ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

IMPACT OF PARAMETRIC DESIGN ON DESIGNING PERFORMATIVE FACADES

M.Sc. THESIS

Delara RAZZAGHMANESH

Department Of Architecture

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PARAMETRİK TASARIMIN PERFORMATİF CEPHE TASARIMI ÜZERİNE ETKİSİ

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Delara Razzghmanesh
(5021121109)

Mimarlik Anabilim Dalı

Mimari Tasarım Programı

Tez Danışmanı: Doç. Dr. Meltem AKSOY

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Delara-Razzaghmanesh, a **M.Sc.** student of ITU **Institute of Architecture / Graduate School of Istanbul Technical University** student ID **502121109**, successfully defended the **thesis/dissertation** entitled "**IMPACT OF PARAMETRIC DESIGN ON DESIGNING PERFORMATIVE FACADES**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Assoc. Prof. Dr. Meltem AKSOY** İstanbul Technical University	....
Jury Members :	**Lect. Prof. Dr. Hakan TONG** Istanbul Technical University	....
	Prof. Dr. Nur ESİN Okan University	....

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To my family,

FOREWORD

I would like to express my deep appreciation and thanks to my advisor Assoc. Prof. Dr. Meltem AKSOY for her guidance and patience. I would also like to thank my mother and father for their unwavering support, encouragement and motivation over the years.

May 2015 Delara RAZZAGHMANESH

(Architect)

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ABBREVIATIONS

BIM	**:** Building Information Modeling
CAD	**:** Computer Aided Design
CAM	**:** Computer Aided Manufacturing
CAE	**:** Computer Aided Engineering
CNC	**:** Computer Numerical Control
HVAC	**:** Heating, Ventilation, Air Conditioning
DIVA	**:** Design Iterate Validate Adapt
NURBS	**:** Non-Uniform Rational B-Splines
RTA	**:** Ready-To-Assemble
SHGC	**:** Solar heat gain coefficient
VT	**:** Visible transmittance
LSG	**:** Light-to-solar gain
FHR	**:** fetal heart rate
LEED	**:** Leadership in Energy and Environmental Design

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IMPACT OF PARAMETRIC DESIGN ON DESIGNING PERFORMATIVE FACADES

SUMMARY

In a simple definition, architecture was aimed to inhabit human inside a space that covers him from wild extreme environmental conditions. During the centuries, it developed and achieved higher levels of complexity and advancements in technology, space organization, style, material assembly and so on. If the first generation of digital modeling programs allowed designers to conceive new forms, a new breed of digital techniques is today discussed for their ability to allow these forms to be controlled and realized. Building is considered as one of the largest energy consuming sectors in most countries and nowadays energy consumption is an important issue in architecture. With the advent of digital technologies and the ability to conceptualize, express and produce complex forms and non-standard buildings the novel direction for supporting performance-based design are beginning to emerge. Parametric design as a new method in architecture for intelligently designing architectural objects based on relationships and rules using the computer, can help for achieving performance-based design. It allows designing complex forms but, it is not just to make buildings more visually compelling but to precisely tune nearly every aspect of their performance, from acoustics to energy efficiency, so the system can be used as a performance-driven process. The parametric models can combine and respond simultaneously to design and its programmatic factors, such as performance design-decisions, and constraints.

Development in computational design and simulation applications are providing methods to improve current design practices, since the uncertainties about various design elements can be simulated and studied from the design inception. Building performance simulations aid in investigating design options and the overall building performance and are an integral part of the design process for energy efficient and high-performance buildings.

Since the façade is one of the most significant contributions to the energy budget as well as the comfort parameters, it is important to focus more on it. By making the

facades more dynamically responsive to the environmental conditions they can fit better to the various conditions and therefore supply better comfort for the occupants. Digital design and fabrication tools now allow us to create highly flexible-adaptive building façade systems that can be customized for different contexts.

Having stated current knowledge and previous researches in mind in this thesis, a prototype of an adaptive façade system using parametric modeling tools is going to be designed and analyzed it, so as to evaluate the performance of that façade response to the day-lighting. The first part of the thesis looks at the importance of digital design and computer in architecture and issue of mass customization as one of its results. Afterwards, the importance of performance-based design is mentioned and the significant role of parametric design as one of the methods to achieve this kind of design is analyzed. The second part of the thesis focuses on the façade systems and analyzes some examples of performance-driven designs using parametric modeling. The last section explained the process of development of adaptive building façade, using parametric design, for the chosen building with considering the day-lighting performance and then analyze the illuminance level of building before and after the implementing the designed facade to compare whether if with implementing the facade can we achieve the optimal illuminance level and to prevent the direct sun exposures or not.

PARAMETRİK TASARIMIN PERFORMATİF CEPHE TASARIMI ÜZERİNE ETKİSİ

ÖZET

En yalın tanımıyla, mimarlık insanı dış çevreden gelen etkenlerden korumaktır. Yüzyıllar boyunca, mimarlık teknolojı, malzeme yenilikleri, stil, mekan organizasyonu ve diğer konularda gelişerek başarılı bir yol kat etmiştır. İlk dijıtal modelleme programları mimarların yeni formları algılamalarına yardımcı oluyordu. Bugün yeni nesil dijital teknikleri mimarlara yaratıkları formları algılama ve kontrol etme imkanını da sağlamaktadır. Bugün yapı sektörü, dünyanın en yüksek enerji tuketimi olan sektörlerden bırıdır. Dolayısıyla enerji korunumu bugün kaçınılmaz olarak en önemli konuların başında gelmelidir. Dijital teknikler gelişmiş ve standard dışı formların tasarımı ve üretimi konusunda oldukça önemli katkılar sağlamaktadır. Bu nedenle performansa dayalı tasarım için yeni yollar ortaya çıkmaktadır.

Bilgisayar her alanda olduğu gibi mimarlık alanında da etkin kullanılan bir araçtır. Ancak bilgisayarın kullanımı, sıklıkla tasarımın teknik hesaplamaları ile tasarımın etkili ifadesi ve sunumu üzerinde yoğunlaşmaktadır. Tasarım aşamasında kullanılması, kullanıcı ile birlikte oldukça gelişime açık bir alandır. Algoritmik düşünce ile gelişen bilgisayar programlama dilleri ve teknikleri, tasarım aşamasında kullanıcının tasarımını daha kolay bir biçimde ortaya koymasını sağlamıştır. Matematik ve bilgisayar bilimlerinin temelini oluşturan algoritma kavramı, zamanla diğer bilimlerin ve disiplinlerin de konusu olmuştur. Bir problemin çözümü için gereken aşamalar bütünü olarak tanımlayabileceğimiz algoritma ve buna bağlı olarak oluşan algoritmik düşünce parametrik tasarımın dayanağını oluşturur. En temel şekli ile parametre, bir durum için tanımlanan ve değiştirilebilen bir nicelik olarak ifade edilebilir ve bu niceliği bir veya birden çok olarak içinde barındıran durum parametrik olarak algılanabilir. Parametrelerin sayısı duruma bağlı olarak değişebilir. Parametreler algoritmik düşüncenin temelinde, algoritma içinde kullanılırlar.

Bilgisayarların çalışma ilkesi herkesin bildiği gibi ikili sayı sistemine dayanmaktadır. Bu ilkede esas olan 0 ve 1 sayılarıdır. İkili sayı sistemi, elektronik devrelere kolay uygulanabildiği gibi algoritmaları da kolay işleyebilmektedir. Algoritma bir problemin çözümü için gerekli adımlar dizisi olarak tanımlanır. Problemin çözümü için birden fazla yol olması durumunda bilgisayarın işleyişine ve şartlara en uygun seçenek seçilir. Bu algoritmik çözümün bilgisayara aktarılması belli kurallar dizileri ile mümkündür.

Parametrik tasarım, mimarlığın yeni bir metodu olarak, bılgısayar ortamında, algoritmalara dayalı tasarımda oldukça önemli bir noktaya gelmiştir. Parametrik tasarım dolayısıyla performansa dayalı tasarım alanında da etkin olarak kullanılabilir. Bina performansı, akustik ve enerji verimliğini kapsamaktadır. Parametrik modeller, performansa dayalı tasarım karar ve kısıtlama programlama faktörlerine oldulça etkin bir şekilde yanıt verebilmektedir. Matematiksel tasarım ve simülasyon uygulamalarının gelişimi, ceryanda olan tasarımın gelistirir. Bina simülasyon uygulamalarının, tasarım seçenekleri ve bina genel performansının incelenmesine

yardımcı olmaktadır. Simülasyon uygulamaları, enerji odaklı binaların tasrımı için ayrılmaz bir parçadır.
Mimari tasarıma bir veri olarak katılan güneş, cephe kimliğinin oluşmasında önemli bir rol oynar.Yapının güneşle kurduğu ilişkide verilen kararlar, yapının fiziksel çevre ile arasında bir sınır oluşturan cephe ve cephe bileşenleri hakkında verilen kararlardır. Bu kararlar yapının bulunduğu iklim koşullarına göre, güneşe karşı nasıl bir tavır alınması gerektiğinin belirlenmesi ile oluşur.

Sürdürülebilir kalkınmanın ve sürdürülebilir mimarlığın gündemde olduğu günümüzde akıllı yapıcepheleri çok farklı şekillerde ve konseptlerde karşımıza çıkmaktadır. Endüstri devrimine kadar cephetasarımları, kısıtlı malzeme ve teknoloji olanaklarıyla ve aynı zamanda enerji korunumu dikkate alınarakoluş turuluyordu. Endüstri devrimi sonrasında ise malzeme ve teknolojideki ilerleme ile yapı cephesitasarımları çok değişmiş, yapıların çevresel etkileri ve binalardaki konfor koşulları düşünülmeden özgürbirş ekilde yapılmaya başlanmıştır.

1970'lerdeki petrol kriziyle birlikte, yapı cephelerinin tasarımları değişmiş, konfor koşullarının daha az ve çevreye daha az zarar veren enerji kaynaklarıyla karşılanması gerektiği anlaşılmış, budönemden sonra sürekli geliş en cephe tasarımları karşımıza çıkmış, halen yenileri karşımızaçıkmaya devam etmektedir. Günümüzde sürdürülebilir mimarlığı sağlayabilmek için daha farklıözellikte cepheler tasarlanmaya başlanmıştır. Bunların çoğu, çevrelerine uyum sağlayan "akıllıyapı cepheleri" olarak adlandırılan özellikteki cephe tasarımları olup her biri farklı bir özellik ilekarşımıza çıkmaktadır.

Cepheler bir yapının enerji tüketimi ve konfor parametreleri konusunda çok önemli bir bileşeni olduğundan cephe tasarımı, kuşkuz tüm mimariden ayrılmayacak şekilde, çok önemli bir yere sahiptir. Sürdürülebilir cephe tasarımında mimarın kontrolündeki tasarım parametreleri lokasyon, yön, form ve kabuğa ilişkin teknik ve tasarımsal özellikler olarak değerlendirilir. Söz konusu parametrelere göre doğru tasarlanmış bir cephe enerji verimli dolaysıyla çevre etkileri düşürülmüş ve konfor şartlarını sağlayan bina tasarımı için büyük önem taşımaktadır.
Özellikle bu çalışma bağlamında, dinamik cephe tasarımlarının çeşitli koşullara yanıt verme konusunda sahip olduklari esneklik nedeniyle yapının enerji performansını yükseltme ve enerji tasarrufu konularında çok daha etkin oldukları savunulmaktadır.
Bu çalışmada mevcut bilgi ve daha önce yapılmış çalışmalar dikkate alınarak parametrik tasarım metodu ile esnek-adaptif bir cephe tasarlama deneyimi gerçekleştirilmiştir. Bu tasarımda araştırmaları ele alarak, parametrik tasrım ile bir esnek-adaptıf cephe sistemi tasarlanıp, aydınlatma analizi yapılacaktır. Bu tasarımda gün ışığına karşı bina performansı incelenmiştir. Gün ış ığı, yalıtımın düş ünülemeyeceği bir ış ık kaynağıdır. Gün ış ığından maksimum yararı sağlamak, gereksinimi duyulan yapı çevresi elemanlarının birbirine etkilerinin anlaş ılmasıyla sağlanabilir. Gün ış ığının bina içerisine alınış ı; ısı farkı, gürültü, yangından koruma, güvenlik, yağış la ilgili sorunlar ve solar radyasyonun malzeme üzerindeki etkileri gibi bir takım problemleri de beraberinde getirir. Gün ış ığının niteliği ve niceliği pencerelerin büyüklüklerine, konumlarına, pencerede kullanılan cam malzemenin özelliklerine, gölgeleme elemanlarının tipi, yönü ve engellere bağlıdır. Buparametreler temel mimari faktörler ile yakından iliş kilidir.
Tezin ilk bölümünde, dijital tasarım ve bilgisayarın mimarlıkta olan önem ve etkisi ve bunun sonüçlarından biri olarak özelleştirilmiş tasarımı anlatılmıştır. Sonra ise, tasarım ve üretimin mimarlık tasarlama ve üretim aşamalarındaki önemi ve etkisi

üzerinde durulmuş, devamında performansa dayalı tasarım ve bu alanda parametrik tasarlama metodunu olasılı etlileri tartışılmıştır.
İkinci bölümde parametrik tasarlama yönetmeleri kullanilarak tasarlanmış performansa dayalı cephe tasarım örnekleri analitik bir bakış açısıyla anlatılmıştır. Son bölümde ise varolan ve halihazırda kullanılmakta olan İTÜ Maslak yerleşkesinde yeralan Teknokent binasının cephesi için gün ışığı performansına dayalı bir cephe tasarım denemesi gerçekleştirilmiştir.

1. INTRODUCTION

"...architecture should perform rather than simply form; structurally, environmentally, economically, programmatically, contextually, or in multiple formal arenas." (Sakamoto and Ferre, 2008).

The European Performance Building Directive states that all new buildings constructed after 2020 should consume "near zero energy" (EPBD 2010). This demand requires that decisions in the early stage of design should consider the potential impact of energy efficiency. There are lots of design options and choosing the appropriate combination of these options is a hard task. Computer based building simulation tools could be used for facilitating these tasks. Recent computer-aided design and engineering (CAD) tools allow architects and engineers to simulate many different aspects of building performance such as energy and lighting (Leighton, 2010). Rapid, near real-time visual output from building simulation models would significantly improve the prediction of performance and enable the optimization of smart, adaptable, net zero energy buildings (Hensen & Augenbroe, 2004). According to Nembrini et al. (2014), computational parametric models are furthermore an effective way to intertwine architecture with indoor climate and energy performance. Programs for computational parametric modelling are suitable to generate such models. In the Grasshopper plug-ins like Ladybug for climate visualisation and DIVA for daylighting simulation are sophisticated tools for generating performance-driven models.

The demand for a more efficient way of controlling the indoor environment has increased with the increased use of large glass facades on office buildings. Office buildings are mostly using glass facades or glass curtain walls, since it is visually appealing and they give view to outside for the inhabitants and access to natural light. These kinds of high glazed facades are highly inefficient since they have low insulation values. U-values for typical wall construction and glazed materials show a large difference (Table1.1, 1.2). The advent of insulated glass units leads to increase the efficiency, but this still is not enough.

Table 1.1 : Insulation values of typical wall constructions (Stein, 2006).

Assembly	Basic construction	Other thermal components	Insulation R-value °f ft² h /Btu	Insulation R-value K m²/w	Assembly U-factor Btu/ °f ft² h	Assembly U-factor W/K m²
Wall	Wood studs, nominal 2in ×4in, 16 in o.c. (50mm×100mm,400mm o.c.)	Exterior air film, stucco, exterior gypsum board, interior gypsum board, interior air film	11	1.94	0.096	0.55
	As above		15	2.64	0.068	0.39
	Wood studs, nominal 2in ×6in, 24 in o.c. (50mm×150mm,400 mm o.c.)		18	3.17	0.065	0.37

Table 1.2 : Insulation values of typical window assemblies (Stein 2006).

			Total windows U Factor			Total windows		
Glazing description and reference number	Layers of glazing &space (outside to inside)	Frame and spacer	Btu/hft² °F	w/m²k	Solar heat gain coefficient (SHGC)	Visible transmitta nce (VT)	Light to-solar gain (LSG)	fetal heart rate (FHR)
Single glazed clear	(3mm)clear	Aluminum no thermal break	1.30	7.38	0.79	0.69	0.87	0
Single-glazed bronze	(3mm) bronze	Aluminum no thermal break	1.30	7.38	0.69	0.52	0.75	-2
Double glazed low-e²	(3mm) low-e 0.08 (3mm) argon	Wood stainless	0.30	1.70	0.44	0.56	1.27	32

The combination of increased building loads and the use of all-glass facades have necessitate a new way to look at building facades. Recently, there has been an increasing interest in incorporating daylighting with architectural and building designs to save building energy consumption (Li and Lam, 2001). It is proven that proper lighting controls integrated with daylighting have a powerful potential for reducing energy consumption in office buildings. Some fixed (non-dynamic) systems are designed (examples are in chapter 3.1) but they could be more efficient if they were kinetic and could adapt dynamically to the changing environmental conditions and could optimize the swapping between shading, day-lighting and natural ventilation. The challenge of developing adaptive, responsive low-energy architecture requires new knowledge about the complex and dynamic interaction between envelope architecture, optimization between competing environmental performance metrics (light, heat and wind indices) and local climate variables (Datta and Hobbs, 2013).

1.1 Purpose of Thesis

In this thesis, the method for designing an adaptive façade will be present. Adaptivity is intended as the capacity of a building to be responsive to a changing context (Negroponte, 1975). In the thesis adaptivity is referenced to performance based architecture. The architectural performance refers to architectural requirements, which confront needs and demands of human actors. In this research daylighting will be the key performance criteria to design the desired responsive façade which respond to sun exposures. The proposed method is based on the principle of parametric design. The basic principle of parametric design is to iteratively modify different parameters of the design while continuously evaluating its performance (Lauridse and Petersen). Parametric modeling is developed in Grasshopper, a plug-in for Rhino 3D, using DIVA (plug-in for Rhino and Grasshopper) for daylighting simulation. The main objective of the process and algorithm is to evaluate the performance of an intelligent adaptive façade, composed of a series of kinetic louvers that actuate in response to dynamic daylighting.

One purpose of this thesis is to investigate the potential of parametric design to positively impact on the designing adaptive facades so that to decrease the need for mechanical systems. In order to perform this investigation exploring into existing solutions that are available and known will be undertaken and in addition to a written documents a prototype of parametric façade system will be designed for the ARI 3

(Advanced Research and Innovation) Building in Ayazağa-ITU, Sariyer, Istanbul, Turkey that is for ITU TEKNOKENT, designed by Hüseyin Kahvecioğlu and Melis Nur İhtiyar in 2012 (Url-1).

The façade of existing office building, has the large amount of glass, so we assume that it does not match with the current need for decreased energy consumption and it enter the direct sun exposures which will annoy the occupants (Figure 1.1). Therefore a performative façade can help to reduce the direct glare and also energy consumption. First we simulate the existing building in Revit, then the façade model will be designed by the use of parametric design. Parametric design in essence is done with the parameters that are in a relationships and the designer can define and edit them during the design process. Parametric design as one of the new methods in architecture can help us to design a parametric adaptable façade system which can help to decrease the need for mechanical systems such as HVAC systems and artificial lighting and supply more comfort for the occupants and it can decrease the energy demand of the building. The façade system is modeled in Grasshopper 3D, developed by David Rutten at Robert McNeel & Associate, a parametric modeling plug-in for Rhino 3D.

Figure 1.1 : Ari 3 Building, Ayazağa-ITU, Sariyer, Istanbul, Turkey, 2012 (Url-2).

Chapter 2 discusses the importance of mass customization in architecture and the aid of the parametric design for achieving performance-based design. In a deep sense, parametric modeling is not new, building components have been adapted to context for centuries. What is new is the parallel development of fabrication technology that enables mass customization (Aish and Woodbury, 2005). Chapter 3 analyzed some existing systems of building facades and some facades that are designed by parametric modeling. Chapter 4 is the case study and the process of designing and lighting analyzing of parametric performative façade for the Ari3 building and comparing the results with the analyses that is achieved by DIVA.

2. TOWARDS PERFORMANCE-BASED DESIGN IN ARCHITECTURE

The industrial revolution had a significant impact on architecture. In the modern era, standardization was a necessary component for the evolution of architecture, as Le Corbusier stated that “architecture is governed by standards”. So with standardized parts, the designs must adhere to a predetermined means of assemblage. Mass production rests on the economic advantages of large numbers of repeated units. But standard and repetitive mass produced buildings did not answer the clients need and limits the capacity of designers to respond with accuracy to the diverse variables that characterize their environment. Now we are in an age of digital fabrication, where the potential output of the Computer Numerically Controlled (CNC) machines is to produce non-repetitive and non-linear production. Computers allow architects and designers to explore things in a much more three dimensional way rather than being restrained by the means of a drawing board and a standard manufacturing technique and doing away with the notions of mass production. With digital fabrication mass customization has become a reality. Mass customization emerges as a paradigm-shift for industrial production, aiming towards the individualization of serially-manufactured units to meet the heterogeneity and dynamism of consumers expectations (Pine II, 1993).

But we are not just considering the form of the product. The performance of that form is more important, as David Leatherbarrow (2005), states: “there are two common ways of missing the reality of the architectural work: one is to see the building as nothing but a system of components intended in design and realized by construction, the other is to view it as a system of representations outlined in composition and experienced in perception”. Rather than this old debate between works that are useful and beautiful, it may be helpful to ask not about the work but about the way the work works. Performance-driven architectural design emphasizes on integrated optimization of various quantifiable performances of buildings, so architects play a vital role in guiding and conducting the performance-driven design.

Parametric design as a new method in architecture is helping to design performative models. In a parametrically defined model, relations between individual design components can be defined and their variables can be altered through a set of rules and constraints which permit intuitive manipulation without losing control over design principles. While engendering explorations and realizations of rich and complex formal possibilities, parametric design can "inject performative potential into the built environment" (Hensel, 2004). "Powerful parametric tools provide both geometric modeling and analysis functions within a procedurally controlled network. "The performance data, such as heat gain, stress and solar radiation can be easily quantified and defined to interact with other parameters" (Anderson et. al, 2012).

2.1 From Mass Production to Mass Customization

Architects have conflicted with the relationship between design and mass-produced building components from their very introduction. Designer in the mass production era have limited range of formal and functional possibilities because of the standard and repititive components. With the advent of dgital design and fabrication architects now have access to powerful tools that can comfort the re-integration of design, analysis and fabrication processes and help to produce novel, non-repetitive building components and assemblies.

