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ATILIM UNIVERSITY 2021

# THE EFFECT OF PARAMETRIC STRATEGIES ON ENERGY EFFICIENCY AND STRUCTURAL OPTIMIZATION: AL SHAAB STADIUM AS A CASE STUDY

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
ATILIM UNIVERSITY

ABDULLAH RAHMAN ALLAWI

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IN
THE DEPARTMENT OF CIVIL ENGINEERING

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Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

Prof. Dr. Ender KESKİNKILIÇ
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I certify that this thesis satisfies all the requirements as a thesis for the degree of **Master of Science in Civil Engineering, Atilim University**.

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This is to certify that we have read the thesis THE EFFECT OF PARAMETRIC STRATEGIES ON ENERGY EFFICIENCY AND STRUCTURAL OPTIMIZATION: AL SHAAB STADIUM AS A CASE STUDY submitted by ABDULLAH RAHMAN ALLAWI and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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## ABSTRACT

THE EFFECT OF PARAMETRIC STRATEGIES ON ENERGY EFFICIENCY AND STRUCTURAL OPTIMIZATION: AL SHAAB STADIUM AS A CASE STUDY

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Eco-friendly building design requires special tools, software, and engineering skills to provide infrastructure and contribute to its integration into construction works. Parametric techniques are mainly designed to create modern and complex forms. However, parametric techniques have also been developed to optimize building designs in terms of energy and reduce construction materials. Parametric solar radiation simulation and topology optimization strategies this research presented using the "Grasshopper 3D" plugins of "Rhino 3D" software. Two forms of prototypes were examined to compare which prototype form provides a better solution for the solar path effect on building envelopes using "Ladybug" and "DIVA" tools with "Grasshopper 3D". The first part of this research focused on designing building envelope design geometry forms with different horizontal and vertical angles to provide the opportunity to reduce construction and costs by placing solar panels parallel to the surface and finding the maximum advantage in surface energy gains. Time is an essential factor in this part, where the fourth dimension, "Time," controls the simulation process by choosing the simulation period on the two Building envelope prototypes. Changing simulation time at different times, seasons, months, and days; provides different results through solar radiation motion on energy-designed geometries. The time directly impacts energy efficiency design in terms of using solar panels for eco-friendly buildings, which are presented in this research. The case study of topology optimization was examined as an example to run the algorithm with the "tOpos" tool with "Grasshopper 3D". In this research, Al Shaab Stadium, as a case study, shows the value of developing a structural edifice with modern parametric tools.

Keywords: Structural optimization, Parametric Design, Energy efficiency, Grasshopper, Solar panels.

## ÖZ

PARAMETRİK STRATEJİLERİN ENERJİ VERİMLİLİĞİ VE YAPISAL OPTİMİZASYON ÜZERİNDEKİ ETKİSİ: BİR DURUM ÇALIŞMASI OLARAK AL SHAAB STADYUMU

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Çevre dostu yapı kabuk tasarımı ile altyapının sağlanması, inşaat işlerine entegre edilmesine katkıda bulunmak için özel araçlara, yazılımlara ve mühendislik becerilerine ihtiyaç duyar. Araştırmada, parametrik algoritmik tekniklerin enerji verimliliği üzerindeki etkisini sunmakta ve yapısal topoloji optimizasyon sürecinin yöntemlerini göstermektedir. Hem enerji hem de yapısal etki, "Rhino 3D" yazılımının "Grasshopper 3D" eklentileri kullanılarak incelenmiştir. Bu araştırmanın ilk kısmı, güneş panellerini yüzeye paralele yerleştirerek yapım ve maliyetleri düşürme olanağı verebilmek için farklı yatay ve dikey açılarına sahip bina kabuk tasarım geometri formları tasarlamak ve yüzey enerji kazançlarında maksimum avantajı bulmaya odaklanmıştır. Hangi prototip formunun enerji verimliliğine daha iyi bir çözüm sağladığını karşılaştırmak için "Ladybug" ve "DIVA" araçlarını "Grasshopper 3D" ile kullanarak karşılaştırmak için iki prototip formu incelendi. Bu araştırmanın ikinci bölümünde, bir stadyum bölümü için yapısal topoloji optimizasyon algoritmalarının sunulduğu örnek olarak, algoritmanın "tOpos" aracı ile "Grasshopper 3D" ile çalıştırılması incelenmiştir. Bu araştırmada, bir vaka çalışması olarak Al Shaab Stadyumu, yeni parametrik araçlarla yapısal bir yapı geliştirmenin değerini göstermektedir.
Anahtar Kelimeler: Yapısal optimizasyon, Parametrik Tasarım, Enerji verimliliği, Grasshopper, Güneş panelleri.

*To my family*

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# INTRODUCTION

Energy efficiency and environmental are the most current essential issue that countries paying attention to it worldwide. Modern computer tools help to enhance buildings design worldwide. This research aimed to use modern parametric strategies to develop Al-Shaab stadium design for energy efficiency and structural optimization. The purpose of choosing this stadium is back to its historical value, high temperature of weather that can be used to generate energy.

## 1.1 Historical background

Such as many considerable other historical engineering achievements, the concepts of stadiums first appeared in antique Greece and Rome. Hippodromes, circuses, and many other games generate the idea of design stadiums to serve increasing spectators. (Figure 1) shows the stadium of Athens, another name is “Panathenaic,” which was first built in 331 BC and reconstructed in 1896; for the first modernistic Olympic games. The stadium had a capacity of 50,000 spectators with 46 rows. [1]

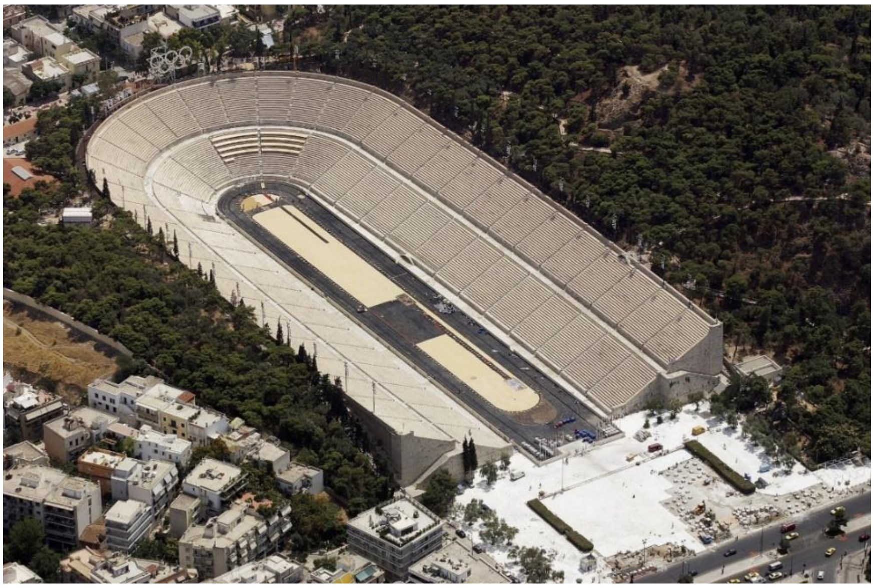


Figure 1. 1 Panathenaic stadium [2]

Since the appearance of football or soccer in the nineteenth century, the playing area was one of the essential facilities to organized for the spectators to provide a comfortable and better view of the match. The playing area, known as the stadium or stadia, is a place or venue particular for outdoor sports, activities, concerts, and events enclosed by stands from the sides to allow spectators to watch the events. Considerable changes in football stadia's engineering and economic improvement have been more intense over the most recent two centuries to stay aware of and reflect changes to the public community. Football was just one of the sports games. Most of the other games do not exceed the general framework of pure sporting competition. In football, it has long gone beyond the dreams of nations towards the global leader from the gateway to sports competitions in this global forum.

Apart from the political employment of the game of football, especially in the third world countries, no one can deny that this game, since its early beginnings, has found a foothold in the sentiment of the people, whether those who live in rich countries or those that live in less wealthy countries or poor. The football game constitutes an outlet for these people, raises competition, and limits members of society.

However, in addition to its simple nature, football bears another character, FIFA's organizational character, the global organization in charge of the game founded at the beginning of the last century and included dozens of international federations in its membership.[3]

The interest in the sport grew in the Middle East countries in the mid-twentieth century. There was a need to build a large stadium.

The story of the Olympic stadium, Baghdad stadium, or sports city began in 1955 when king Faizal II commissioned the reconstruction council to assign international designers to massive Baghdad projects, such as the opera house university complex and the ministry buildings. The reconstruction council commissioned the office of the famous Swiss designer, Charles Edward, or known as Le Corbusier, to design a large sports stadium that turned into the idea of an Olympic city. [4]

Le Corbusier completed the designs proposal, shown in the (Figure 1.2), and (Figure 1.3). Moreover, they were sent to Baghdad in May 1958, and the reconstruction council approved them on July 12, 1958. The designs included the following:

- A football field with 50,000 spectators.
- Swimming pool with 5000 spectators.
- Games hall with a capacity of 3000 spectators.
- Outdoor playgrounds, sports facilities, parking for cars and bicycles, green spaces with grass lawns suitable as multiple playgrounds and trees fed by water from the Tigris River.

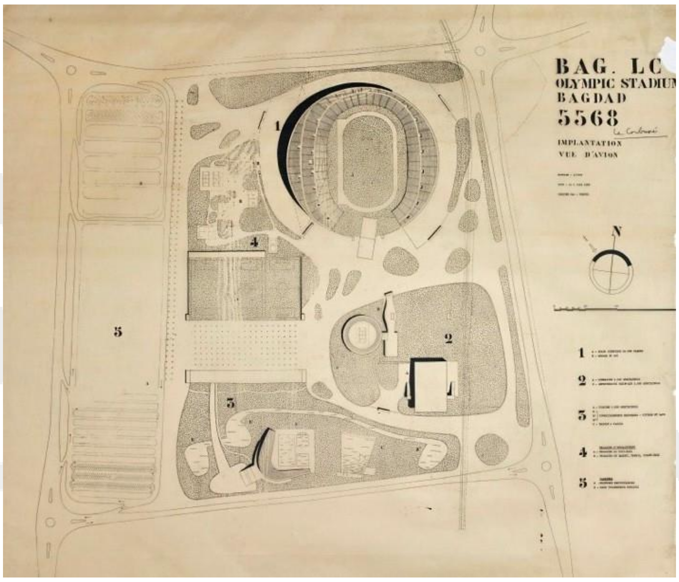



Figure 1. 2 Olympic Stadium Baghdad, Le Corbusier (proposal 1) [5]

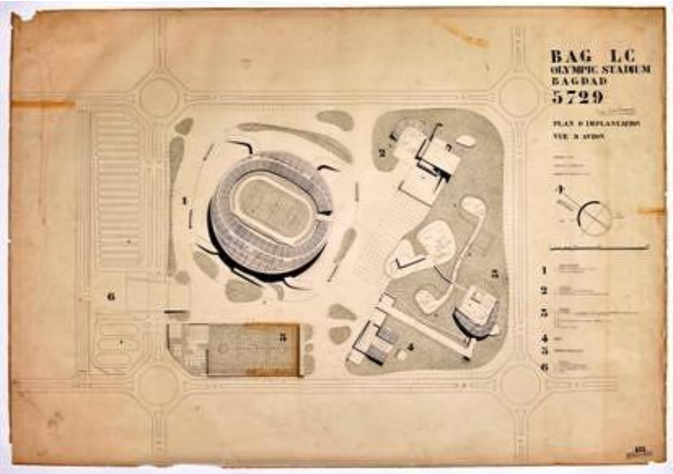



Figure 1. 3 Olympic stadium Baghdad, Le Corbusier (proposal 2).[5]

Meanwhile, a Portuguese company tried to propose building several facilities and projects in Iraq to strengthen relations with the Iraqi government and Portugal; and compete with Le Corbusier's proposal. Portuguese engineers won with them a proposal to design the stadium and other sports facilities for financial reasons. In 1961, the cornerstone was placed for the stadium. The cost of stadium construction was one million dinars. The area of it 200,000 m², and the capacity of stands is 40,000 spectators, 30,000 spectators on the curved stands, and 10,000 spectators on the side of the straight side. Also, it had athletics track of tartan. The lighting system is consisting of four lighting towers with a height of 55 meters. The complex contained two training stadiums, volleyball, basketball, handball, tennis fields, and an Olympic swimming pool[5].

Al-Shaab International Stadium (Figure 1.4) was opened in November 1961, where the opening match was held between the Baghdad team and Benfica with 60,000 spectators, which is more than the stadium's maximum capacity. The stadium was renovated after facing a crisis of bombarded by the U.S. Army during the Battle of Baghdad (2003). The renovated process involved replacing the destroyed seats and the grass with evergreen grass[6].

Figure 1. 4 Al-Shaab international stadium [6]

Stadiums in Iraq had a remarkable development as the latest eco-friendly stadium; there is a newly completed project in 2020, which is the International Shuadaa Stadium. In which solar panels were used in some areas of its roof. More specifically, a small part of the roof includes solar cells with an area of approximately 7000 square meters installed on the roof of the stadium that will provide it with 1200 KW. This stadium is the only environmentally friendly facility in Baghdad[7].

### 1.2 Research question

- Will introduce interactive parametric strategies in redesigning Al-Shaab stadium help obtain energy efficiency?

### 1.3 Research hypothesis

The hypothesis is divided into the two-hypotheses for comparing two prototypes in the pros and cons of developing Al-Shaab stadium for energy efficiency as follow:

Hypothesis (H0): The effect and value of using prototype (01) "shell form" on the energy efficiency design.

Hypothesis (H1): The effect and value of using prototype (02)" cylindrical form" on the energy efficiency design.

In this research, the solar energy simulation process is explained using parametric algorithms. The purpose of used two prototypes only backs to the concept of this research explored the parametric strategies for energy design. Furthermore, examined only two prototypes were sufficient to investigate the impact of parametric methods on the geometry. The idea of using shell form and cylindrical, as popular increasing the roof area, raises the possibility of earning more solar radiation; but solar radiation values change by time, geometry from, and shades area. Subsequently, the solar impact simulation is divided into three major parts: radiation, sunlight hours, and shade simulation; to examine the difference between the prototypes to maximize the energy efficiency.

## 1.4 Objective of the study.

This research scope is to carry out an experimental investigation on the parametric strategies to enhance the energy efficiency in stadium design to apply the following objectives:

1- Reviewing new parametric tools that help structure designers to optimize the topology of structure.

2- Using the parametric algorithmic techniques to simulate the solar effect on geometry.

3- This research aims to support designers determining the perfect location for solar panels in static geometry form by providing an instance of weather data effect through the design process.

4- Expansion of the stadium to accommodate a more significant number of spectators, in line with the notable increase in Baghdad population's number since the stadium's construction until today.

5- Presenting a modern study about stadiums to develop a stadium design with the latest FIFA requirements in stadium design.

## 1.5 The importance of the study

There is an insufficiency of a clear perception of the value of developing an essential of an ancient architectural edifice and revive it with the new architectural language to serve aesthetics and functionality simultaneously. The following points illustrate the statement of the problem:

1- The stadium is losing its societal and historical value due to its lack of development effectively from its inception until today. The stadium's shape is not keeping pace with the modern way of stadiums designing worldwide[6].

2- The stadium's design is old, and it is not keeping pace with the modern last standards of FIFA from several architectural and functional aspects. Whereas, FIFA has extensively developed the basics of building the stadiums since the time they were built the stadium in the middle of the last century until the present time; that was one of the reasons for banning Iraq from hosting international and regional matches like the Asian Football Cup (AFC) and Arabian Gulf Cup (AGC)[3].

3- Take advantage of solar energy and high weather temperature in Baghdad to improve the energy efficiency of the stadium to be an eco-friendlier structure.

4- Baghdad's weather is always sunny and scorching most of the year, as summer temperatures reach over 45 degrees Celsius. The amphitheaters are designed openly, which causes them to be exposed to the sun's rays. The amphitheaters are designed openly, which causes them to be exposed to the sun's rays directly without cover, which is the reason for damage to the plastic seats and direct sunlight on the spectators.

5- The stadium's lighting system is the towers system, and this system is considered outdated and incompatible with current FIFA standards. It is also not suitable for modern TV channel systems in streaming matches, as they need good lighting to stream a high-quality picture. The new amphitheater cover design will provide two benefits; the first, the lighting system will depend on eco-friendly energy; second, it will be more modern form and function.

6- The lack of tourist places and recreational facilities in Baghdad resulted from the considerable population inflation. Therefore, it became necessary to find solutions to this problem.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Previous studies review

E. Yaroni's study [1] describes the evolution of stadium designs since the Greeks and Romans ancient times. Also, the challenges faced by the architects and structural engineers to design the stadiums. Furthermore, it shows how players' and spectators' needs inspire designers to find creative innovations for stadiums, like in skyscrapers, giant bridges, and other facilities.

P. Caponi [8] presents the techniques of Luigi Moretti's parametric theory in architecture. Also, it shows Moretti's recommendations by leaving the empiricism thinking in the design and using the parametric method include procedures, tools, and objectives. Furthermore, Moretti's parametric stadium design logic and science-based models following the discussion of the new technological era.

P. Shepherd, R. Hudson [9] shows the success of new design technology by integrating parametric techniques to model design across all disciplines. Also, architects and structural engineers collaborate by responding to immediate changes without redesigning or re-analyzing the structure. Furthermore, it presents how a single parametric model manages the time sequence of the project, starting from architectural plans to manufacturing.

C. Ben Bacha and F. Bourbia [10] illustrates the initial results about optimizing the dynamic shading in facades design using the parametric technique. Also, it explains that the exterior facade is the frontier between the climate and the building. Therefore, the architects should consider the climate change in the building's designs, which cannot continue ignoring. Moreover, it shows the effect of simulations of the surrounding climate on a building and the potential glare by the solar penetration to the indoor spaces.

J. L. Paramio, B. Buraimo, and C. Campos [11] discuss the economic importance of stadiums and their effect on the construction of stadium's methods. Moreover, it classifies stadia's main economic and architectural factors for four generations starting from early 1920 to the present. Also, the analysis presents the transition take advantage of commercial opportunities from modern to postmodern that were ignored formerly by the clubs. Postmodern stadiums require new techniques in their design and operation.

F. Koçyiğit,[12] shows the applying of the concept of zero-energy buildings using the "Design Builder" program to simulate the energy effect on a building to retrofitted the energy system scenarios to diminish the energy consumption. Also, indicates the reducing amount of 95% of energy consumption that can be saved using renewable energy such as wind and solar power for a high school building.

E. Touloupaki and T. Theodosiou [13] highlights energy efficiency in buildings design. And the effect of parametric simulation tools on the architectural and structural design. The parametric design aimed to minimize modeling time across all design disciplines and to simplify tasks. Moreover, the article explores the importance of these tools that could do revolutionize design in the future.

Atsushi Shiota and Ayumi Tada [14] shows a new manner in converting raster data simulation results to vector data. Also, it presented how to analyze the solar radiation amount and the correction of these data. Although mentioned, the ability to change the amount of yearly and monthly radiation can be converted to the time axis, such as hourly or daily basis, into the database. Furthermore, present the links between these data and cloud computing services and predict the generation of solar power systems depending on radiation prediction data.

J. de S. Freitas, J. Cronemberger [15] indicates the importance of PV simulations tools in 3d modeling and the demand for knowledge with PV simulation tools, especially at the beginning of the design stages of designing a building. Also, his article highlights the use of entire facades or parts of it to install photovoltaic modules on the functional areas. Furthermore, the integration between photovoltaic and facades is capable reduce enormous energy costs in buildings.

M. S. Roudsari and M. Pak [16] describes the ladybug tool features compared to environmental tools. Also, showing the instant response of environmental information behavior changing on a building through the design process.

C. de C. Lucarelli [17] discusses the designing system of a canopy for hot climates in Brazil. Based on the tree leaves concept, the inspiring source of canopy design in the paper prioritizes a modular depending on the simulation of solar radiation. Furthermore, the study's central methodology divides into three parts: simple parametric simulation using Ladybug®, using Octopus® for monitoring the final script and optimize the canopy parts form. The final canopy was designed for a particular climate zone, and for other regions, a few changes in the algorithms needed to optimize the design with another climate zone.

A. S. Berleze [18], illustrates experimenting two models for improving the thermal ventilation performance. The article focuses on the simulation's optimization methodology in the process of design. The thermal simulation process EP file (EnergyPlus) was used to determine the size of the windows for the models. Furthermore, the article shows the improvement of thermal performance of about 98% in the high-temperature period and 49% in the cold season. Also, the paper mentioned that optimization and simulation could indicate with accuracy the prepare designs parameter.

A. Hasan [19], highlights 2a new approach for the bifacial solar panels with sun dynamic movement effect simulation using COMSOL Multiphysics. The article used several water conditions, with various module positioning, where the photovoltaic solar station assumed floating on water. This experiment found that the solar panels got about 55% for the north/south facing and around 31% east/west facing. Furthermore, the research assumed the evaluation of energy efficiency for the photovoltaic module is proportion to a mono-facial photovoltaic.

S. Zhang [20], shows the values in design buildings by putting into consideration the thermal impact on it instead of using largely glazed facades. The research experimented with the impact of designing building decisions like window characteristics, on thermal comfort and indoor thermal sensation. Also, the research introduced a simulation framework to combine the effect of ankle draft and the solar radiation effect that increases or decreases the levels of thermal sensation, respectively. The simulation explained in this research used the single-zone model by using Toronto, Canada climate to clarify the impact of parameters of window's design on thermal sensation with visualization method approach.

M. Shafique [21], describes an integration for a photovoltaic system with green roofs to enhance energy efficiency. The steady present benefits of renewable energy and the challenges of implementing large-scale photovoltaic green roofs, needed data, and awareness lack long-term advantages. Furthermore, the article illustrated the factors participating in PV-green systems' performance over long-term use. Finally, the paper encouraged collaboration between policymakers and designers from all disciplines to improve the effectiveness of the photovoltaic-green roof systems worldwide.

