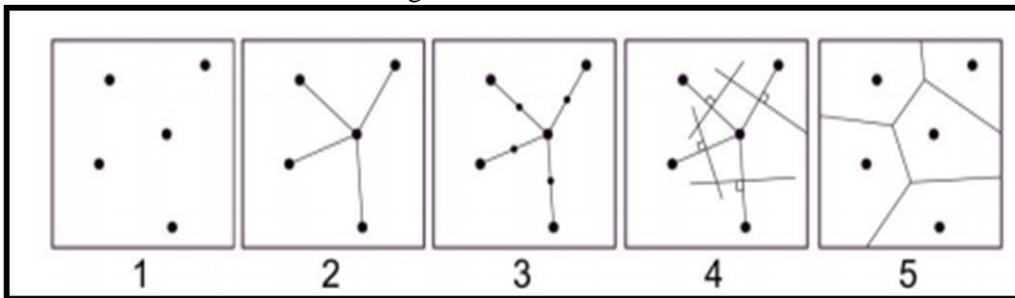


Fig (4b) Steps of drawing Voronoi diagram.

Sarah Merhej (2017) Voronoi diagrams retrieved from shamra-academia.com 10/1/2021

Voronoi and Architecture:

Modern design methods are based on an understanding of nature and concepts of self-organization of biological systems and their representation using mathematical models.(4) The impact of the development of science, mathematics, and computer programs on architectural thinking. Mathematics was applied in computer programs to create various architectural forms, architects and designers made use of the aesthetic features and structural systems of things found in nature(25) . Many of them used Voronoi diagrams to design their various architectural projects. They used the concept of Voronoi diagrams in generating innovative design forms, examples of which are:

- Project Archaeological Museum Mayan Ruin, Tulum, Mexico. The museum was designed by the designer Andrew Kudless. In this project, the researchers used the Voronoi Cell Organization System (Spaces). The walls and ceiling of the museum consist of three-dimensional Voronoi tiles. The structure is directly related to the rock walls at the Tulum site. The purpose of this research is to use parametric algorithms, in forming cellular spaces; this design includes a set of

computational methods based on Voronoi algorithms. (22)

- Project NET LAB is a roject of a designer called G Nome. The purpose of this paper is to use parametric algorithms in creating cellular spaces. This design includes a set of computational methods based on Voronoi algorithms summarized in the plug-in. It is added to the digital design process that allows for repeated modification, addition, and deletion of the design(6).
- The AIRSPACE TOKYO project was designed by FAULDERS STUDIO. Digitally create a design for the Voronoi cross-pattern inspired by plant biocytes. The lighting passing through the Voronoi holes creates a mysterious feeling of movement, and the lighting creates shadows that interfere with the cube building giving the viewer a sense of the interference and randomness of the cube (19).

Architectural projects inspired by Voronoy plans and the development of digital programs used to create Voronoy plans are still being followed up. Figure (5-6).

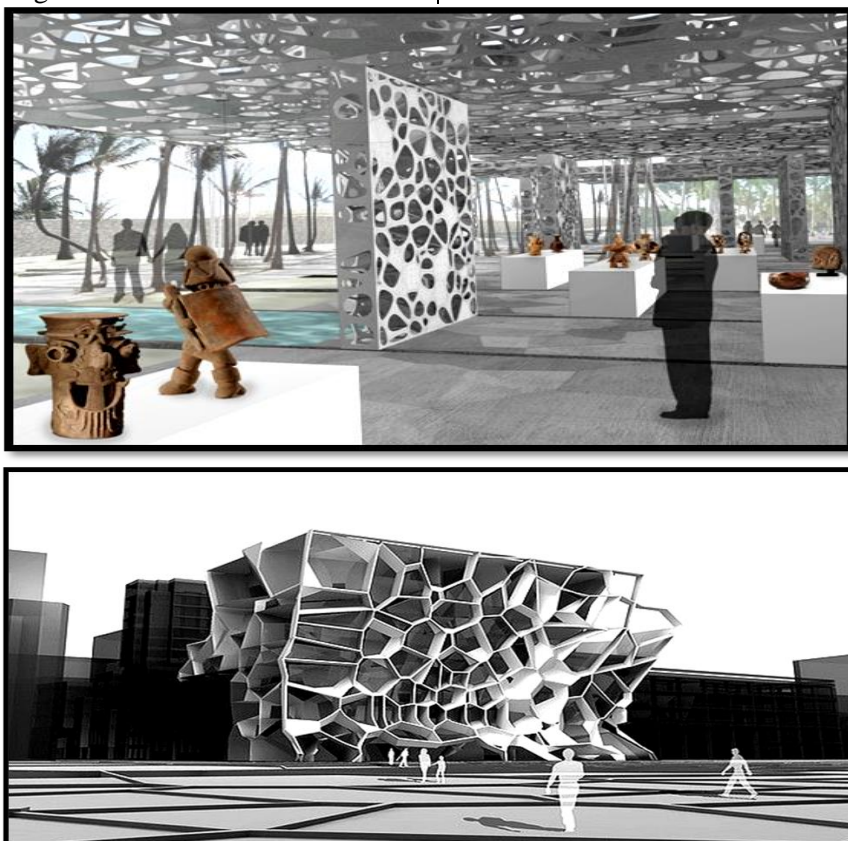


Fig.(5) Project Archaeological Museum Mayan Ruin, Tulum, Mexico. The museum was designed by the designer Andrew Kudless. In this project, the researchers used the Voronoi Cell Organization System (Spaces).