2.1.1 **Modern Era and Mass Production**

Modern Architecture is famous with characteristics like: simplicity in form, industrial manufacturing, elimination of ornaments. The evolution of late twentieth-century design can be investigated by considering some of its dominant themes, such as mass production, information technology, transportation and the workplace (Whalley ; Kolarevic & Malkawi, 2005). Architecture and industrial design are both a response to and reflection of the society that we live in (Kolarevic & Malkawi, 2005). Prefabrication in architecture was mentioned in 20^{th} century and it leads to the protocol of mass production. In that era homes were assembled from standardized parts. Le Corbusier (1986), states that: "architecture is governed by standards which are a matter of logic, analysis and precise study".

In the international market for building products and services, companies add value and profit by preparing "kits" of RTA (ready-to-assemble) products, which that value is added off-site, in delivery, and in assembling or installing the kit on-site (Piroozfar & Piller, 2013). Some examples of kits include sunrooms, delivered in boxes ready for assembly, and kitchens from IKEA (Normann and Ramirez, 1993). When modular building kits were first introduced, they offered advantages over traditional methods of construction, including efficiencies in component production, predictable construction processes, compact and efficient transportation, and rapid assembly using general labor (Graham, 2012). These options led to transporting the building components all over the world with low costs even in non-industrialized nations and it was the advantage of using mass-produced components in architecture

As Walter Gropius stated in 1964: "…the idea of prefabrication was seized by manufacturing firms who came up with the stifling project of mass producing whole house types instead of component parts only" (Figure 2.1).

Figure 2.1 : Modern architect, Louis Hellman, (Wiley- Academy, 2001).

Before the implementation of digital technologies, in particular CAD/CAM systems, the construction and assembly processes used in architecture were a direct consequence of industrial manufacturing and the logic of mass production and standardization (Dunn, 2012).

In the building industry, the creator of the building component has no connection with the design itself and it is just producing components that are suitable for any kind of situation and it is simple and repetitive in form. In fact neither the architect nor the engineer legally has any control over the construction process. Because of this arm's length relationship between architects and building construction, contractors are generally hired based on how cheaply and efficiently they can construct a building, not on the basis of whether they can bring special insights or knowledge to the design process (Kolarevic & Klinger, 2008). In this case the designer have limited choices for his form for example a brick is a standardized component which is cheap and interchangeable but it is not generally used for the curved walls with vertical joints and right-angled corners. When the construction components are modular and standardized, the forms of buildings naturally get characteristics of standardized modules.

According to Khabazi (2010), "Nowadays catching the philosophy of 20th century is not answering the need of architecture and clients". Designers knew that products should be as the demand and style of the clients. The famous saying by Peter Drucker (1954), still holds true: "It is the customer who determines what a business is". This is where mass customization has became a necessity. With mass customization it is possible to product objects and components based on the customer's demand and style.

2.1.2 **Computation, Digital Fabrication and Mass Customization**

Computation is redefining the practice of architecture in a way that it is developing digital tools that produce chance in design process, fabrication and construction. Computation allows designers to extend their abilities to deal with extremely complex situations. Sean Ahlquist and Achim Menges (2011), define computation as "the processing of information and interactions between elements which constitute a specific environment; it provides a framework for negotiating and influencing the interrelation of datasets of information, with the capacity to generate complex order, form, and structure." But also the term computation can be defined as the use of computer to process information through an understood model which can be declared as an algorithm. Therefore designers through computation as any other techniques of architectural design have the ability to generate unexpected results. For example when an architect writes a computer program to solve a design problem, further options can then be explored through modifications to the program- sketching by algorithm (Peters, 2007). Algorithms in a simple way of defining are the written codes that can be understood by the computer language. Architecture is currently experiencing a shift from the drawing to the algorithm as the method of capturing and communicating designs (Peters and Kestelier, 2013).

We are now in the age of digital fabrication, with digital fabrication mass customization has become a reality and at times a necessity. Mass customization proposes new processes to build using automated production, but with the ability to differentiate each artifact from those that are fabricated before and after. The ability to differentiate, to distinguish architecture based upon site, use, and desire, is a prerequisite to success that has eluded our predecessors (Kieran and Timberlake, 2004). Mass customization corresponds to the technologies and systems to deliver goods and services that meet individual customers (Tseng & Jiao, 2001). According to other definition from Joseph Pine (1993), mass-customization is “developing, producing, marketing, and delivering affordable goods and services with enough variety and customization that nearly everyone finds exactly what they want”. As an early examples of customizable façade, shading devices on the outer facades of the Bibliothèque Nationale deFrance in Paris (Figure 2.2) can be represent, where the users can choose to open or close the laminated vertical timber louvers to strike a balance between the desired level of natural lighting inside the building and the heat gain of the internal spaces, thereby maintaining the indoor comfort light and heat levels (Piroozfar and Piller, 2013).

Figure 2.2 : Facades of the Bibliothèque Nationale deFrance, Paris, architectural firm: Dominique Perrault, 1996 (Url-3).

With the aid of computer, architects can facilitate the re-integration of design analysis and fabrication process and therefore produce novel, non-repetitive building components (Figure 2.3). 3D CAD utilizing solid or Boundary Representation (BREP) objects are as a heart of new digital tools. Solid and BREP modeling allows designers to create assemblies and objects that can be analyzed by Computer Aided Engineering (CAE) and fabricate using Computer Aided Manufacturing (CAM) process. After that information from CAD will import to Computer Numeric Control (CNC) fabrication machines such as plasma cutters or 6-axis milling machines. These machines can produce non-standard, non-repetitive building components and forms. Digital fabrication machines such as cardboard cutters, laser cutters and CNC milling are used now. It is now possible to write computational tools to generate any kind of geometries. So it can be argued that in the computational design, tools need to be more closely connected with the building process and the integration with the fabricators are the significant part of informing the computational design.

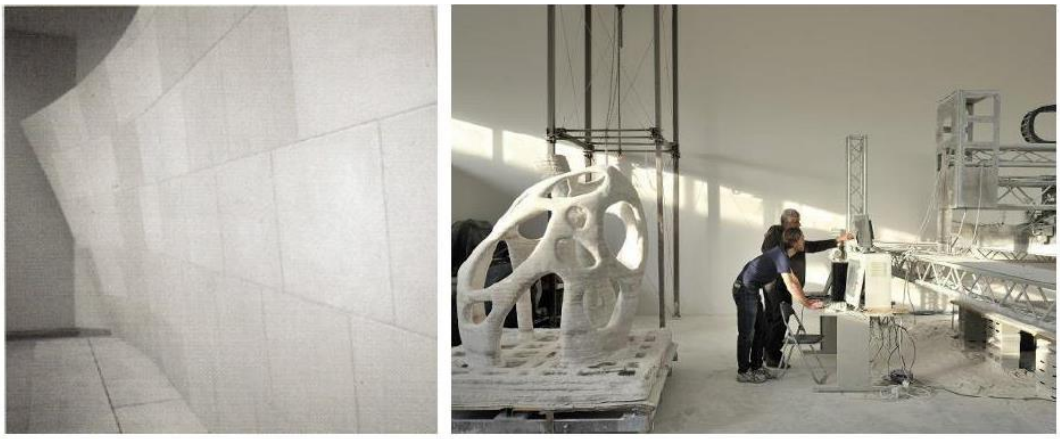

Figure 2.3 : Gehry Partners used custom-milled masonry for the Walt Disney Concert Hall (left). In the future, additive fabrication processes, such as Enrico Dini’s masonry “printing” machine (right) may allow designers to create large and complexly shaped masonry units without the need for milling or molding.

Architects are no longer constrained by the limits of traditional construction techniques; designs can now be fully conceived in three dimensions. More profoundly, architecture can be guided by the same laws that control and shape the world around us, an organic approach to design based on exploring solutions through performance (Whalley, 2005).

According to Kolarevic (2003), “in avant-garde contemporary architectural design, various digital generative and production processes are opening up new territories for conceptual, formal and tectonic exploration, articulating an architectural morphology focused on the emergent and adaptive properties of form". Nowadays performance-based design has significant role in the building's optimization process. The increasing interest in performance as a design paradigm is largely due to the recent developments in technology and cultural theory and the emergence of sustainability as a defining socioeconomic issue (Kolarevic, 2005).

Mass customization enables flexibility in serial production through effective management of higher amounts of information content. These enhanced possibilities may inform buildings able to respond with higher accuracy to complex environmental conditions (Mitchell, 2004).

Nowadays, performance-based design has the ability to offer models which have both performance and generative principles. Doing performance analysis and optimizing the design effectively and efficiently used to be challenging. Lately, the rapid improvement of digital technology and its application in architecture have changed the field dramatically. The emersion and development of performance simulation tools make quick performance analysis possible and nowadays architects and engineers proactively use them in their designs.

2.2 Performance-based Design Through Parametric Modeling

Performance-based design is generally an approach in which building performance becomes the guiding factor in design. Performance-based models in architecture could be defined as the production of building performance simulation for the modification of geometrical form towards the objective optimization decision. The term performative may represent a combination of two of the profound characteristics of digital design. Digital design supports transformation and generation of a geometrical model or form and also supports evaluation of environmental performance based upon simulating physical conditions such as solar or structural loadings. It is the possibility of an integration of evaluative simulation processes with digital 'form generation' that is implied by the term Performative Design. Parametric design as a new method in architecture allows designers to generate forms based on the performance criterias. The possibilities of customization and parameterization offered by the interfaces of advanced building-performance simulation software and digital design tools have now enabled architects to conduct performance-based design explorations.

2.2.1 **Performance-based Design Definition**

Energy consumption has an important role on the environmental concerns, occupant comfort and financial issues, so the decision of the designer in the early stages of the design can has significant impact in the reduction of energy consumption and in this case performance became a grateful approach in the design process.

In the late 1950s, performance emerged in humanities in linguistics and cultural anthropology in particular and in other research fields as a fundamental concept of wide impact (Kolarevic, 2005). Digital building performance aids and performance-based designs were mainly pioneered in the late 1960s and early 1970s. For example, the first use of computer graphics for building appraisal was in 1966, the first integrated package for building performance appraisal appeared in 1972 (Maver, 2002). Common building performance factors are environmental factors, such as solar gain, aerodynamics, and heat loss, structural factors such as load and stress, and social factors such as view and privacy.

Performative architecture can be described as having a capacity to respond to changing social, cultural and technological conditions by perpetually reformatting itself as an index, as well as a mediator of (or an interface to) emerging cultural patterns (Kolarevic,2005). The issue of performance is not an easy task and is not just isolation or some linear progression, in contrast they are engaged in the early stage of design by relying on various parties involved in the design of building. In such a highly “networked” design context, digital quantitative and qualitative performance-based simulations are used as a technological foundation for a comprehensive new approach to the design of the built environment (Kolarevic and Malkawi, 2005). Chris Luebkeman (2003), in his “performance-based design” article, describes performance-based design like this: “Performance-based design is really about going back to basics and to first principles, taking into account the experience one has gained over time as well as field and laboratory observations about non-linear behavior of elements and components. It is the combination of first principles with experience and observations that is the fundamental potential of the design philosophy. It places the design imperative back in the hands of the designer and more importantly, it also places responsibility and accountability back into the designer's hands in a very obvious way. One can no longer hide behind building codes".

Design is a part of a complex context that includes environmental conditions, social and cultural considerations, economy, materiality, and technology and the complexity of the surroundings can be solved with the aid of computational means such as parametric and generative systems. Responsiveness of design is a direct result of the incorporation of novel design, modeling, and fabrication tools**.** Nowadays, the advanced development in the digital modeling of integrated performance-based generation gives an important priority of experimental design and development in architecture (Kolarevic, 2003 ; Kolarevic & Malkawi, 2005). In particular, the emergence of new computational modeling software, which allows parametric systems and complex "biological" organization to be generated and explored, offered new avenues of holistic design production and detailed component manufacturing for the architectural designer (Dunn, 2012).

The performance-based design techniques has significant role in the optimization of the building. In the architecture, the optimization is represented as a fitness function which can be found in the nature activates such as, a special state of equilibrium, performance, or best achievable economy of means (Chalabee, 2013).

The ability to model, analyze and fabricate complex objects is important for building optimization, but these processes require integration, which is where parametric modeling comes in.

2.2.2 **Principle of Parametric Design**

Architects use computer-aided tools for visualizing their ideas and models. However, most of these models are built in a way that it is difficult to modify them interactively. Parametric design gives solution to this problem by allowing architects to specify relationships among various parameters of their model so that they can change a few parameters and the remainder of the model will react and update accordingly to the pre-set associative rules. Until recently, parametric design was understood as software made exclusively for manufacturing in aerospace, shipping and automobile industries. However, designer's demands for flexibility to make changes without deleting or redrawing in a computer has pushed the incorporation of parametric modeling as standard tools in traditional CAD programs (Barrios, 2004).

Parametric design is done with the aid of parametric models (Hernandez, 2006). A parametric model is a computer representation of the geometric, in this geometric some attributes are fixed that called *constrained* and some attributes are varies that called *parameters*. Branko Kolarevic (2003), described parametric design in the following way: "In parametric design, it is the parameters of a particular design that one declared, not its shape. By assigning different values to the parameters, different objects or configuration can be created". The parameters are not just numbers relating to Cartesian geometry they could be performance-based criteria such as light levels or structural load resistance, or even a set of aesthetic principles (Burry, 2003). In the parametric design the designer changes the parameters to find the best solution for the design and the whole model adapt and reconfigure it-self to the new values of the parameters. Finding the ideal solution for the design is not an easy task, it requires rigorous thinking. Parametric design has historically evolved from simple models generated from computer scripts that generate design variations (Monedero, 2000) and every time the script is done with different parametric values. In the architectural design industry, parametric design tools are utilized mainly on complex building form generation, multiple design solution optimization, as well as structural and sustainability control (Yu et al, 2013).

The design principle expressed in parametric associations allows the designer to explore an array of design options through time, revisit previous design alternatives and improve the design artifact during the design process (Aish and Woodbury, 2005). As Hao Ko, a design director at the architectural firm Gensler, explains, "The designer is setting the rules and parameters, with the computer doing the iterations. This gives designers more flexibility to explore designs, and we can make changes faster". Figure 2.4 shows the example for designing a reciprocal frame truss, by parametric modeling. Each rafter is supporting the one behind of it. If the rafters increase in depth, a corresponding increase in the slope angle results in a way that would not result in the same change in a warren truss (Burry, 2003). Modeling this truss in traditional 3D programs is hard because the designer could not attempt changes easily.

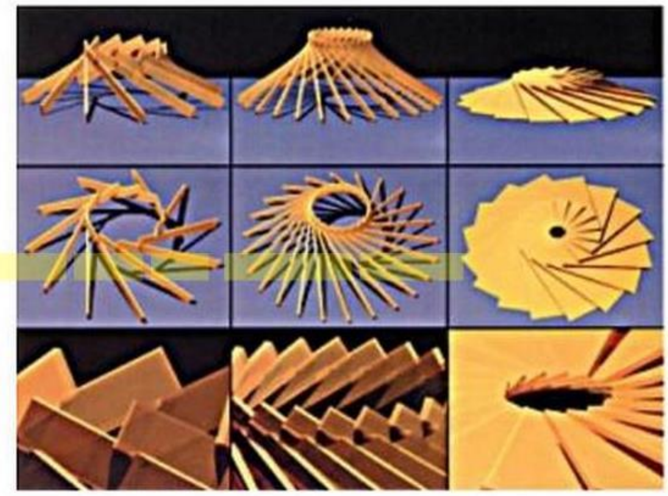

Figure 2.4 : Reciprocal frame truss: parametric variation (Kolarevic, 2003).

Parametric modeling have become popular in the world of architecture, CAD software's like CATIA, Bently's Grasshopper plug-in for Rhino and many others are the applications that support this kind of modeling. Associative and parametric geometry, describe the logic of design proposals rather than just the form of it. This kind of design helps to create powerful interactive tools that allow designers to explore and optimize various possibilities while reducing the amount of design time.

Gero (1994), mentioned two main areas in the development of the computer aided design: "the representation and production of the geometry and topology of designed objects" and "the representation and use of knowledge to support or carry the synthesis of designs". First category indicates the general use of the CAD system with the aim of automating the design, second category is about the generative approaches that focused on computation as an aid to design process. Parametric design is a computational method that can act both a generative and analytical method during design. Parametric systems are mainly based on algorithmic principles. Therefore, it is important to mention the role of algorithm; derived from the name of a Persian mathematician, Mohammad Ibn Musa Kharazmi (The words algorism and algorithm stem from algoritmi, the Latinization of his name), an algorithm is defined as a set of precise instructions to calculate a function. In the world of computer, an algorithm can be seen as a mediator between the human mind and the computer processing power and is a set of instruction given by a human to be performed by a computer, so an algorithm can describe either the way a problem is to be addressed (Terzidis, 2006). An algorithm takes one value as an input, do some computational steps to transform the input and finally produce one or more value as an output. According to Jabi (2013), algorithmic thinking calls for a shift of focus from achieving a high fidelity in the representation of the appearance of a design to that of achieving a high fidelity in the representation of its internal logic. The advantage of algorithmic thinking is that it can build '… consistency, structure, coherence, traceability and intelligence into computerized 3D forms' (Terzidis, 2003). Algorithms can computationally make the design entities such as geometric form, design variables, data structures, mathematical operation, etc. therefore this level of control over the design let the designer to evaluate every condition and respond properly. So an algorithm can deal with the design complexity and make change.

Parametric design is a dynamic, rule-based process controlled by variations and parameters, in which multiple design solutions can be developed. According to Woodbury, it supports the creation, management and organization of complex digital design models (Woodbury, 2010).

Figure 2.5 shows the numerous geometric arrangements of British Petrol headquarters in Sunbury by p.art (parametric applied research team) at Adams Kara Taylor, that the innovative design of the roof is based on parametric approach by using Digital Project. P.art is the experimental research team at AKT (Adams Kara Taylor) and they work with a diverse range of architects and designers for the creative processes. For the British Petrol headquarters in Sunbury different geometric arrangements were tested to achieve desirable aesthetic quality and structural viability to provide solar shading to the courtyard and let entering the natural daylight to the suitable levels of atrium. The roof shapes' curvature was varied in both lower and higher triangular panels across the radial directions. The triangular panels of the roof were extruded from 3 toroids. All the overall geometry of the roof was built from the geometrical definition of toroids, since all the components were related and derived from that toroids. For example the angle of curvature of roof surface was determined by the parametrized length of the radiuses of the toroids (Figure 2.6). Also with increasing the distance between higher and lower roof structure, the light penetration increased. With traditional programs for changing any of the parameters it required to rebuilding the model over and over to fixed the determinations of the design. On contrary, with using parametric modeling it is possible to change any parameter of the design in any stage of the designing process.

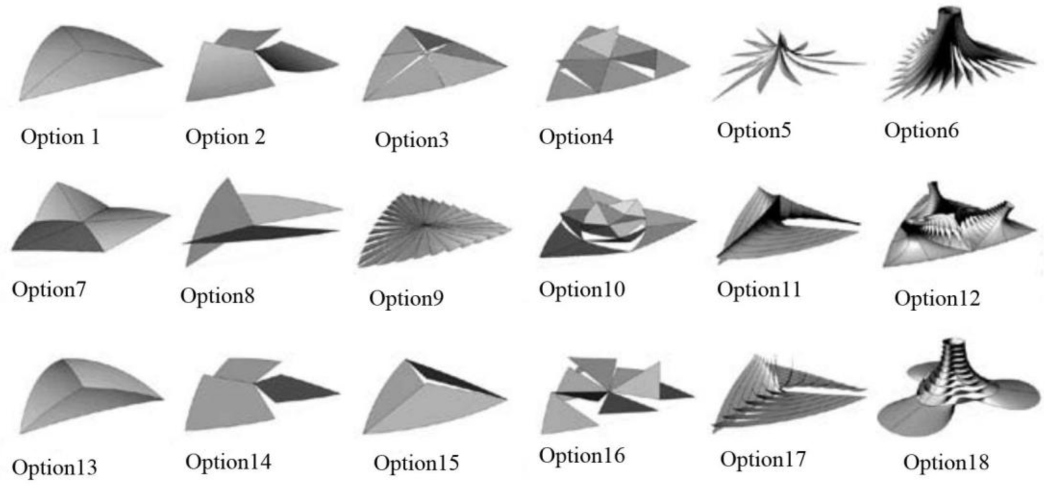

Figure 2.5 : British Petrol Headquarter in Sunbury by by p.art (parametric applied research team) at Adams Kara Taylor, 2012 (Sakamoto and Ferre, 2008).

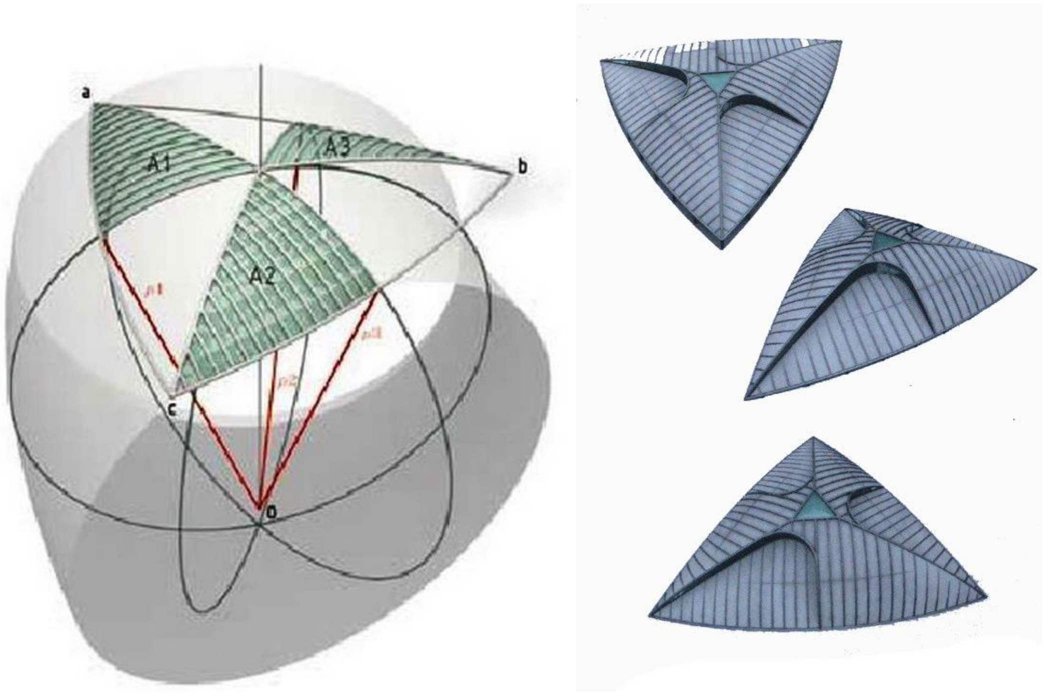

Figure 2.6 : The diagrammatic representation (The main nodes and surfaces) of the British Petrol Headquarter model (Gursel, 2012).

Designers in parametric design environment preferred to build a correct relationship system rather than correct model, they switch between the script interface like Grasshopper, and geometry interface like Rhino after changing the parameters they go back to examine the model.

