Interactive Eco-Cell Parametric Shading Structure Simulation (Hexagonal Shell of Light) by using Parametric Environmental Tool

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Abstract. Software and methods (such as Parametric modeling) could be effective for architects and engineers to improve the design and reparametrize modeling. These methods will help develop the best solutions for improving the sustainable design. A challenge for designers is to integrate daylight and shade study with optimization into the design process. For achieve accurate results, most of the building environmental performance simulation tools need a large amount of time and repetition. Furthermore, the combination of daylight and energy performances has always been an issue, as different software packages are needed to present detailed calculation. This paper describes the control of codes and calculations that modern designers can use to produce new structures as opposed to specifically design them. The paper reviews paradigm shifts in architecture, and gives a description for parametric design and parametric design types, Also, The Paper introduces Eco-cell simulation study using Rhino and Grasshopper as a new tool of parametric design. An Eco-cell is an interactive hexagonal cell that achieves environmental concepts. The paper explores this environmental study by using Ladybug plug-in to study sunlight analysis and radiation analysis. EPW file is used to draw the sun path and finally the simulation study to control the whole cell structure. The Paper used the evolutionary solver Galapagos to attain the most effective result in daylight quality by controlling interactive hexagonal cell structure.

Keywords: parametric modeling; simulation tools; generative algorithms; Rhino Grasshopper; Galapagos, environmental software

1. Introduction
The way architects design buildings will change when using parametric modeling. It’s a new way to design a system that depends on the variations of the parameters. The use of algorithms creates a computer-generated object that develops the adaptation of a complex system and that may be the foundation for the new intention in understanding architecture. This paper reviews the use of codes in architecture and the parametric design different techniques.

2. Scope & Limitations of the study
The paper will trace the various aspects and processes that are influencing generative design.
The paper addresses the last 20 years as they witnessed many worldwide occasions, in both political and technological fields, that have the best impact and significantly moved and influenced the Sustainable structure.

The research will emphasize the “Eco-Cell” of the interactive parametric structure as it is the basis of the structure.

3. The Use of Code in Architecture:
The use of codes in architecture became an extremely successful way to describe a mathematical framework with transforming in codes and equations [1].

3.1. New Environments with a System of Codes:
The generative power of algorithms has opened an infinite range of using computation and this empowered the architects to establish new designs with an orderliness of codes. So, the recently released power of codes and algorithms provides the architects with the power to produce innovative forms.

Architectural education is that the base of digital modeling and visual image of architectural buildings and currently there is a revolution in 3D software packages supported parametric modeling [2].

3.2. Graphical Algorithms Software Editors:
Coffee and Grasshopper are computer programs that present graphical calculation editors. these programs straightforwardly connected to 3D demonstrating tools and permit intelligent parametric modeling. these programs give the architects the possibility to produce an expansive scope of complex forms that can be altered interactively [2].

4. Paradigms Shifts in Architecture:
Since the eighteenth century, dominant typologies supported the concept of return architecture to its natural beginning, and as the dominant typologies are served to legitimize the creation of architecture and urban forms so we will review the settled typologies for architectural development [3].

4.1. The Order in Classical Architecture:
The form in the classical architectural encoded by social rules which gives the design a formal way. The main concepts in the order of classical architecture are formal parts of the design, cartesian 3dimensional, set coordinates among the order, connected with the orders and colonial system [3].

![Fig.1. The Order in Classical Architecture.](image)

4.2. Modernism Dominant Concepts in Architecture:
The shift in paradigms and transcendence of ideas in design has become a new challenge, it provides the architecture form a dynamic shape and cannot be determined by fixed types.
The idea of form in architecture will change from a set typology to new form generating method that is logical to the nature of the prodigies the emerging form are reaching to be a mark of a way of growing as a traditionally fixed method of formation and alteration, (Figure 2) [3].