Ginger Hughes (2007) Unusual shaped buildings & bridges frompinterest.com on 9/1/2021



Fig.(6b) Project AIRSPACE TOKYO was designed by FAULDERS STUDIO. He created a digital design for the intertwining Voronoi pattern representing plant biocytes. Night lighting passing through the Voronoi holes creates a mysterious feeling of movement. On the left is a schematic diagram of the Voronoi diagram and the bottom of the cube building inspired by the Voronoi.
 Ryota Atarashi(2012)Thomas Faulders Architecture retrived from arch2o.com on 9/1/2021

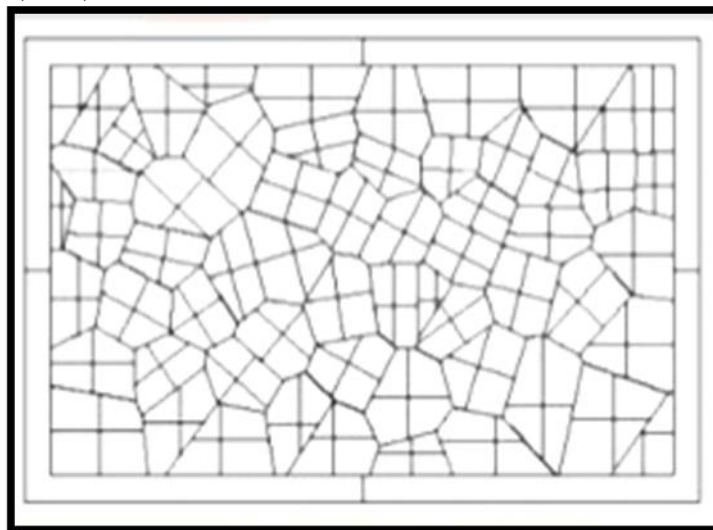


Fig.(6) Project NET LAB is a project of a designer called G Nome. The purpose of this paper is to use parametric algorithms in creating cellular spaces. This design includes a set of computational methods based on Voronoi algorithms summarized in the plug-in

Bahraminejad. F&Babaki .k , 2015- Application Of voronoi diagrams as an architectural and urban planning design tool, Vol.5

Voronoi furniture:

The furniture designers were inspired by the Voronoi Diagram, and some designers designed a series of furniture inspired by the Beehive in the Voronoi pattern using special mathematical algorithms, the honeycomb seat bears large weights even though the material used in the manufacture is very thin, and allows light to

penetrate From which. The seat is on display at Taiwan Land Corporation Cultural Salon in Taipei, Taiwan(18).

Other designers have designed a project that explores using a generative design based on mathematical algorithms of the Voronoi Diagram iteratively to create complex shapes that are created iteratively innovatively(20) Many

designers use the Voronoi Diagram in designing

various furniture units. Figure (7-8)

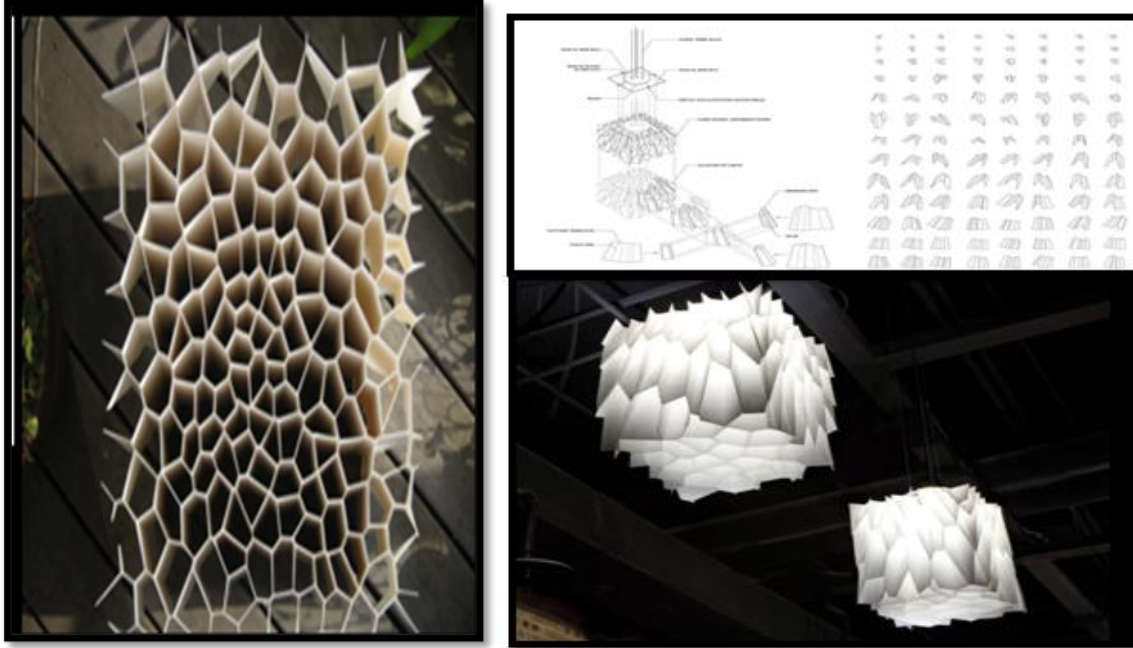


Fig (7) a series of furniture inspired by a Voronoi honeycomb structure.

keisuke toyoda (2016) Voronoi Honeycomb Furniture Series retrieved from marchitizer.com on 10/1/2021