F. Calise [22], indicates European Union Countries efforts to enhance energy efficiency and the token actions for the urban design energy strategies improvements. The paper shows a methodology that helps to understand the energy consumption measurement better to reduce the environmental impact, which backed benefits for any municipality to use it as a development strategy. The research provided an estimation survey of energy-saving actions for a limited region in the north and south of Turin and Naples' Italian weather zone. The collected data were energy-saving for three types of usage: family usage, older people, and young people. Also, it measured the megawatts per year of a building's energy thermal heating; and shades impact from building on other buildings that increase the heating energy consumption and its impact on increasing energy consumption cost. Furthermore, the research presents the benefits of using photovoltaic energy covers to reduce the demand for total energy consumption and the ability to install these systems in the south by taking advantage of high solar radiation values in these zones.

A. Al-saggaf [23], shows the architectural design impact on buildings cooling systems that increase the energy consumption in high-temperature climate regions climate. The research provides three glazings opens sizes samples for the same building and considers several factors such as building envelope, building orientation, plan form, complexity, story height, and spans. These parameters had a remarkable impact on the cooling demand in high-temperature climate zones. The framework of the paper provided a simulation for shade's impact on building orientation. The paper analyzed the monthly heating gains and losses for each model. Finally, the research recommends that the architects and engineers reduce the energy consumption impact on the environment.

P. Hoseinzadeh [24] discusses a design proposal for a high–rise building considering the primary goal of design is energy consumption optimization. In this research, the design tried to combine the facade design with photovoltaic panels for a high–rise building to reduce the monthly electricity consumption by 20%, at least by reducing the thermal energy consumption. Also, the paper shows the systems application's feasibility evaluation with the Honeybee plugins in Grasshopper 3D, which works with EnergyPlus data. The research took the meteorological data of Tehran, Iran, as a location for energy plus weather data "EPW" in the simulation process. Mainly the article measures the glazing recommended dimension for lighting and the other PV panels in the building design prototype.

A. Eltaweel [25], illustrats a dynamic automated louver system that responds to the solar radiations and controls them with parametric validation strategies. The goal of providing this system is to create various illuminance inside the space, reflecting the sunrays from outside into the room. The validation of the system was designed with Grasshopper 3D as a parametric workflow then implemented with a physical prototype to provide realistic results information. The design stage used the simulation in Grasshopper 3D tools such as Ladybug and Honeybee to measure the solar impact for interior spaces and the radiation values inside the rooms.

T. Ghandriz, [26] presents how to generate multi-solution for geometry using topology optimization and consider the instance response through the design process. Furthermore, it shows the highest strength of optimized bodies with a minimum quantity of materials.

S. Sotiropoulos, G. Kazakis,[27] shows the methodology of topology optimization using "Grasshopper 3D" to create a conceptual structure design depending on the development of C# source code. The test used a sample of mesh with 2D and 3D model imported to Rhino 3D, once as beam and second as a column; then calculate the meshes that transform the loads. The resulting form of the structure back to transferring the loads was presented as new conceptual geometry by neglecting the parts not transferring the loads. Furthermore, this proposal presents the importance of this method, which provides an approach of solutions to the conceptual design by topology optimization to design the structures that cannot be acquired with standard approaches.

## 2.2 FIFA standards and current stadium geometry

To understand the case study in this research, first, there is a need to understand the stadium's current geometry and the important FIFA recommendations related to this framework.

### 2.2.1 Stadium Stands

The form of Al-Shaab Stadium stands represented in two parts; The first part is in the form of C-shaped and stands, rising from the middle and low on both sides, the second part is in the form of a straight line, and the edge of the VIP part is located here (Figure 3.1). The VIP compartment side is covered with a concrete frame and steel covers over it. The shape of the concrete structure consists of two main pieces: the first piece is a beautiful, slim arch that starts from the floor outside the stands and ends inside them, while the second piece is a support for the concrete arch in the form of an inverted letter "V." Furthermore, there are two openings between the straight and arched parts where the stands do not merge (Figure 3.1) and (Figure 3.2)[1].

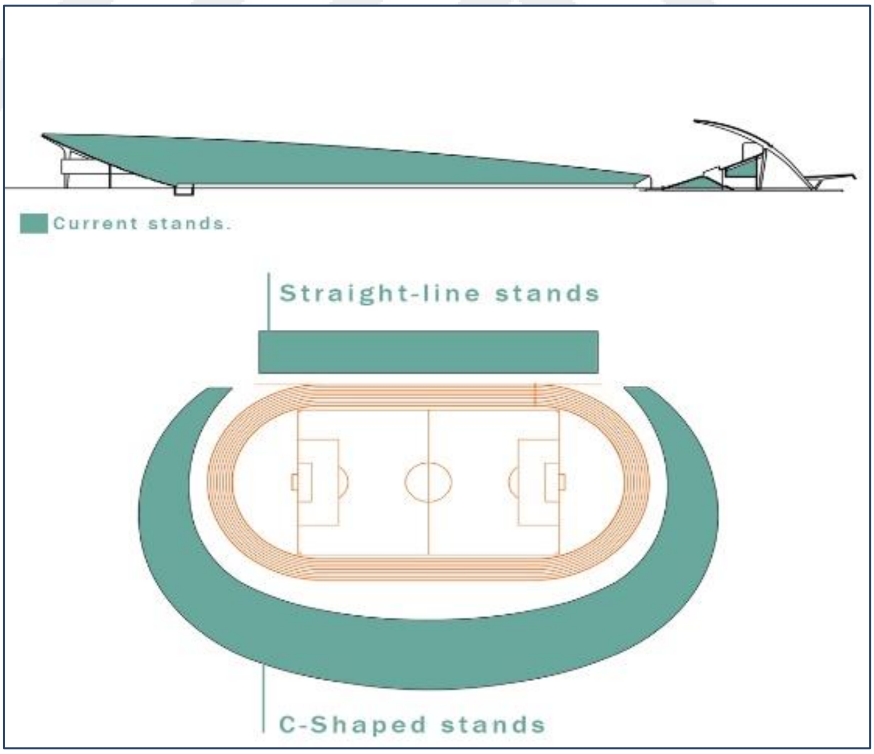



Figure 2. 1 Stadium stands shape, (a) Sections, (b) – Top view. (Drawn by the author Abdullah Allawi)

Figure 2. 2 Real photos for the structure of the straight-line stands cover. (Photo by the author Abdullah Allawi)

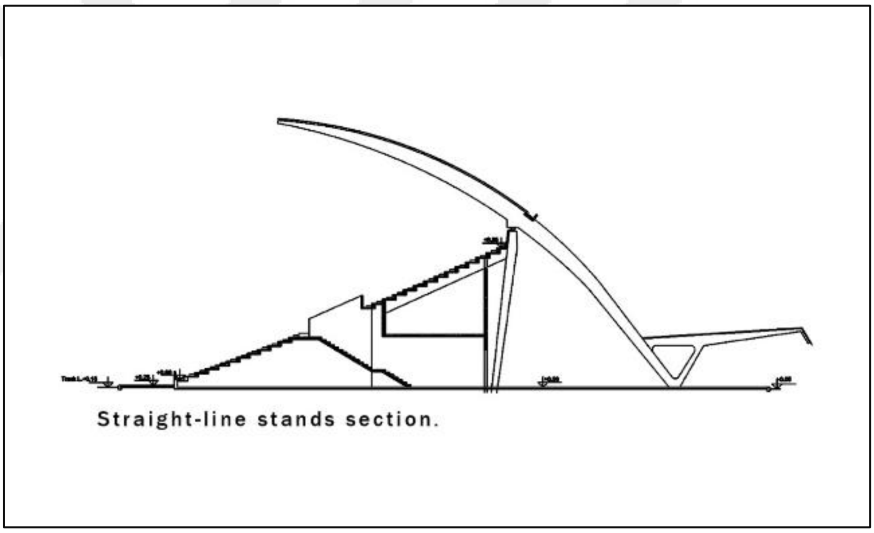



Figure 2. 3 A section in the current stands structure's cover. (Drawn by the author Abdullah Allawi)

The expansion process of the stadium's capacity help hosts more spectators, which will be explained as follows:

This proposal suggests merging the current form with additional stands as one oval volume shape. The first purpose of creating this oval geometry is to help prepare the oval roof model for energy analysis as coming in the next sections. Second, is increasing the stadium's capacity for solving the Issue of insufficiency of seating for spectators. (Figure 3.4).

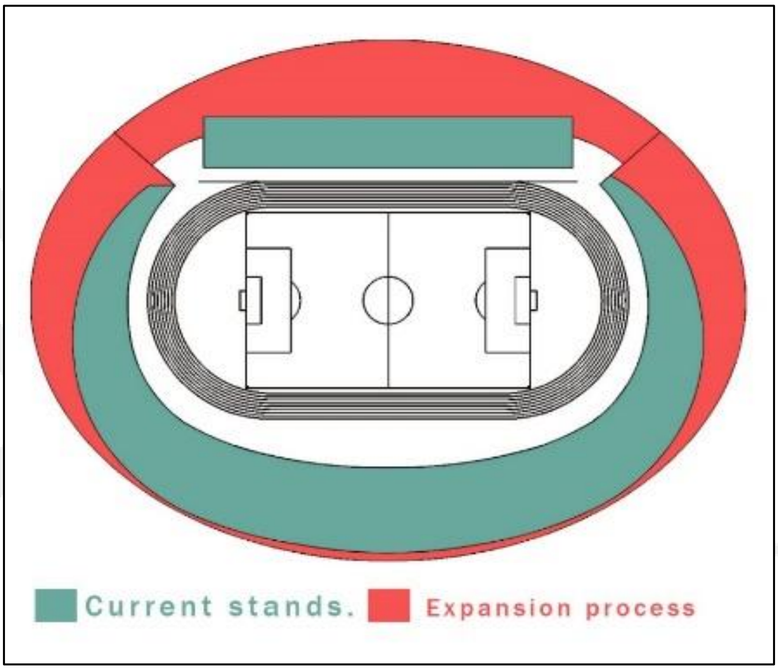



Figure 2. 4 Expansion process proposal. (Illustrated by the author Abdullah Allawi)

FIFA standards show that the distance between any corner to the maximal spectator seat should not be more than 190 meters, and the optimal distance is a 90-meter radius from the center of the playing field. VIP compartment should be at the optimal distance from the view of the playing field. The new design, which suggests increasing the stand's capacity process, should be compatible with FIFA standards. (Figure 3.5)[3].

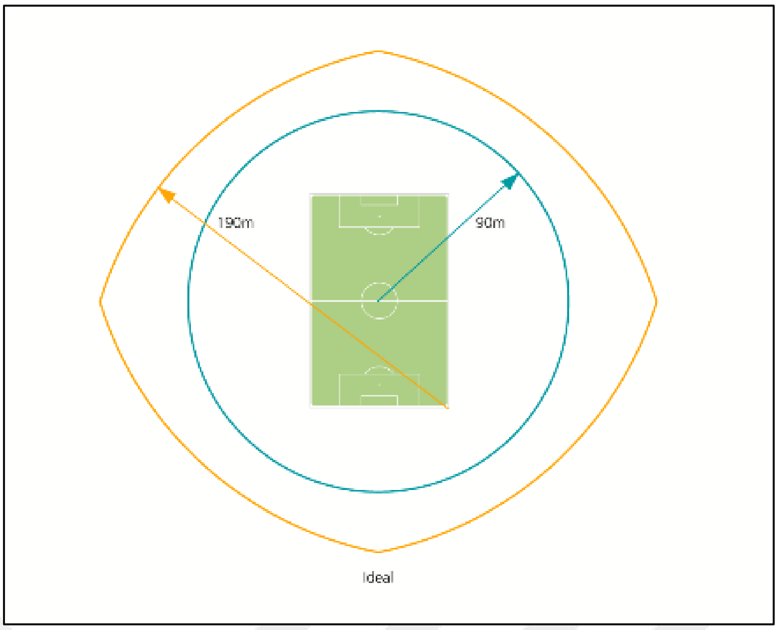



Figure 2. 5 Maximal and optimal distance for spectator seats [3]

The expansion process increases the stadium capacity by adding a seating area, as shown in (Figure 3.6) in red lines. The new spectator's area following FIFA recommendations and standards to view range as mentioned above (Figure 3.5).

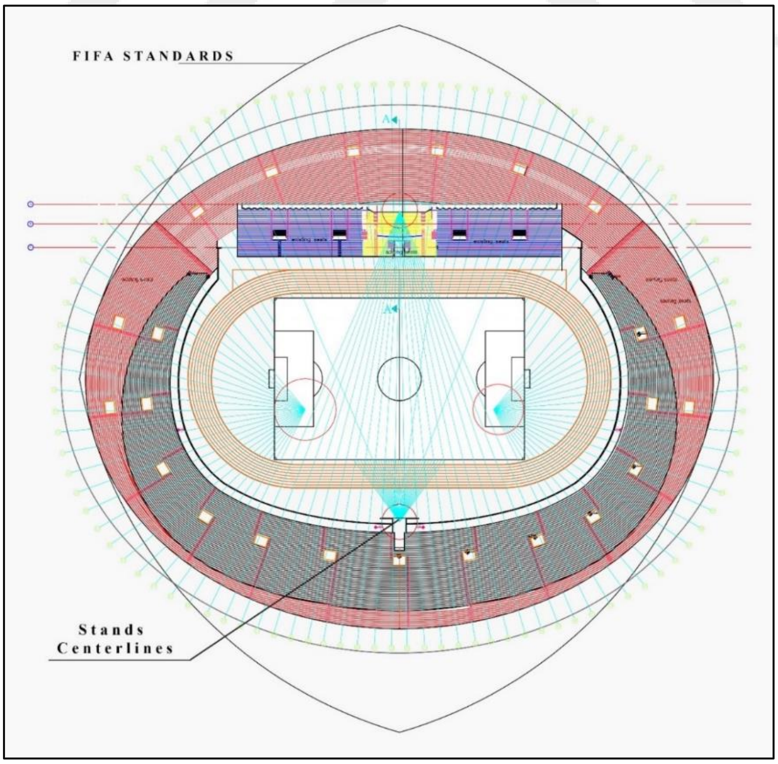



Figure 2. 6 New stadium plan proposal. (Drawn by the author Abdullah Allawi)

The importance of adding cover for the stadium is not for covering the stands area but also for other purposes such as the things related to the surrounding areas. Surrounding areas such as neighborhoods are residential complexes, and other facilities may be affected by a large structure close to these facilities in terms of noises and other effects. Therefore, an important issue in the design or expansion process is the relationship with the community for this structure. Where some analysis for the design should be into considerations. A good analysis of FIFA standards helps to relieve the effects of the architectural edifice on neighbors. Where in time traffic of matches crowd management is essential and reducing the noise, lighting control, could be managed or helped to managed through the stadium geometry design. FIFA requirements suggest that it would be better if the field ground level is lower than the surrounding area to minimize the noise and manage the lighting effects. Furthermore, good landscape design and elements such as trees, flower beds, and plants can provide massive visual and functional advantages to the community that lives around these projects. Reducing the impact of noise and the lighting through the stadium's design enhances the reality and perception that the project respects the neighbors and environment. The issue of this research case study is that the current stadium is still in the same original design since it has opened, where to now it is considered old for the current stadium formation. Most of the stands an uncovered, and it is not following the current FIFA standards in terms of lightings and noise isolation. Covering the stands does not isolate the noises and control the lighting only; it also protects the equipment such as chairs and other equipment for direct exposure to sunlight cause damage and the equipment resulting from temperatures. (Figure 2.7 c) shows the current stadium in the case study lighting system, and (Figure 2.8 b) shows FIFA stadium cover requirements. Therefore, the development of the stadium needs to follow new FIFA standards with these design principles.

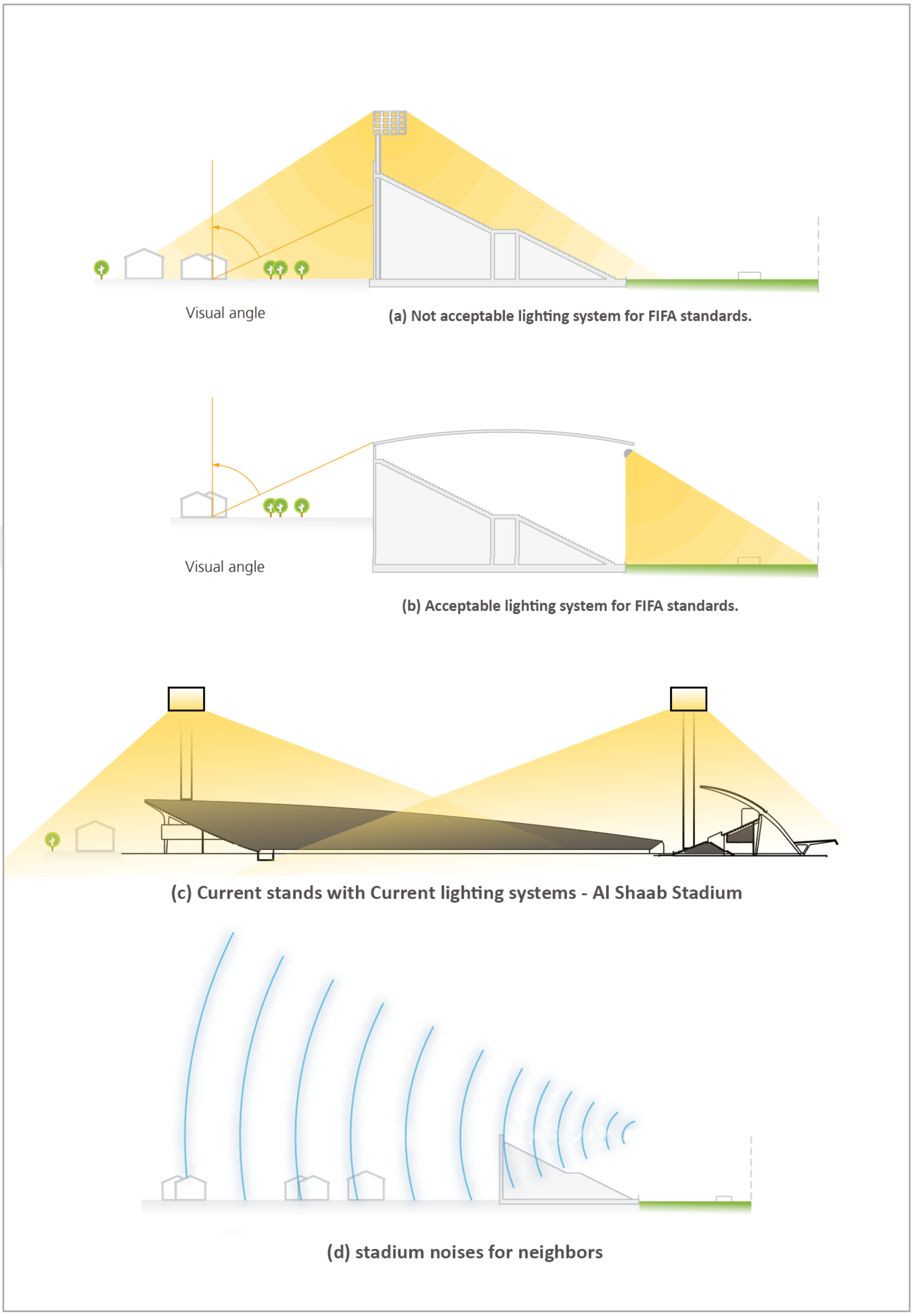



Figure 2. 7 (a) Not acceptable lighting system for FIFA standards [3], (b) acceptable lighting system for FIFA standards [3], (c) current lighting system for Al-Shaab stadium (Illustrated by the author Abdullah Allawi), (d) Stadium noises waves [3]

Covering the stands for noise isolation or providing a lighting system is essential. Still, another important factor in designing the stadium cover is the playing field area and shades. The field grass should get the sun to grow, and through the playing matches time shades areas are not acceptable during the match. The shaded area caused by the stadium's cover may confuse the players by moving from sunny to shade areas and making the playing a little more complicated. The Issue of reaching sun to grass is designed for nature grass usage.

Furthermore, shade areas may cause visual annoyance for cameras and spectators and reduce the pleasure of watching players. Thus, the cover should not exceed more than the stand area. Fortunately, the case study Al Shaab stadium's design consists of this feature, where the playing field is located at an appropriate distance from the stands. This distance allows the sunlight to reach the playing field ground without shades issue. (Figure 2.8) explains the FIFA requirements for these specifications.