Patrik Schumacher, partner at Zaha Hadid Architects, has named the new movement in architecture following the *modernism* as *Parametricisim*. According to him: “We must pursue the parametric design paradigm all the way, penetrating into all corners of the discipline”. And he points out that the fundamental themes in parametric design include versioning, iteration, mass-customization and continuous differentiation (Schumacher, 2009):

- Versioning

The term versioning refers to the process of creating versions or variations of a design based on varying conditions. Parametric software allows the designer to create a prototype solution that rather than being cast in static CAD file format, is wired almost as a string puppet would be (Wassim, 2013). This wiring allows the design solution to create new versions when new conditions arise.

- Iteration

The term iteration refers to cycling through or repeating a set of steps in the case of parametric architecture, iteration can, in principle, create variation at every pass through the same set of instructions (Wassim, 2013). Using a parametric system, which gave immediate feedback, the designer can produce solutions and test them rapidly by iterating through many possibilities with different set of parameters, which this, can be also a powerful tool for optimization.

- Mass-customization

One of the important roles of industrial revolution is the idea of mass production. As mentioned in previous chapter, factories and robots are able to produce thousands copies of the same component. With the advent of digital fabrication technologies, now it is possible to change the manufacturing instructions between each object and fabricate any forms that is modeled by parametric design that was impossible with conventional ways.

- Continuous differentiation

Continuous differentiation alludes to a feature of versioned, iterative and mass-customized parametric work that allows to difference to occur within a continuous field or rhythm (Wassim, 2013). For example parametrically varied instance, curve or field maintain their continuity to other instances while uniquely responding to local conditions.

Parametric design tools have its own advantages and disadvantages. As mentioned before parametric design is based on the relationships of its parameters, but establishing the relationships of these parameters is a hard task. It is initially very time-consuming as Robert Woodbury explains: ‘Parametric design depends on defining relationships and the willingness and the ability of the designer to consider the relationship-definition phase as an integral part of the broader design process… this process of relationship creation requires a formal notation and introduces additional concepts that have not previously been considered as part of “design thinking” ’ (Woodbury, 2010).

Parametric model can be classified in to two categories:

1. Models that perform variations:

Parametric variation also known as variational geometry is based on the declarative nature of the parameters, in this model the attributes are parametrized based on the desired behavior. With changing each attributes a new design instance is created. The collection of these design instances is called a *family* of design. Figure 2.7 shows two parameterization schemata of a rectangular shape.

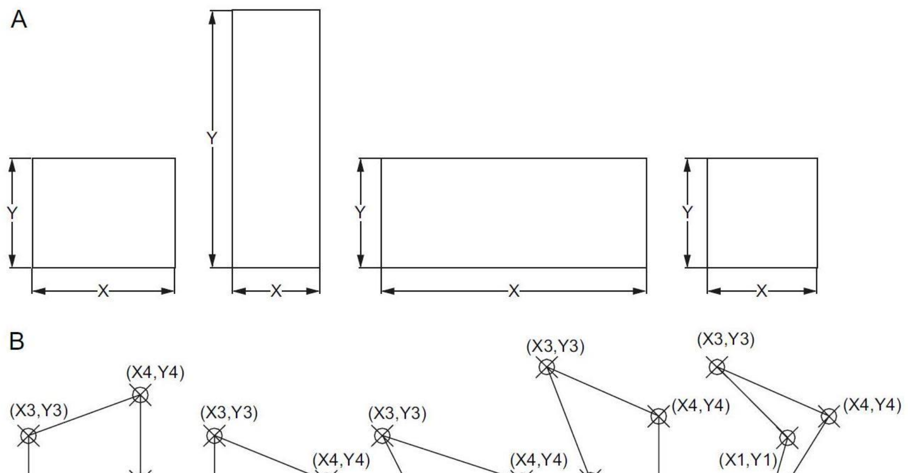

Figure 2.7 : (A) the rectangale is parametrized with its height and length attributes, (B) rectangle is parametrized by its vertices, in both models with changing the attributes the family of design is generated (Barrios, 2006).

Parametric forms are flexible enough for representing complex curves and surfaces. Ruled surfaces have been extensively utilized in architecture. The curves and surfaces produced by NURBS provide a high degree of formal control via ‘control points’, ‘weights’ and ‘knots’ (Dunn, 2012). The Paramorph, designed by DeCOi in 1999 is a good example of presentation of ruled surface (Figure 2.8). Paramorph specially used by Mark Burry, for describing the attitude of topological forms. Paramorph in geology is a change in the structure with keeping the same composition. Paramorphs in Mark Burry’s point of view are: ‘forms that have consistent topology but unstable topography’ (Burry, 2003).

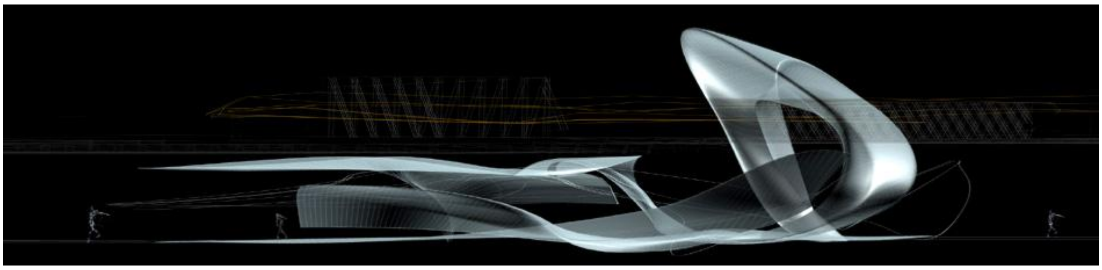

Figure 2.8 : Paramorph designed by DeCOi in 1999 (Prousalidou, 2006).

2. Models that generate new design by combination of geometrical entities:

Parametric combinations “also known as associative geometry models, or relational models” (Barrios, 2006), is a second sort of parametric design and the aim of Parametric combination is to create more complex structures according to rules. The important aspect in this model is the spatial relations of combination between the components, by combining components in different ways various design solutions are created. Figure 2.9, shows the various combinations of different components.

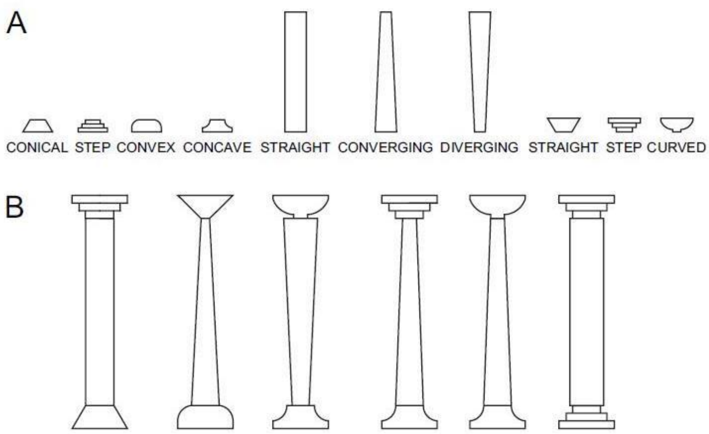

Figure 2.9 : (A) the column design is divided into base, shaft and capital components; and there are different designs for each of them. (B) a

family of column designs is the result of the combination of these elements according to the rules (Barrios, 2006).

2.2.3 The Positive Effect of Parametric Design for Performance-based Design

How to evaluate the relation between a form and its performance is one of the design challenges when designing with digital models. According to Tang (2014), Computation and nonlinear thinking promote performance based design. Computational design is more than creating 3-D models, they create new environments in which to explore designs and simulate performance. The computation approach offers a non-linear process that contains parameters that perform actions based on the quantifiable relation in an open-end design loop (Anderson & Tang, 2010). “Designers can use parametrically controlled variables to produce alternative solutions for comparison. This approach completely transforms the design process and allows for performance-driven design and simulation to be integrated into the design process” (Tang, 2014). “Parametric systems are different from conventional tools: they are adaptable and responsive” (Kolatan, 2006). While engendering explorations and realizations of rich and complex formal possibilities, parametric design can “inject performative potential into the built environment” (Hensel, 2004). Phil Bernstein, an architect and vice president at the software maker Autodesk, believes parametric technology will help make new buildings more environmentally sustainable. Architects are able to rapidly test design permutations and understand how the optimization of one aspect of the design, such as day-lighting, affects other aspects by combining parametric modeling with analysis tools. Potentially performance-evaluation can inform parametric model and modify the geometrical model, leading to performance-based generative processes (Oxman, 2008). The benefits of parametric technology can similarly be seen in Gensler’s soon-to-be-completed Shanghai Tower, which is 630 meters and will be the second-tallest tower in the world and the tallest in China (Figure 2.10). Its twisting, curved form was an aesthetic choice, but by plugging that geometry into a Grasshopper, the designers were able to tweak the shape to minimize the force of winds on the façade. As Ko, design director at the architectural firm Gensler explains, “If you have a tall tower like that, you’re studying the different degrees of rotation. It would be tedious if you had to do it manually. Using rotation as one of the parameters, you can run through the various iterations to get to the final situation”.

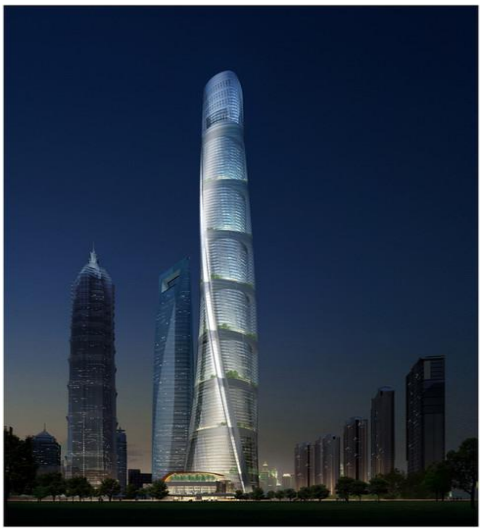

Figure 2.10 : Shanghai Tower, by Gensler architects, China, 2014 (Url-4).

One of the key attributes of parametric modeling technique that is essential to performance-based design is what Burry calls the “meta-design”, or the parametrically variable model (Burry, 2003). A “Meta-design” approach supports transformation. “Burry’s classic work on the digital formulation of the geometry of the Sagrada Familia Cathedral of Gaudi exploits these design transformational capabilities of parametric modelers” (Oxman, 2008). Located in Barcelona, Spain, the Temple of the Sagrada Familia was designed by Antonio Gaudi between 1883 and 1926. Gaudi used physical parametric models to optimize the shape of the cathedral according to aesthetical or structural criteria (Lauridsen and Petterson, 2014). One of the simple parametric models of Gaudi was the cylinder shaped by two circles connected with rings (Figure2.11), while rotating one of the circles, the overall shape of the cylinder changed as well, so the rotation degree of the circle was the varying parameter of this parametric model.

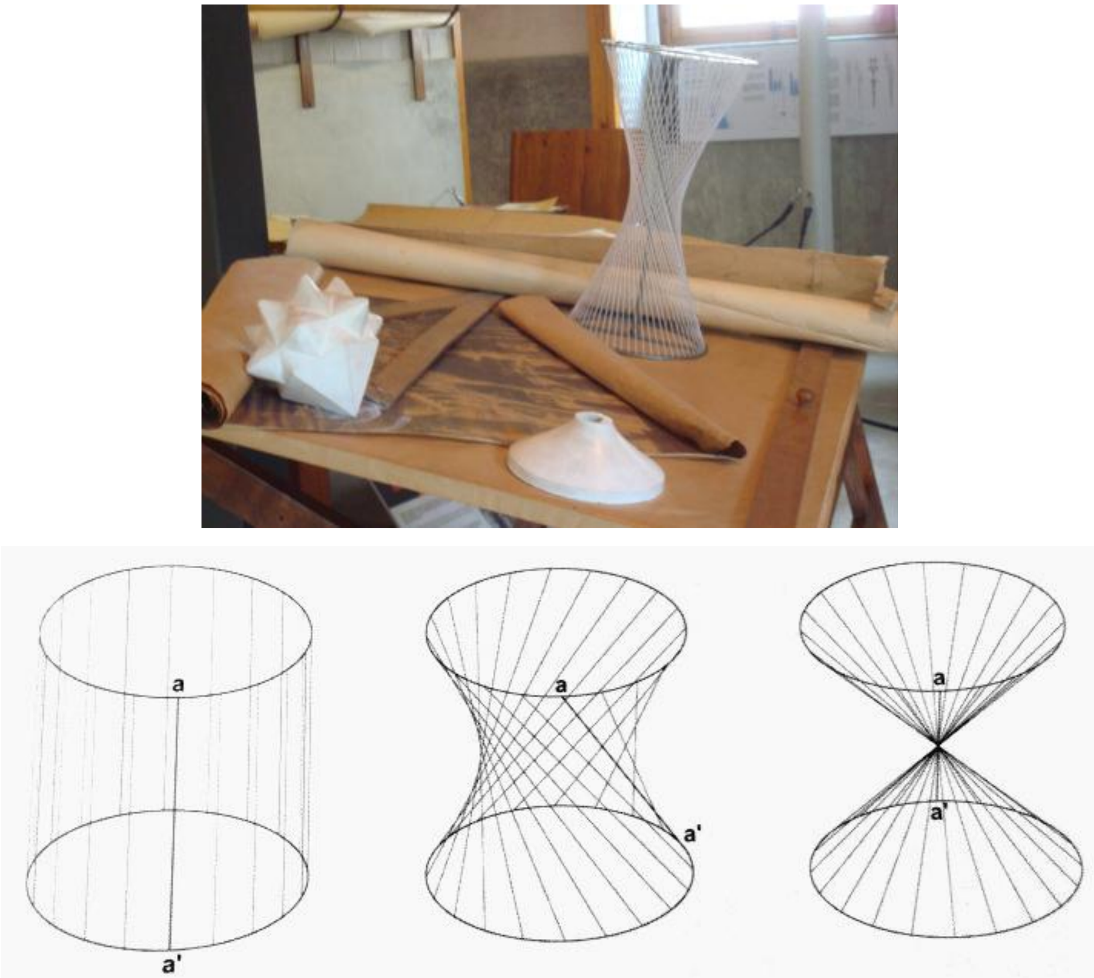

Figure 2.11 : Parametric model of the cylinder made by Mark Burry (Lauridsen and Petterson, 2014).

Building Information Modeling (BIM), a form of parametric objected meta-data management has also an important role in the optimization process. BIM helps integrate and streamline the design, fabrication and construction process by facilitating such things as part tracking, real-time cost estimating, clash detection, trade coordination and construction sequencing, automatic code compliance checking, as-built feedback loops.

Deferral is a new strategy in parametric modeling. A parametric design commits to a network of relations and defers commitment to specific locations and details (Woodbury, 2010). It means that it does not matter how and where to locate the initial points and lines because you can change it anytime. For example, a graph representing a roof structure may have the roof's support lines as its inputs and may produce different roofs designs depending on the location of the support lines.

In the following some existed examples of parametric design are presented that are demonstrating the use of parametric design for the roof structure and a terrace canopy. Without the using of parametric design these forms could not be produced:

Project: International Terminal Waterloo Station

Architect: Nicholas Grimshaw

Place: London

Year: 1993

Design of roof structure of International Terminal Waterloo Station in London by Nicholas Grimshaw and partners is a good example of earliest demonstration of parametric modeling (Figure 2.12).

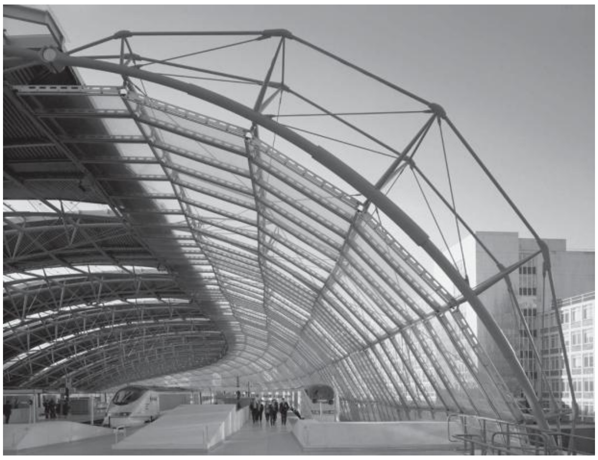

Figure 2.12 : International Terminal Waterloo in London by Nicholas Grimshaw, 1993 (Url-5).

Site condition is a way that train track curves through the station. Fitting the curve to its location can be deferred, it means that in any stage of design process designer can change the orders. The roof structure have 36 arches with different dimensions, instead of designing each arch seperately a genetic parametric model was developed in which “the size of the spam and the curvature of arches were related by assigning different values to the spam parameter” (Kolarevic, 2003).

Robert Aish used a model in “CustomObject” system which later became Generative Components to craft the original model. (Figure 2.13).

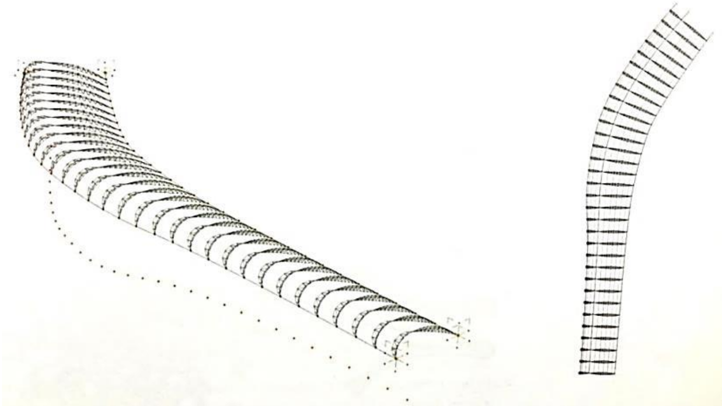

Figure 2.13 : Roof structure of Waterloo Station. Using parametric modeling, the exact location of the structure can be changed at the very end of the modeling process (Woodbury, 2010).

Project: AA Component Membrance

Architect: The Emergent Technologies and Design Group

Engineer: Buro Happold

Place: London

Year: 2007

The “AA Component Membrane”, a terrace canopy designed at the Architectural Association, the form was simultaneously optimized for sun, wind, drainage and views using a parametric model combined with various computational analysis techniques including fluid dynamic wind flow analysis, precipitation analysis, stress analysis, and solar analysis. The canopy was designed by the Emergent Technologies and Design MSc / March Programme in collaboration with Buro Happold, one of London’s leading engineering firms and it was designed by using the rich parametric logic enabled by GenerativeComponents (Figure2.14).

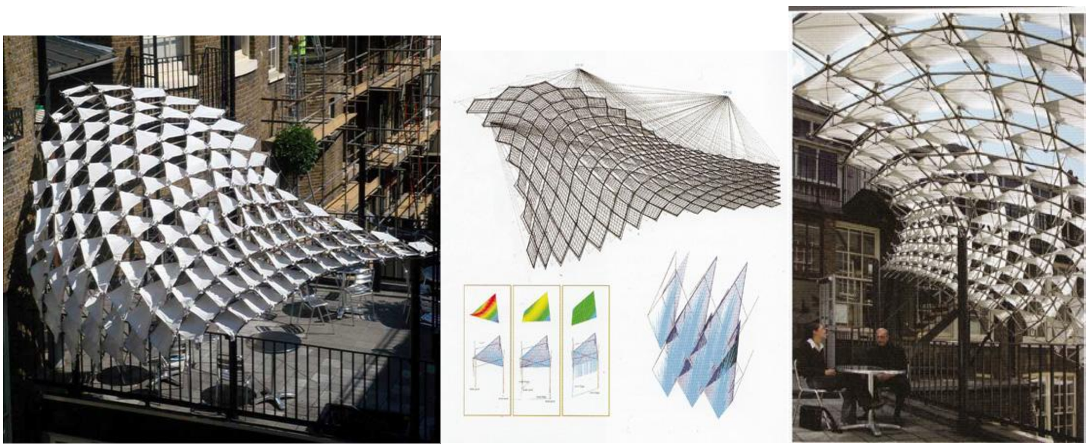

Figure 2.14 : : “AA Component Members”, a terrace canopy, London, 2007 (Url-6).

3. PERFORMANCE-BASED FACADE DESIGNINGS

As the world gives increased focus on energy efficiency and occupant comfort, there is now an emerging need to include sustainability–related performance aspects within design, most notably energy and daylighting (Lagios et al., 2010). Façade plays an important role in providing daylight. Thus, they have a substantial positive impact on the occupants (Li & Tsang, 2008).

There are lots of buildings which their façade is with glazing materials. Mies van der Rohe’s Seagram’s Tower, New York (1958), was an iconic building that influenced the design of office towers for decades. It was one of the highly glazed uniform designs, but these kinds of design present many challenges for energy efficiency and occupant comfort (Figure 3.1). It is important to diagnose that large openings, while providing persuasive aesthetics and visual contact with the outside and the daylight, could be problematic because of the overheating, load bearing structures and the high cost of the insulation. It is also important to mention that large panes of glass, are not cheap. Therefore, the need for shading and proper material should be considered.

Figure 3.1 : Seagram building, Mies van der Rohe, New York, 1958 (Url-7).

Designing buildings for better energy efficiency has been a global call for many years now, more especially after the global energy crisis of the early 1970s. With changing attitudes today towards energy conservation, environmental emissions, the sustainability of materials and the comfort of occupants, the intent of using climate-control is considering more.
The important role of the façade of a building simply is to protect the inhabitants from the outside environment but they also have many other tasks. They are responsible to let the weather to inside for the building breathe. They are responsible to keep inhabitants secure while also allowing them to view the outside. By making the facades more dynamic and adaptive they can respond better to the various conditions and supply more comfort for the occupants. Façades not only shape the appearance of building, they also determined the indoor climate, energy consumption and operating costs of a building. Wiggington (2002), states: "The façade of a building can account for between 15% and 40% of the total building budget, and may be a significant contributor to the cost of up to 40% more through its impact on the cost of building services".
"A building envelope might plan an active role in reducing a building's energy consumption by altering its own shading properties and triggering the heating and cooling system based on information about temperature and sunlight" (Jamin, 2011). With this, the occupants will require less action to change their own environment for work and start to focus more with fewer interruptions.

To fulfill the users' needs, designers have explored advanced techniques on building façades, which represent a significant part of any architectural project, besides acting as the medium between the indoor and outdoor environments (Wigginton and Harris, 2002).

According to Aksamija (2013), "for designing high-performance façade some basic strategies are included such as: orienting and developing geometry and massing of the building to respond to solar position, providing solar shading to control cooling loads and improve thermal comfort, using natural ventilation to reduce cooling loads and enhance air quality, minimizing energy used for artificial lighting and mechanical cooling and heating by optimizing exterior wall insulation and the use of daylighting" (Aksamija, 2013). "While engendering explorations and realizations of rich and complex Formal possibilities, parametric design can inject performative potential into the built environment" (Hensel, 2004).