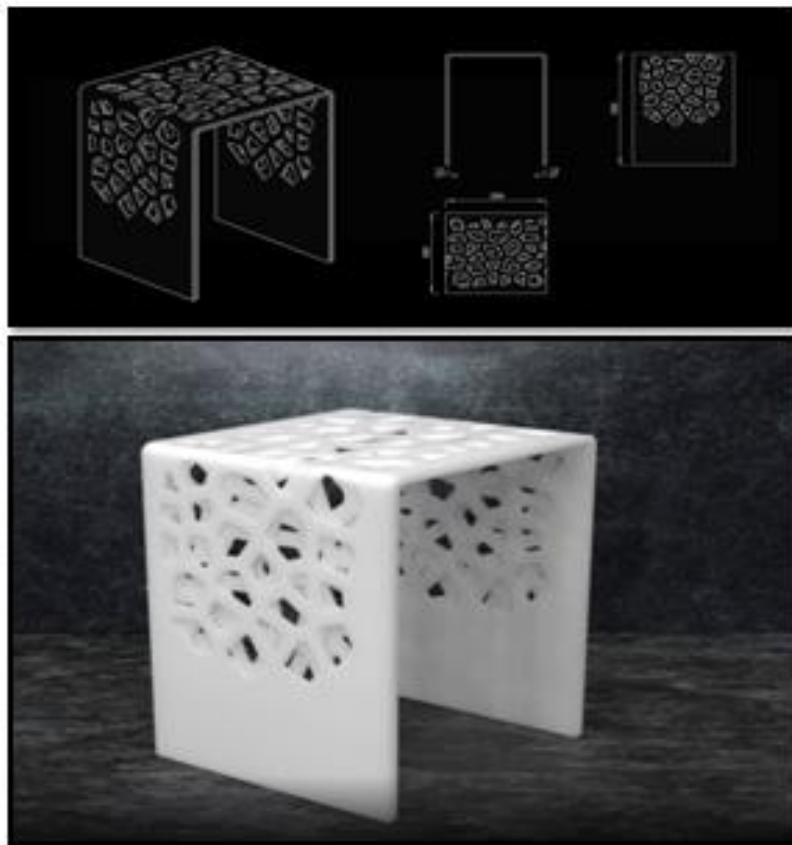


Fig (8) some designers have designed a project that explores using a generative design based on mathematical algorithms of the Voronoi Diagram iteratively to create complex shapes that are created iteratively innovatively.

Anderson Koyama(2016) Voronoi retrieved from behance.net on 10/1/2021

The Concept of "Voronoi Diagram" and its impact on the formation of Scenic Design :

"Design is not a single object or dimension. Design is messy and complex." -- Natasha Jen,

designer and educator(26)

In the era of algorithmization tools, the "Voronoi diagram" can be one of the new concepts that can be applied to generate unique creations and

designs suitable for designing various theatrical scenes such as fictional, fantasy, fashion shows, celebrations, and other theatrical performances.

It will open new horizons in designing creative scenes(27). Applying advanced numerical algorithms to the Voronoi diagram making modifications and repetitions with addition and deletion can create innovative designs of high complexity(4) .

The researcher presented many proposed designs that were influenced by the idea of the Voronoi diagram, with its complex structures in designing theatrical scenes that suit different theatrical performances.

Thanks to scientists and specialists, systems that use complex codes and algorithms for programs such as (Maya, Rhino) can be used in the design of the Voronoi diagram, and this allows to design formations and combinations with complex curves in a way that was not possible to design them using traditional methods.

The experiment in artistic design aims to find innovative and unfamiliar visions and relationships through the designer's subjectivity and methodology, so it was said that people differ in art and are similar in science(15).

The researcher presented several proposed designs inspired by the "Voronoi diagram", with its complex curved structures. The researcher designed several theatrical scenes suitable for ceremonial shows, fashion shows, fictional shows, and others. The following designs are distinguished by their dependence on high complexity structures.

Mainly, the researcher applied several commands to modify the shape and design with three-dimensional computer programs on the "Voronoi

diagram", and through experimentation, overlaying, grouping, deleting, addition, repetition, and other commands in specialized computer programs; they were applied to obtain several innovative designs of high complexity.

The researcher proposes to use advanced technology in the design of the theatrical scene, using 3D printing technology, through the design of the theater scene inspired by the aesthetics of the "Voronoi diagram" with advanced computer programs. Then she converted it into a digital file with a special extension for printing, and then the researcher inserted the file into a 3D printer, which would print the theatrical scene in layers with high accuracy of several millimeters, piled on top of each other and affixed to special materials. And plastic can be used in the implementation of the scene.

The steps taken by the researcher to design highly complex scenes, drawing inspiration from the voronoi diagram, can be summarized as follows:

1- The researcher designed the main voronoi diagram in a two-dimensional manner, using specialized computer programs.

2-The designer started making the three-dimensional of the main voronoi diagram with specialized computer programs .

3- The researcher applied the digital computer commands to the voronoi diagram and transformed it into several forms ranging between simplicity and complexity and suitable for different theater performances.

4- The researcher proposes to implement the complex scenes inspired by the voronoi diagram using the 3D printer using the material of plastics, to obtain the scenes more accurately in implementation. Fig (9),(10) .

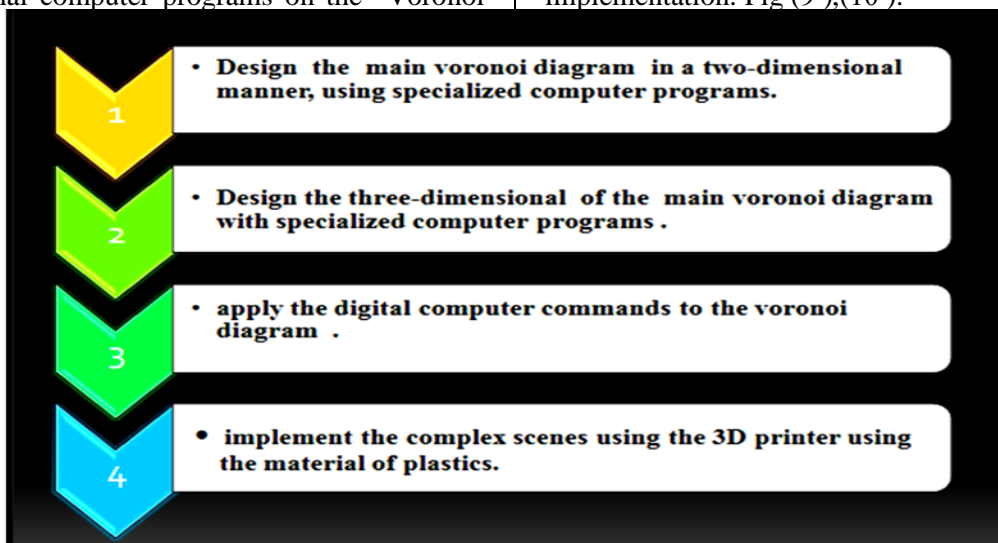


Fig (9)The steps taken by the researcher to design highly complex scenes, drawing inspiration from the voronoi diagram