Fig.2. Shifting in the idea of form generation

4.3. Morphogenesis Process:
Defined as the order of the system created by the alternative element’s relation.
To get the overall idea for the design, (Figure 3) [3].
Generative Ribbon Pavilion project is an example of the morphogenesis process of creating a continual generative curved surface, (Figure 4) [5].

Fig.3. A Morphogenesis Process Components

Fig.4. Parametric Morphogenesis & Generative Process

5. Parametric Design:

5.1. Digital Media in Architecture:
During the previous fifteen years, computerized media in engineering was utilized as a part of various ways and impacted the entire field of construction and design [4].

5.2. New Architecture Techniques of Computational Concepts:
From one perspective, the digital revolution gives different potentials for the design process. Then again numerous subjects from various fields affected the design.
The new mathematical point of view gives the architect a new way to perceive the space and to modify forms and structures in a mathematical framework by using computational ideas. Estimations of parameters are utilized to explain the connections between the forms. Therefore, inter-dependencies between shapes can be built up and their performance under change can be characterized (numerically and geometrically) [4].

Parametric Design Types:
Parametric design has affected the improvement of digital architectural design, where we can recognize:
- Conceptual parametric design.
- Constructive parametric design.

6. The Interactive Cell Structure Simulation:
The application is a hexagonal interactive cell that changes the area of the cells with the movement of the sun.

6.1. The Main Points for the Study of the Interactive Hexagonal Structure:
The study of the interactive hexagonal cells is based on the following points (Figure 5):
- Sun path study for the structure,
- Visualize Climate Data using Ladybug plugin,
- Shadow Study and Radiation Study.

Fig.5. Main graph for the study and the tools used in the study

6.2. Generate Interactive Hexagonal Shading Structure:
In this section, the author will apply the steps for generating (modeling) an interactive hexagonal structure using Rhino and Grasshopper for parametric optimization.
First using hexagonal cells command in the lunchbox to generate the structure of the Hexagonal cells (Figure 6-7-8) [6].

Fig.6. Hexagonal Cells Generation.
Using point attractor to draw the sun for the interactive cell structure by using domain command in grasshopper start domain 0.2 and end domain 1.2 to control the cells opening and closing with the sun movement, (Figure 9).

Using surface closest point to connect the domain with the centers of the cells of the interactive structure, (Figure 6-11) [6].

Using bake component to get the result of the cell-interactive structure. Finally, we obtain the interactive cell structure connected with the sun (point attractor) in grasshopper script, (Figure 10).
7. Lady Bug Environmental Analysis:

7.1. Sun Path Study:

7.1.1. Location Identification using EPW File:
Here the author starts the analysis of the Interactive Hexagonal Cell Structure.
The structure is located in Cairo so the study is dealing with a hot climate region.
Latitude: 30.13
The timing of the study was chosen from May 21 to December 21 to avoid high sunlight during the hottest periods of the year.
1. Specify the location (Figure 12).
2. Open EPW file and state weather file icon and download EPW Weather File and 3. Connect with world map for all EPW Files, [6].

![Fig.11. Import EPW Weather File](image)

![Fig.12. Choose the Location for the study](image)

Copy and paste the URL in a panel in grasshopper and connect it. (Figure 13)

![Fig.13. URL in a panel to connect with a weather file](image)

Draw 3D chart to connect with EWP weather file (Figure 14).
Fig. 14. 3D Chart command in Lady-bug.

Connect the sun path with the location of the EWP weather file. Using series component in math in grasshopper icons, for example, to put a series of number from 1 to 12 month in the year. Then connect with annual hour chart, (Figure 15) [7].

Fig. 15. 3D Chart

7.1.2. Draw Sun Vectors:
Draw sun vectors and get its numbers from the Lady-Bug Plug-in to visualize it on the surface of the Interactive-Cell Structure (Figure 16).

Fig. 16. Sun Vector

7.1.3. Draw Solar Fan:
Visualizing the solar fan on the interactive structure in yellow color (Figure 18). In this study, the author draws the fan to visualize the data of the sun and to analysis the interactive cell structure by using sun hours’ analysis component in Cairo-Egypt at different months in the year.
Fig. 17. Sun Vector Lines.