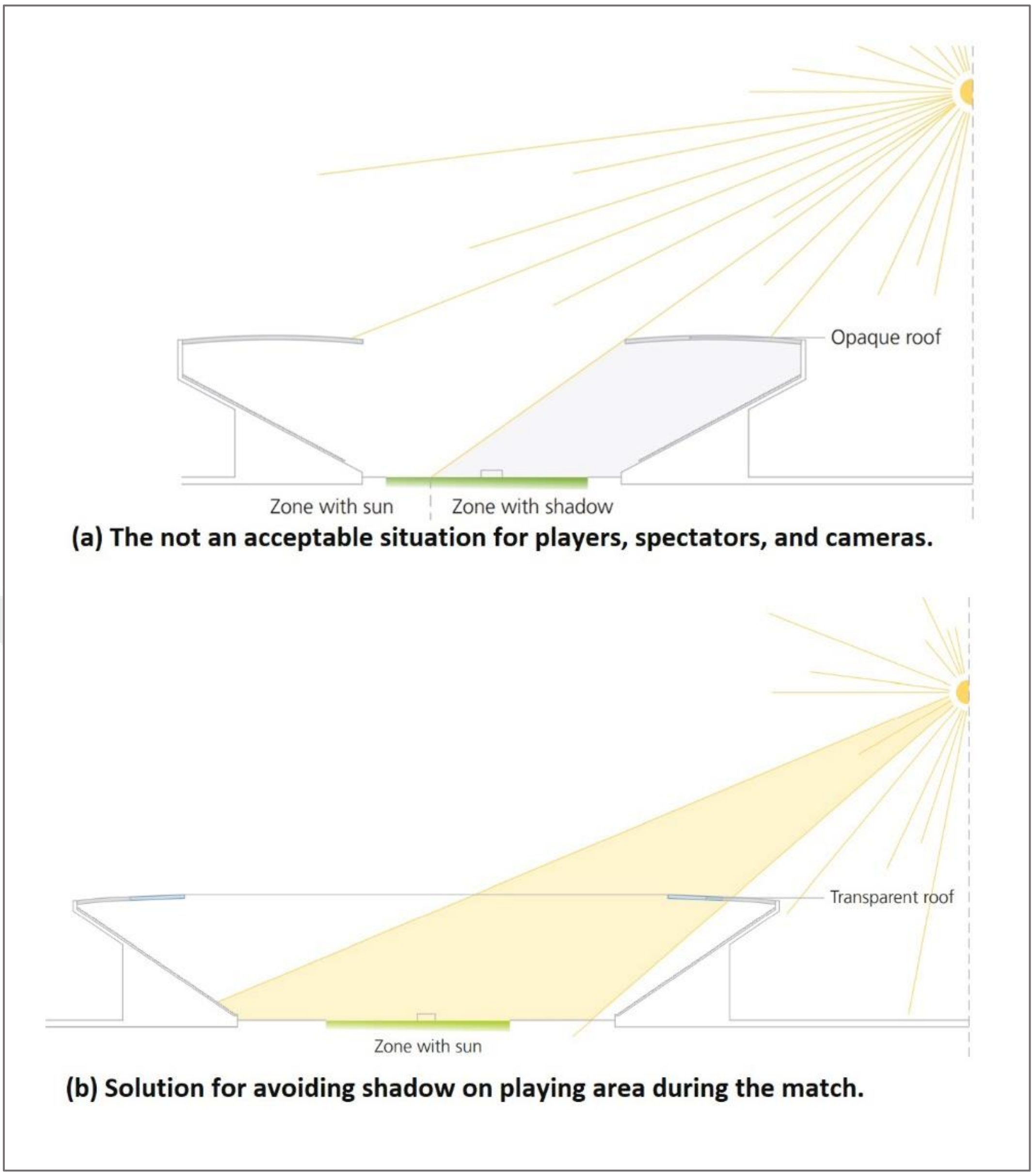



Figure 2. 8 Stadium cover requirement of FIFA (a) Not acceptable covering system for FIFA standards, (b) acceptable covering system for FIFA standards [3]

### 2.3 Literature review indications

The purpose of previous researchers mainly between the usage of several products, to produce perception for some impact of these programs or tools on the facilities design. The variety of computer programs in buildings or facilities design produce a variety of results and options. The design methods depend on some factors such as engineering skills, program knowledge, and the available technology. As mentioned in this chapter, the concept of parametric methodology in design or analysis provides for Luigi Moretti's Italian architect. However, the technology was not available enough to validate it last century. From that time until recently, using it becomes possible with technology improvement and parametric design becoming more popular.

The motivation of using the parametric strategies in simulation the impact of energy efficiency, environment, and economy back to the reasons below:

- The previous studies focused on finding the optimum energy efficiency solution without determining the optimum solar panel locations in large-scale buildings.
- The previous studies energies' solutions provided expensive solutions such as dynamic solar panels or dynamic mechanical solutions. The mechanical solution increases the materials, maintenance costs, and time of construction.
- Applying the concept of the solar simulation on vast structures such as stadiums.
- Experimenting different geometries forms for the solar simulation to maximize the benefit of the static form where the geometry changing can provide several solutions.
- The previous studies mainly focused on interior sunlight reaching and heating, and other studies focused on dynamic solar systems. This research focuses on the exterior form and static facade solar systems.
- As mentioned above, the topology optimizations concept is still on limited scale examples. This research tested on the larger-scale structure, such as stadium covers, columns, and chanterelles.

The perceptions above provide indicators of this research in the next methodology chapter to validate the objectives of this study's parametric strategies.

# CHAPTER 3

# METHODOLOGY

## 3.1 General

One of the fundamental parameters that help us achieve the study's outcomes is exploring the possibility of utilizing the modern instructions of stadium designs. This research relied on the comparative method to compare the analysis between two prototype proposals tested to show the sun effect on geometry using parametric algorithms. In this case, the process of sun effect simulations used "Grasshopper 3D" software for radiation, hours of daylight, and shadows to generate the parametric algorithms. The purpose of using parametric simulation was to enhance energy efficiency for the stadium. Additionally, for the structural design and optimization, the generative design has also been used to optimize the stadium design structure, which helps reduce the material's quantity used in the formation of the structure, and their costs significantly. In this study, the solar gains affecting the building were investigated with the help of the "Grasshopper" program, and energy gain-loss calculations were made with the help of environmental data. The obtained data and shell design samples were compared. All together shows the impact of parametric on the environment and energy as follows.

## 3.2 Ladybug simulation

The stadium exterior cover will be designed according to energy efficiency. Before determining the perfect locations of the solar panels, Baghdad city meteorological data variation throughout the year should be known. A "Grasshopper 3d" plugin called "Ladybug" has been used; This tool allows us to simulate and visualize the radiation and the sun hours per day on the form geometry. Two forms were created to simulate, one is a cylindrical shape, and the second is a shell shape to compare them and see which one is better to get more hours and radiation. The stadium's surrounding context ignores the area in the simulation because the area beside is an open area and no high-rise structures or buildings (Figure 3. 1).

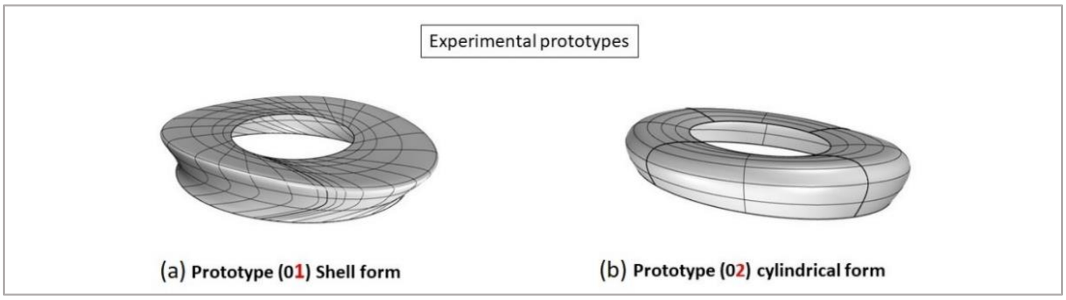



Figure 3. 1 Experimental prototype, (a) prototype (01) shell form, (b) prototype (02) cylindrical form. (Illustrated by the author Abdullah Allawi)

### 3.2.1 Ladybug algorithm

Ladybug is an environmental analysis tool that works as a plugin with Grasshopper 3D for Rhino 3D. It provides environmental data such as meteorological data, radiation, and hours of sunlight with a climate data source file is known as the EnergyPlus weather (epw) file. The tool provides climate diagrams and graphics to perceive climate impact on the design and form geometry. The shown flowchart in (Figure 3.2) explains the general concept Ladybug algorithm. Rhino 3D and Grasshopper plugins must be available as a working environment for this tool.

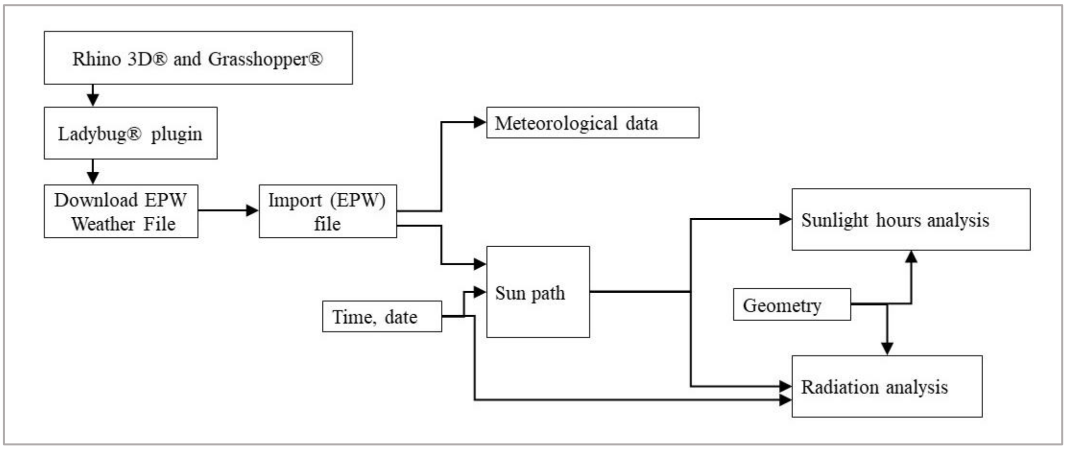



Figure 3. 2 Flowchart of Ladybug algorithm workflow. (Illustrated by the author Abdullah Allawi)

The algorithm presented in (Figure 3.3) contains all simulation components as groups. Each group presented in color as the function work. The components are: Importing the EPW file, sun path, analysis period, color controlling parameter, radiation analysis, and sunlight hours analysis component.

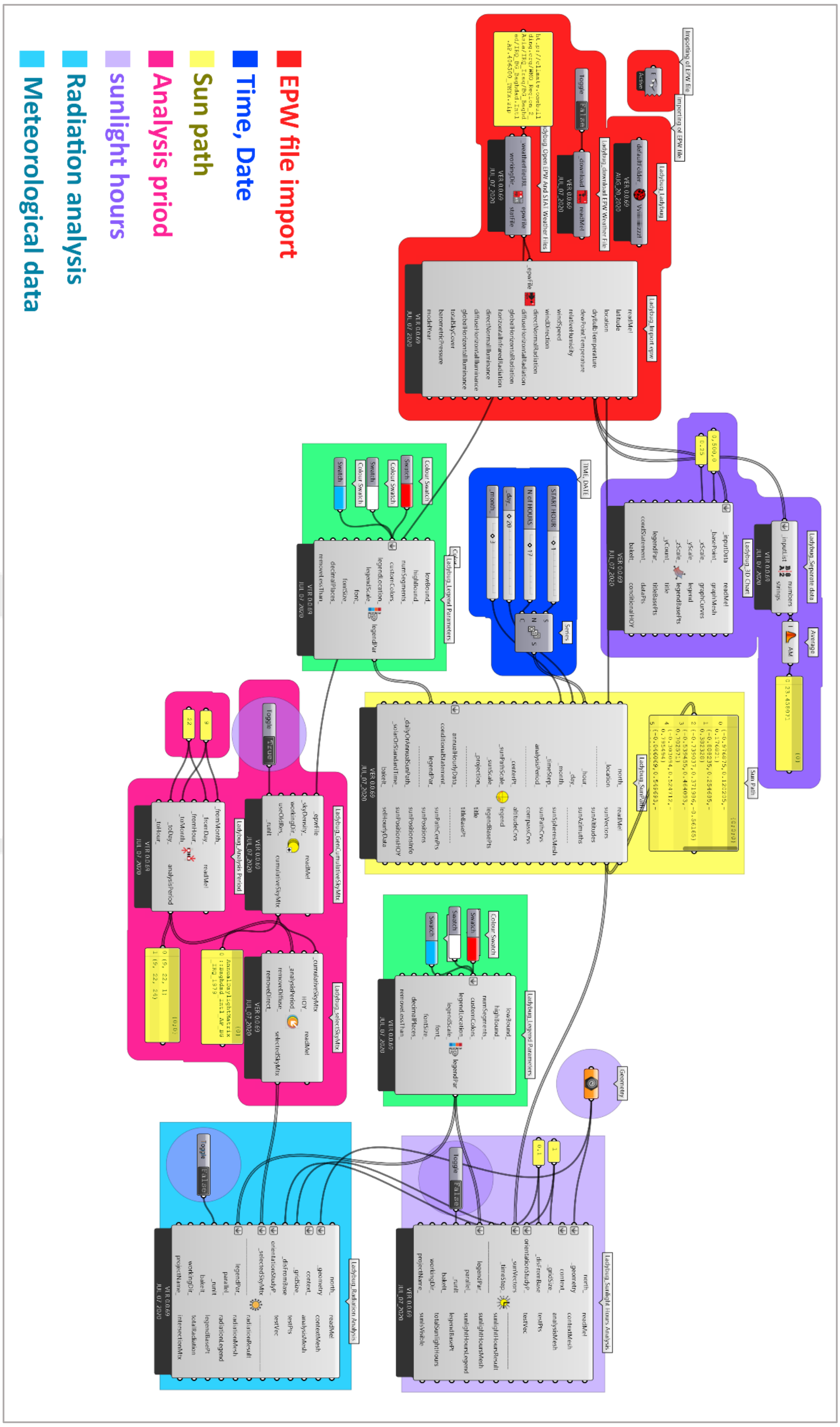



Figure 3. 3 Ladybug algorithm. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

First, the "Ladybug Ladybug" to run and check the tool installation is correct, this component refers to run, and in Grasshopper, the running of this tool is called flying. Therefore, before going to any next component, the output of this tool should contain the " Vviiiiiiiiiizzz!" phrase otherwise, the plugin will not work. To run the simulation first, the EPW file should be download and linked to the algorithm (Figure 3.4) presented the groups of components to import the file from the internet to Grasshopper.

To download the EPW Weather File, the component "Ladybug_download EPW Weather File" opens the web page for the plugging website, and it shows the world map and dots to select the location of the construction closest point for it. As shown in (Figure 3.5), the webpage of this component opened after linking the "Toggle" button to "True."

To open the EPW file in the algorithm after downloading it, there are two ways: first, link the file with the tool "Ladybug_Open EPW And STAT Weather Files" using the "file path" parameter. The second and easiest way is coping the link from the previous tool and use it in the "panel" parameter. The output of this tool is (Generic Data) to able the next component of providing the “Ladybug_Import epw” data for analyses.

The "Ladybug Import epw" component works to import a list of environmental data to Grasshopper and detailed information about EPW file structure. The primary two outputs of this research simulation are "location" and "dryBulbTemperature" parameters. The "location" provides a list of weather location data and links it with the "sun path" component. The "dryBulbTemperature" provides hourly dry bulb Celsius temperature for other components.

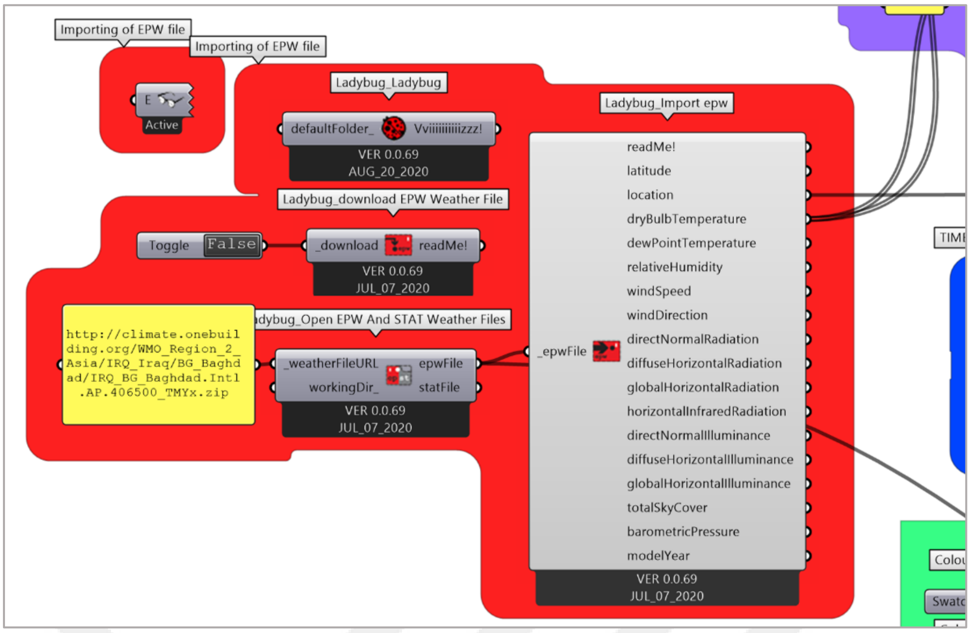



Figure 3. 4 EPW importing components group. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

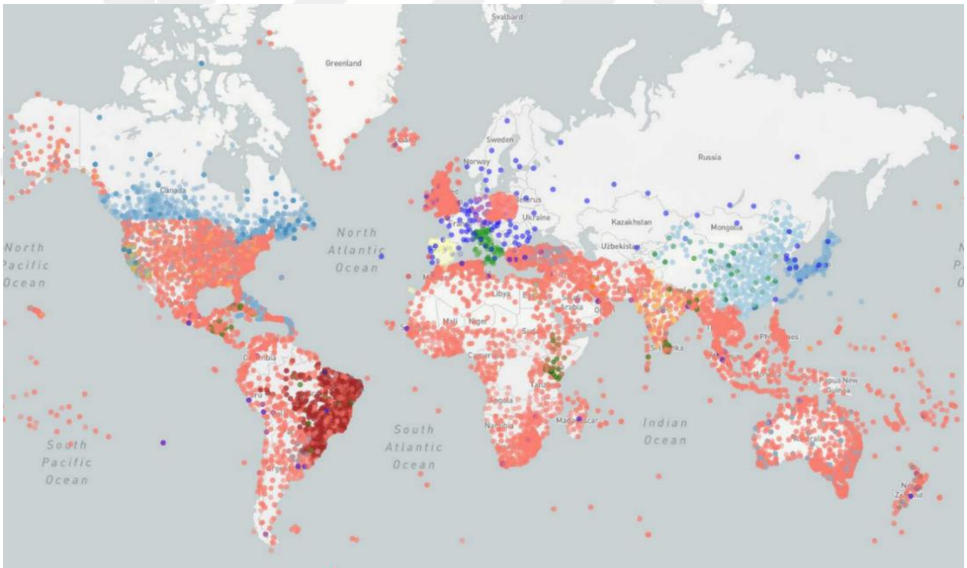



Figure 3. 5 The "Ladybug_download EPW Weather File" output. (Exported image from Ladybug website, link: https://www.ladybug.tools/epwmap/)

To generate meteorological data chart "Ladybug_3D Chart " is the component that create simulation data or the climate data in Rhino 3D scene. The inputs of this tool are a list of data from "dryBulbTemperature" parameter and the other parameters is the " _basePoint_" is to locate the charts in Rhino 3D scene. Furthermore, the "_xScale_" parameter is to scale the charts size of the charts, it can be control by "panel" or "numberslider" parameters.

The "Average" component provides the arithmetic of yearly temperature degree in Celsius, and it links with "Ladybug_Separate data " component to separate text from numbers in the previous tool outputs the perform the mathematical average process. The (Figure 3.6) shows the meteorological data group of Ladybug algorithm.

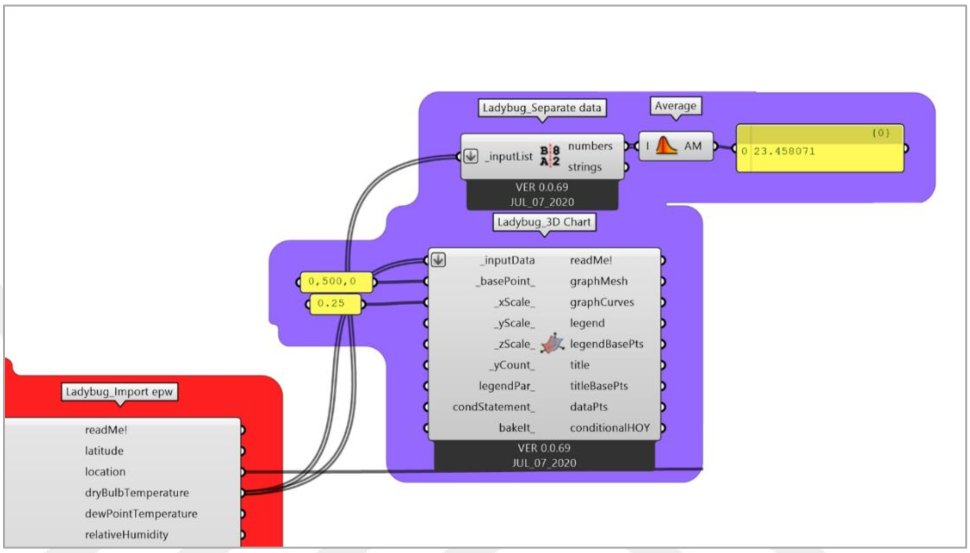



Figure 3. 6 Meteorological data group of Ladybug algorithm. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

The component "Ladybug_SunPath" creates a 3D sun-path in the scene of Rhino 3D. The input of this component is the location data from the "Ladybug_import_epw" component and the time data "Hours, day, and month" linked with this company through "numbersilders" parameter. Creating a range of hours "Series" parameter is used before linking it with the sun path component. To create custom colors of simulation and for the data presenting, the "Ladybug_Legend Parameters" component changes the colors of meshes in Rhino 3D scene and its links with "Colour Swatch" to select a proper results color. The output of "Ladybug_SunPath" is the "Sun vectors" for the sun direction to use is at "Ladybug_Sunlight Hours Analysis." In (Figure 3.7) shows the sun path group of the Ladybug algorithm.