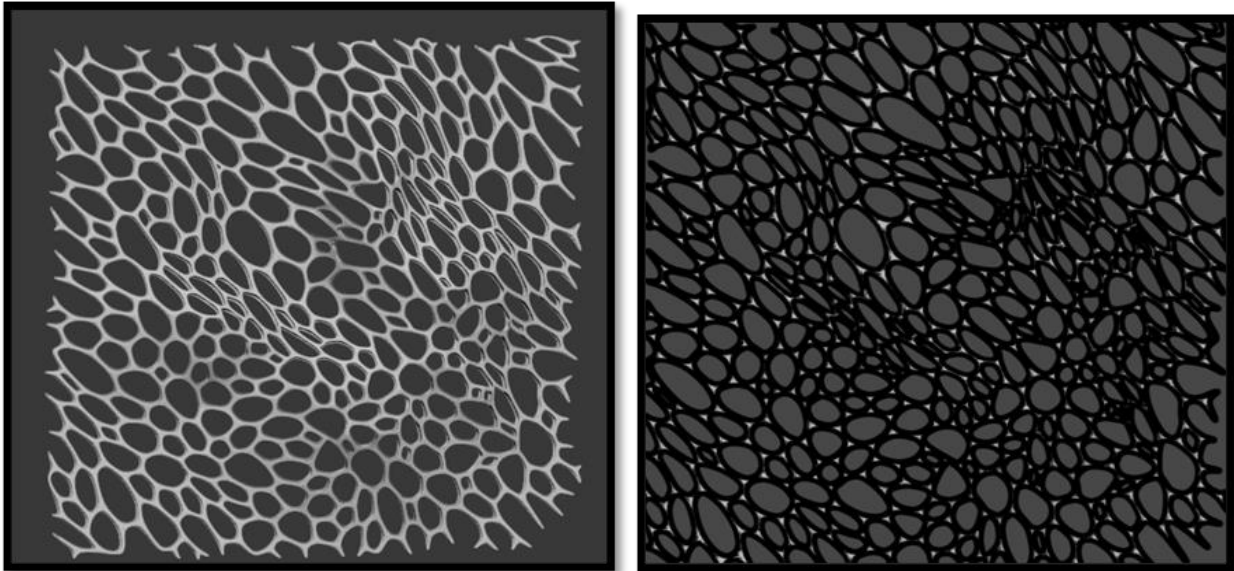


Fig (10) the left, The researcher designed the main voronoi diagram in a two-dimensional manner, using specialized computer programs to the, The right designer started making the three-dimensional of the main voronoi diagram with specialized computer programs .

The first scene:

"Design can be art. Design can be aesthetics. Design is so simple, that's why it is so complicated." -- Paul Rand, graphic designer(26).

The experimental design is subject to interrelated intellectual processes that allow deletion and addition, and the design is created step by step through which new relationships appear(9).

The first idea is inspired by the free shapes and structures of nature, the form is "Voronoy's diagram of complex curves. Using advanced 3D computer modeling software, the stage scene is suitable for carnivals, lyrical performances, and science fiction". .

The design is characterized by the use of highly complex, curved textures, giving scenes the visual scene a sense of dynamism, flow, and movement throughout. In a variety of different directions, the formation is created by a dynamic flow that indicates expansion and movement and eliminates visual differences between the vertical and horizontal elements, Fig (11).

The second scene:

"Design creates culture. Culture shapes values. Values determine the future." -- Robert L. Peters, designer and author (26)

The second design has complex curved configurations, and the design is based on the concept of "Voronoi". The researcher designed the landscape using advanced 3D computer design

programs and made changes to the shapes of the curves. The researcher created the second scene in a more complex way than the first design in a way that creates visual surprises Figure (12).

The third scene:

"Styles come and go. Good design is a language, not a style." -- Massimo Vignelli, Italian designer (26).

The design is more dynamic informs and is inspired by curved forms of "Voronoi diagram", more smoothly, and the researcher uses sophisticated software applications to design them, the design has developed and intricately intertwined curves that could not be designed or implemented with traditional techniques. fig(13).

The fourth scene:

"Design is intelligence made visible." -Alina Wheeler, author(26).

The design tends towards the complexity of the interrelationships between its vertical units that make up the scene, inspired by the concept of Voronoi by increasing the curves and flows in the shapes and their intersections and wrapping each other in a multi-directional kinematic design in the design Fig (14).

The fifth scene:

"Design is thinking made visual. - Marina Caramagno, Visual Designer at USEEDS(43).

In the fifth design, the degree of complexity increases, overlapping, bending, flowing, rotating,

deleting, adding, and intersecting the lines that form the shape in vertical units. It was originally inspired by the concept of Voronoi and the

researcher used computer programs to manipulate the design Fig(15) .