3.1 Adaptability, Flexibility and Kinetic Motions in Facades

Recent computer-aided design and engineering (CAD) tools allow architects and engineers to simulate many different aspects of building performance such as energy and lighting (Leighton, 2010). This process includes evaluation of kinetic façade systems.

Katy Velikov and Geoffrey Thun (2012), argue that the building envelope "as the building component most directly exposed to sun and wind, is the most effective site for innovations in energy savings and alternative energy generation". Innovative performance-driven envelope designs that are proceeding in architecture today, often include innovation in material, environmental feedback from sensors and kinetic automation. This trend in façade design as described by Velikov and Thun has changed the designers procedure "from form to performance" and "from structure to envelope" (Velikov & Thun, 2012, p. 75).

Buildings are in a connection with various ranges of unfavorable environmental conditions which requires the envelopes to respond intelligently and automatically to these environmental changes and user demands. An 'intelligent façade' is a façade that incorporates variable devices whose control adaptability enables the building envelope to act as a climate moderator. The result of using the facade in this way is to reduce the amount of artificial energy for achieving comfortable internal conditions since it has the ability to accept or reject free energy from the external environment.

The word "intelligent" was first used at the beginning of the 1980s to describe buildings, together with the American word "smart" (Wigginton and Harris 2002). Moreover, the Intelligent Building Institute (IBI) presented one of the first definitions of intelligence in buildings:

"An intelligent building is one which provides a productive and cost effective environment through the optimization of its four basic elements – systems, structure, services, management and the inter-relationship between them. Intelligent buildings help building owners, property managers, and occupants realize their goals in the areas of cost, comfort, convenience, safety, long-term flexibility, and marketability. There is no intelligence threshold past which a building "passes" or "fails". Optimal building intelligence is the matching of solutions to occupant needs. The only characteristic that all intelligent buildings have in common is a structured design to accommodate change in a convenient, cost-effective manner”. After that, building facades that have the intelligent features known as “Intelligent building skin”, because the skin makes the greater part of the intelligent system in the buildings and the intelligent façade should have dynamic capabilities to interact with seasonal climate changes and environment in order to led to the reduction in the energy consumption inside the indoor spaces. Velikov and Thun (2012), define intelligent envelopes as ones which incorporate computation, automated technologies, building control systems, sensors and adaptive elements. Dynamic shading devices, energy conserving panels and louvers are among the adaptive elements used in intelligent building envelopes.

HelioTrace design is the example of an intelligent adaptive building envelope. The HelioTrace façade system merge three different systems—kinetic shades, the building enclosure, and internal mechanicals—into an adaptive façade that seeks to minimize energy use while maximizing user comfort. Its developers claim an effective shading level of 78 percent and an annual peak solar gain reduction of 81 percent. For designing the façade a high-performance glass curtain wall was used, it included two exterior device for the curtain: opaque panels that project from the mullions, perpendicular to the façade and 50-percent perforated panels firmly fixed parallel to the building envelope. Both programmed to respond to daily sun path. Each square shaped opening is fully covered with 4 vertical triangular folding shading surfaces (Figure 3.2).

Figure 3.2 : HelioTrace building envelope system, by Skidmore, Owings & Merrill, NewYork, 2010 (Url-8).

One type of intelligent skin is smart-kinetic facades. Smart-kinetics is the flexible adaptability of building facades to respond to the changing environmental conditions, taking into account the human interaction and behavior (El Sheikh, 2011). Smart kinetics can act both as a *primary system* and *independently system* as a skin layer and can be designed as performance-based elements.

- Primary system like operable windows which open and close according to need.
- Independently systems like external louvers that are secondary skin and operate independent from the main skin. The use of secondary systems allows for more creative design and geometries.

One of the early examples of the façade system which could foresee the changes and that could be adapted to suit its use is the IGUS factory designed by Grimshaw in 1982. Herman Miller, the furniture manufacturer wanted a building at Chippenham, England, that could anticipate changes for future from Grimshaw. It was a big warehouse but with office usage in future. Grimshaw designed a cladding system with pressed aluminum to have long-term flexibility. The warehouse does not need a window and ventilation system but an office needs windows and ventilation system so the solution was designing a skin that could be change in future. Figure 3.3 shows how the clamps and skin works and how the panels are pressed back onto the skin.

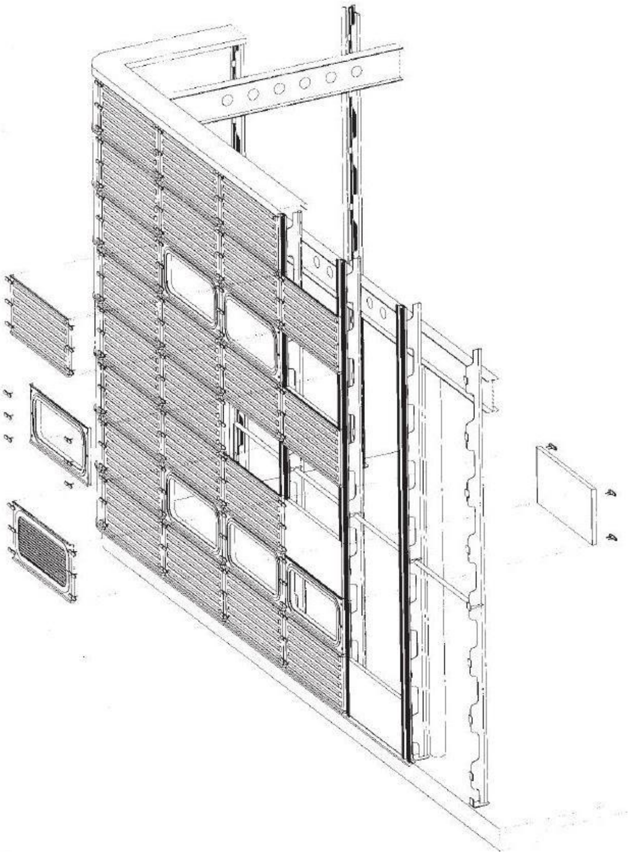

Figure 3.3 : The facade detail, IGUS factory, Cologne (1990– 2000), architect: Grimshaw (Kolarvic & Malkawi, 2005).

Mentioning that a façade is the exterior shell of a building, it should act as an environmental filter towards energy-reduction, daylighting, ventilation, and excellent quality of indoor spaces. Many different examples illustrate the façade as an important filter layer that are aiming for forming better indoor environment. Mashrabiyya, brise-soleil, high-mass walls are some traditional methods of reducing the effects of sun glare. Mashrabiyya and brise-soleil are good examples, which deal with both thermal and daylighting issues.

Mashrabiya or Shanasheel is an element of traditional Arabic architecture which given to a type of projecting oriel window enclosed with carved wood latticework located on the second floor of a building or higher, often lined with stained glass (Url-9). The Mashrabiyya is one of the best example of a passive environmental façade that controls daylighting and natural ventilation of indoor environment (Figure 3.4). They adopted the Mashrabiyya in most Egyptian Islamic houses (Kenzari and Elsheshtawy, 2006).

Figure 3.4 : Egyptian Mashrabiyya (Url-9).

Another example is Brise Soleil, an architectural feature of a building which reduces heat gain, is a technique that was popularized by Le Corbusier in buildings with large surface areas of glazing (Melendo et al, 2008). This performance-based pattern allows the penetration of low-angle sun in winter for passive heating and the blockage of high angle sun during summer. It is the variety of permanent sun-shading structures, ranging from the simple patterned concrete walls popularized by Le Corbusier in the Palace of Assembly (Url-10). north facade of Gustavo Capanema Palace designed by le Corbusier in 1935, is also a famous example that shows the efficient use of brise soleil in Rio de Janeiro (Figure 3.5).

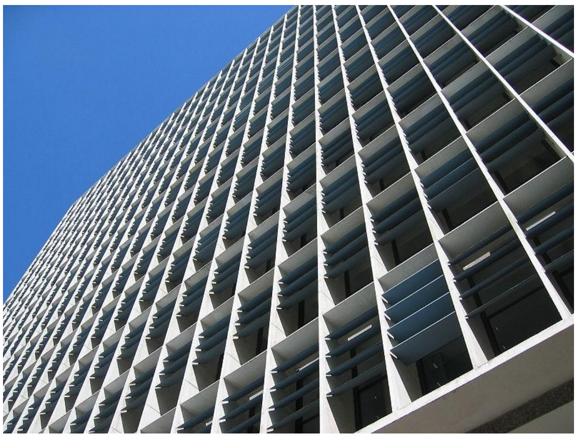

Figure 3.5 : north facade of Gustavo Capanema Palace designed by le Corbusier, 1935 (Url-10).

Brought forward the project is representing a recent example of kinetic façade. By kinetic façade we mean a dynamic facade, pertaining to or characterized by energy or effective action. The best type of kinetic facade is one that is responsive, something that responds readily to appeal efforts or influences.

Project: Q1 Headquarters Building
Architect: JSWD Architekten
Location: Essen, Germany
Year: 2010

The Headquarter Building also known as Q1 is 165 feet, is the clear center of operations on campus. The highly efficient sun protection system has a significant role in the overall appearance of Q1 (Figure 3.6). The circa 400,000 stainless steel lamellas are oriented in response to the location of the sun and enable light redirection without blocking the view. The facade is shaded by 3,150 kinetic "feathers" that open and close based on user input and sensor data. It can vary from 0 to 90 degrees of openness to provide as little or as much shading from the sun as possible. The Q1 building has been awarded a gold certificate by the German Society for Sustainable Building (DGNB). "The detail of the sun shading system is the character of the whole," JSWD co-founder, Jürgen Steffens says. Steffens says. "When you look at the building in the evening when the sun is going down, it is absolutely amazing to see what the stainless steel does with this red light."

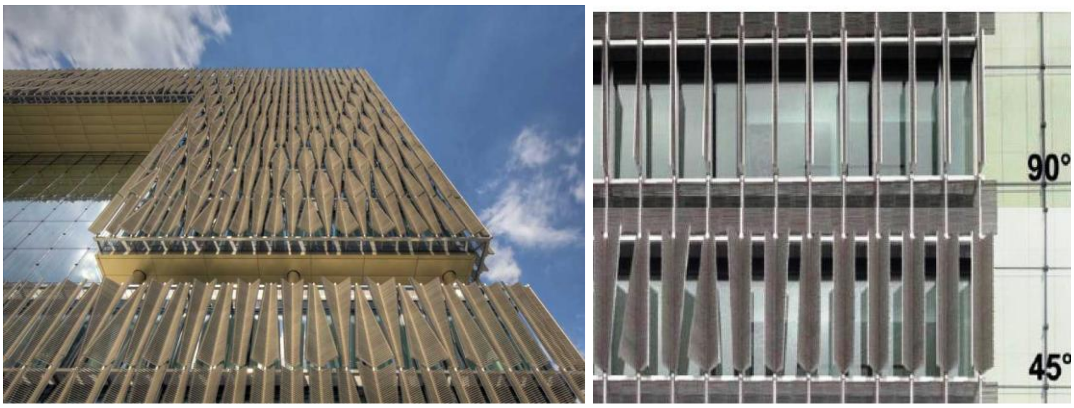

Figure 3.6 : Q1 Headquarters Building by JSWD Architekten, Germany, 2010 (Url-11).

3.2 Use of Parametric Design for Performative Facades

According to Aksamija (2013), "for designing high-performance façade some basic strategies are included such as: orienting and developing geometry and massing of the building to respond to solar position, providing solar shading to control cooling loads and improve thermal comfort, using natural ventilation to reduce cooling loads and enhance air quality, minimizing energy used for artificial lighting and mechanical cooling and heating by optimizing exterior wall insulation and the use of daylighting" (Aksamija, 2013). "While engendering explorations and realizations of rich and complex Formal possibilities, parametric design can inject performative potential into the built environment" (Hensel, 2004).

The "performance-based design" approach presented by Oxman proposes integrating 'environmental performance criteria' within associative and parametric design models for performance optimization (Oxman, 2008). Parametric design is a generative tool in architectural design. Because they are based on algorithms, during design process they offer computational control over design geometry. Their adaptability and ability to change design criteria make parametric models useful for designing kinetic and dynamic designs. Design means the act of designing an object and that object is the end result (design as an artifact) while generative design does not specify the design artifact, instead encodes the "making" of the artifact. Therefore, generative systems are said to precede formation over form, which indicates a fundamental shift from the modeling of a designed "object" to modeling of the design's "logic" (Leach, 2009). As a parametric design tool, Grasshopper allows for the creation of a kinetic system that can respond to multiple inputs and outputs with the use of a genetic algorithm.

Form and energy are linked when we want to achieve performance-based design. Performative design principles can be entered both, first or during the design process. The Aviva Stadium in Dublin, Ireland and the façade of the Kilden Performing Arts Center in Kristiansand, Norway are two works that are exemplary of these two approaches.

Project: Aviva Stadium

Architect: Populous (Formerly HOK sports architecture)

Engineer: Buro Happold

Location: Dublin, Ireland

Year: 2010

A performative parametric approach was used for the designing the Aviva Stadium (Dublin, Ireland) at the first of the design (Figure 3.7). This stadium was designed by Populous (formerly HOK Sports Architecture) and engineered by Buro Happold. On the architectural side, form explorations were being made in response to certain criteria such as concourse width, floor area ratios and beautifying the shape. On the engineering side, the structure of the roof trusses and cladding systems designed as a rain screen consisting of inter-locking louvers. Parametric model allowed the integration of the design processes of the form, structure and façade, allowing the ability to change. Each part had its own function and beauty. Through the establishing of computational design process each part also maintained an association with all other parts. The stadium was developed and executed using a combination of Robert McNeel & Associates' Rhinoceros and Bentley Systems' GenerativeComponents. The design of each section of the stadium's radial structure was important. Each section consisted of a large, shallow arc beginning at the base of the building and composing its facades; a second, smaller and deeper arc, tangential to the first and making the transition between the façade and the roof; and finally a straight line also tangential to the smaller arc and functioning as the roof (Wassim, 2013). The sharing of the parametric model across the other design members and the fully integration of the engineering analysis applications could realized the benefits of a parametric approach (Hudson et al., 2011).

Figure 3.7 : Aviva Stadium, Dublin, Ireland, 2010, by Populous and Walker (Url-12).

Figure 3.8 shows a diagram of the design and workflow between architects (Populous) and the engineer (Buro Happold). The design surface allowed a smooth BIM collaboration between the architect and the engineer.

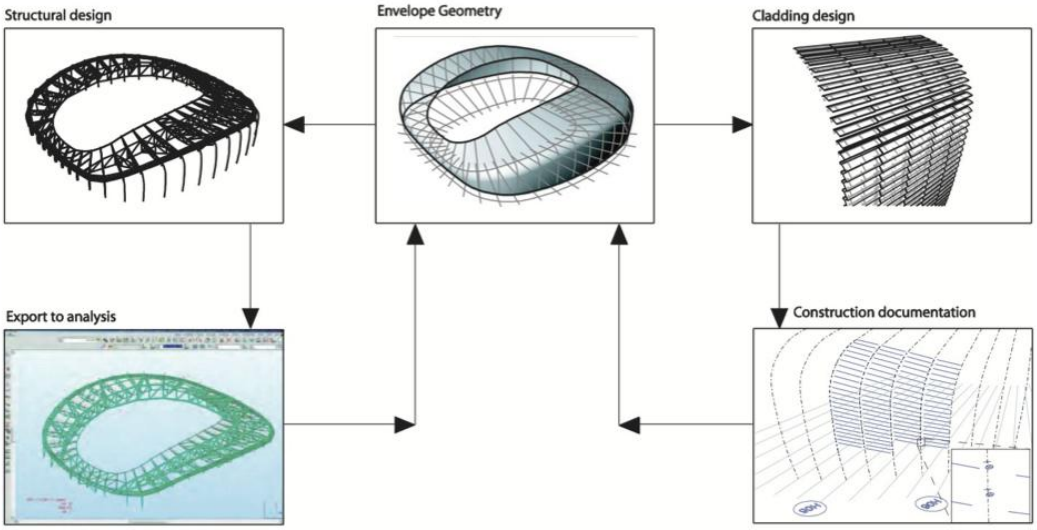

Figure 3.8 : Diagram of the design development stages (Url-13).

Project: Façade of Kilden Performing Arts center

Architect: ALA Architects

Engineer: Designtoproduction Company

Location: Kristiansand, Norway

Year: 2011

The façade of Kilden Performing Arts center in Kristiansand, Norway designed by ALA architects and engineered by the "designtoproduction company" is another example of the parametric modeling, which parametric system was used during detail design for the parametric optimization of form and performance (Figure 3.9). The roof is clad by straight oak boards that are only twisted around their longitudinal axis. Therefore, "all generatrices had to be aligned with the building axes, a demand that could not be met with the default 'loft' method found in standard CAD packages, but needed a custom NURBS definition" (Scheurer and Stehling, 2011). The mathematically precise definition and the exact positions of the roof beams, as well as their assembly details were worked out with parametric modeling.

Figure 3.9 : Kilden Performing Arts Center, Kristiansand, Norway, 2011, by ALA Architects (Url-14).

This part presents some examples of performative facades which are modeled by parametric design. Parametric design is used for reducing glare and improving daylight penetration in these examples.

Project: Façade of Al Bahar Towers

Architect: Aedas Architects

Location: Abu Dhabi

Year: 2012

The façade of Al Bahar towers in Abu Dhabi is also another example of responsive façade which is modeled by parametric design (Figure 3.10).

Figure 3.10 : Al Bahar Towers, Abu Dhabi, 2012, Aedas Architects (Url-15).

The weather of Abu Dhabi will show a week of intense sunshine and temperature always above the 100 degrees Fahrenheit, in such a condition architects will focus on the environmental design as their top priority. For these towers, Aedas Architects designed a responsive façade which takes cultural cues from the traditional “Mashrabiya” as mentioned before. Using a parametric design for the geometry of façade panels, the shading system was completed in June 2012 by the computational design team. The novel shading screen faces, computer-controlled, operates as a curtain wall, were designed with two meters distance with the exterior facade of buildings, in a separate frame. Each triangle was coated with micro fiberglass and programmed to respond to the movement of the sun as a way of reducing solar gain and glare. It is estimated that the screen reduces solar gain in more than 50%. The team was able to simulate the panel’s response to the sun exposures and changing angles of panels during the different days of the year. Each of the two towers comprises over 1,000 individual shading devices that are controlled via the building management system, creating an intelligent façade. (Figure3.11).

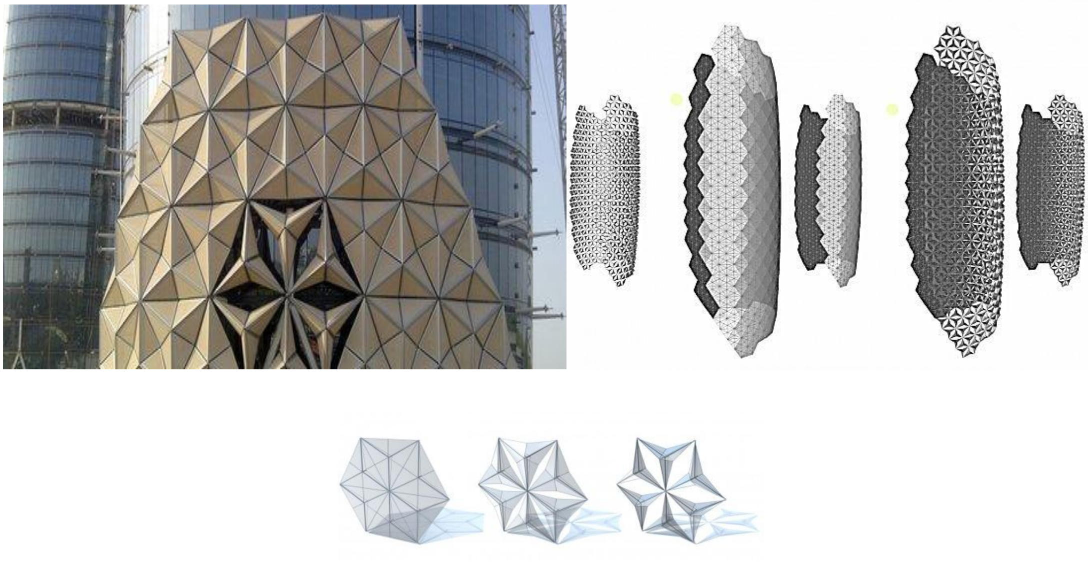

Figure 3.11 : Fiberglass coated triangles are programmed to respond to the movement of the sun (Url-15).

The independent screen located two meters outside the buildings’ exterior and operates as a curtain wall. Panels respond to the movement of sun as to reduce solar gain and glare. Each unit comprises a series of stretched PTFE (poly tetra fluoro ethylene) panels and is driven by a linear actuator that will progressively open and close once per day in response to a pre-programmed sequence that has been calculated to prevent direct sunlight and to limit direct solar gain to a maximum of

400 watts per linear meter. The effects of this system are comprehensive: reduced glare, improved daylight penetration, less reliance on artificial lighting, and over 50% reduction in solar gain, which results in a reduction of CO_2 emissions by 1,750 tons per year.

“At night they will all fold, so they will all close, so you’ll see more of the facade. As the sun rises in the morning in the east, the Mashrabiya along the east of the building will all begin to close and as the sun moves round the building, then that whole vertical strip of Mashrabiya will move with the sun,” said Peter Oborn, the deputy chairman of Aedas.

Project: Façade of South Australian Health and Medical research Institute (SAHMIRI)

Architects: Woods Bagot

Location: Adelaide SA, Australia

Year: 2013

Famed for its appearance, the triangulated and textured façade of the 2,500m^2 South Australian Health and Medical Research Institute (SAHMRI) is another example of parametric designed façade (Figure 3.12). The exterior of the structure is made of 15,000 steel-framed triangles that form a dia-grid – a diagonal grid – and was designed to maximize natural daylight while minimizing sun glare and energy use. Each triangle panel has a moulded metal point integrated into the piece that varies in width and angling depending on sun exposure.

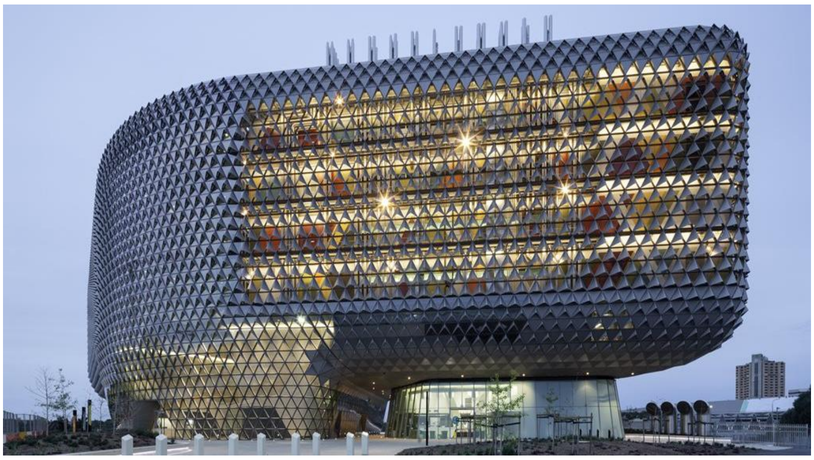

Figure 3.12 : South Australian Health and Medical Research Institute (SAHMRI), by: Woods Bagot, Adelaide SA, Australia (Url-16).