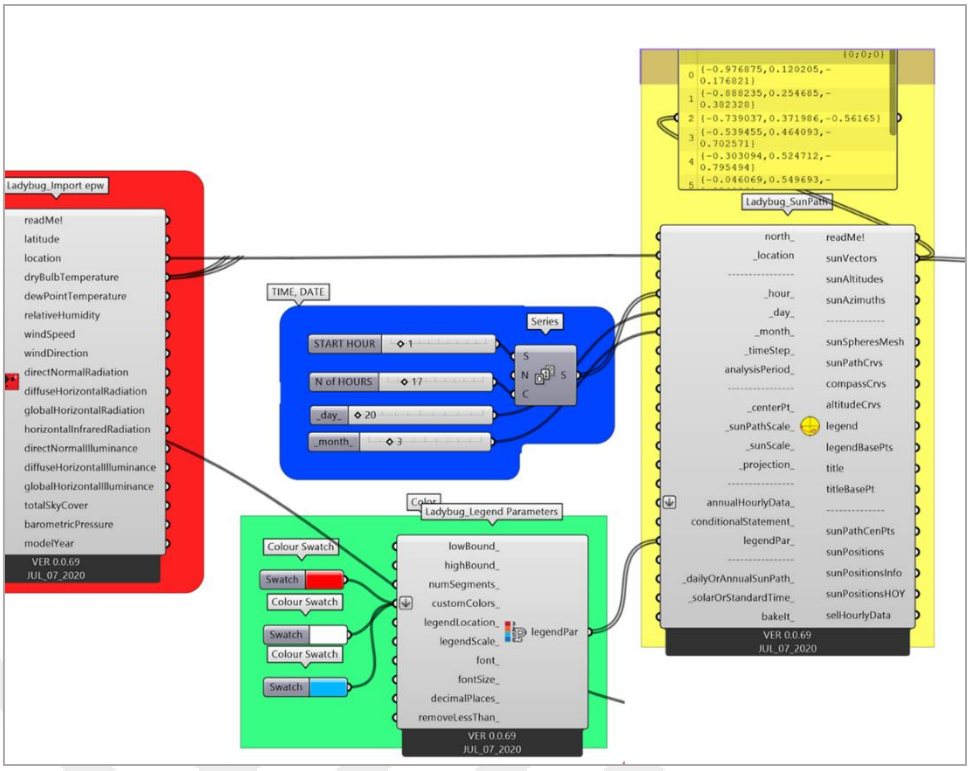



Figure 3. 7 Sun path group of Ladybug algorithm. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

The "Ladybug_Sunlight Hours Analysis " component calculates the hours' number that reached the input form geometry. The solar data input by the sun vectors of the component "sun path the geometry is linked with the "Geo" component. Furthermore, the results colors can be controlled by the "Ladybug_Legend Parameters" component. To run this component, the "_runIt" parameter linked with the "Toggle" parameter and turned to "True" to start analyzing the selected form geometry. The (Figure 3. 8) shows the group of "Ladybug_Sunlight Hours Analysis " component of the Ladybug algorithm.

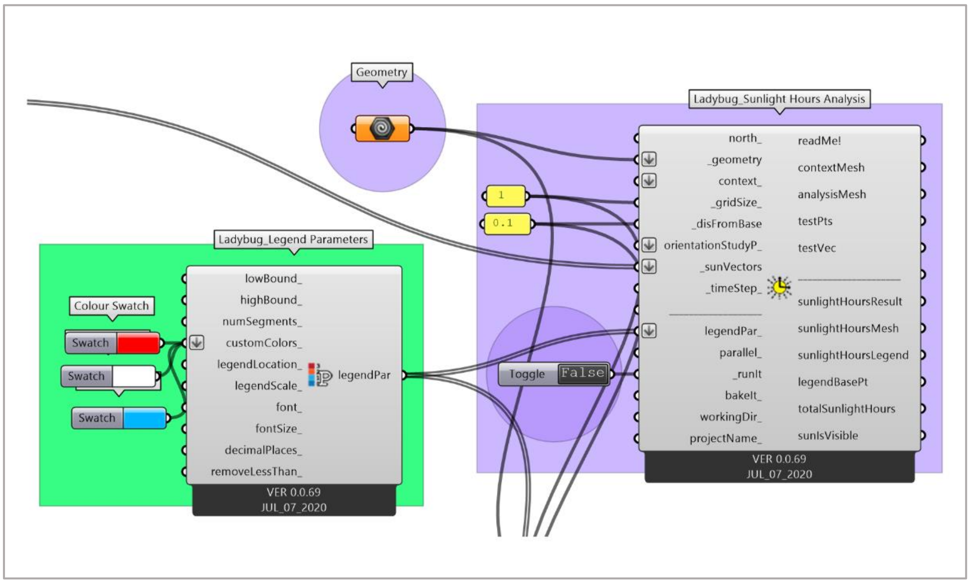



Figure 3. 8 Sunlight hours analysis of Ladybug algorithm. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

The component "Ladybug_GenCumulativeSkyMtx" basically calculates the hourly sky's radiation for all the year days. Furthermore, to choose a particular sky matrix hour in the year or for a specific analysis period, the component is linked to "Ladybug_selectSkyMtx." The component "Ladybug_selectSkyMtx" links with the "Ladybug_Analysis Period" component to determine the analysis period precisely. If it links without values, the analysis period takes the entire year as the default period. The (Figure 3. 9) shows the analysis period group of the Ladybug algorithm.

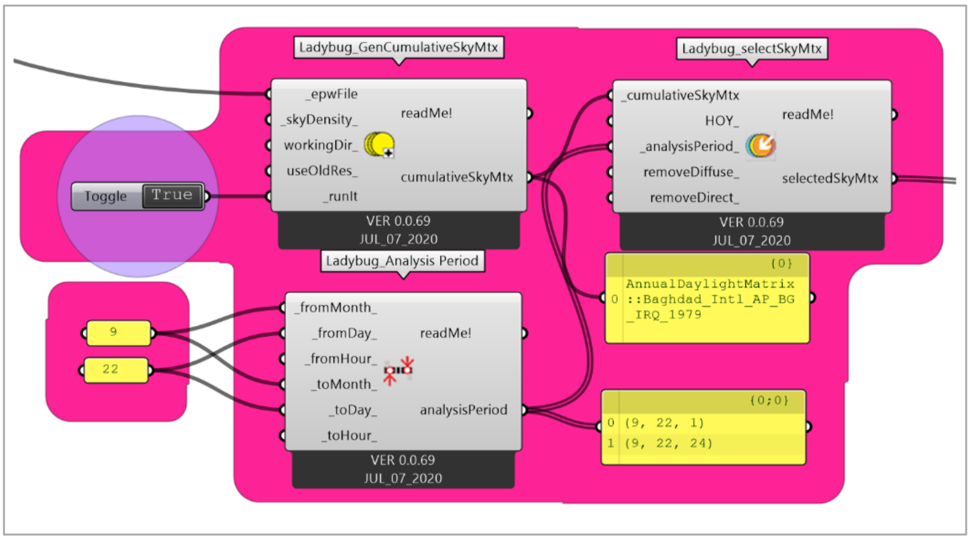



Figure 3. 9 Analysis period group of the Ladybug algorithm. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

The final Component of the Ladybug algorithm is "Ladybug_Radiation Analysis," basically designed to simulate the solar radiation analysis on a selected geometry in Rhino 3d scene. Furthermore, the component is used to determine the radiation energy values on surfaces. The radiation values are represented by kilowatt per meter square; These radiation values are used to study the impact of solar energy on geometry form. Figure 3.10 shows the "Ladybug_Radiation Analysis" of the Ladybug algorithm.

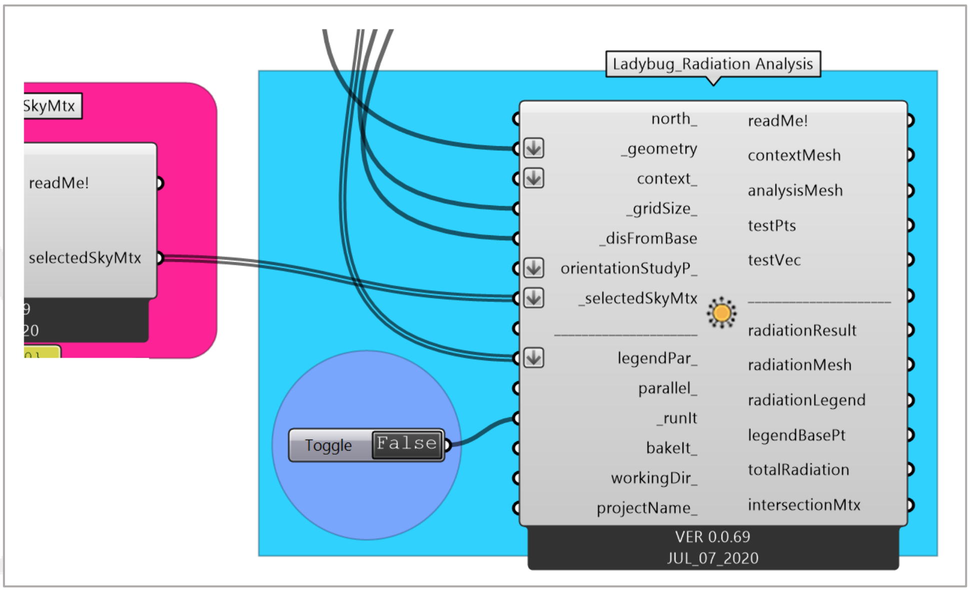



Figure 3. 10 The “Ladybug_Radiation Analysis" component of the Ladybug algorithm. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

### 3.2.2 DIVA algorithm

To optimize the ceiling surfaces that will use the solar plates, shadow analysis will be the final key factor for this stage. Nevertheless, the shadow analysis will be showing in the black and white abstract view from using the "DIVA" tool. DIVA tool is another environment Grasshopper plugin used to analyses environmental data [14]. The Diva algorithm in (Figure 3.12) works with the same concept of the Ladybug tool. The component "solar arc" links with the prototype geometry, and the other component is the "EPW" file linked with the "path" to the "solar arc" component. The final Issue is that the analysis period can be connected directly using the "Numberslider" component, but to set an hours’ range "Series" component used with "Numberslider" components and link it with the "solar arc" component. The shown flowchart in (Figure

3.11) explains the general concept Diva algorithm. Rhino 3D and Grasshopper plugins must be available as a working environment for this tool.

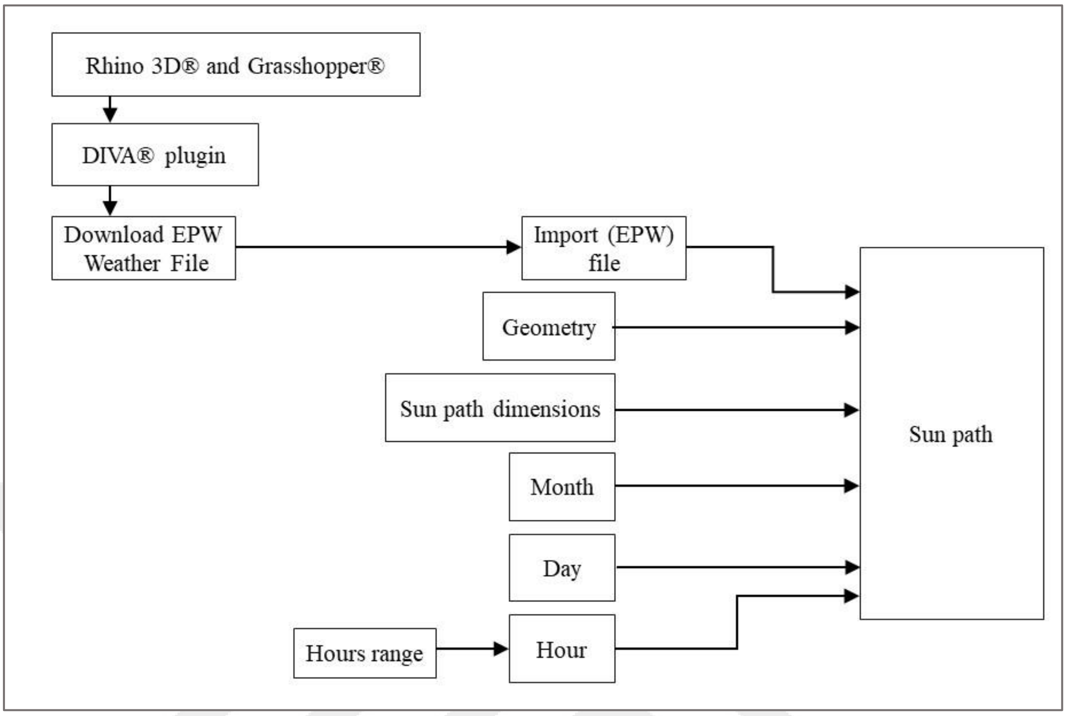



Figure 3. 11 - Flowchart of Diva algorithm workflow. (Illustrated by the author Abdullah Allawi)

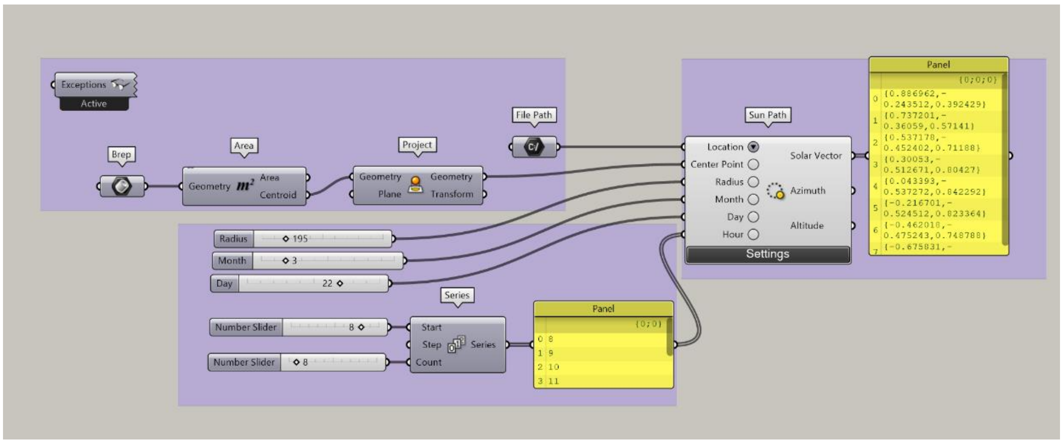



Figure 3. 12 Diva algorithm. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

### 3.3 Structure Enhancement impact on environment and economic

With Building Information Modeling (BIM) methods, it is aimed to optimize material layout and structures for a three-dimensional model as a mathematical process topology optimization. Topology optimization works to maximize performance for a structural system by determining the necessary parts of geometry that can resist the applied forces. Topology optimization's importance is to minimize materials used to the applied load and extract the structure's unnecessary volumes. Therefore, it is directly related to reducing the costs of construction. The concept of topological optimization began in the nineteenth century, and it wasn't validated till the end of the eighties of twenty centuries. In 1992 first algorithm was introduced by Steven and Xie with the name (Evolutionary Structural Optimization "ESO").[28]

There are two essential aspects of the algorithm are:

- Ability to change the topology of structure transcending shape optimization.

- Optimization process development is an evolution-based procedure.

The concept of Evolutionary Structural Optimization "ESO" has been applied with actual structure design for an office building named "Akutagawa". The exterior wall is generated by an analysis of the applied forces on the wall. The (Figure 3.13 a) show the process of implementing ESO method, and it show the changes in the walls through the amendment process. The (Figure 3.13 b ) show real photo for Akutagawa office building.[29]

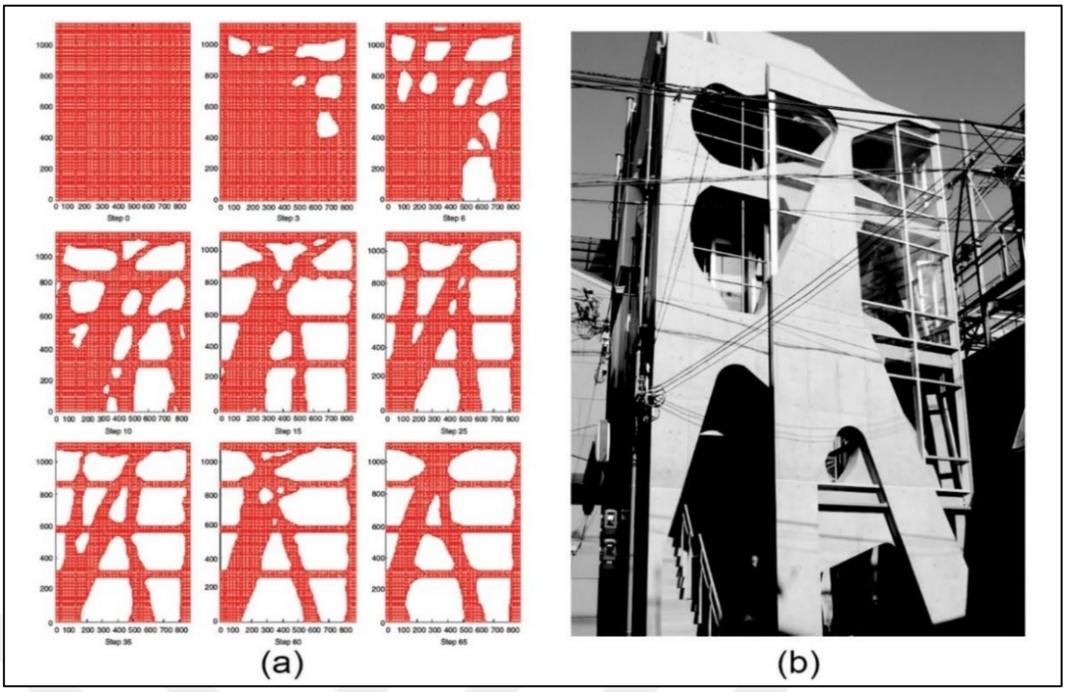



Figure 3. 13 (a) process of ESO, (b) real photo Akutagawa office building [29]

### 3.3.1 Millipede tool

In the parametric algorithmic there are tools to analyze transferring the applied forces, such as "Millipede" which it developed to calculate structural optimization for a two-dimensional structure. The initial thing before applies the geometry to the analysis process is finding the optimal geometry dimensions. As simple example for a rectangle beam with two-dimensional boundary region, the first step is identifying the used component to Grasshopper such as support type, loads type. In this two-dimensional experiment the supports require to be concerning as fixed rotation and displacement for both directions. The loads in this test identified in Y direction with negative value. The materials properties set as reinforced concrete from stock section in the tool. The tool calculates the maximum displacement vale in the structure, this value can be used to present or visualize the deformation of the object. (Figure 3.14) show the optimization process and the strain deformation behavior of the simply supported beam.[28]

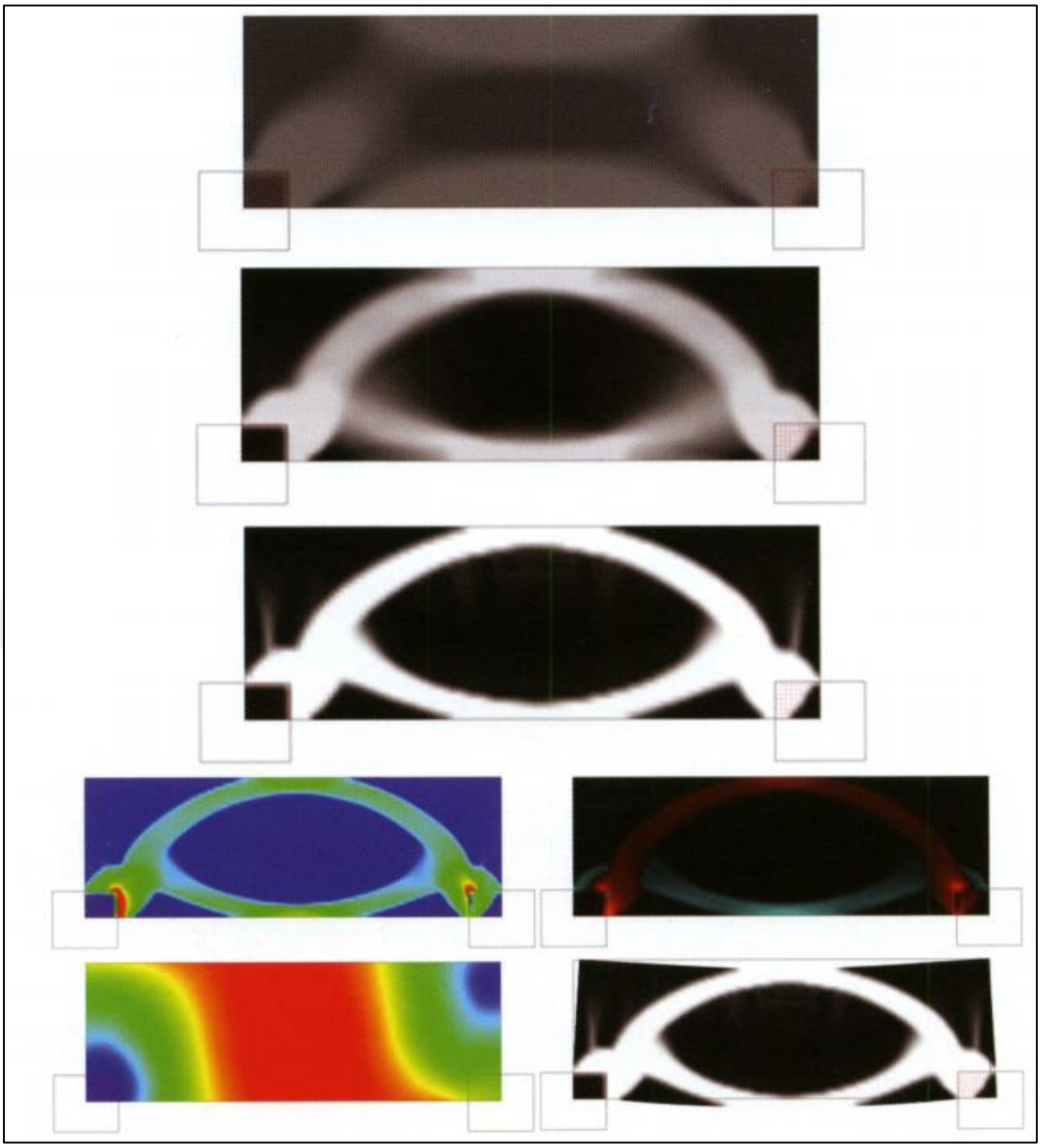


Figure 3. 14 Optimization process and the strain deformation behavior of the MBB beam [28]

### 3.3.2 Topos tool

The "tOpos" tool carries the name derived from the direct words " Topology optimization" linked with Rhinoceros 3D libraries. The tool works with two moods, the first is the CPU mood, and the second is the GPU mood to do the processing and calculations. Without any limitations, tOpos can define asymmetrically formed ground structures, which are responsible for making the Finite Element Model (FEM)[30]. Then making the elements inside the defined boundary and shown as mesh. FEM impacts the final results for the precision of design, shape appearance, and total processing time.[31] The shown flowchart in (Figure 3.15) explains the general concept topos algorithm. Rhino 3D and Grasshopper plugins must be available as a working environment for this tool.