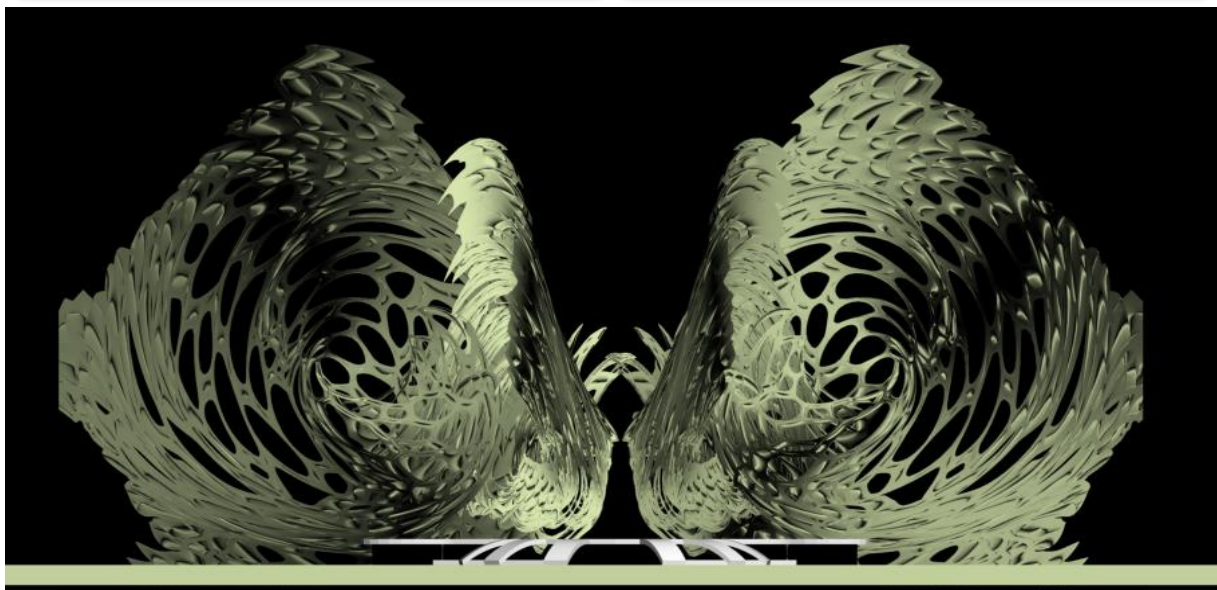
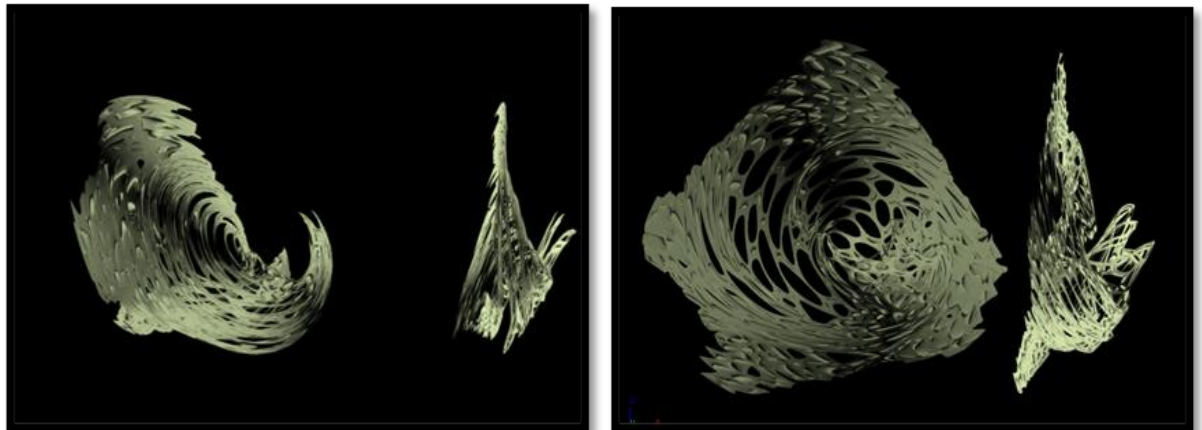


fig (11) The first idea is inspired by the free shapes and structures of nature and inspired by the “Voronoi diagram of complex curves”. above is detailed in the elevation and the side view, in the bottom the elevation.

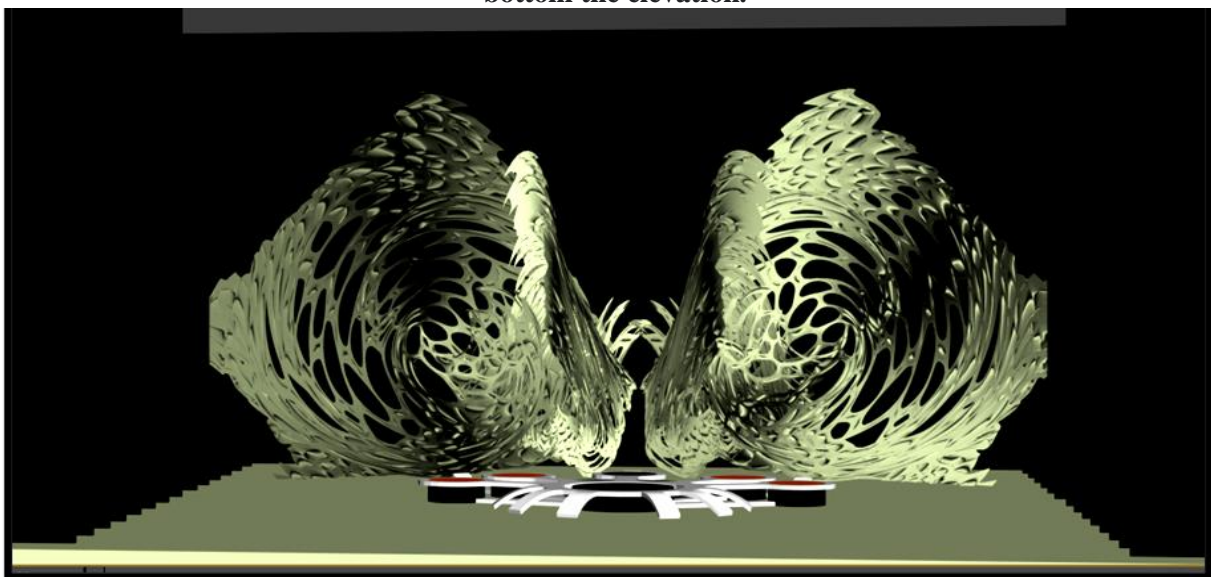


fig (11b)The perspective of the first idea is inspired by the free shapes and structures of nature and inspired by the “Voronoi diagram of complex curves.