Fig. 18. Solar Fan in Color.

Visualize Solar Fan and Interactive Cells from 21 May to 21 December:
On 21 May (Figure 19)

Fig. 19. Solar Fan for the interactive Cell Structure in May
On 21 June (Figure 20)

Fig. 20. Solar Fan for the interactive Cell Structure in June
7.2. Environmental Analysis Studies:

7.2.1. Climate Data Visualization:
This part visualized the environmental data for the location of the simulation study to get the comfort zone from the gradient graph.

7.2.2. Temperature
Visualize the data of temperature range in the simulation location. (Figure 21)

![Temperature Graph for this location](image)

Fig.21. Temperature Graph for this location

7.2.3. Humidity graph
Visualize the data of humidity range in the simulation location. (Figure 22)

![Humidity Graph in Cairo Egypt](image)

Fig.22. Humidity Graph in Cairo Egypt

7.2.4. Wind speed graph
Visualize the data of wind speed range by colors in the simulation location (Figure 23)

![Wind Speed Graph for in Cairo Egypt](image)

Fig.23. Wind Speed Graph for in Cairo Egypt

7.2.5. Radiation study
Visualize the data of Radiation range by colors in the simulation location (Figure 24)

![Direct Normal Radiation Graph in Cairo Egypt](image)

Fig.24. Direct Normal Radiation Graph in Cairo Egypt
7.3. Radiation Analysis for the Interactive Hexagonal Structure:
Visualizing radiation analysis on the interactive structure in a colored chart, the blue color expresses the lowest radiation value and the orange color express the highest value of solar radiation in Cairo-Egypt. (Figure 25)

![Radiation Analysis on Plan](image)

**Fig.25. Radiation Analysis on Plan**

![Radiation Analysis 3D Hexagonal Structure](image)

**Fig.26. Radiation Analysis 3D Hexagonal Structure**

7.3.1. Solar Shading Analysis:
Visualizing Shading Analysis using Galapagos plugin by connecting the analysis period component with the sun path. (Figure 27)

![Sun Path](image)

**Fig.27. Sun Path**
Visualizing shading analysis on the interactive cell structure in Cairo-Egypt and see the video and record. (Figure 30).

7.3.2. Galapagos Solar Shadings and Daylight Optimization:
The simulation is using Galapagos plugin for 50 times and at the end, it gives the researcher the best result that could be achieved to solve the equation, in this interactive cell structure, the goal is to achieve maximum shading and maximum daylight quality and what shall control the cell structure opening size.
In the simulation, the author uses a component called expression to achieve an equation that has two variables, maximum daylight quality (which means we need more sun rays on the structure), and less solar gain (which means fewer sun rays on the structure). [6]

This is the Expression component equation consist of:
The equation $+X -Y$.
X equals the sun rays. (Figure 33)
Y equals the surface grid points. (Figure 34).
The simulation takes approximately one hour and then we obtain the result. To achieve the equation, we give Galapagos (the evolutionary solver) to get the minimum solar gain and maximum daylight. (Figure 35) [6].

8. Conclusion:
Since the introduction of performance simulation in buildings, several software packages have been developed to cover the needs of the building industry. Even though precision and levels of complexity differ with them, most exact programming generally requires information from clients. In addition, an extended procedure of experimentation is required for testing distinctive methodologies and acquiring acceptable outcomes. The combination of parametric design with simulation tools has started another potential outcome to overcome these subjects by providing the architect the ability of testing and looking at and choosing the most ideal answer for 3D dimensional structures.

This paper is the practical study for Eco Interactive Shading Structure using Ladybug Plugin environmental tool to study a sunshade cell structure to get the ideal design for its members by using several studies on the shade.

Finally, the research recommends all architects should start putting structure system as a main issue when they start the Eco-design process. Also, more concern could be adapted for studying different patterns not only the hexagonal. So, the architect should put it in his intention while designing Eco-Structure.

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