“We thought about what is the best way considering the environmental considerations and did some parametric modeling” architecture project director, Woods Bagot’s Anoop Menon, said. The model was produced by Rhino and Grasshopper software. The complex façade structure is a combination of a structural steel dia-grid sub-frame with an external aluminium suite and double glazed (high performance low E glass) triangular panels, woven mesh panels, and perforated and solid aluminium infill panels. The sunshades have been designed and orientated for optimum thermal and light efficiency (reducing also heat load and glare), and sizes vary for that reason (Figure 3.13).

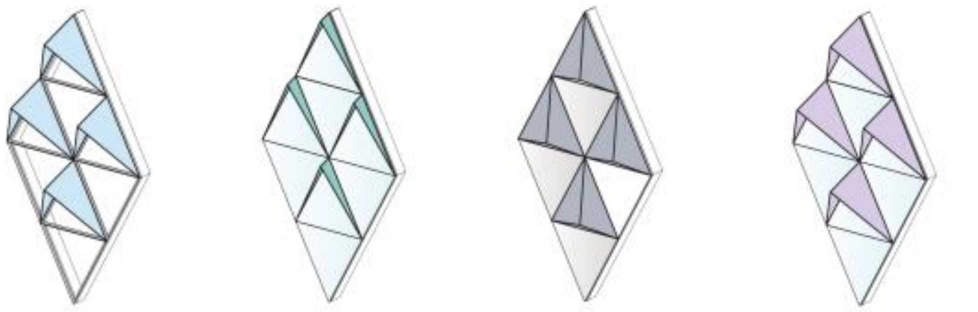

Figure 3.13 : The shade hood of each window is a different size, depending on exposure to the sun (Url-16).

Woods Bagot used parametric modeling tools to integrate environmental, programmatic and formal requirements into the façade design, and to ensure that the building form achieves its optimized solar orientation through passive design of floor plates that respond to the internal program and provide maximum daylight where needed. For instance, the enclosed lab support spaces are located along the western façade to provide protection from the harsh afternoon sun.

3.3 Daylighting Performance in Facades

“Architecture is the masterly, correct and magnificent play of volumes brought together in light. Our eyes are made to see forms in light…” (Le Corbusier).

A high integration of design and research between architects, computational designers, and consultants is important to achieve innovation and efficiency. Communicating to the designer the importance of integrating performance-based approaches in the early design stage and their impact on the design, may shift the logic of executing an architectural project.

As a design feature, the use of daylighting for a building creates more productive and pleasing space for the people within. The moderation of light levels which enters a place, creates comfortable environment. Successful daylighting is more than adding additional windows or large skylights. "It involves thoughtful integration of design strategies, which address heat gain, glare, variation in light availability, and direct-beam penetration into a building" (Ander, 2003, p.1). Design decisions are often include shading devices, size of windows, glazing materials, reflectance and interior finishes. As an efficiency measure, daylighting is most efficient during the sunny afternoons, when it can supply the need for electric lighting, so daylighting has an important role to reduce the buildings overall energy consumption. Daylighting may potentially play a key role in supporting "sustainable" development (Ander, 2003).

Daylighting control is an important aspect in designing facades. It is very easy to predict and control the movement of the sun, as Givoni (1998) states, "The sun travels in a predictable manner using diurnal and annual patterns". The path that a sun takes is dependent on the location of the building, most importantly, the latitude, or the distance from the Equator.

The integration of daylighting into the design phase, through design tools and computation, results in the improved performance of daylight harvesting and therefore tackles issues of human comfort and energy efficiency. One example of performance-based integration is the design simulation, and validation of intelligent features in building skin design and its impact on daylighting performance.

The field of building simulation research has developed tools to calculate the performance requirements (solar gain, daylight penetration, heating and cooling loads, ventilation, water use) of a building (Shaviv, 1999; Malkawi, 2004).

Energy efficiency in buildings is influenced by the behavior of architectural spaces, part of which can be attributed to daylighting. Daylighting performance is envelope-dominated. For example, designing fully-glazed façades minimizes the efficiency of the envelope, despite allowing huge amounts of daylight into a space.

Many office use electric lights during the day, when it is unnecessary and daylight strategies can be replaced by it. A variety of results have shown that suitable lighting controls integrated with daylighting have a powerful potential for reducing energy consumption in office buildings. Field measurements and simulation studies have showed that the energy saving potential by utilization of daylighting is about 30%-40% for constant lighting system (Opdal & Brekke, 1995). So for the energy conservation and also for the human health it is important to take into account the daylighting strategies during the design phase. Proper use of daylighting cannot only reduce energy consumption effectively, but also improve the indoor visual comfort. People prefer natural lighting than artificial lighting as it gives the best color rendering and matches with human visual response (Li & Lam, 2003).

The following quote explains the importance of natural light on the human health:

“Light synchronizes the human biological clock with day, night and seasonal rhythms. A lack of natural daylight can lead to disorders of the automatic nervous system, loss of energy, fatigue, a tendency towards self-isolation and metabolic disorders. Conversely, intensive light therapy has been shown to support the healing process” (Koster 2004).

Daylighting design is a key aspect of building rating systems such as Leadership in Energy and Environmental Design system (LEED). It uses metrics such as Daylight autonomy (DA), which is the percentage of annual work hours during which all or part of a building’s lighting needs can be met through daylighting alone (Reinhart et al., 2006).

Horizontal and vertical fins have been successful techniques in controlling the light deflection, vertical fins are used on east and west façade, where the sun angle is low and horizontal fins are efficient on south facades that the sun angle is high.

Daylighting is a crucial asset for office design, but it is variable. Some architects, like Aalvar Aalto, Louis Kahn, and Le Corbusier, addressed daylight through architecture, emphasizing its importance (Schiler, 1997). Indoor spaces suffering inadequate daylighting levels during daytime experience illumination levels (quantity) out of the recommended range, and uneven distribution of daylighting (quality). They also suffer the need for electric lighting to compensate for the limitation of daylighting depth into the space. The design profession is currently undergoing technological advancement which will allow for better daylight performance, targeting greater energy savings and reduced electricity consumption. This will happen by bringing daylight deeper into the space, maintaining desired illumination levels (quantity), and achieving even luminous distribution (quality).

An optimal visual environment in office spaces, achieved through the use of daylight, is crucial for employees' comfort, productivity, and morale (Dasgupta, 2003).

Several design consideration impacts the light effect of the building. For hot climates, when harshness of direct light is the worse problem, filtering by curtains, overhangs or horizontal and vertical louvers can be a good strategy to block the direct beam from the sun. Moveable louvers and panels can be controlled electronically to respond to the changing weather conditions, for example block the direct beam light during the summer when sun angles are high while allowing some sun penetration during cold seasons.

Different organizations suggested different light levels for an office spaces. The recommended illumination level according to the Illuminating Engineering Society of North America (IESNA) for a typical office space is 200-500 lux. The NRC Institute for Research in Construction recommends a level of 400 – 500 lux for general office work (National Research Council Canada, "NRC Canada). These values can be higher or less in some areas of the space, under certain conditions. In general, the IES lighting handbook defines values ranging from 100 to 1500 lux as acceptable (Table 3.1).

Table 3.1 : The recommended range of illumination in foot-candles for office spaces (IES lighting handbook illumination).

Type of space	Foot-candles
Corridors, stairways, washrooms, book shelves	10-20
Secretarial desks	30
Routine works(reading, transcribing, mailing, etc)	100
Accounting, book keeping, Auditing	150
Conference tables	30

(to convert to lux multiply the values by 10.76)

Sky conditions vary the quantity of the light entering the building. According to Ander (2003), three types of sky conditions are utilizing to estimate illumination levels within a space: overcast sky, clear sky and the cloudy sky. Overcast sky is the most typical type of sky condition that in it at least 80% of the sky is hidden by clouds. Clear sky is less bright than the overcast. This sky condition is defined which no more than 30% of it is obscured by clouds. The cloudy sky is a sky that 30% to 80% of the sky dome is obscured by the clouds.

4. CASE STUDY

In this chapter an adaptable and responsive façade using parametric design will be designed for the existing Ari-3 office building in Turkey, Istanbul, Istanbul Technical University by Hüseyin Kahvecioğlu, Melis Nur İhtiyar and Cem Altun taht was constructed in 2012. This Building was selected as the case study since we wanted an office buidling and also it was more easy and available to reach and achieve the plans and detail plans of the building.

First issue of the design is considering the climatic and environmental conditions of the case study. Then the façade system will be designed using Grasshopper and the key parameters and inputs of the design will be proposed, while the designing process we will consider the optimization criteria for enhancing the lighting performance. The goal of the optimization is to reducing visual discomfort with sttop entering the direct beam from sun while maintaining good daylight penetration. While searching the performance of a daylight system it is important to consider not only the amount of daylight that can enter the building, but also the amount that cannot be admitted due to visual discomfort problem (Nabil and Mardaljevic 2005). Therefore, it is also necessary to consider the behavior of the building's occupants, and when and how they will allow daylight inside the rooms (Reinhart and Voss 2003).

4.1 Analysis of Climatic and Environmental Conditions of ARI3 Building

Environmental condition plays an important role in design assumption. The study focuses on the climatic and geographical conditions of Istanbul, Turkey.

Istanbul is the largest city in Turkey which is located in north-western Turkey within the Marmara Region on a total area of 5,343 square kilometers. The Bosphorus is connecting the Marmara and Black sea. According to the Köppen–Geiger classification system, Istanbul has a borderline Mediterranean climate, humid subtropical climate and oceanic climate, due to its location in a transitional climatic zone (Figure 4.1). Northern half of the city, as well as the Bosporus coastline, express characteristics of oceanic and humid subtropical climates, because of humidity from the Black Sea and the relatively high concentration of vegetation. The climate in the populated areas of the city to the south, located on the Sea of Marmara, is warmer, drier and less affected by humidity (Url-17).

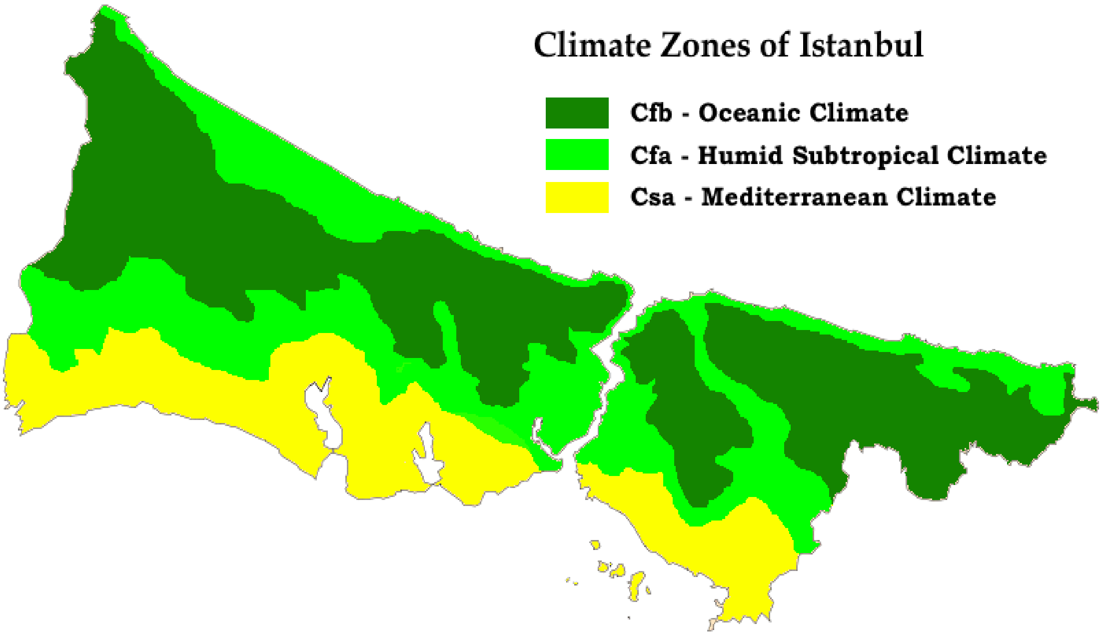

Figure 4.1 : Climate zones of Istanbul (Url-18).

The highest and lowest temperatures ever recorded in the city are 41.5 °C (106.7 °F) and −11 °C (12.2 °F) (**Table 4.1**).

Table 4.1: Climate data for Istanbul (Url-17)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	22.0 (71.6)	23.2 (73.8)	29.3 (84.7)	33.6 (92.5)	34.2 (93.6)	40.5 (104.9)	41.5 (106.7)	39.6 (103.3)	35.4 (95.7)	34.0 (93.2)	26.5 (79.7)	25.8 (78.4)	41.5 (106.7)
Average high °C (°F)	8.3 (46.9)	8.8 (47.8)	10.7 (51.3)	15.3 (59.5)	20.0 (68)	24.6 (76.3)	26.5 (79.7)	26.7 (80.1)	23.5 (74.3)	19.1 (66.4)	14.7 (58.5)	10.7 (51.3)	17.41 (63.34)
Daily mean °C (°F)	5.6 (42.1)	5.6 (42.1)	7.0 (44.6)	11.0 (51.8)	15.6 (60.1)	20.4 (68.7)	22.8 (73)	23.0 (73.4)	19.7 (67.5)	15.6 (60.1)	11.4 (52.5)	7.9 (46.2)	13.8 (56.84)
Average low °C (°F)	3.0 (37.4)	3.0 (37.4)	4.2 (39.6)	7.7 (45.9)	12.1 (53.8)	16.5 (61.7)	19.4 (66.9)	20.0 (68)	16.7 (62.1)	13.0 (55.4)	8.9 (48)	5.4 (41.7)	10.83 (51.49)
Record low °C (°F)	−11.0 (12.2)	−8.4 (16.9)	−5.8 (21.6)	−1.4 (29.5)	3.0 (37.4)	8.5 (47.3)	12.0 (53.6)	12.3 (54.1)	7.1 (44.8)	0.6 (33.1)	−1.4 (29.5)	−7.0 (19.4)	−11 (12.2)
Average precipitation mm (inches)	104.2 (4.102)	77.3 (3.043)	69.5 (2.736)	46.4 (1.827)	33.5 (1.319)	32.8 (1.291)	32.7 (1.287)	40.8 (1.606)	58.9 (2.319)	86.8 (3.417)	102.2 (4.024)	125.0 (4.921)	810.1 (31.892)
Avg. precipitation days (≥ 0.1 mm)	17.8	15.5	13.7	10.6	8.1	6.2	4.4	5.1	7.5	11.1	13.3	17.5	130.8
Mean monthly sunshine hours	71.3	87.6	133.3	180.0	251.1	300.0	322.4	294.5	243.0	164.3	102.0	68.2	2,217.7

İTÜ Arı Teknokent, Arı 3 building is located in the Istanbul Technical University main campus of Istanbul, Maslak, Turkey (Figure 4.2).

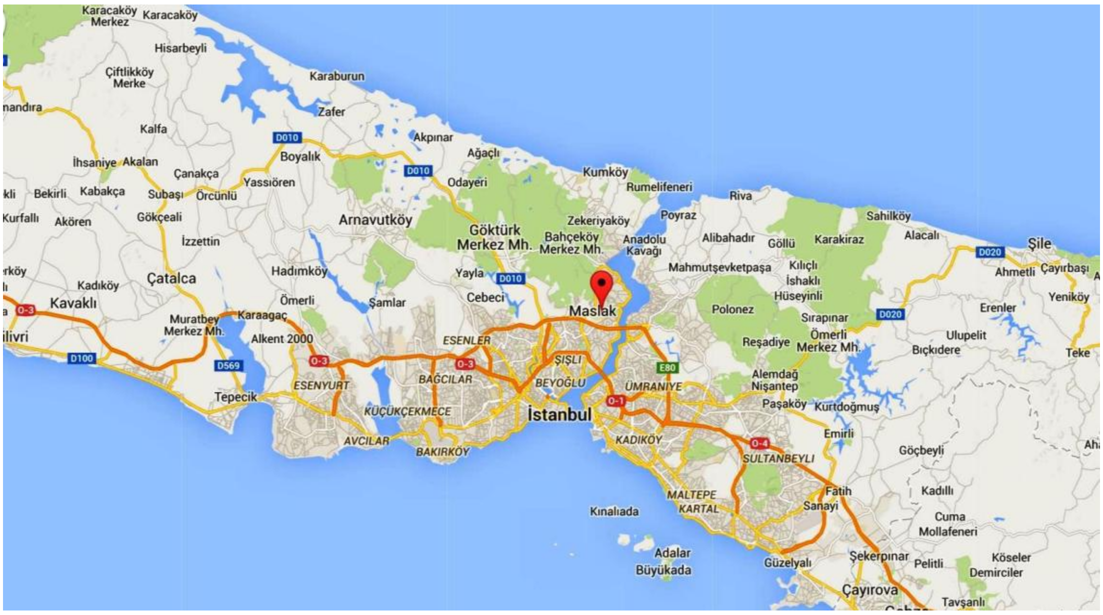

Figure 4.2 : The place of project in the city scale (Url-19).

As it is shown in the map the position of the project is in a humid subtropical climate zone. The exact coordination of the project is 41°6'27"N and 29°1'56"E. Figure 4.3 shows the exact position of the Ari 3 building.

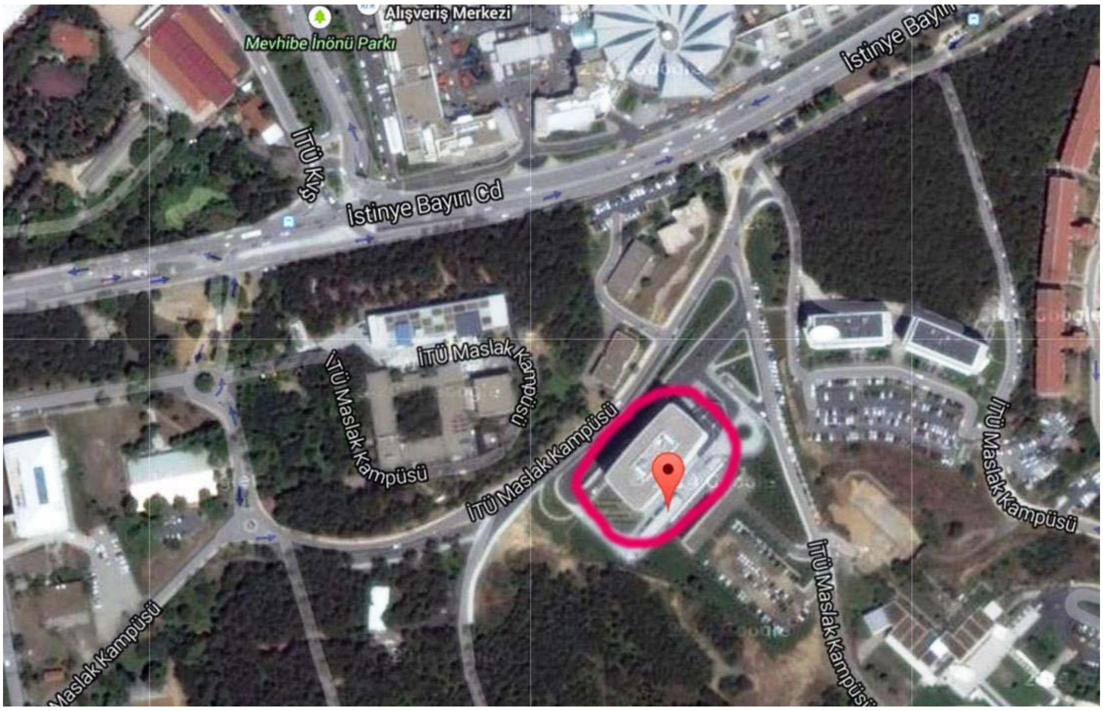

Figure 4.3 : The exact position of the ARI3 building in the site.

The challenge of developing adaptive, responsive low-energy architecture requires new knowledge about the complex and dynamic interaction between envelope architecture, optimization between competing environmental performance metrics (light, heat and wind indices) and local climate variables (Datta and Hobbs, 2013).

Climate changes and rising energy costs are reasons that necessitate designing buildings that are efficiently respond to climate changes and reduce the costs. Parametric system is extended from the individual user to climate conditions, factors like sun, heat, air, water etc. “The developed parametric system allows the creation of buildings that are conceived ideally for the specific climate, site and usage” (Matcha, p. 686).

As mentioned before the aim is to design a performative façade that respond to the sun exposures to block the direct glare and direct sun beam. So the side of the façade that get direct solar radiation is so critical. Figure 4.4 shows the site plan and north direction of the plan as to decide where to put the desired façade to act better in respond to the sun.

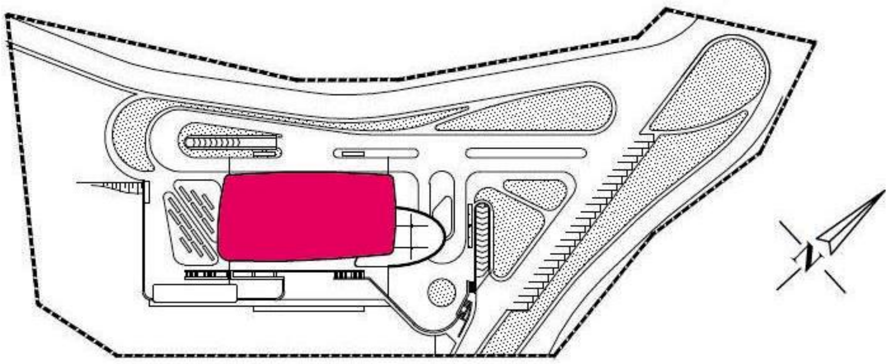

Figure 4.4 : Site Plan of the project.

4.2 . Model Structure and Key Parameters

The form of the façade is hexagon cellules, hexagon is selected because of its symmetric shape and also it is inspired by the Istanbul Technical University’s arm that is beehive .

For the Facade form, the early problem was how to create a staggered pattern across a flat surface, which was required in order to achieve the hexagonal tiling. Parametric software can easily define a surface with a point grid across it, with a given U and V values.

Then we will have a hexagonal surface and for making this façade adaptable and responsible each of the cells or panels will orient according to the sun exposures so that to reduce glare and prevent direct sun beam.