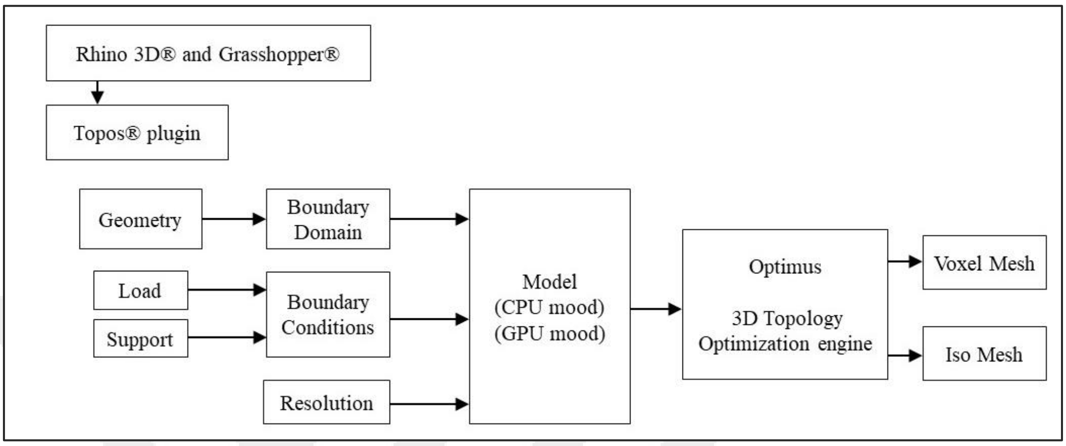



Figure 3. 15 Flowchart of Topos algorithm workflow. (Illustrated by the author Abdullah Allawi)

### 3.3.2.1 Pre-processing

The first step is defining the input variables, and the FEM model is built. The "Model" component needs to link with the three-dimensional geometry and material properties for the geometry, such as Poisson factor and young module; then, it should link to the "Boundary Domain" component. The second essential component is the "Boundary Condition" to define the support and applied load for the model. The third component is "Boundary Properties" if any opens in the geometry or fixed region need to identify to structure. Other factors affect the speed of processing, such as the "Resolution" component and iterations value. (Figure 3.16) shows the components in the tOpos algorithm.

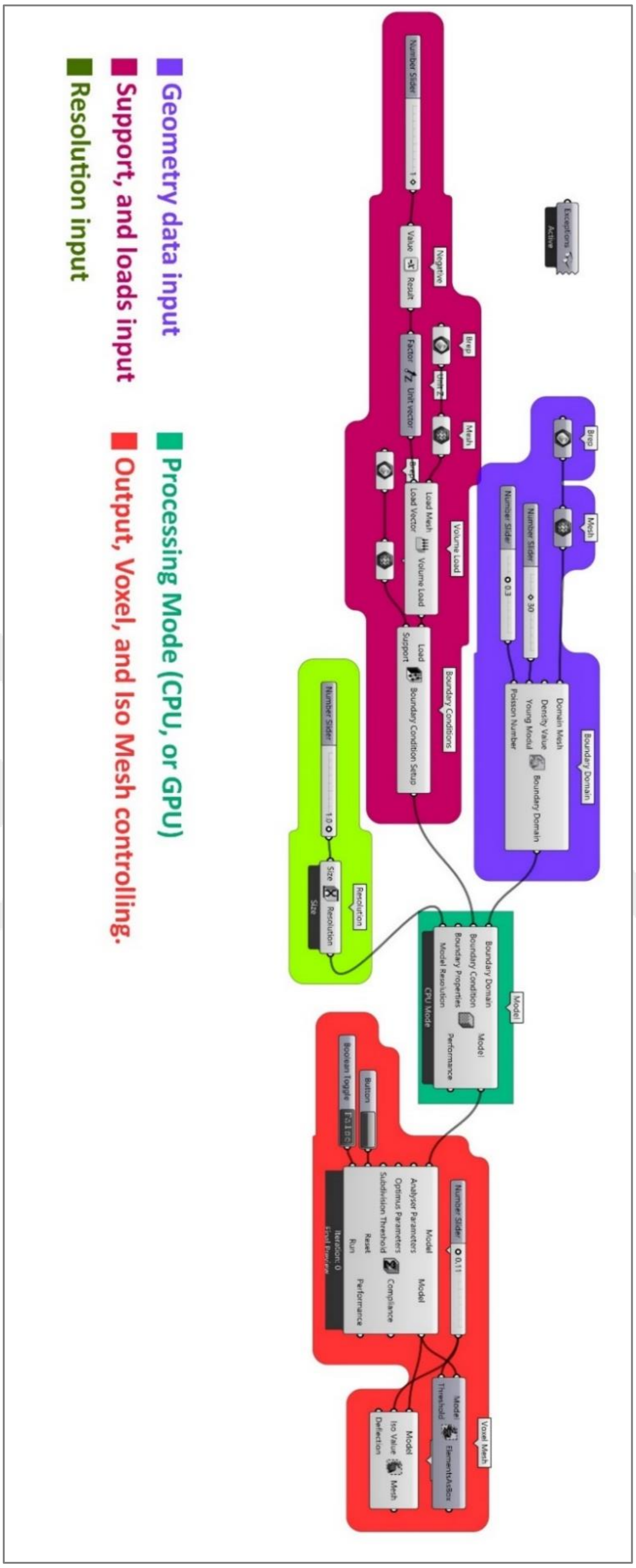



Figure 3. 16 Topos algorithm. (Exported image from Grasshopper 3D, by the author Abdullah Allawi)

#### 3.3.2.2 Post Processing

After inputting the required geometry and boundary conditions data, the results can be represented into different formations by controlling the density of meshes sizes. Two-component can be chosen for determining the relevant result, and the first is "Iso mesh" for soft meshes as shown in (Figure 3. 17 c), and "Voxel mesh" for cubic pixel view as shown in (Figure 3. 17 b). The "Threshold" factor for both Iso and Voxel mesh controls the size of meshes and topology density. The "Threshold" factor for Voxel mesh controls the size of meshes and topology density, and the "Iso value" factor controls the size of meshes and topology density for the "Iso Mesh" component. As shown in (Figure 3. 17 a), the applied load on an experimental prototype geometry generates different results, and it can be controlled by changing the value of the "Iso value " factor for the "Iso Mesh" component to achieve a proper design. The values were (0.11 - iso value) at the (Figure 3. 17 d), (0.40 - iso value) at the (Figure 3. 17 e), (3.39 - iso value) at the (Figure 3. 17 f), and (0.20 - iso value) at the (Figure 3.17 g). the chosen proper design required a structural and material experience.

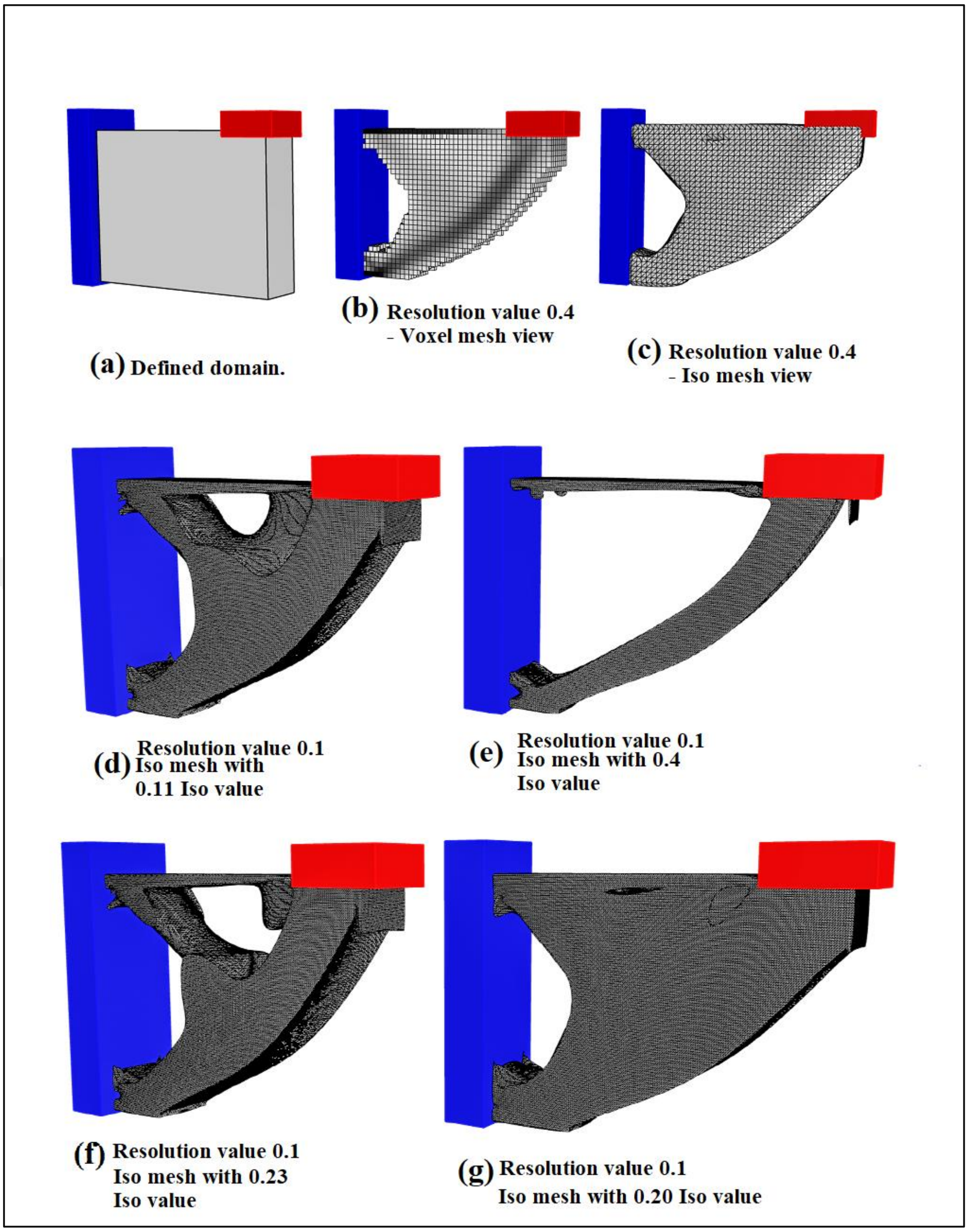



Figure 3. 17 Topology optimization; Voxel mesh, and Iso mesh. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 General

The result chapter contains two major sections after exploring the algorithmic technique in different parametric tools, "Ladybug, DIVA 4.0, and tOpos. The first discusses the weather simulation results and effects; and the second discusses and reviews the topology optimization result and its impact on the environment and economy.

## 4.2 Meteorological data results

Baghdad is located in the middle of Iraq in the alluvial plain of the Mesopotamian valley, and Al-Shaab Stadium is located on the east of Baghdad city. The climate in Baghdad is characterized by being hot and dry during the summer months. In winter, temperatures reach below zero on some days of the year, with sunlight available most of the year.

To find out the temperature variation impact on the building's design at Baghdad, the temperature variation must be known first, by extracting it using the Energy Plus Weather File (EPW) information in the “Grasshopper” through the tool “Ladybug,” which provides temperature information according to the location of the building or the city geographically. Providing this information is essential to know if the site is suitable for using energy panels or not. Also, knowing the temperatures throughout the year qualifies us to conduct the radiological analysis of the sun in the coming stages (Figure 4.1) (Figure 4.2).

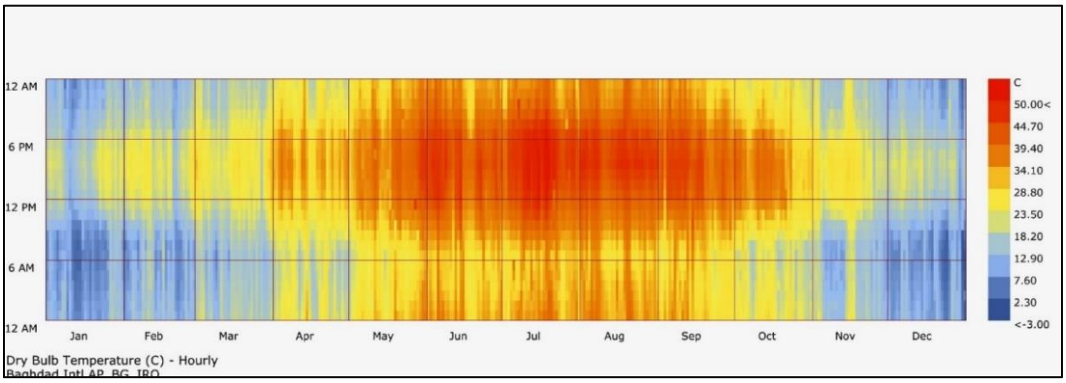



Figure 4. 1 Baghdad's temperature hourly variation (2020). (Exported image from Rhino3D scene, by the author Abdullah Allawi)

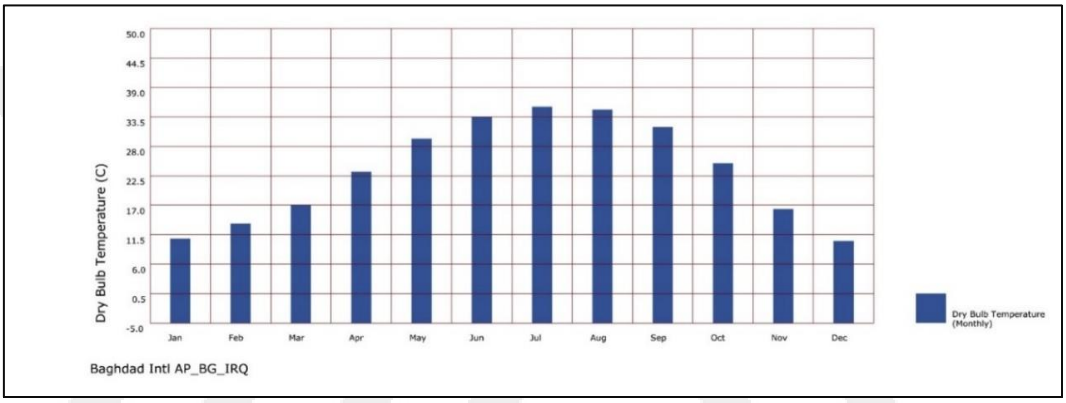



Figure 4. 2 Baghdad's dry temperature monthly variation (2020). (Exported image from Rhino3D scene, by the author Abdullah Allawi)

### 4.3 Results of solar radiation simulation

An essential aspect of the analysis process is solar radiation analysis. The experiment for two prototypes (shell form) and (cylindrical form) has used the algorithmic design of the "Ladybug" tool, one of the Grasshopper environment plugins. Solar radiation analysis improves the eco-friendly buildings in case of using solar plates system as primary electric supply. Equinox times have been chosen for analysis [9].

### 4.3.1 The analyses for prototype (01) Shell form

#### 4.3.1.1 March

During March, solar radiation analysis is high on the roof and less on the stadium's sides shell form. The radiation value was (0.25 - 7.17) kWh/m$^2$. (Figure 4.3)

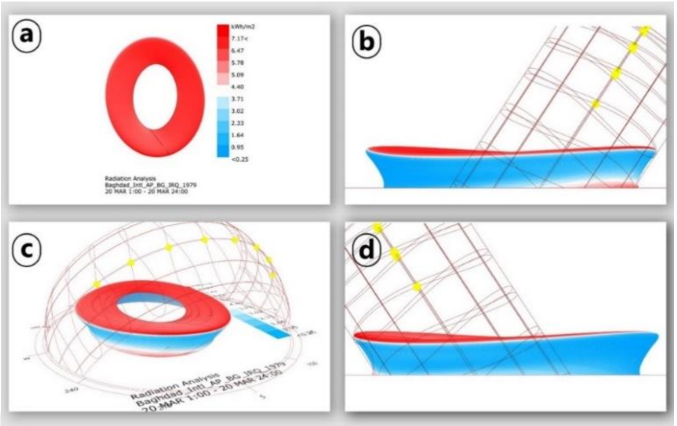



Figure 4. 3 Radiation analysis shell form (March), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.3.1.2 June

Solar radiation analysis during June: the radiation was also high on the roof, and less on the stadium's sides sell mass. The radiation value was (0.36 - 8.17) kWh/m$^2$, which shows a slight increase in the radiation level. (Figure 4.4).

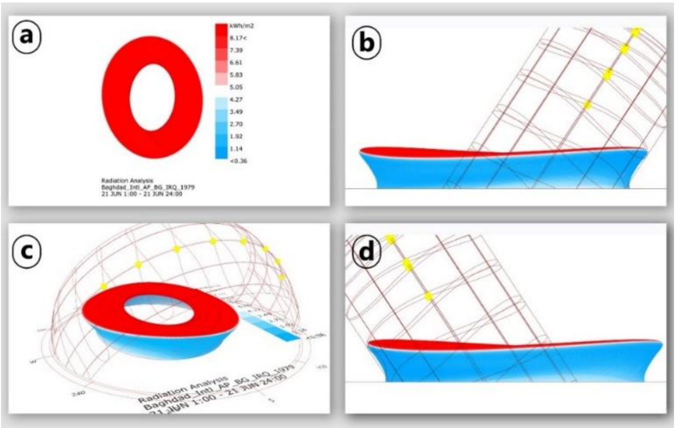



Figure 4. 4 Radiation analysis shell form (June), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.3.1.3 September

Solar radiation analysis during September: the radiation was also high on the roof, and less on the stadium's sides sell form. The radiation value was (0.25 – 7.04) kWh/m$^2$, which shows a slight decrease in the radiation level (Figure 4.5).

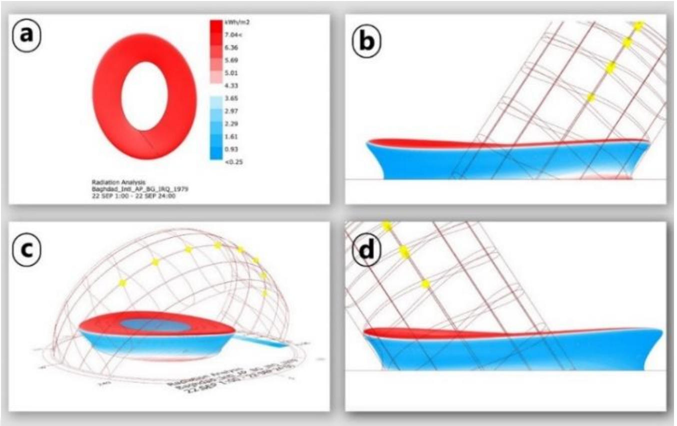



Figure 4. 5 Radiation analysis shell form (September), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.3.1.4 December

Solar radiation analysis during December: the radiation was also high on the roof, yet there was a slight increase in the radiation from the south side of the stadium's sides Shell form. The radiation value was (0.17 - 4.64) kWh/m$^2$, which shows a slight decrease in the radiation level. (Figure 4.6)

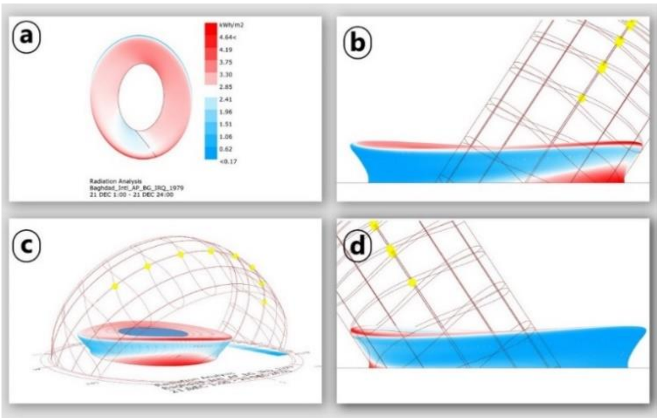



Figure 4. 6 Radiation analysis shell form (December), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

### 4.3.2 The analyses for prototype (02) cylindrical form

#### 4.3.2.1 March

Solar radiation analysis for during June, the radiation was also high on the roof, and less on the stadium's sides sell mass. The radiation value (0.36 - 8.17) kWh/$m^2$, which shows a slight increase in the radiation level. (Figure 4.7)

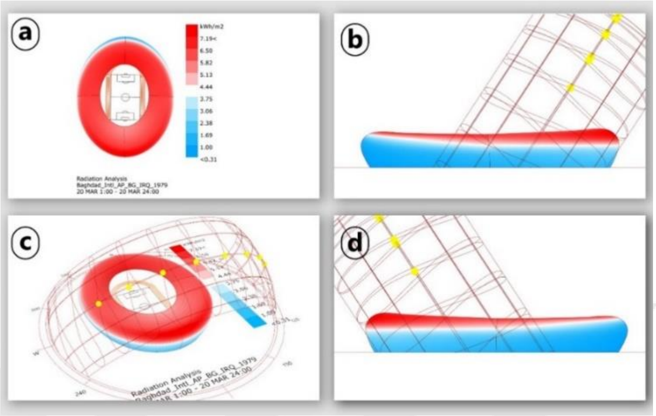


Figure 4. 7 Radiation analysis cylindrical form (march), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.3.2.2 June

Solar radiation analysis during June: the radiation was also high on the roof, and less on the stadium's sides sell mass. The radiation value was (0.36 - 8.17) kWh/$m^2$, which shows a slight increase in the radiation level. (Figure 4.8)

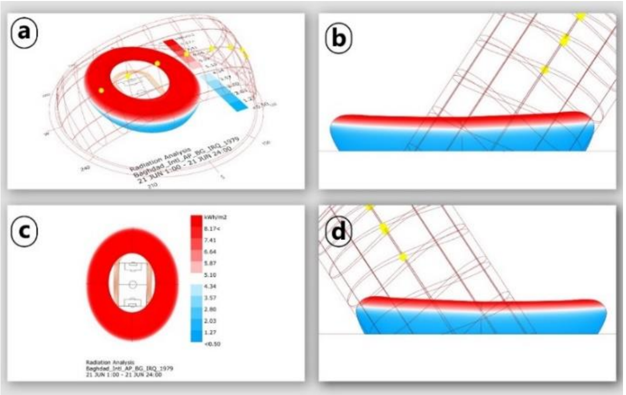


Figure 4. 8 Radiation analysis cylindrical form (June), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view**.** (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.3.2.3 September

Solar radiation analysis for cylindrical form during September, the radiation was high on the roof with a wide coverage on sides of the stadium. The radiation value between (0.31 – 7.06) kWh/$m^2$ (Figure 4.9).