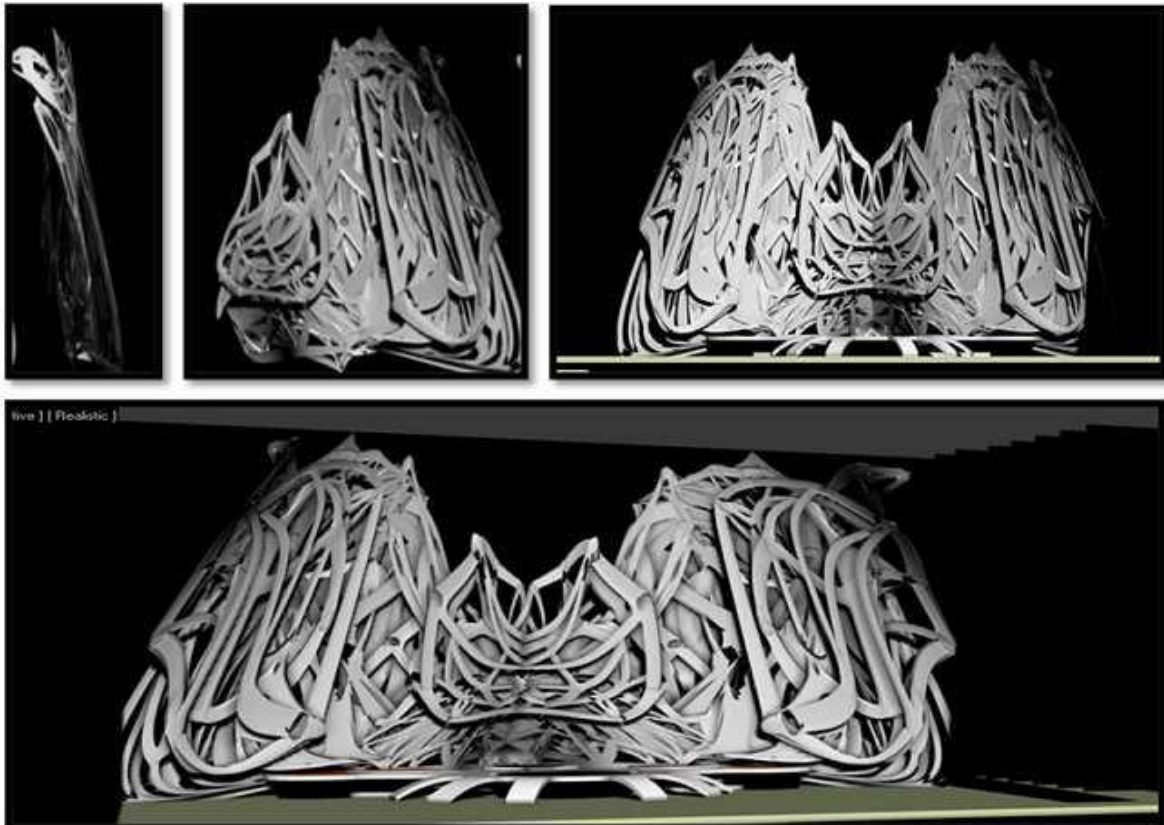


fig (12b) The second idea is inspired by the free shapes and structures of nature and inspired by the “Voronoi diagram of complex curves”. above is detailed in the elevation and the side view, in the bottom the perspective.

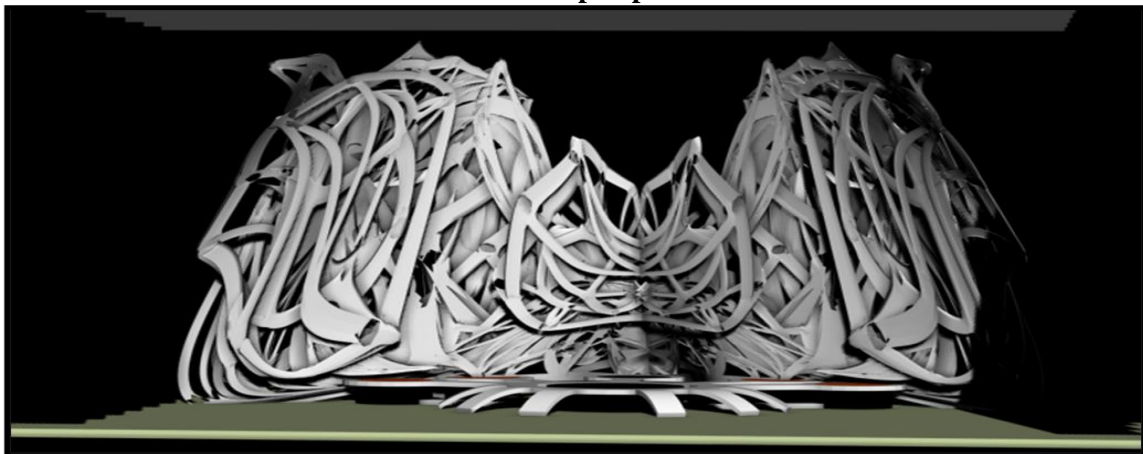
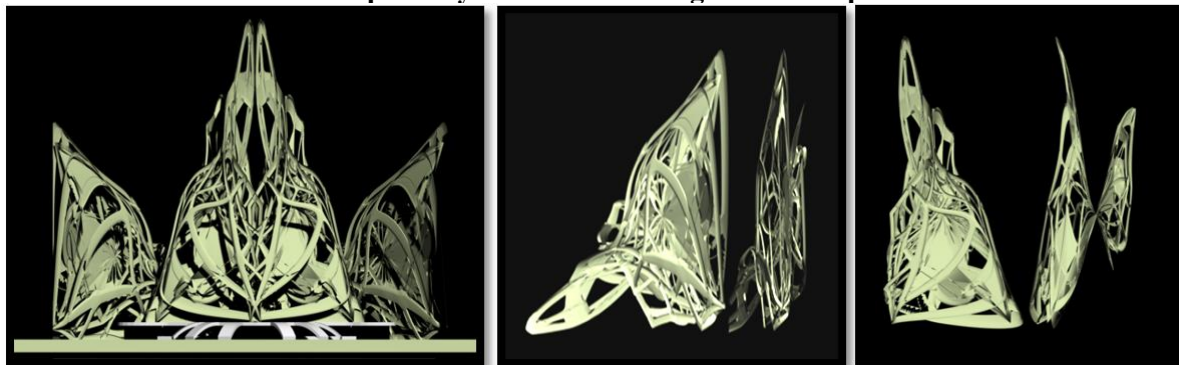
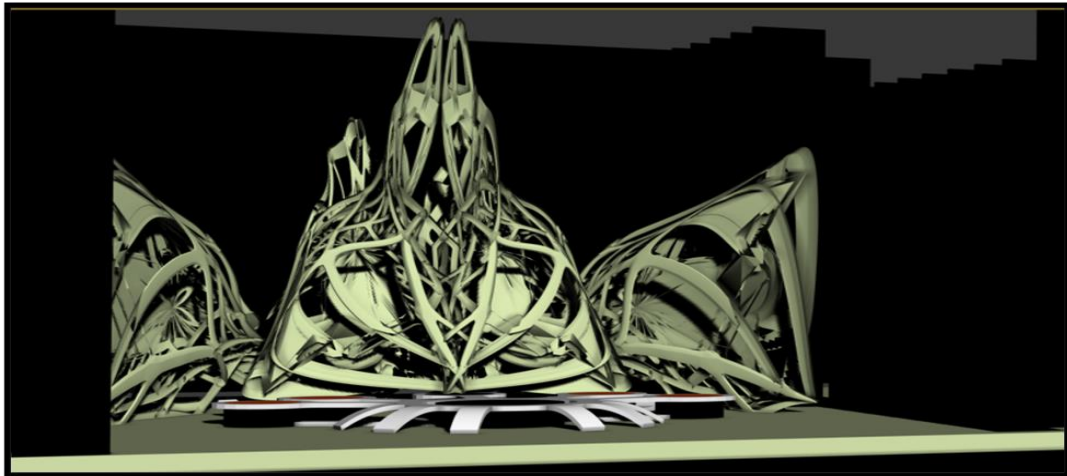