The earlier setup of the panel components required only two inputs; origin of the hexagon cells and orientation. To be able to change the responsive nature of these panels in the façade, the orientation input needs to be revised. If the panels are able to respond to a point in space, this point can change the orientation of the panels as it moves across the face of the façade. The point behaves as an attractor and can be used to define the sun, so new set of parameters is developed within the model to define the path of the attractor or sun.

4.2.1 **Attractor; Sun Path and Sun Positions**

The surface panels here are designed to rotate facing an attractor, in this case the sun. The solar path was extracted from the plug-in "Ladybug" for Grasshopper to help get the precise location and angle of the sun in Istanbul, Turkey. Building geographical location is important when generating the diagram; to determine the height, angle, and level of direct sun exposure. The plug-in here helps us to obtain this information by providing a component that is directly linked to a geographical and climatic database to provide the required information.

In ladybug by connecting the weather information file of the Istanbul, it gave us some information that by connecting the outputs to the sun-path component input the sun path is created (Figure 4.5). Given that the path of the sun is precisely known, designers are able to calculate the altitude and azimuth of the sun on any specific date and time in any location worldwide.

As we saw in the table of climatic condition of Istanbul July is the warmest month and the sunshine hours in it is also high so for analyzing our case study we select July for the analyzing month. For the hour’s parameter we set it from 1 to 24, to see all the sun positions during 24 hours as it bring the radiation and light

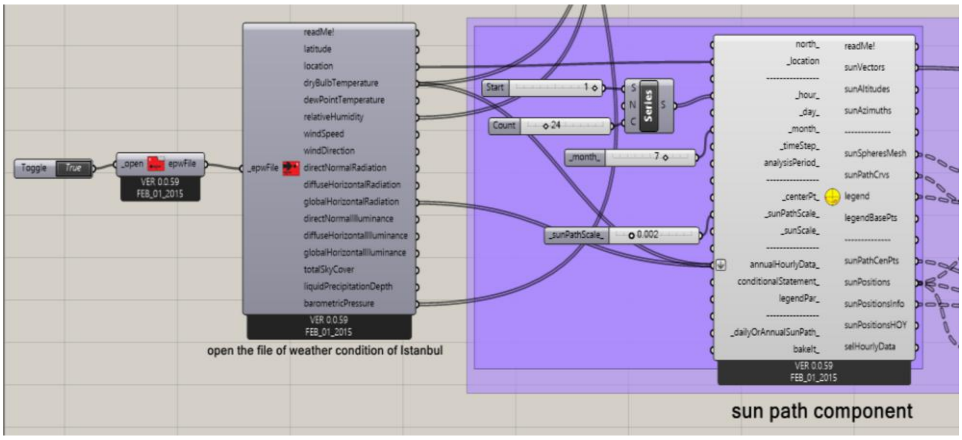

Figure 4.5 : Producing the sun position and sun path in Grasshopper.

So in result in Rhino window we have the sun-path and sun positions and also information about the radiation (Wh/m^2) and temperature(C°) (Figure 4.6).

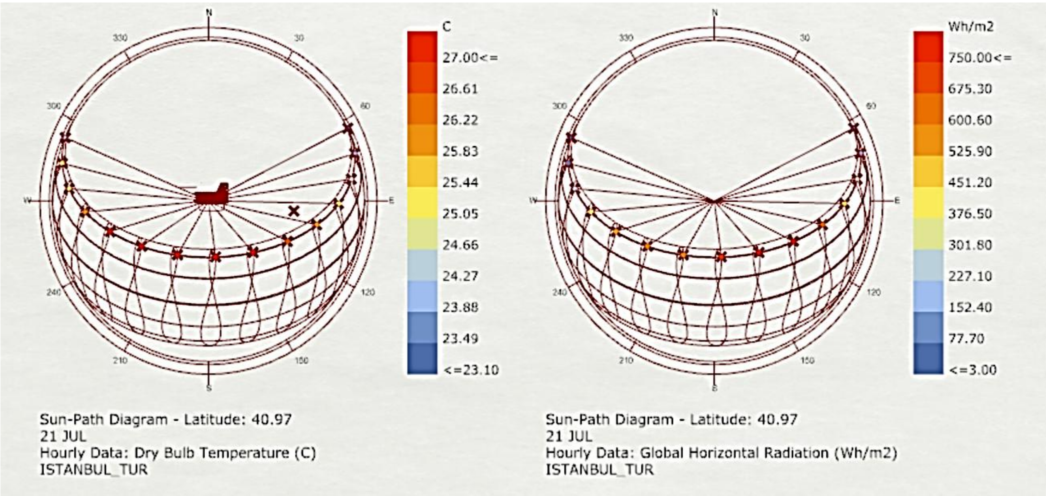

Figure 4.6 : sun path and sun position for 21 of July during 24 hours.

Since we gave series to the hour parameter for every single sun during the 24 hours the information about the sun position and the temperature is displaying (Figure 4.7).

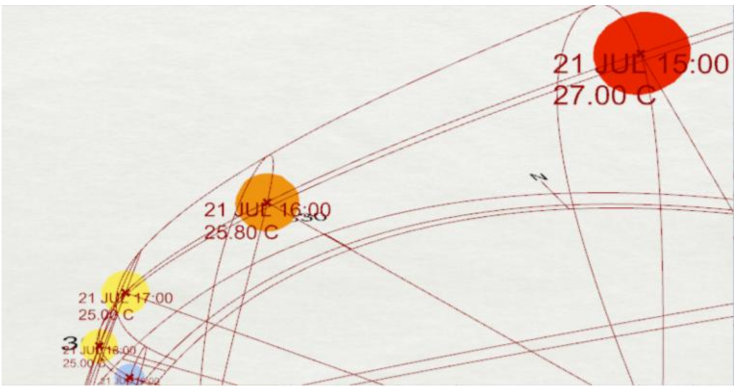

Figure 4.7 : Sun position during 24 hours.

For better visualization by connecting the center point of the sun and the sun position it gives sun vectors and by lofting them we can see the solar pan (Figure 4.8). The panels of the model are rotating towards the sun (attractor) based on their vectors from sun to each of the normal vector of the panels. Normal vector is the vector that is perpendicular to that surface. To further explain, the normal direction on each panel is programmed to reorient itself towards the sun sphere's centroid, thus making the entire panel change its surface to face the sun.

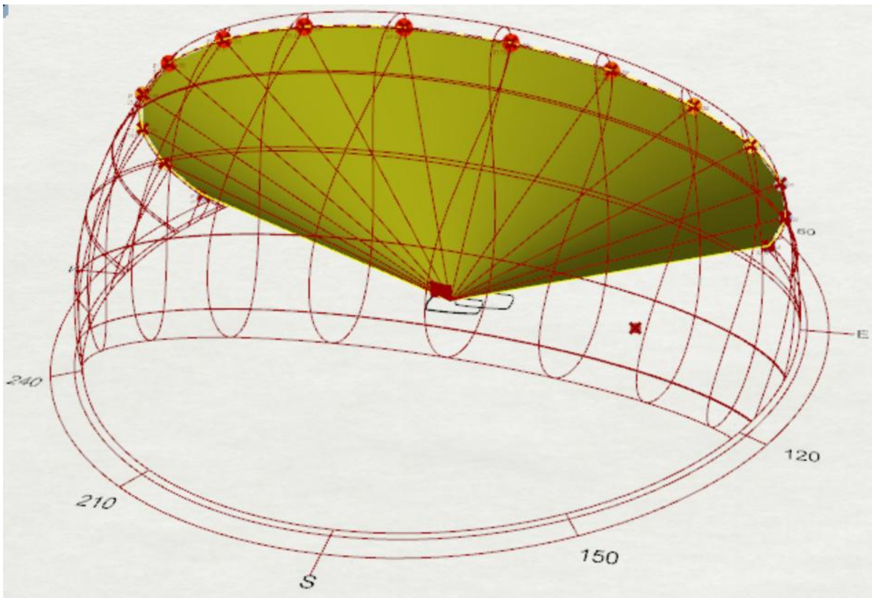

Figure 4.8 : Solar pan during 24 hours.

4.2.2 **Façade Model and Key Parameters**

Step 1: The first element to design is the main surface of the façade. The surface can be modeled in the Rhino or can be created from parametric edge lines in Grasshopper. We create it with Grasshopper. Since the undesired sun beams are in south part of the façade so we allocate the surface just for the south part of the façade (Figure 4.9). The proposed sun-tracking façade is designed as a second layer in front of the main existed façade.

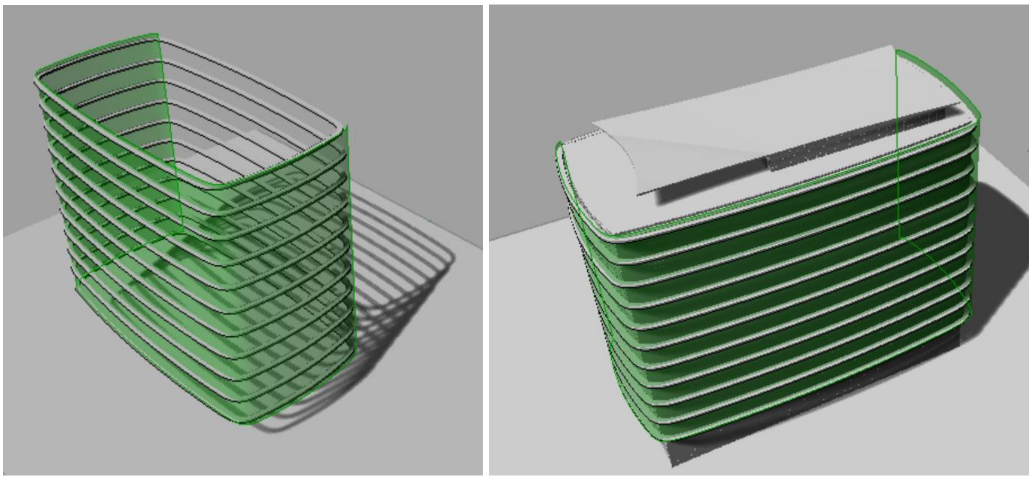

Figure 4.9 : The surface of the façade on the south side of the building.

Step 2: Once the surface is set, the model or the panels are mounted on it. The hexagonal panels were designed by the "Lunchbox" the plug-in for Grasshopper (Figure 4.10). The panels are rotating to protect the interior spaces from the undesired sun radiation.

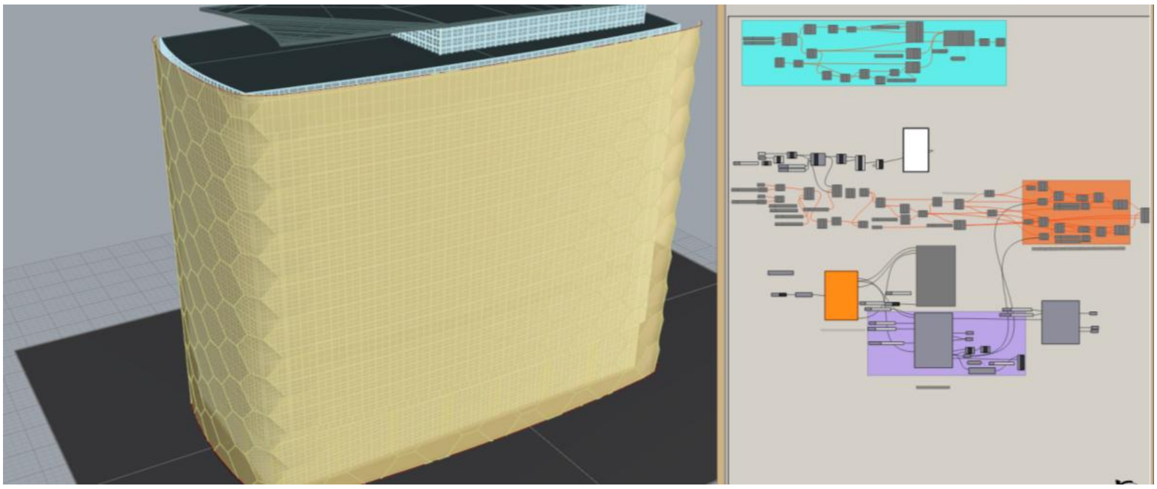

Figure 4.10 : Hexagonal surface created by Lunchbox.

The number of modules on the surface depends on the division parameters. They should be set based on the scale and dimension of the surface as well as the proportions of it. The numbers of Hexagons in X and Y axis is 25 * 37, so in total there are 925 hexagon cells (Figure 4.11).

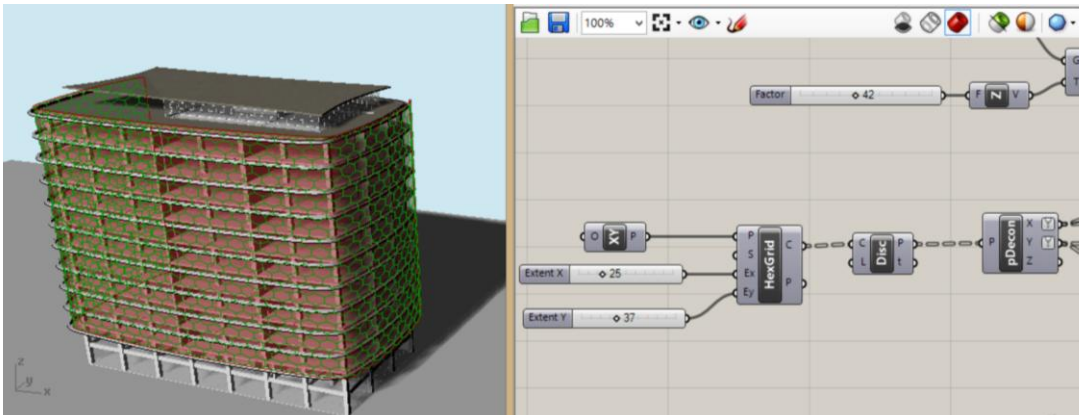

Figure 4.11 : Number of hexagon grids in X and Y axises.

Step 3: Each hexagon grid was scaled based on their center points to create the aluminium frame. With 'solid difference' component, the difference between main hexagons and scaled hexagons was found and the frames were created and by drawing a line between upper and lower grid vertices the hexagons were divided into two parts (Figure 4.12).

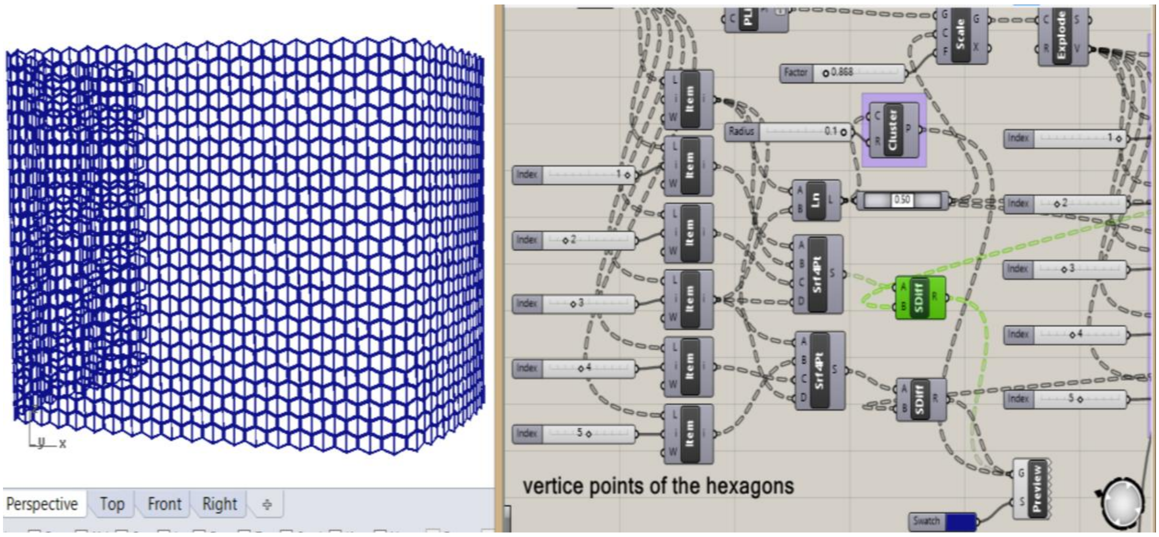

Figure 4.12 : Creating the frames by subtracting the main hexagons and the scaled ones.

Step 4: The hexagons were exploded to extraxt the grids and the grids' vertices were listed to create each panel from four points of them (Figure 4.13).

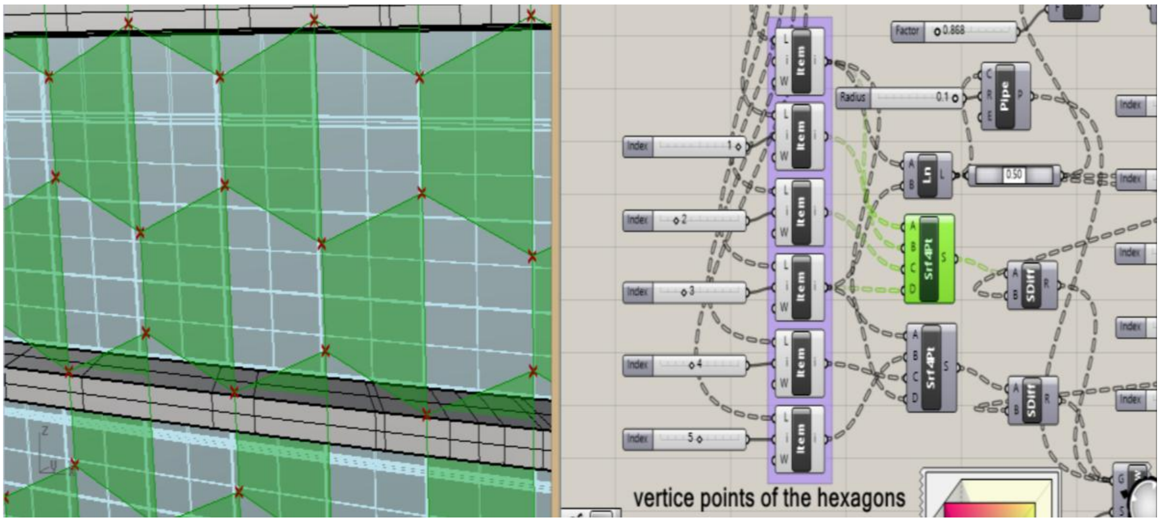

Figure 4.13 : Creating the panels from 4 vertices of hexagons.

Step 5: The two parts are connected with a steel pipe between them. Each of two divided cells are rotating based on the sun movements according to the vector between the normal vector of each cell and the vector from the sun that was produced by ladybug plug-in. (Figure 4.14).

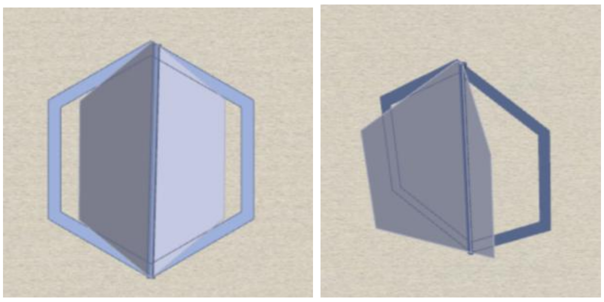

Figure 4.14 : The model of each panel.

Step 6: Last step was Fitting the panels to the curved surface that was a hard task and it was so time consuming to find the solution algorithm. For mounting the model onto the surface, the surface should be divided in desired U and V values and the module should be defined as a geometry object. The UV coordinates of the each hexagon vertices was the UV coordinates of the desired surface. Populating the curved host surface vari with computationaly self-adapting panels, so the parametric pattern was constructed.

The panels do have different rotation angles, and the reason is that, each one has a different surface normal that is different from the panel next to it, and that is based on each panel's surface. The general rotation angle is between 0° and +90° for left-side panels and 0° and -90° for right side panels (Figure4.15).

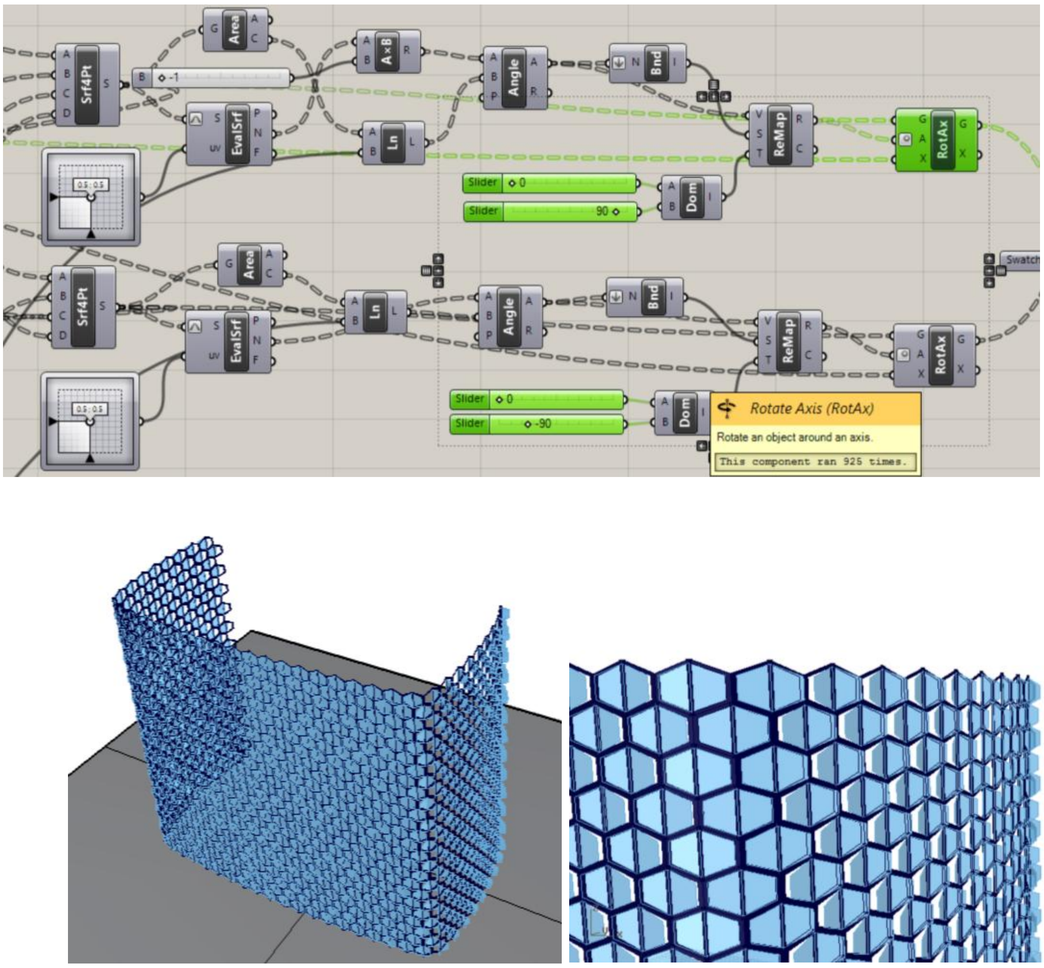

Figure 4.15 : Different rotation angles of the panels in different hours.