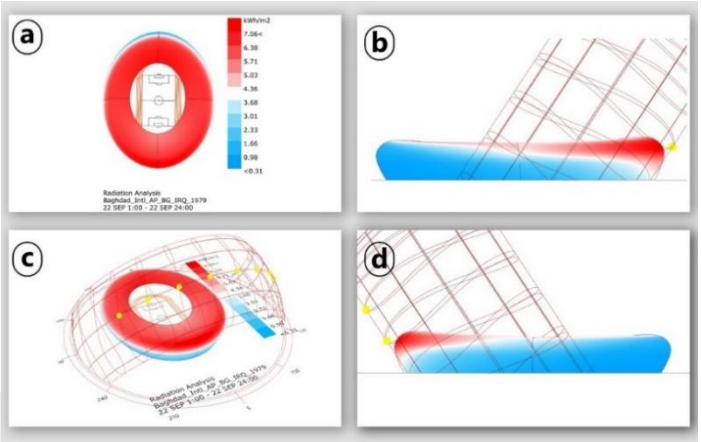



Figure 4. 9 Radiation analysis cylindrical form (September), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.3.2.4 December

Solar radiation analysis for cylindrical form during March, the radiation was high on the roof with a wide coverage on sides of the stadium. The radiation value (0.21 – 4.72) kWh/$m^2$, which shows a slight decrease in the radiation level. (Figure 4.10).

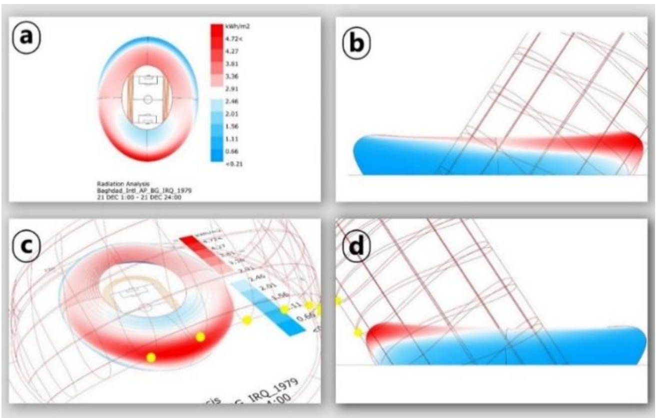



Figure 4. 10 Radiation analysis cylindrical form (December), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

### 4.4 Results of hours of sunlight simulation

Another aspect after solar radiation analysis is analyzing the number of hours to determine solar radiation's time during the day where the surfaces have hours of exposure to the sun. The same tool, "Ladybug," for analyzing the sun's radiation, is also used to analyses the hourly sunlight for analysis period of the year equinox time. [12][13]. The analysis process is divided into prototype masses, one shell shape, and the second cylindrical shape.

#### 4.4.1 The analyses for prototype (01) Shell form

##### 4.4.1.1 March

During March, sunlight hours analysis was also high on the roof, yet there was a slight increase in the number of hours from the south side of the stadium's sided Shell form (Figure 4.11).

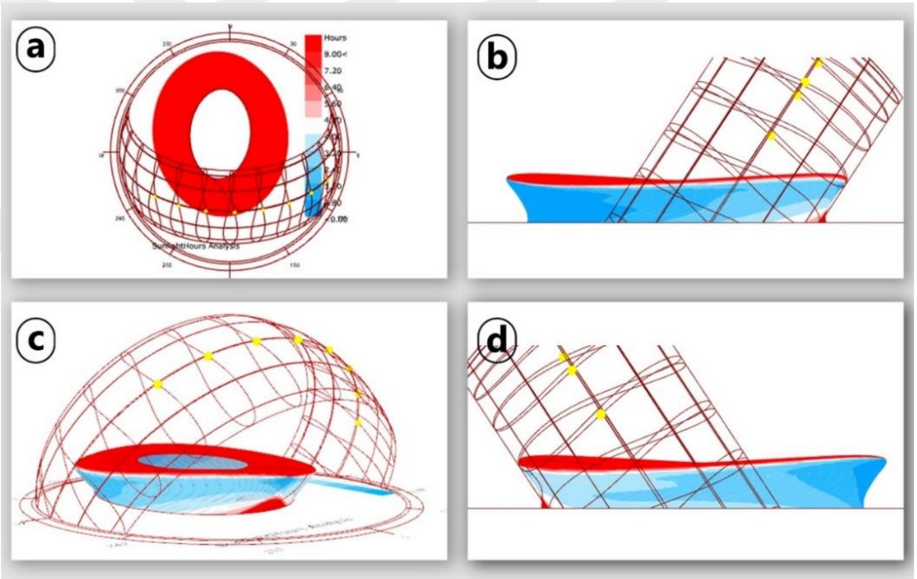



Figure 4. 11 Hours of sunlight analysis Shell form (March), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.4.1.2 June

During June, sunlight hours analysis was also high on the roof, yet there was a slight decrease in the number of hours from the sides of the stadium's sided Shell form. (Figure 4.12)

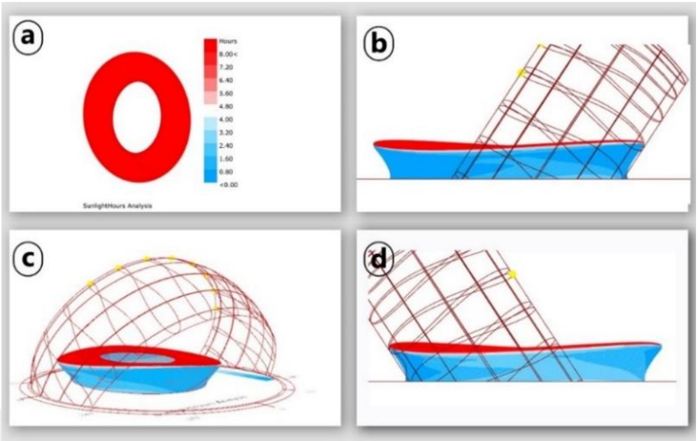



Figure 4. 12 Hours of sunlight analysis shell form (June), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.4.1.3 September

During September, sunlight hours analysis was also high on the roof, yet there was a slight increase in the number of hours from the south side of the stadium's sided Shell form (Figure 4.13)

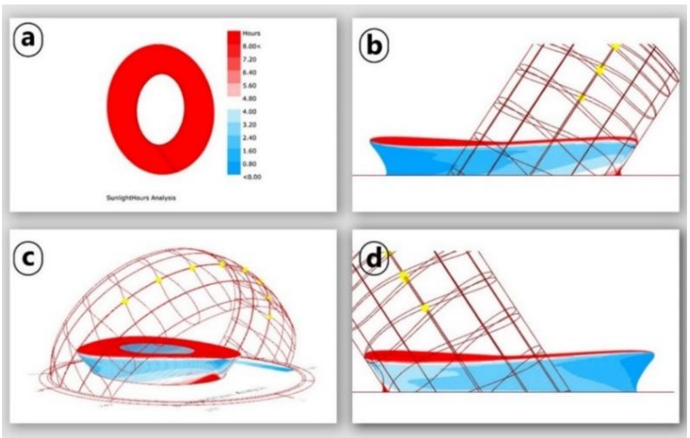



Figure 4. 13 Hours of sunlight analysis shell form (September), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

### 4.4.1.3 December

During December, sunlight hours analysis was also high on the roof with a noticeable increase in the number of hours from the south side of the stadium's sided Shell form. (Figure 4.14)

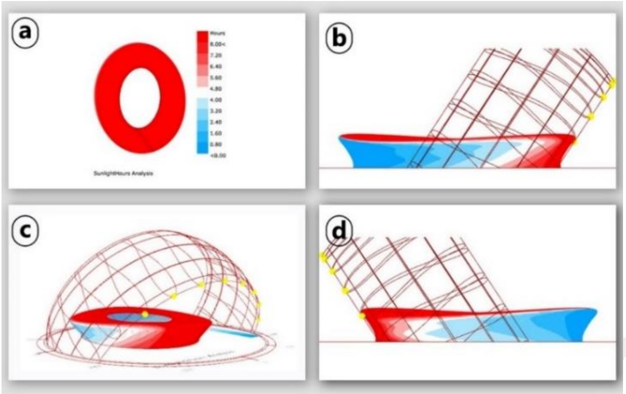


Figure 4. 14 Hours of sunlight analysis shell form (December, (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

## 4.4.2 The analyses for prototype (02) cylindrical form

### 4.4.2.1 March

During March, sunlight hours analysis was also high on the roof, yet there was a slight increase in the number of hours from the south side of the stadium's sided of the cylindrical form (Figure 4.15).

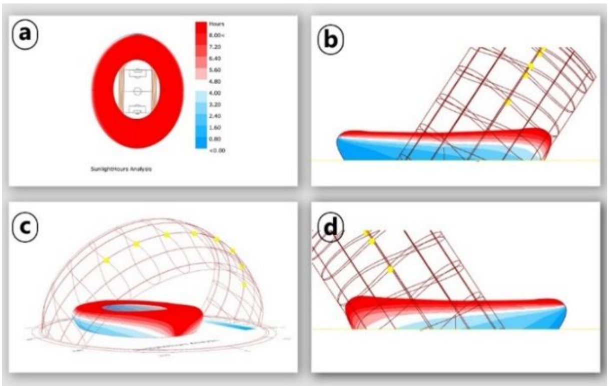


Figure 4. 15 Hours of sunlight analysis cylindrical form (March), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.4.2.2 June

During June, sunlight hours analysis was also high on the roof, yet there was a slight decrease in the number of hours from the stadium's sided of cylindrical form (Figure 4.16).

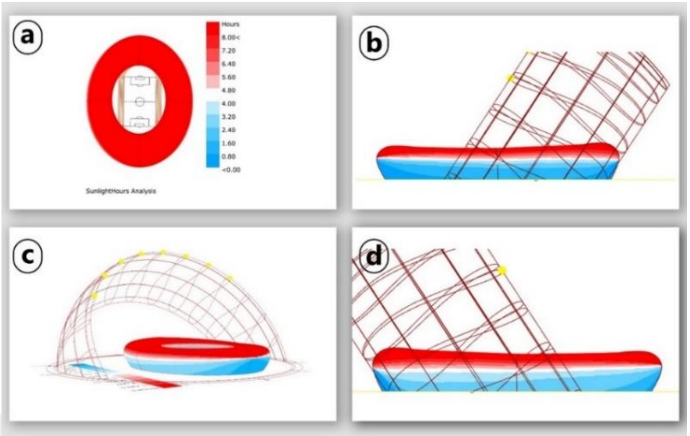



Figure 4. 16 Hours of sunlight analysis cylindrical form (June), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.4.2.3 September

During September, sunlight hours analysis was also high on the roof, yet there was a slight decrease in the number of hours from the stadium's sided of cylindrical form (Figure 4.17).

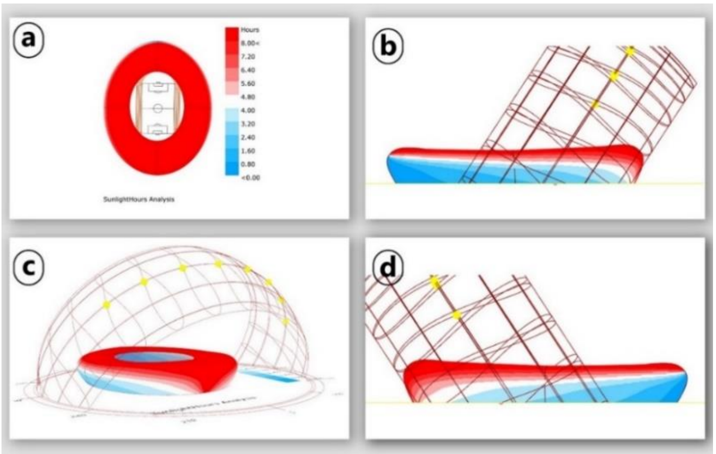



Figure 4. 17 Hours of sunlight analysis cylindrical form (September), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.4.2.4 December

During December, sunlight hours analysis was also high on the roof, yet there was a huge increase in the number of hours from the stadium's southside of cylindrical form (Figure 4.16).

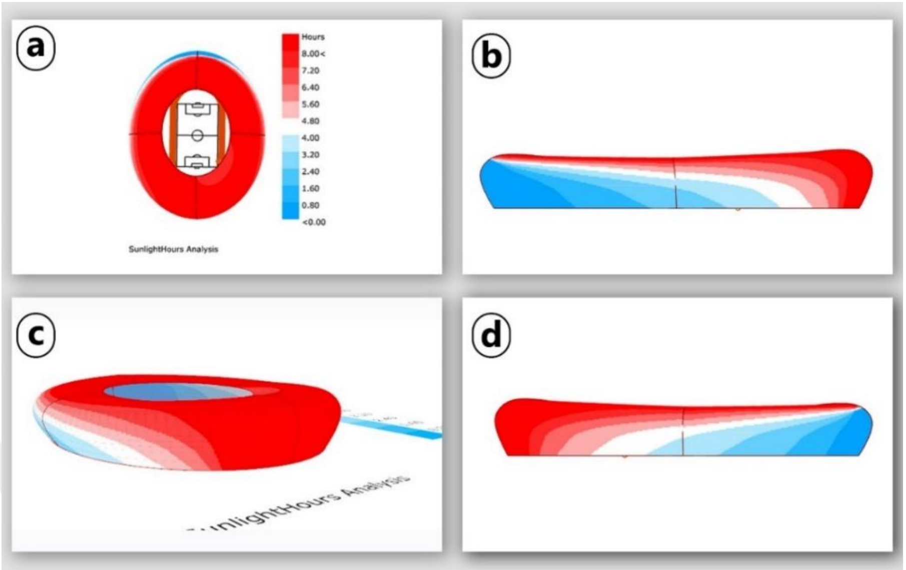



Figure 4. 18 Hours of sunlight analysis cylindrical form (December), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

### 4.5 Results of shadow simulation

To optimize the ceiling surfaces that will use the solar plates, shadow analysis will be the final key factor for this stage. Nevertheless, the shadow analysis will be showing in the black and white abstract view from using the "DIVA" tool. DIVA tool is another environment Grasshopper plugin used to analyses environmental data [14].

### 4.5.1 The analyses for prototype (01) Shell form

#### 4.5.1.1 March

During March, Shadow analysis was also high on the form sides of the shell form (Figure 4.19).

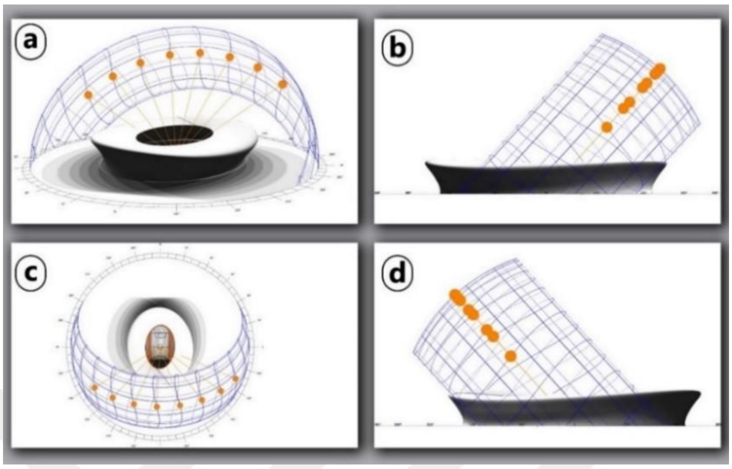



Figure 4. 19 Shadow analysis shell form (March), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.5.1.2 June

During June, Shadow analysis was also high on the form sides of the shell form (Figure 4.20).

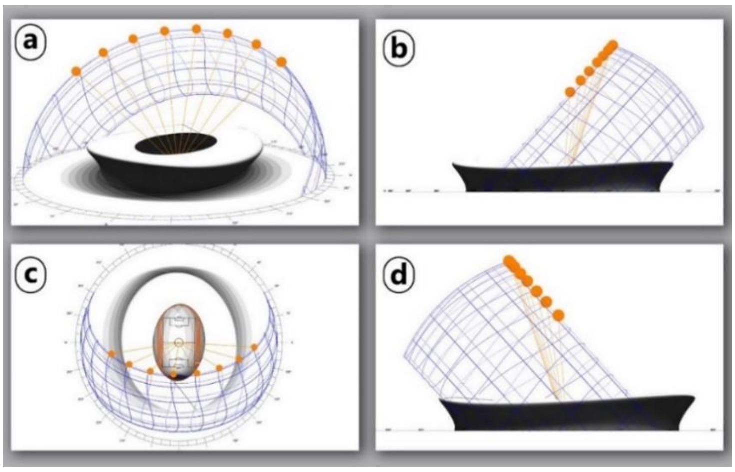



Figure 4. 20 Shadow analysis shell form (June), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.5.1.3 September

During September, Shadow analysis was also high on the form sides of the shell form (Figure 4.21).

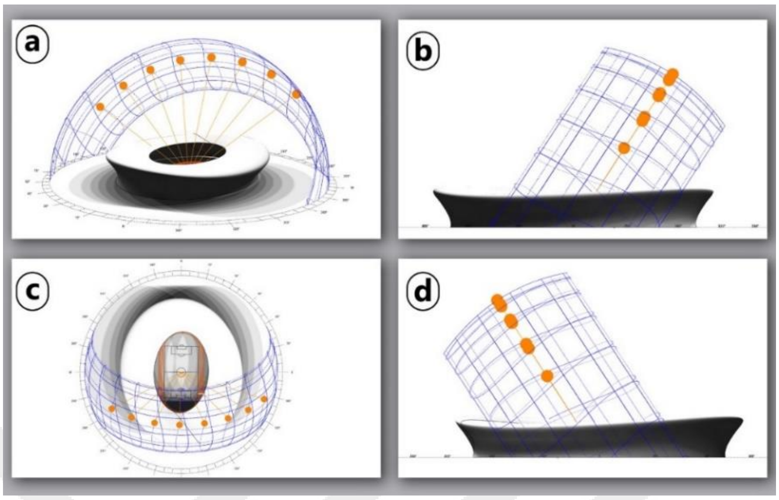



Figure 4. 21 Shadow analysis shell form (September), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.5.1.4 December

During December, the shadow analysis was also high on the form sides of the shell form, and less shadow on the south side (Figure 4.22).

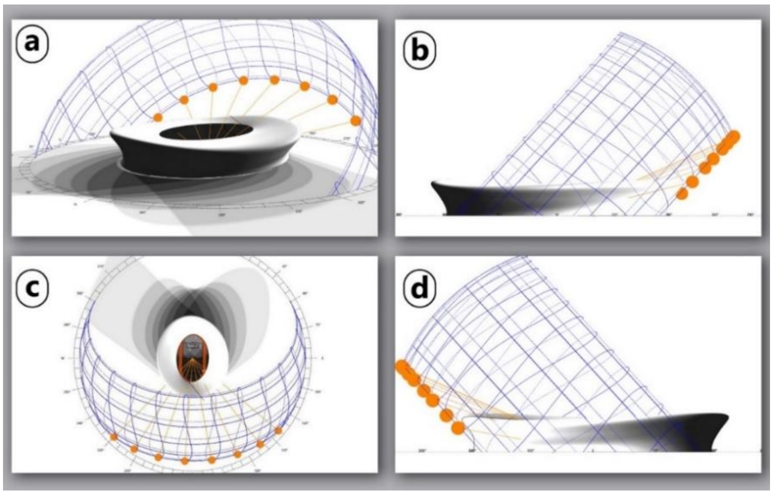



Figure 4. 22 Shadow analysis, shell form (December), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

### 4.5.2 The analyses for prototype (02) cylindrical form

#### 4.5.2.1 March

During March, the shadow analysis was also high on the form sides of the shell form, (Figure 4.23).