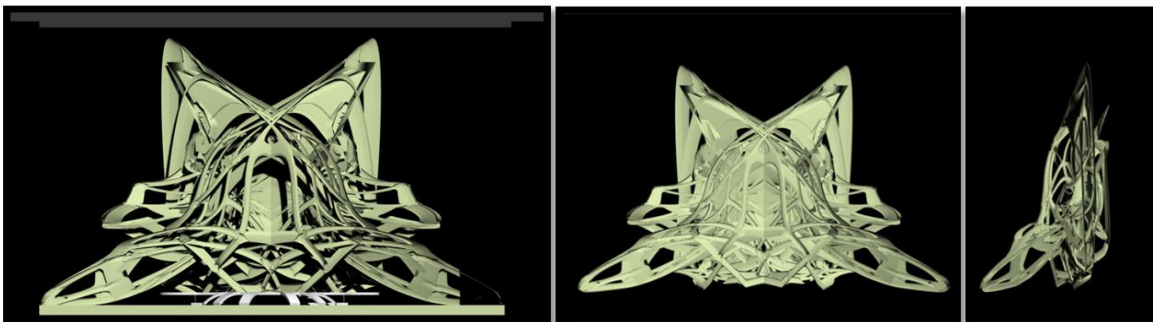
fig (12b)another perspective of the second idea is inspired by the free shapes and structures of nature and inspired by the “Voronoi diagram of complex curves.



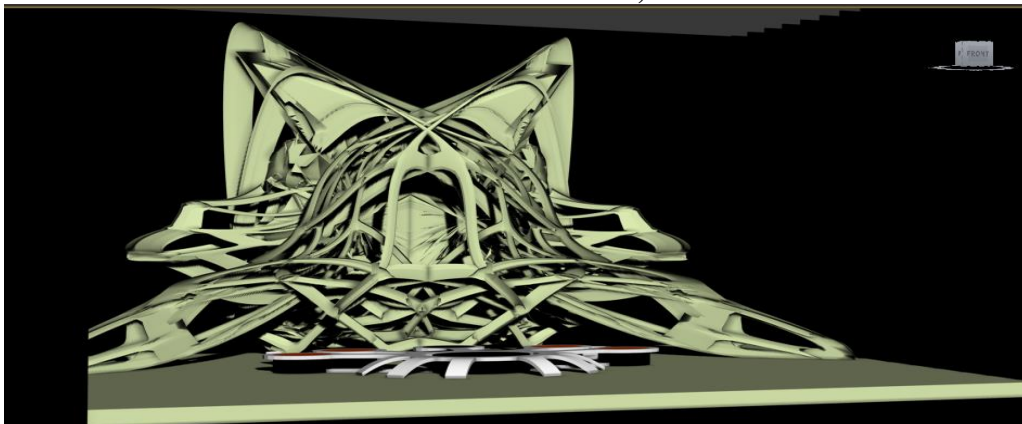
fig(13) The third design is influenced by the idea of "Voronoi" in a complex way. to the right is detailed in the elevation and the side view, the left the elevation.