With changing the hour component the sun position is changing and the rotation of the panels change as well (Figure 4.16).

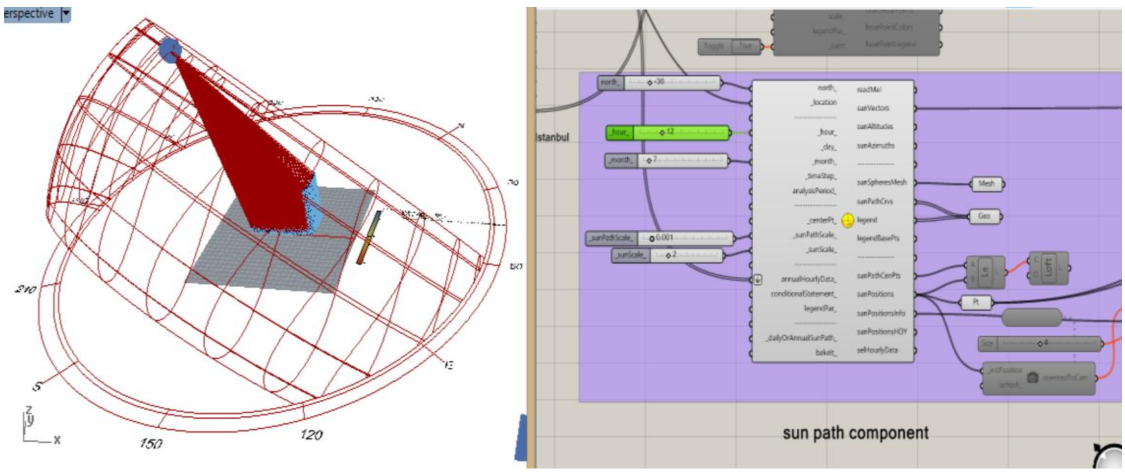

Figure 4.16 : Sun position at 12:00 pm and the vectors between sun and the normal vector of each panel.

The whole process of parametric design and algorithms is shown in figure 4.17.

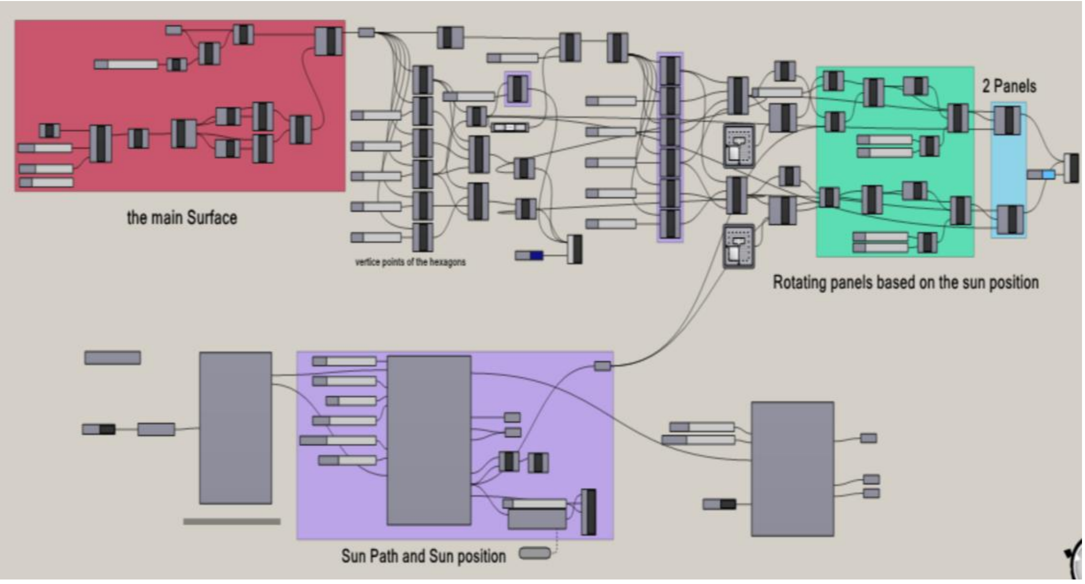

Figure 4.17 : The whole process of design on Grasshopper.

The surface here, included 925 hexagon panels and all of which are supported by the aluminium frame. The material of the panels are ETFE (Ethylen Tetra Floro Ethylen), which is a lightweight, transparent, recyclable and strong, fluorine-based plastic that can be used as an eco-friendly construction material. It weighs only 1% of similar sized glass panels. Even when the panles are closed it is possible to see through it, so it does not make dark the interior spaces.

For the structure part the panels are rotating based on their axis which is an aluminium pipe. This pipes could be joint to the aluminium frames which are on the current existed façade of building (Figure 4.18).

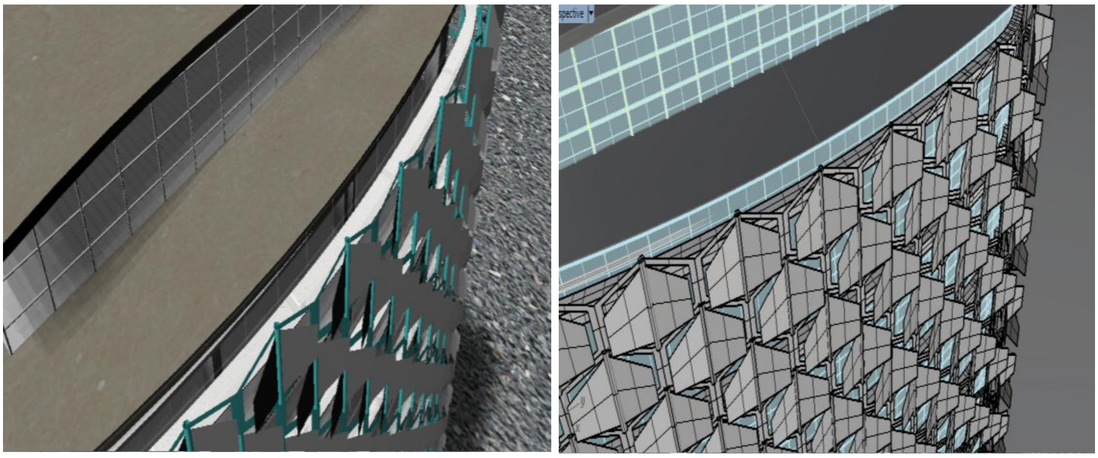

Figure 4.18 : The joint part of the frames and the existed farme of the building.

4.3 Day-lighting Analysis Using DIVA

In architecture simulation is defined as digital tool to foretell the environmental and structural performance of the building, therefore it has a significant role in the performance-based design.

The DIVA (Design Iterate Validate Adapt) is a plugin for Rhinoceros and Grasshopper, which allows the modeling, simulation and optimization in one setting. It works with Daysim and Radiance in same interface. Grasshopper allows the designer to simulate the building envelope and directly connect the generative model with the DIVA simulation in a way that when a parameter in the parametric model is changed, it effected on the whole simulation outcome. DIVA for Grasshopper has contained both (Daylight Analysis) component which simulate daylight availability within the space and VIPER component which calculates energy consumption. This technique permits the quick visualization of daylight and energy consequences from an architectural model where users can easily test several design alternatives for daylight and energy performance without manually exporting to multiple software (Jakubiec & Reinhart, 2011).The DIVA version used in the algorithm is version 3.0.0.6.

First we simulate the 3-D model of the ARI-3 building in Revit and separating the geometry into its different layers (Floor, walls, glazing parts, ceiling, etc.) (Figure 4.19).

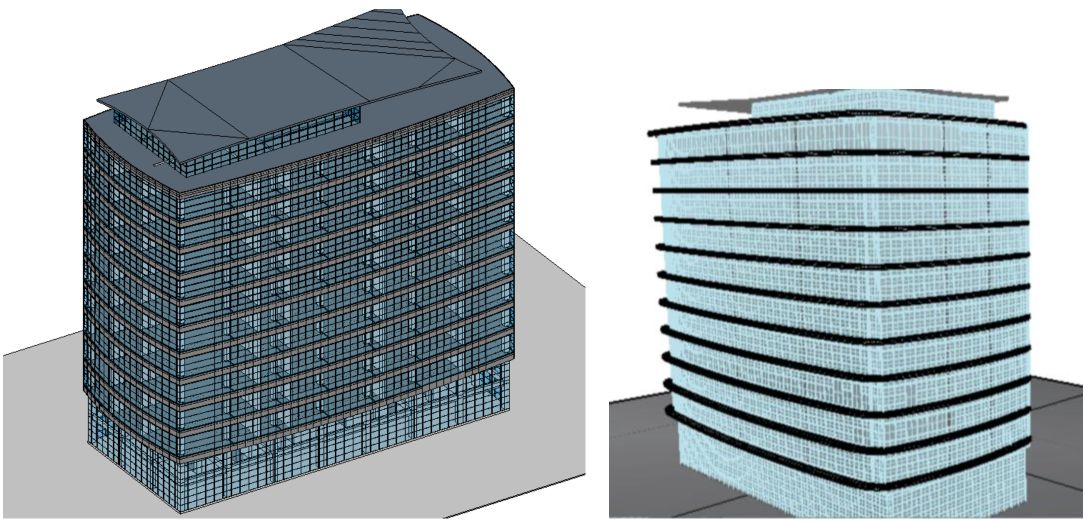

Figure 4.19 : The 3-D model of ARI3 building produced with Revit.

4.3.1 **DIVA Lighting Analysis for the Current condition of building**

DIVA for Rhino has a user-friendly interface, which one uses to choose the type of lighting test, sky condition, solar date and time, and desired illuminance range.

To run the analysis in DIVA/Rhino, four parameters should assigned; the location of the project, the analysis nodes on the desired plane, the materials of the elements and the type of analysis (Figure 4.20). Within the context of this study, the “lighting test” was set to “illuminance values,” for the calculation of illuminance nodes evenly distributed over the working plane.

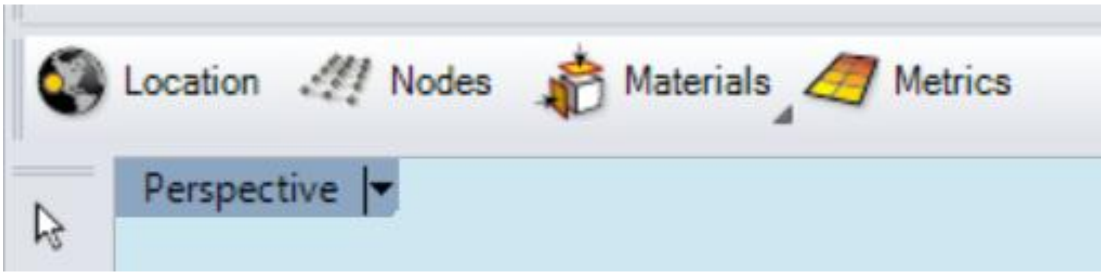

Figure 4.20 : DIVA simulation components in Rhino interface.

The sky condition was set to either “sunny clear sky with sun”. Solar dates and times used in the study were July 21st at 09:00, 12:00, 15:00 and 18:00. The range of desired illuminance was set to 300-1500 lux, according to the IES recommended range for office spaces. Any value smaller than 300 lux or greater than 1500 lux was highlighted in the simulation results in the form of a percentage.

The last floor (12th floor) was set for the analysis. The chosen space was assumed to have a 6 mm double glazed window that is 3.60m wide and 1.80m height. To separate the daylighting with artificial lighting, all the lamps were assumed as off during the measurement. To obtain the daylighting illuminance distribution in the whole indoor space accurately, the measurement grid points is 6910 in total.

Step 1: To run the analysis in Rhino, first we should set the location file, which is an “.epw” file of the Istanbul.

Step2: We setup the nodes of analysis and select the desired floor surface. For this analysis the last floor of the building is selected. İt contained 6910 measuring points (Figure 4.21).

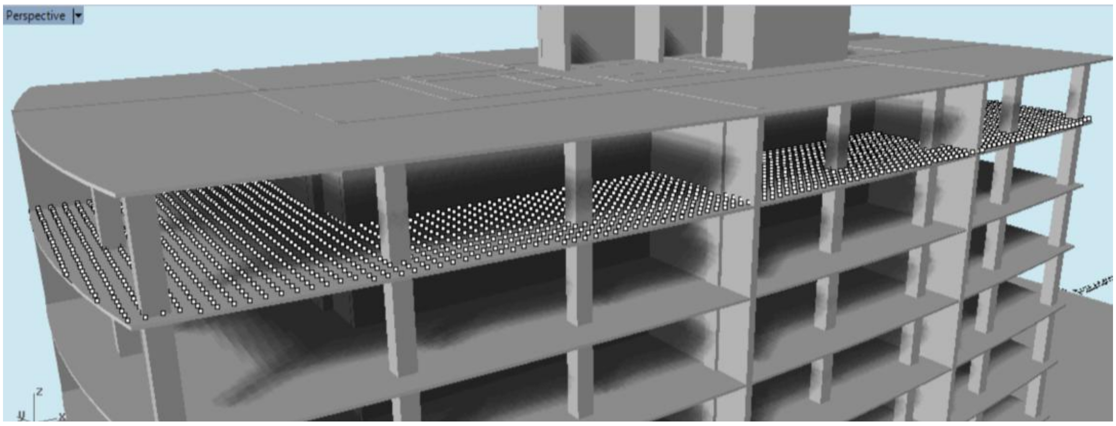

Figure 4.21 : Analysis nodes on the last floor.

Step3: Next step is the assigning of the materials to the entire objects of the model (Figure 4.22).

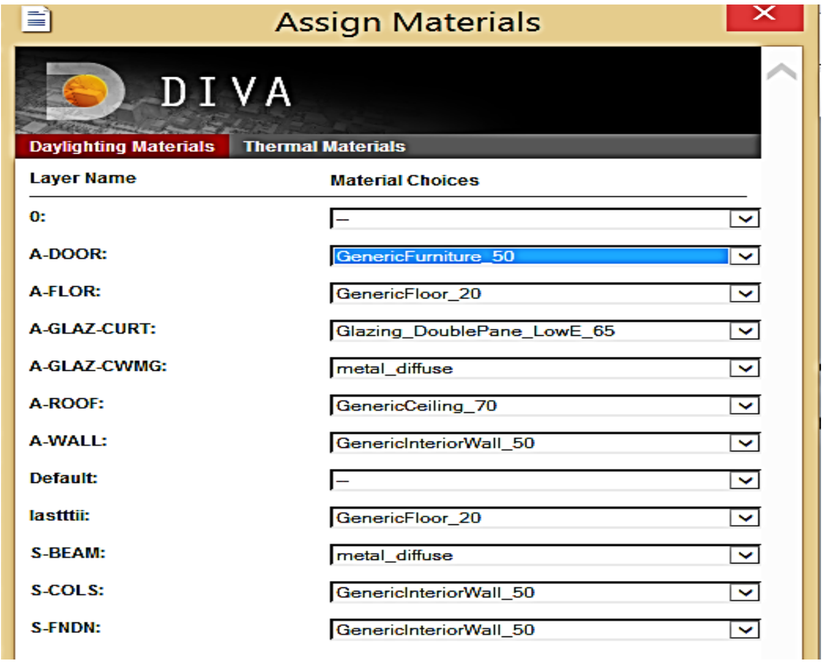

Figure 4.22 : DIVA assigning material for each element of the building.

Step 4: At the end we select the sky condition and date and time of the wanted analysis. For the sky condition the 'clear sky with sun' and the field measurement was conducted on July, 21, at 12:00, 13:00, 15:00 and 18:00 (Figure 4.23).

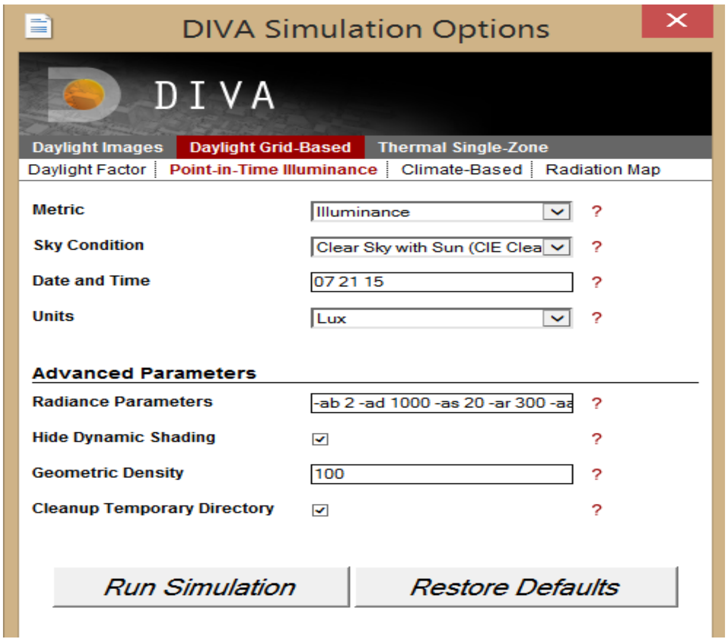

Figure 4.23 : Type of the analyse, sky condition, date and time of the desired analyse.

Then we run the simulation after some minutes it asked to define the minimum and maximum luminance that 300 to 1500 lux was assigned (Figure 4.24).

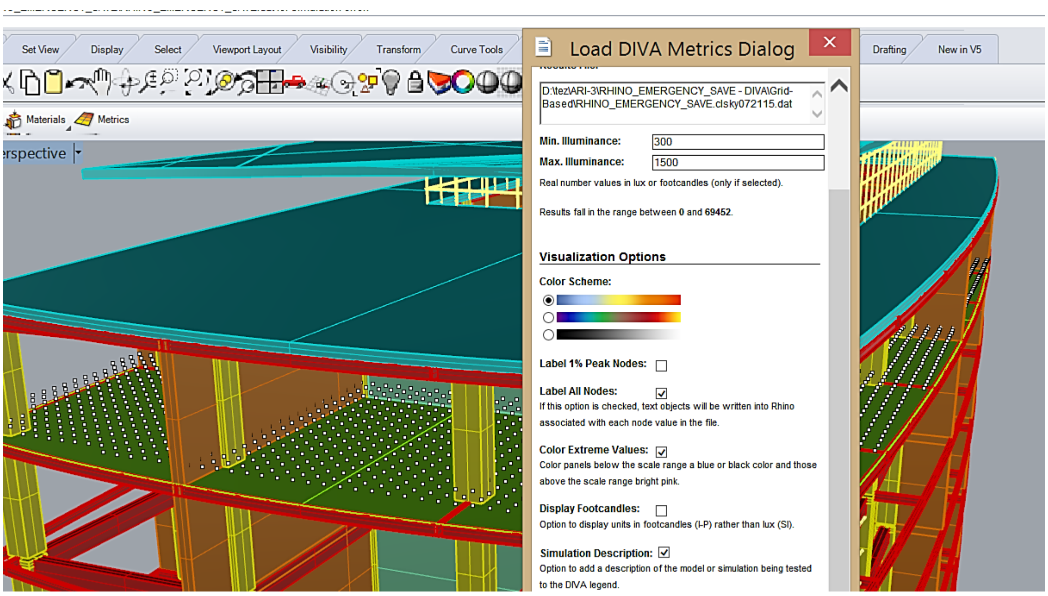

Figure 4.24 : Minimum and maximum illuminance level.

The analysis results are displayed on the chosen floor surface and each node is presenting the amount of lux that it gets (Figure 4.25-28).

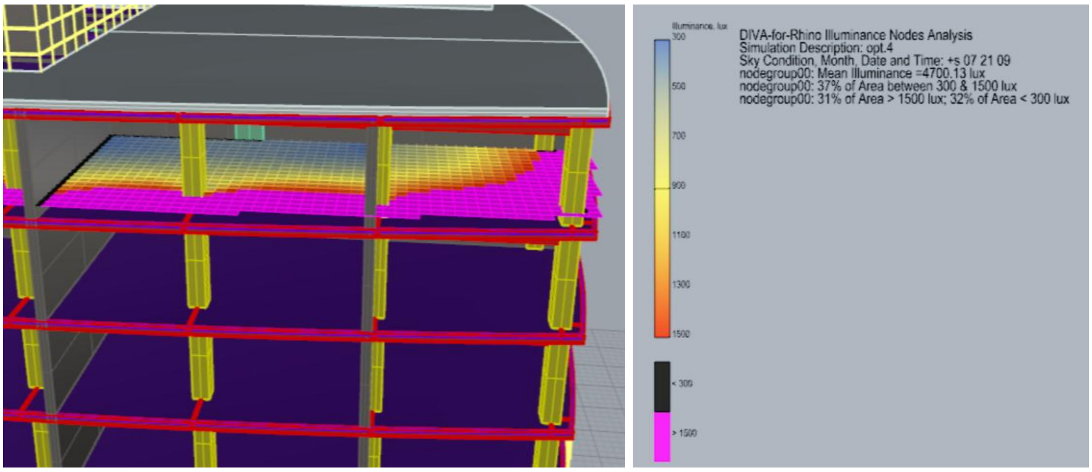

Figure 4.25 : The analysis result of the luminance levels for 21st of July at 09:00.

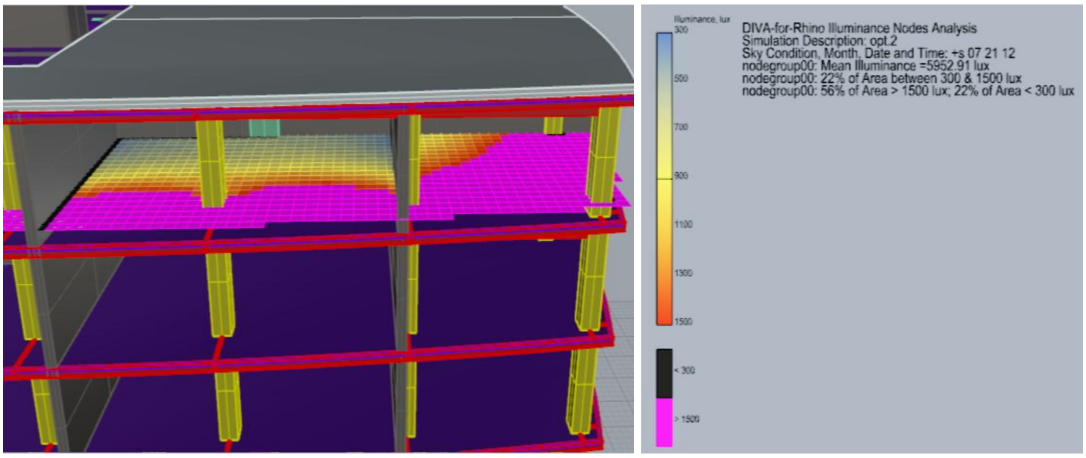

Figure 4.26 : The analysis result of the luminance levels for 21st of July at12:00.