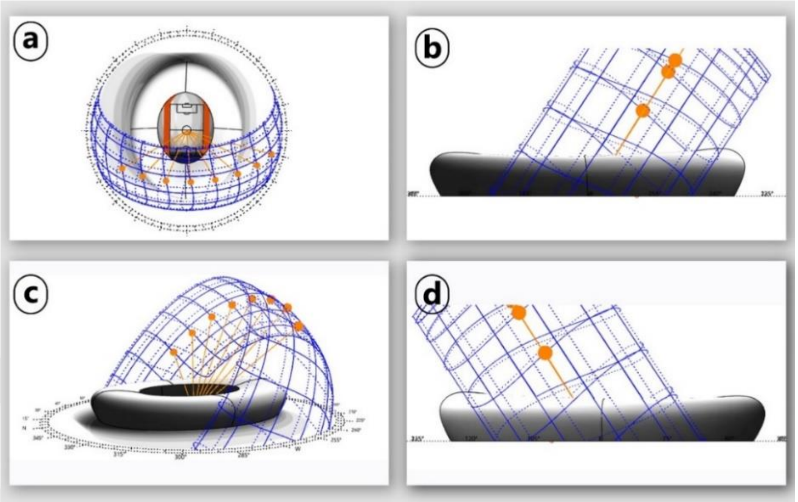



Figure 4. 23 Shadow analysis, cylindrical form (March), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.5.2.2 June

During June, the shadow analysis was also high on the form sides of the shell form, (Figure 4.24).

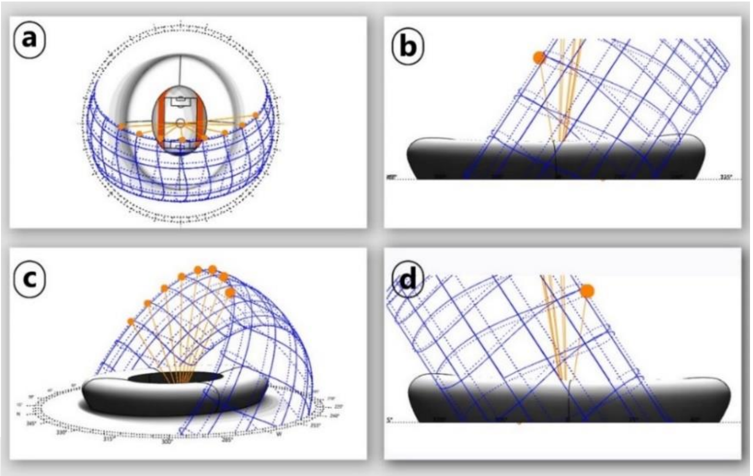



Figure 4. 24 Shadow analysis, cylindrical form (June), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.5.2.3 September

During June, the shadow analysis was also high on the form sides of the shell form, (Figure 4.25).

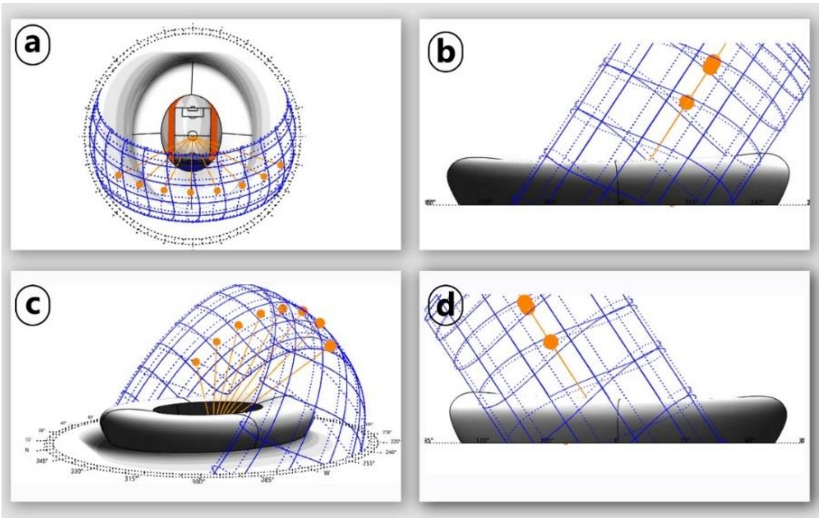



Figure 4. 25 Shadow analysis, cylindrical form (September), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

#### 4.5.2.4 December

During June, the shadow analysis was also high on the form sides of the shell form, and less shadow on the south side (4.26).

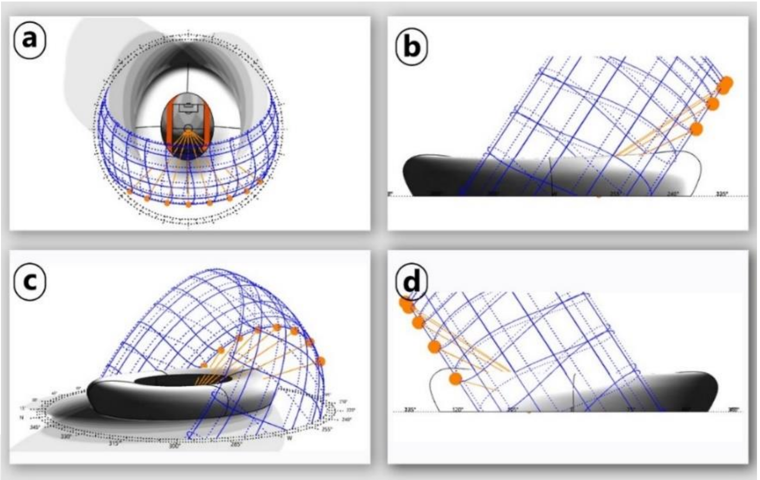


Figure 4. 26 Shadow analysis, cylindrical form (December), (a) Top view, (b) Left view, (c) Perspective view, (d) Right view. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

## 4.6 Simulation results summary

The simulation results summary shows the analysis illustration and values for each prototype (01) and prototype (02) and compare between it as below:

### 4.6.1 Solar radiation analysis results

Ladybug tool extracts the values of radiation shown in (Figure 4.27). These values are explained by unit "kWh/m$^2$," and the colors change to the setting colors in the algorithm (Figure 3.10). According to the selecting experimenting times (Equinox time), the maximum value was 8.17 kWh/m$^2$ in June, and the lower value 0.17 kWh/m$^2$ in December; (Table 4.1).

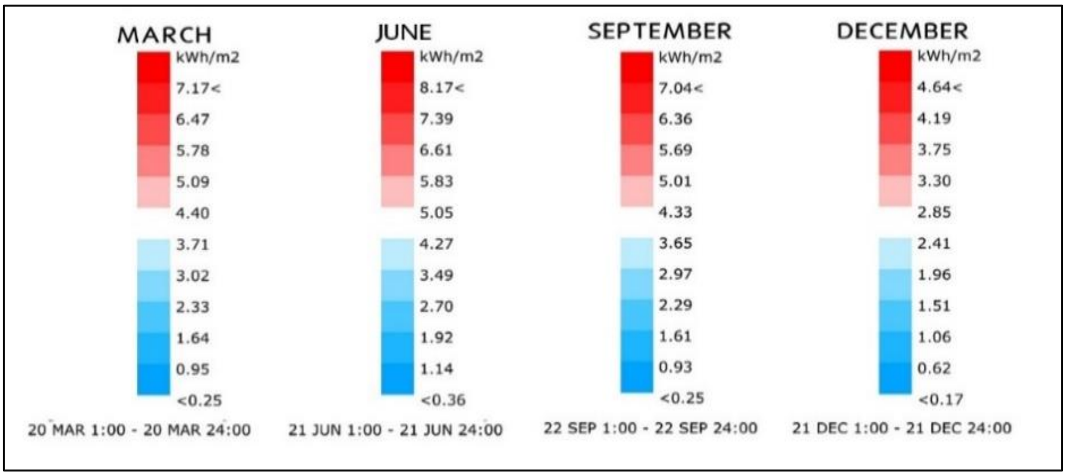
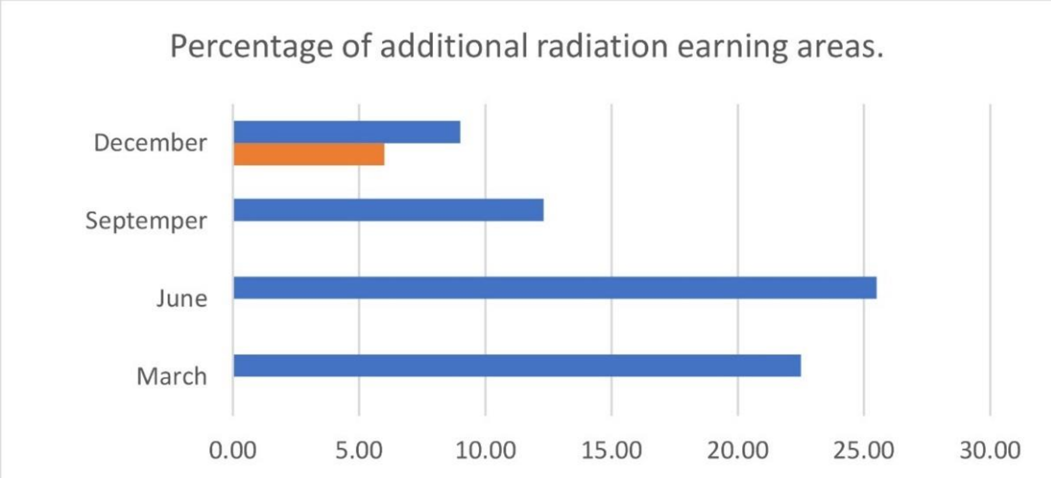



Figure 4. 27 Solar Radiation Values (kWh/m$^2$). (Exported images from Rhino3D scene, by the author Abdullah Allawi)

Table 4. 1 Maximum and minimum solar radiation values (kWh/m$^2$). (Illustrated by the author Abdullah Allawi)

| Radiation Values (kWh/m$^2$) - Equinox Time | | | |
|---|---|---|---|
| March | June | Septemper | December |
| 7.17 | 8.17 | 7.04 | 4.64 |
| 6.64 | 7.39 | 6.36 | 4.19 |
| 5.78 | 6.61 | 5.69 | 3.75 |
| 5.09 | 5.83 | 5.01 | 3.3 |
| 4.4 | 5.05 | 4.33 | 2.85 |
| 3.71 | 4.27 | 3.65 | 2.41 |
| 3.02 | 3.49 | 2.97 | 1.96 |
| 2.33 | 2.7 | 2.29 | 1.51 |
| 1.64 | 1.92 | 1.61 | 1.06 |
| 0.95 | 1.14 | 0.93 | 0.62 |
| 0.25 | 0.36 | 0.25 | 0.17 |

As shown in (Figure 4.28), The prototype (02) cylindrical form presents better performance than the prototype (01) shell form in the radiation earning area. For radiation analysis of March, the radiation earning area of the prototype (02) increases by 22.5% than the prototype (01). For June, the radiation earning area of the prototype (02) increases by 25.5% than the prototype (01). For September, the radiation earning area of the prototype (02) increases by 12.3% than the prototype (01). For December, the radiation earning area of the prototype (02) increases by 9%, and only 6% increases for the prototype (01).

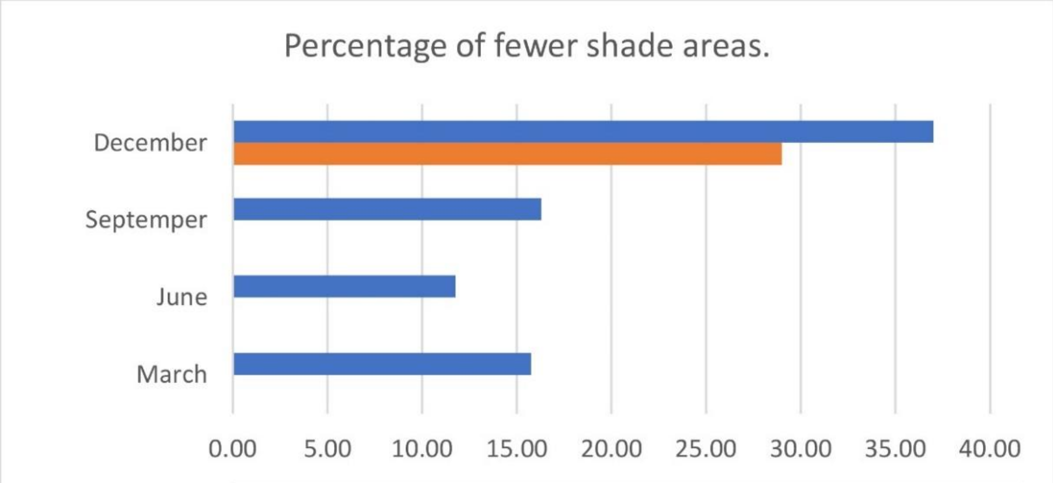



| | March | June | Septemper | December |
|---|---|---|---|---|
| Prototype (02) | 22.50 | 25.50 | 12.30 | 9.00 |
| Prototype (01) | 0.00 | 0.00 | 0.00 | 6.00 |

Figure 4. 28 Percentage of additional radiation earning areas. (Illustrated by the author Abdullah Allawi)

### 4.6.2 Shadow analysis results

As shown in (Figure 4.29) shadows analysis, the prototype (02) cylindrical form presents better performance than the prototype (01) shell form, with fewer shade areas. The shade areas of March of the prototype (02) are less by 15.75% than the prototype (01). For June, the shade areas of the prototype (02) are less by 11.75% than the prototype (01). For September, the shade areas of the prototype (02) are less by 16.3% than the prototype (01). For December, the shade areas of the prototype (02) are less by 37%, and only 29.3% decreasing the prototype (01).




| | March | June | Septemper | December |
|---|---|---|---|---|
| Prototype (02) | 15.75 | 11.75 | 16.30 | 37.00 |
| Prototype (01) | 0.00 | 0.00 | 0.00 | 29.00 |

Figure 4. 29 Percentage of fewer shade areas. (Illustrated by the author Abdullah Allawi)

### 4.6.3 Sunlight hours analysis results

As shown in (Figure 4.30), sunlight hours analysis, the prototype (02) cylindrical form presents better performance than the prototype (01) shell forming the sunlight hours earning area. Where the sunlight hours earning area of March, the prototype (02) increases by 45.5% than the prototype (01). For June, the sunlight hours earning area in the prototype (02) increases by 29.5% than the prototype (01). For September, the sunlight hours earning area in the prototype (02) increases by 40% than the prototype (01). For December, the sunlight hours earning area in the prototype (02) increases by 46%, and only 29% increases for the prototype (01).

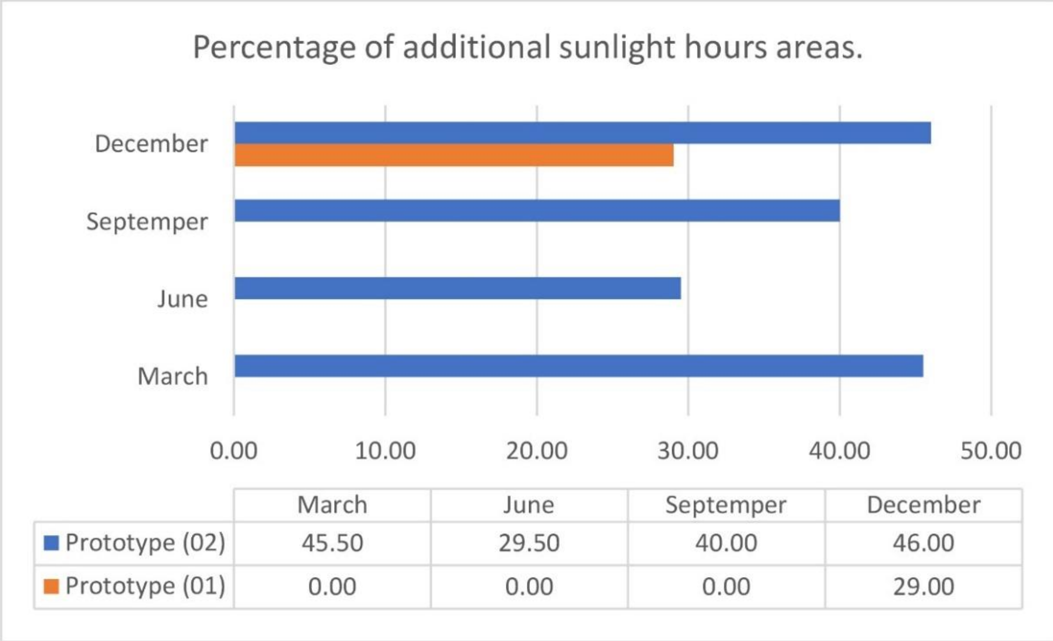



Figure 4. 30 Percentage of additional sunlight hours areas. (Illustrated by the author Abdullah Allawi)

As clearly shown in the tables above, the cylindrical form prototype (02) presents better performance than the shell form. The concept of increasing the stadium's surface to earn more roof area for solar plates, as in the case of shell form, may not be perfect. The increasing of surfaces as cantilevers may increase the cost of the construction. Furthermore, it could complicate the structural design and the construction methods. So, simulate the effect of climate on a building is very essential, it helps to understand the pros and cons of a design for a function not only form.

## 4.7 Results of topology optimization impact on environment and economy

### 4.7.1 Case study test with tOpos results

After explaining the tOpos tool work flow in the previous chapter, next experiment was a testing for a section in the stadium prototype (Figure 4.31). Before using the tool first, a section has been prepared to optimize a structured topology. This tool allows to modify the geometry and extract the experimented section. The purpose of using the Lunchbox tool is to prepare the section without redrawing manually. If any change in geometry in the future, the algorithm shown in (Figure 3.40) will be a better solution for saving design time.

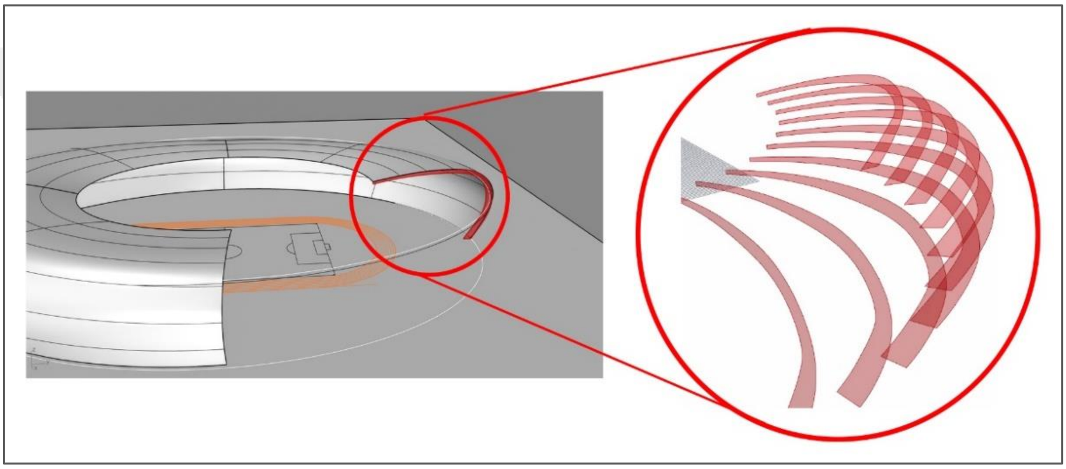


Figure 4. 31 Stadium section. (Illustrated by the author Abdullah Allawi)

After extracting the experimental section from the cylindrical form shapes surface, topology optimization was done using the "tOpos" plugin in Grasshopper algorithm (Figure 3. 38). The algorithm's applied load was 1.1 kWh/$m^2$ (solar panels load, live load, and dead load), without considering wind loads (Figure 4. 32).

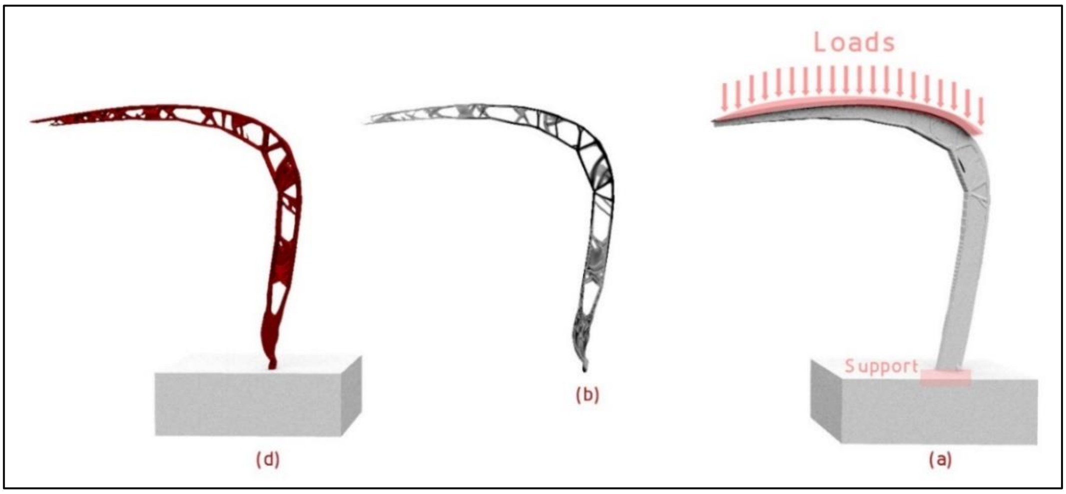



Figure 4. 32 Topology optimization for a section sample. (a) loads, and support. (b) pixel result. (d) Final result. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

For post processing, the optimization results represented in both of voxel mesh (Figure 4.33 a), and Iso mesh (Figure 4.33 b) to give better understanding how the optimization behavior in the prototype section. The behavior of applied loads through the geometry, and deduction of unnecessary parts from geometry.