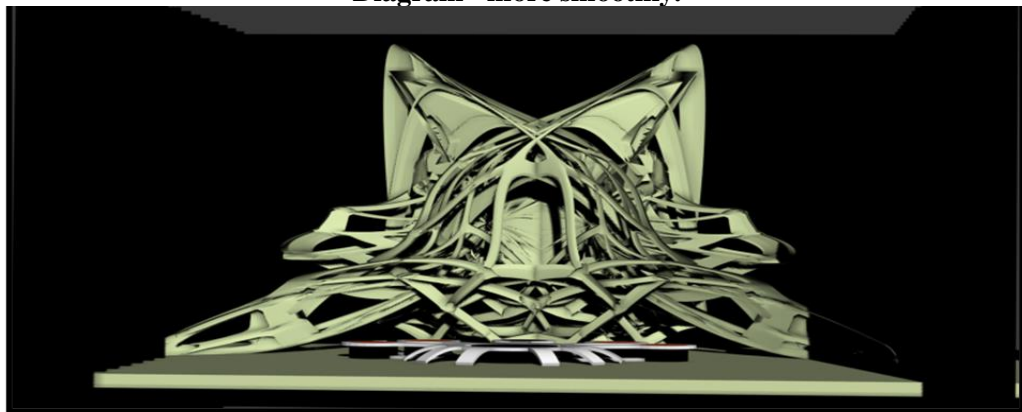
fig(13b) another perspective the third design is influenced by the idea of "Voronoi" in a complex way



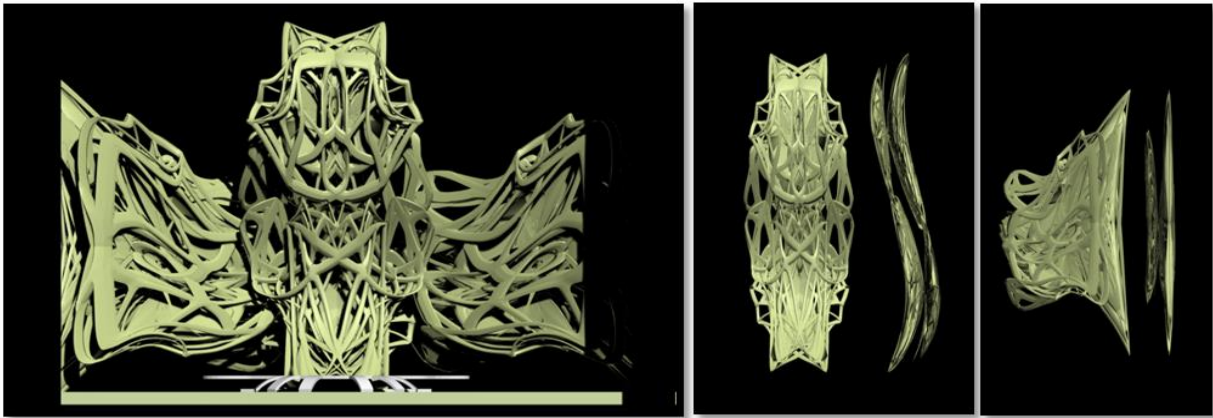
Fig(14) The fourth design, the researcher uses advanced software applications to design them. above is detailed in the elevation and the side view, in the middle of the elevation.



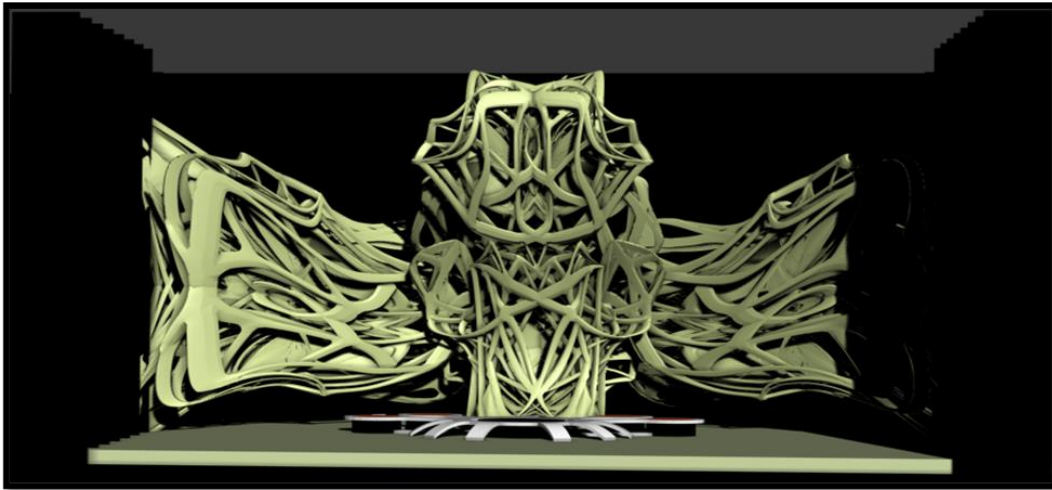
Fig(14b) The fourth design is more dynamic and is inspired by the curved shapes of "Voronoi Diagram" more smoothly.



Fig(14c) The fourth design is more dynamic and is inspired by the curved shapes of "Voronoi Diagram" more smoothly.



Fig(15) the fifth design tends towards the complexity of the interrelationships between its vertical units that make up the scene, inspired by the concept of Voronoy by increasing the curves and flows in the shapes and their intersections and wrapping each other in a complex shape and it was implemented using modified 3D printing technology. above and bottom is detailed in the elevation and the side view.



Fig(15b) the elevation, and at the bottom the perspectives of the the fifth design .

Results :

In today's information explosion era, Creative concepts and innovative designs are the basis for the advancement of our world. New patterns and concepts emerged that depend on development in mathematics, biology, and computer sciences. Among those new concepts that are inspired by nature as the basis of the design, the "Voronoi diagram", which is a scheme inspired by the shapes of nature, such as butterfly wings, ground crevices, and other natural patterns characterized by beauty and organization.

Architects and designers took advantage of the various aesthetic features and structural systems of the Voronoi diagram, ranging from randomness to organization, and applied them in their design projects. The researcher made use of the different shapes and compositions of the Voronoi diagram and presented several design proposals for theatrical scenes suitable for different theatrical performances, and finally the results and recommendations.

Recommendations:

- The researcher recommends expanding the study of modern and advanced trends and concepts in design and making use of them in creating various creative designs for theatrical scenes.
- The researcher recommends expanding the study of advanced three-dimensional digital computer programs to benefit from them in the formation and creation of complex creative design solutions that could not be reached by traditional design techniques.

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