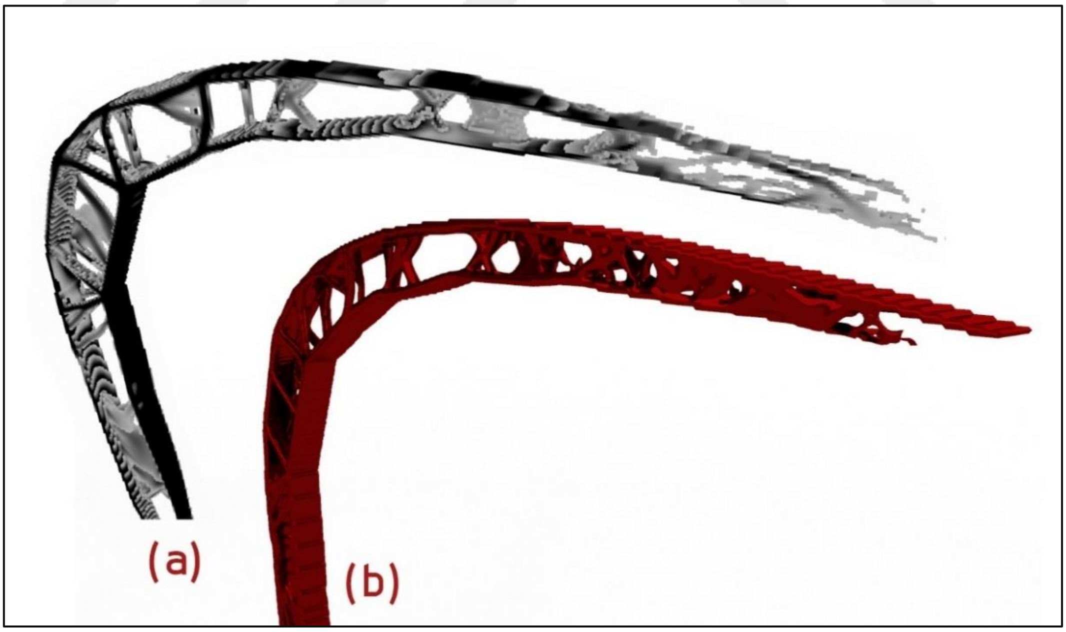



Figure 4. 33 A section in stadium cover section (a) Voxel mesh. (b) Iso mesh. (Exported images from Rhino3D scene, by the author Abdullah Allawi)

### 4.7.2 The tOpos tool result dissection

Before explaining the impact of structure enhancement on the environment, the tOpos tool shows a very huge difference in the optimization processing time. Processing time depends on two main factors, the first is choosing the processing mood CPU solver mood or GPU solver mood. The GPU mood is worked well with the CUDA of Nvidia GPUs, which is design to accelerate processing time. But in this research case, as mentioned in cases one and two (Figure 3.39) and (Figure 3.43), the GPU solver mood did not work and cause windows to crash on mid-range GPU. This mood needs new Graphics cards such as GTX or RTX generations of Nvidia to works and solves some processing issues to make it run on mid-range laptops or computers. The second mood is CPU solver mood, which is design to be a second option for mid-range hardware equipment, as shown in the (Table 4.2) below the time of processing changes when the "Resolution" number changes in the algorithm. The resolution factor works on increasing the quality of output geometry and make the model smoother by reducing the meshes areas such as Voxel meshes or Iso meshes. In these cases, the resolution absolute values were (0.1) and (0.4). The tool solvers' steps were: resolution value, optimization iteration, compliance and sensitivity computation, model compliance computation, sensitivity filtering application, densities update, and total time elapsed. The parametric tools show a huge development in the way of programming of these tools but this for the architectural side. For the Structure side, it still needs more development to be conceded as a design reference.

Table 4. 2 tOpos processing time (s), with CPU solver. (Illustrated by the author Abdullah Allawi)

| tOpos processing time (s),with CPU solver. | | | | | | | |
|---|---|---|---|---|---|---|---|
| Resolution value | Optimisation Iteration | Solved by Iter:170 | Compliance and Sensitivity computation | Model Compliance computation | Sensitivity filtering application | Densities update | Total Time Elapsed |
| 0.4 | 0 | 0.363408 | 0.001994 | 0.000098 | None | 0.001912 | 0.367414 |
| 0.1 | | 86.68435 | 0.168958 | 0.100216 | None | 0.091638 | 87.045164 |
| | | Solved by Iter:161 | | | | | |
| 0.4 | 1 | 0.338367 | 0.006219 | 0.000091 | 3.20E-06 | 0.001809 | 0.34649 |
| 0.1 | | 89.446365 | 0.163812 | 0.000694 | 6.00E-06 | 0.06696 | 89.677838 |
| | | Solved by Iter:182 | | | | | |
| 0.4 | 2 | 0.379314 | 0.002519 | 0.000097 | 3.00E-06 | 0.001822 | 0.383756 |
| 0.1 | | 91.365705 | 0.182889 | 0.00098 | 3.30E-06 | 0.066902 | 91.61648 |
| | | Solved by Iter:176 | | | | | |
| 0.4 | 3 | 0.369606 | 0.002645 | 0.000089 | 3.00E-06 | 0.001975 | 0.37432 |
| 0.1 | | 91.066768 | 0.156023 | 0.000692 | 7.90E-06 | 0.062005 | 91.285498 |
| | | Solved by Iter:176 | | | | | |
| 0.4 | 4 | 0.367235 | 0.002578 | 0.000125 | 4.50E-06 | 0.007663 | 0.377607 |
| 0.1 | | 88.574541 | 0.161456 | 0.000791 | 3.10E-06 | 0.278964 | 89.015756 |
| | | Solved by Iter:545 | | | | | |
| 0.4 | 5 | 1.12252 | 0.00261 | 0.000105 | 4.00E-06 | 0.008019 | 1.13326 |
| 0.1 | | 330.453936 | 0.168573 | 0.000646 | 7.20E-06 | 0.275988 | 330.899154 |
| | | Solved by Iter:456 | | | | | |
| 0.4 | 6 | 0.958142 | 0.002631 | 0.000082 | 2.20E-06 | 0.007747 | 0.968605 |
| 0.1 | | 335.975803 | 0.176262 | 0.000715 | 6.60E-06 | 0.280852 | 336.43364 |
| | | Solved by Iter:706 | | | | | |
| 0.4 | 7 | 1.453584 | 0.002156 | 0.000097 | 2.70E-06 | 0.00792 | 1.463762 |
| 0.1 | | 481.11682 | 0.156464 | 0.151602 | 5.60E-06 | 0.26799 | 481.692884 |
| | | Solved by Iter:487 | | | | | |
| 0.4 | 8 | 1.006194 | 0.002575 | 0.000094 | 4.00E-06 | 0.008098 | 1.016967 |
| 0.1 | | 380.704902 | 0.158246 | 0.000616 | 5.40E-06 | 0.446287 | 381.310058 |
| | | Solved by Iter:915 | | | | | |
| 0.4 | 9 | 1.897605 | 0.002548 | 0.000091 | 2.20E-06 | 0.008025 | 1.908272 |
| 0.1 | | 479.796691 | 0.155544 | 0.165849 | 3.80E-06 | 0.288838 | 480.406928 |

Using non-friendly materials in the construction is an essential factor effect on the environment, and using materials such as steel and cement in others with standard quantities could increase the construction cost and $CO_2$ emissions. Where the cement using increased from the midst of the last century until today (Figure 4.34 - a), also the use of steel increased from the midst of the last century until today (Figure 4.34 - b). [32]

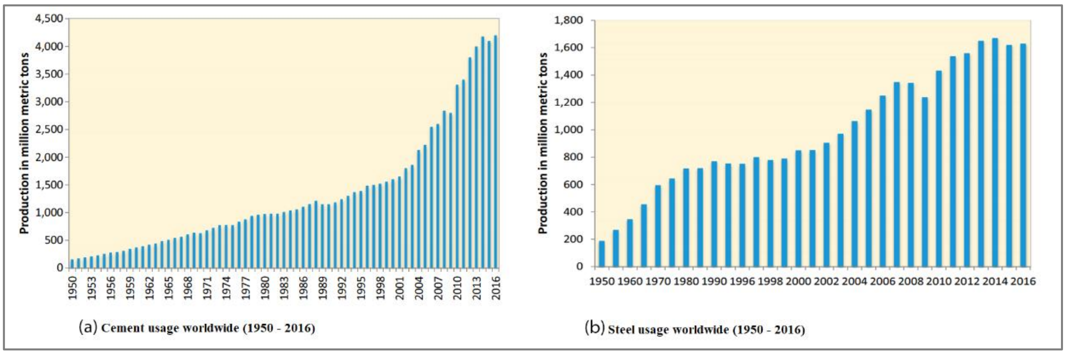



Figure 4. 34 Total worldwide cement and steel production 1950–2016, (a) cement production, (b) steel production[32]

Topology optimization aims to reduce the quantities of materials where it directly affects the cost of construction and environmental impact. In the case study of this research (Figure 4.32), the materials decrease in the stadium section experiment about (35 %) of the basic geometry. This rate of decreasing materials helps to decrease the cost of construction and shows the value of the new practice of technology in the design structure. The parametric techniques show high flexibility of instant response through the design process. The parametric tools show a huge development in the way of programming of these tools but this for the architectural side. For the Structure side, it still needs more development to be conceded as a design reference. To understand the level of development of these tools, (Table 5) below shows the difference between the architectural weather simulation tools, and topology optimization tools; and shows the pros and cons for each other.

Table 4. 3 Parametric tools Comparison. (Illustrated by the author Abdullah Allawi)

| **Comparison factor** | **Structure tools (Topology optimization tools: TOPOS)** | **Architectural tools (Simulation tools: Ladybug, DIVA 4.0)** |
|---|---|---|
| **Hardware requirements** | High | Medium, Low |
| **Processing time** | Long time | Short time |
| **Interactive view** | Slow | Fast |
| **Easy to use** | Normal | Normal |
| **Accuracy** | Low | High |
| **Range of functions** | Limited | Multi-functional |
| **Programming level** | Beginner | Advanced |

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

Energy and the environment essential factors that should be considered in both structural and architectural designs, to minimize the harmful impact on the climate. In this study, structural and architectural integration was done using parametric techniques with the "Grasshopper 3D" plugin with "Rhino3D" software. The parametric algorithmic design tools show higher flexibility to simulate the solar effect on designing a building or the stadium in the case study for energy with two experimented prototypes and comparing between the prototypes. The second using of parametric techniques was topology optimization's impact on the economy and environment. The findings below as below:

- The ability to simulate the solar effect on the geometry to choose proper solar panel surfaces that could earn more solar radiation.
- Determining the maximum earning the amount of sunlight hours on geometry to detect the solar panel's surfaces in adequate locations in the geometry.
- Choosing fewer shades areas that can prevent solar radiation from reaching more surfaces in the geometry.

As mentioned in chapter four, the prototype (02) shows better performance than prototype (01) in earning more solar radiation for an average of 17.3 % increasing area surfaces. And fewer shades by an average of 20.2 % fewer than the prototype (01). Finally, the average of 40 % more earning sunlight hours for the prototype (02) than prototype (01). The reason for better performance for the prototype (02) back to the geometry design, with smooth edges or curved chamfered corners for the stadium stands cover. While the prototype (01) was designed with cantilever edges, which prevent the solar radiation from reaching the sides of the geometry and cause shades areas instead of light. Furthermore, determining the proper solar panels depends on the needed radiation value, as shown in (Figure 4.1). Energy designers can determine the radiation values for the panels using the red color that ranges between 2.85 kWh/$m^2$ to 8.17 kWh/$m^2$ or depending on a specific design to operation of electrical equipment such as lighting, air conditioners, and other facilities.

The second part of this research findings regards the topology optimization impact on the environment and economy. The parametric technique provides several tools for architectural design and also for structural engineering, such as generative design and topology optimization. The research finding as explained below shows the optimization tool "tOpos" review and the scientific criticism to the parametric algorithmic efficiency in this Issue:

- The tool "tOpos" basically designed to optimize an already designed 3D geometry and processing domain.
- As shown in (Table 4.2) increasing the model resolution courses increasing in the final mesh quality and increasing processing time. Furthermore, the final mesh could be smother meshes by controlling the "Iteration value" for the "Voxel mesh" component or "Iso value" for the "Iso mesh" component.
- As shown in (Figure 3.444) the topology optimization process helps to decrease the geometry materials by 35.2 % which directly affects the cost of construction and environment from another side by reducing the used materials.
- The drawbacks of this tool, it cannot be considered as a structural design tool because modifying the materials and details is very limited. The second reason is needed already designed section, so the tool cannot suggest a specific recommendation such ad enforcement in the final results.
- The GPU mood is basically designed to accelerate the processing time, but sometimes this mood course program crushing.
- This tool needs structural knowledge to use, so it is designed for civil engineers, and architects need to dealing with loads to run it.
- The other tools such as the "millipede" tool faced a lot of crushing and very beginner level of programming, which prevent this tool to be common use tool in this field.

The last part of this research finding regards the societal value of developing Al shaab stadium. In the case of developing this historical edifice for the middle east and Baghdad city to host sports with sustainable design, the impact as follow:

- It will inspire other engineers in Baghdad to design more facilities as modern buildings with taking care the sustainability and the environment.

- The abundance of solar radiation and high weather degrees could benefit from using solar panels in developing the stadium.

- Using modern design methods such as parametric design will create a new architecture language for Baghdad in particular, and Iraq, in general, and more engineering value to the design that helps to introduce these concepts to engineers and students in Baghdad, where they are still using traditional methods.
- Develop a stadium design with the latest FIFA requirements in stadium design will allow the stadium to host international matches and regional and continental tournaments such as the Arabian Gulf Cup and the Asian Cup.

## 5.2 Limitations

The research limitations are as follows:

- The simulation analysis for the energy impact tested only two prototypes to explain the simulation concept using parametric strategies. Where experimenting with more prototypes is unnecessary, regards actual design implementation with different simulation location specifications.
- The research focused on using the Ladybug tool for the radiation simulation and sunlight hours and used Diva for shadows simulation. The reason for using Diva for shadows is back to the results of the Diva plugin are more accurate than other plugins in shadows simulation.

- The structure optimization process focused on reducing inefficient materials and their impacts on the economy. The structure optimization is not structural design; the structural designers should design the dimensions of the domain or the geometry before making the topology optimization.

### 5.3 Recommendations

The impact of finding modern solutions for structural design and architectural design is a very important issue to maximize the benefits of geometry and constructions. After the design, simulation, experiment, and reviewing the parametric algorithmic design the recommendations of this research as below:

- The "Ladybug" tool will be more helpful if it provides more information about solar panels' total earning energy, systems efficiency, and approximate solar system cost.
- The "tOpos" tool needs more programming upgrading to be more useful in generating new geometry resulting from the topological optimization process.
- The "tOpos" tool, would be better if it contains more options for customizing the materials information and providing direct options such as wood, steel, aluminum, steel, and concrete; to facilitate the design process.
- Finally, this research praise structural and architectural engineers to use the ways of design that's make people lives by providing solutions that's enhance energy efficiency, environment, and climate.

# REFERENCES


[1] E. Yaroni, “Evolution of Stadium Design.” BASc. thesis, Massachusetts Institute of Technology, U.S.A, 2012.

[2] P. Barker, “When the first Olympic Stadium came alive again.” Internet: https://bit.ly/3azo8EQ, Apr. 8, 2021 [May. 11, 2021].

[3] Fédération Internationale de Football Association (FIFA), “Football Stadiums – Technical recommendation and requirements 5th edition.” Switzerland. 2011.

[4] R. Baudouï, “Bâtir un Stade: le Projet de Le Corbusier pour Bagdad, 1955–1973,” in *Azara*, Jun. 2008, pp. 91–102.

[5] W. Khider, “The story of the design and construction of Al-Shaab International Stadium.” Internet: https://bit.ly/3sJIbGV, May. 11, 2019 [Aug. 29, 2020].

[6] A. Al-Mashhadani, “Story of Al-Shaab stadium. An Iraqi facility was never built like it before.” Internet: https://www.ishtartv.com/viewarticle,64637.html, Nov. 27, 2015 [Sep. 2, 2020].

[7] A. Nouri, "Al-Habibiya Stadium, a strategic location and an architectural masterpiece in Baghdad." Internet: https://bit.ly/3Ca7TdA, Jul. 9, 2018 [Feb. 22, 2021].

[8] P. Caponi, F. Cutroni, and L. Rhode-Barbarigos, “Revisiting the ‘M Stadium’ project by luigi moretti: A forgotten model of parametric architecture,” in *Proceedings of IASS Annual Symposia*, Oct. 7, 2019, pp. 2247–2256.

[9] P. Shepherd, R. Hudson, and D. Hines, “Aviva Stadium: A parametric success.” *Int. J. Archit. Comput.*, vol. (9)(2), pp. 167–185, Jun. 1, 2011.

[10] C. Ben Bacha and F. Bourbia, “Effect of kinetic facades on energy efficiency in office buildings - hot dry climates,” in *11th Conference on advanced building skins*, vol. (1), 2016, pp. 458–468.

[11] J. L. Paramio, B. Buraimo, and C. Campos, "From modern to postmodern: The development of football stadia in Europe." *Sport Soc.*, vol. (11)(5), pp. 517–534, Aug. 11, 2008.

[12] F.B. Koçyiğit, M.A. Zinkçi, M. Sayesthnom, and C. Turhan, "Feasibility of Nearly-Zero Energy Building Retrofits By Using Renewable Energy Sources in an Educational Building." *J. Sci. Perspect.*, vol. (3)(4), pp. 311–318, Oct. 29, 2019.

[13] E. Touloupaki and T. Theodosiou, "Optimization of Building form to Minimize Energy Consumption through Parametric Modelling." *Procedia Environ. Sci.*, vol. (38), pp. 509–514, 2017.

[14] A. Shiota, A. Tada, S. Yamada, K. Yokozawa, T. Kerdphol, and Y. Mitani, "Construction of Solar Radiation Simulation Database and Solar Radiation Simulation System using GIS and Application to the Agriculture Field." *Acta Sci. Agric.*, vol. (3)(10), pp. 02–09, Sep. 5, 2019.

[15] J. de S. Freitas, J. Cronemberger, and R. M. Soares, "Using Rhinoceros Plugins Grasshopper And Ladybug To Assess BiPV Façades In Brasília," in *Proc. Build. Simul. Conf. IBPSA*, vol. (160), Nov. 2020, pp. 4467–4472.

[16] M. S. Roudsari and M. Pak, "Ladybug: A parametric environmental plugin for Grasshopper to help designers create an environmentally-conscious design," in *Proc. BS Conf. Int. Build. Perform. Simul. Assoc.*, Aug. 2013, pp. 3128–3135.

[17] C. de C. Lucarelli, J. C. Carlo, and A. C. P. Martínez, "Parameterization and solar radiation simulation for optimization of a modular canopy." *PARC Pesqui. em Arquitetura e Construção*, vol. (10), Apr. 2019.

[18] A. S. Berleze, A. de B. H. Brasileiro, and M. M. Silvoso, "Multi-objective optimization of the geometry of single-family housing to improve thermal performance." *Ambient. Construído*, vol. (21)(2), pp. 41–65, 2021.

[19] A. Hasan and I. Dincer, "A new performance assessment methodology of bifacial photovoltaic solar panels for offshore applications." *Energy Convers. Manag.*, vol. (220), Article ID 112972, 9 pages, Jun. 2020.

[20] S. Zhang, J. P. Fine, M. F. Touchie, and W. O'Brien, "A simulation framework for predicting occupant thermal sensation in perimeter zones of buildings considering direct solar radiation and ankle draft." *Build. Environ.*, vol. (183), Article ID 107096, 15 pages, Jun. 2020.

[21] M. Shafique, X. Luo, and J. Zuo, "Photovoltaic-green roofs: A review of benefits, limitations, and trends." *Sol. Energy*, vol. (202), pp. 485–497, 2020.

[22] F. Calise, F. L. Cappiello, M. Dentice d'Accadia, and M. Vicidomini, "Energy efficiency in small districts: Dynamic simulation and technoeconomic analysis," *Energy Convers. Manag.*, vol. (220), Article ID 113022, 22 pages, May. 15, 2020.

[23] A. Al-saggaf, H. Nasir, and M. Taha, "Quantitative approach for evaluating the building design features impact on cooling energy consumption in hot climates." *Journal of Building Engineering*, vol. (211), Article ID 109802, 24 pages, Mar. 15, 2020.

[24] P. Hoseinzadeh *et al.*, "Energy performance of building integrated photovoltaic high-rise building: Case study, Tehran, Iran." *Energy Build.*, vol. (235), Article ID 110707, 10 pages, Mar. 15, 2021.

[25] A. Eltaweel, Y. Su, M. Hafez, and W. Eltaweel, "An automated louver with innovative parametrically-angled reflective slats: Prototyping and validation via using parametric control in Grasshopper along with Arduino board." *Energy Build.*, vol. (231), Article ID 110614, 14 pages, Jan. 15, 2021.

[26] T. Ghandriz, "Structural Topology Optimization of Multibody Systems having contacts between flexible bodies," in *ECCOMAS Thematic Conference on Multibody Dynamic*s, Oct. 2015, pp. 67–70.

[27] S. Sotiropoulos, G. Kazakis, and N. D. Lagaros, "Conceptual design of structural systems based on topology optimization and prefabricated components." *Comput. Struct.*, vol. (226), Article ID 106136, 18 pages, Jan. 1, 2020.

[28] A. Tedeschi, *AAD Algorithms-Aided Design: Parametric Strategies Using Grasshopper*. Brienza - Italy: Le Penseur Publisher, 2014, pp 405-432.

[29] H. Ohmori, “Computational morphogenesis: Its current state and possibility for the future.” *Int. J. Sp. Struct.*, vol. (26)(3), pp. 269–276, Sep. 1, 2011.

[30] E. Oñate, " Composite beams," in *Structural Analysis with the Finite Element Method. Linear Statics*, 1st ed., vol. (2). J. Samper, Barcelona Spain, 2013, pp. 150-232.

[31] S. Bialkowski, “tOpos GPGPU Accelerated Structural Optimisation Utility for Architects.” *ECAADE,* vol. (1), pp. 679–688, Sep. 2017.

[32] N. D. Lagaros, “The environmental and economic impact of structural optimization.” *Struct. Multidiscip. Optim.*, vol. (58)(4), pp. 1751–1768, May. 10, 2018.