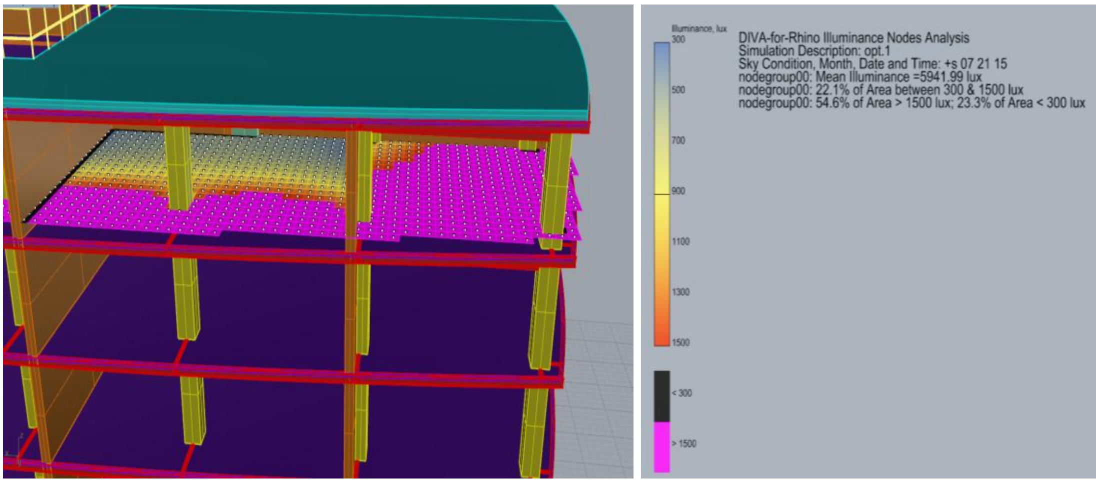

Figure 4.27 : The analysis result of the luminance levels for 21st of July at15:00.

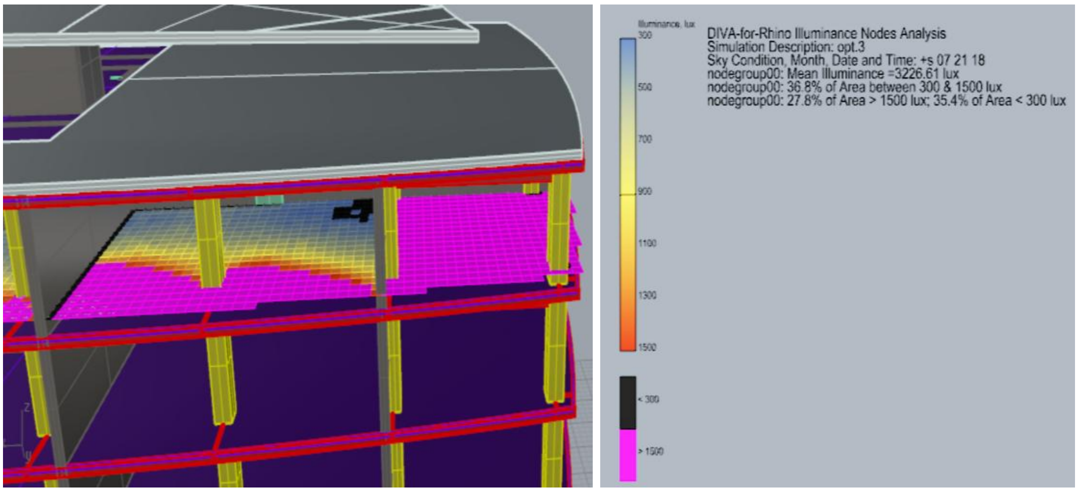

Figure 4.28 : The analysis result of the luminance levels for 21st of July at18:00.

With DIVA we also have possibility to analyze Daylight Autonomy. Daylight Autonomy is the percent of occupied times of the year for which the minimum illuminance requirement is met by daylight alone. For this analyse the target illuminace was set to 500lux. The results of this analyses is shown in figure 4.29 and 4.30.

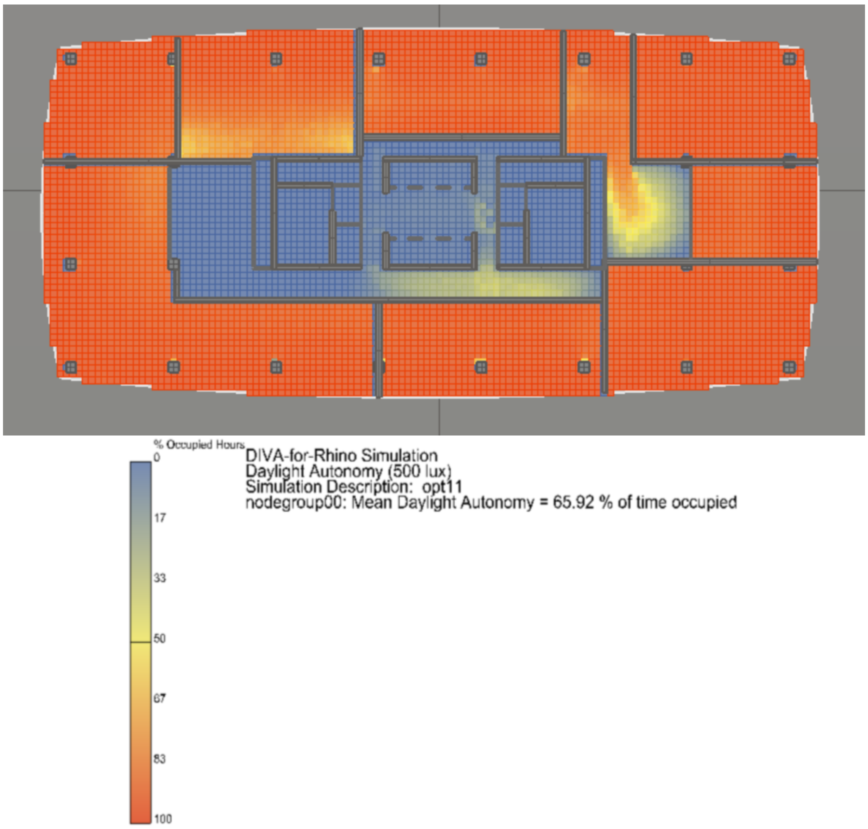

Figure 4.29 : Daylight Autonomy Analysis.

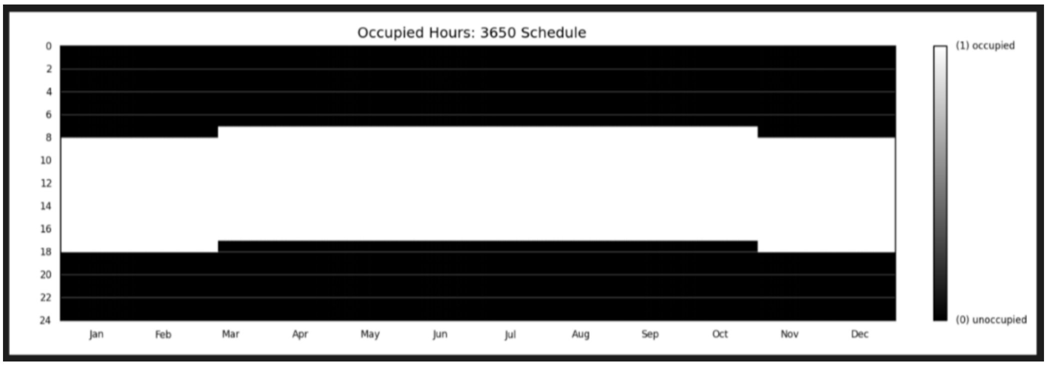

Figure 4.30 : Daylight Autonomy Analysis Table based on Month and Hour.

4.3.2 **Analysis Results:**

Daylight area is 70% of the floor. These informations are by Daysim simulation report:

Daylight Factor (DF) Analysis: 70% of all illuminance sensors have a daylight factor of 2% or higher.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 66% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 67% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 71% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 53% for active occupant behavior.

Useful Daylight Illuminance (UDI): The percentage of the space with a $UDI_{<100-2000lux}$ larger than 50% is 23% for active occupant behavior.

The total annual hours of occupancy at the work place are 3650.

Time / Percent	9:00 AM	12:00 PM	15:00 PM	18:00 PM
Mean luminance	4700 lux	5952 lux	1941 lux	3226 lux
Nodes between 300& 1500 lux	37	22	22	36
Nodes higher than 1500 lux	31	56	54.6	27.8
Daylight Autonomy	60			

Figure 4.31 : Analysis results before implementing the facade.

4.3.3 **DIVA Lighting Analysis with Considering the Parametric Facade**

For analyzing the building after adding the designed facade, first the designed panels and the frames in Grasshopper are 'baked' to Rhino model. Since the analyses are in four time zones (9:00, 12:00, 15:00, 18:00), each time we change the 'hour' parameter of 'sun position' in Ladybug and then bake the geometries to the Rhino model.

In Rhino like the previous steps we assign the location file, the grid nodes which the analyses are observed, the material of each objects and specifying the type of analysis.

For the frames, aluminium material and for the panels semi-translucent ETFE was assigned.

The analysis type is illuminance nodes and illuminance level was set to 300 to 1500lux. The analysis results are displayed on the chosen floor surface and each node is presenting the amount of lux that it gets (Figure 4.31-34).

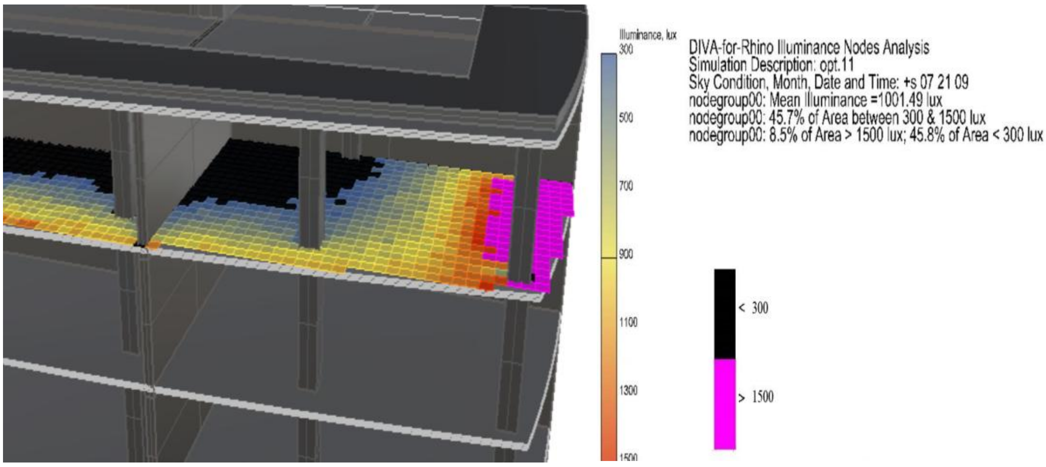

Figure 4.32 : The analysis result of the luminance levels after adding the parametric facade for 21st of July at 09:00.

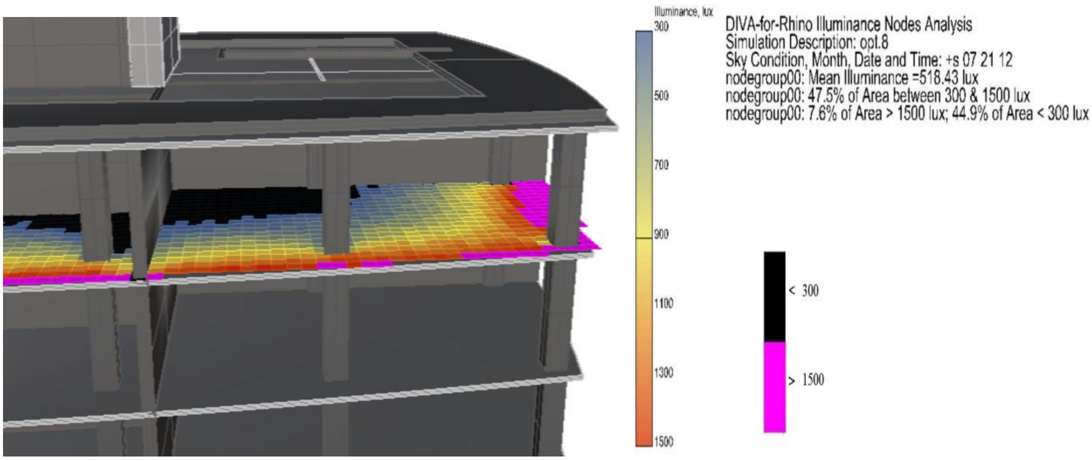

Figure 4.33 : The analysis result of the luminance levels after adding the parametric facade for 21st of July at 12:00.

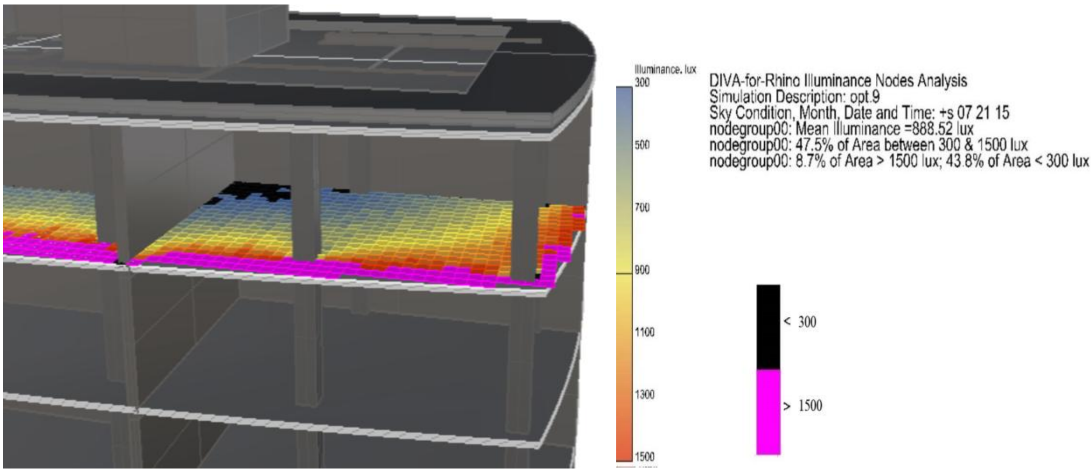

Figure 4.34 : The analysis result of the luminance levels after adding the parametric facade for 21st of July at 15:00.

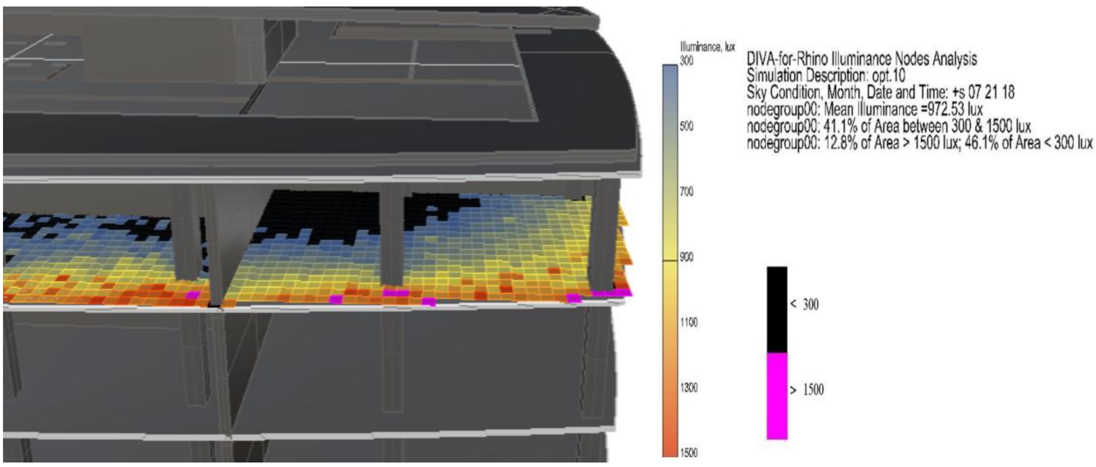

Figure 4.35 : The analysis result of the luminance levels after adding the parametric facade for 21st of July at 18:00.

With zooming into the nodes we can observe the illuminance value of each node (Figure 4.35).

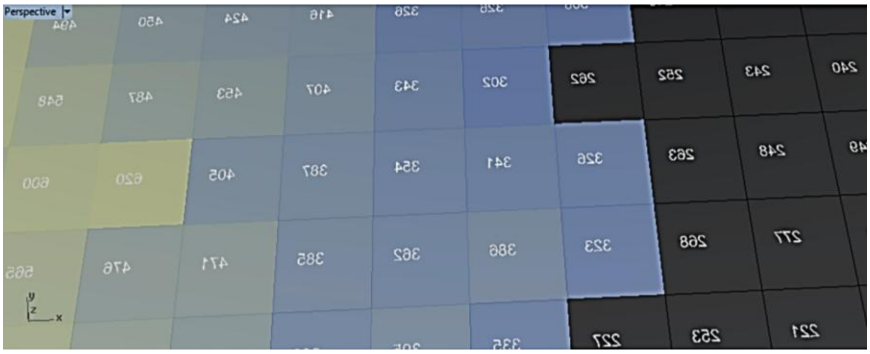

Figure 4.36 : Illuminance value of each node.

Daylight Autonomy analysis was also done for this case so see the percentage of annual daytime hours that a given point in a space is above a specified illumination level. Target illuminance was set to 500 (Figure 4.36-37).

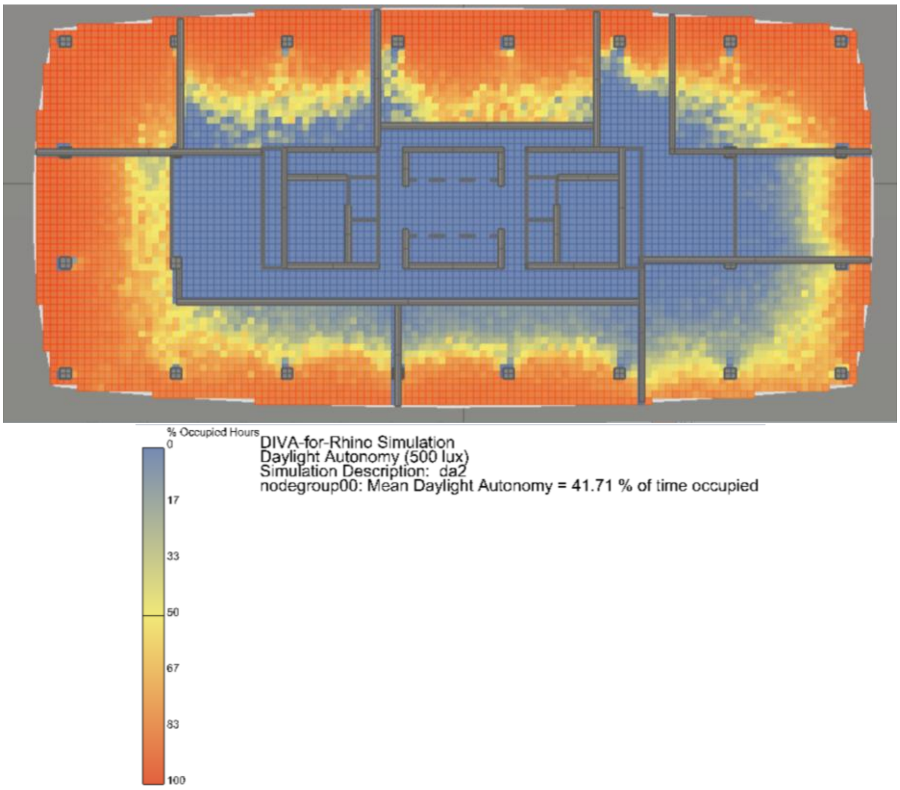

Figure 4.37 : Daylight Autonomy analysis result.

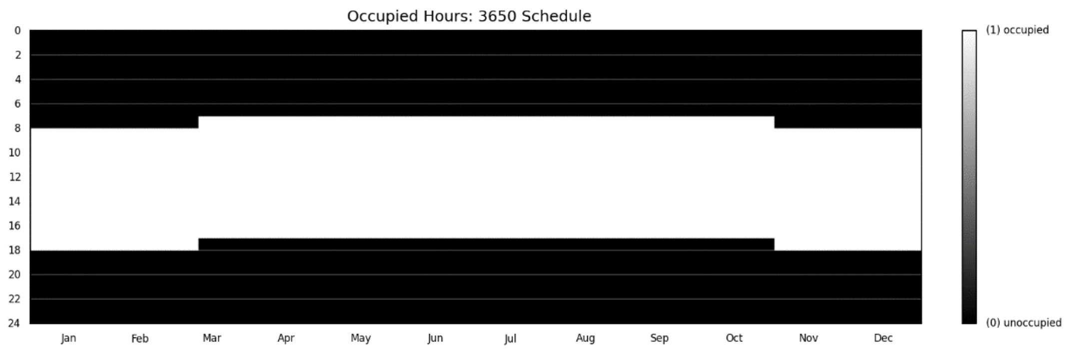

Figure 4.38 : Daylight Autonomy Analysis Table based on Month and Hour.

4.3.4 **Analysis Results with considering the parametric façade:**

Daylight area is 46% of the floor. These informations are by the Daysim simulation report, by considering that there is no electric lighting system specified for the scene:

Daylight Factor (DF) Analysis: 43% of all illuminance sensors have a daylight factor of 2% or higher.

Daylight Autonomy (DA) Analysis: The mean daylight autonomy is 42% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% is 46% for active occupant behavior.

Continuous Daylight Autonomy (DA) Analysis: The mean continuous daylight autonomy is 54% for active occupant behavior. The percentage of sensors with a DA_MAX > 5% is 15% for active occupant behavior

Useful Daylight Illuminance (UDI): The percentage of the space with a $UDI_{<100\text{-}2000lux}$ larger than 50% is 57% for active occupant behavior.

Time / Percent	9:00 AM	12:00 PM	15:00 PM	18:00 PM
Mean luminance	1001 lux	518 lux	888 lux	972 lux
Nodes between 300& 1500 lux	45	47.6	47	41
Nodes higher than 1500 lux	8.5	7.6	8.7	12
Daylight Autonomy	41			

Figure 4.39 : Analysis results after implementing the facade.

5. METHODOLOGY

5.1 States of Selected Program

Sketch-up, 3dsMax, Maya, etc. are the commonly used modeling programs among architects. Lately Rhinoceros has gained popularity since it has powerful modeling capability, especially for complex geometric shapes. In addition, Rhinoceros provides an effective user development platform called Grasshopper, thus enabling architects to customize for some complex projects with special needs.

Technique of performance-driven architectural design based on Rhinoceros/Grasshopper is valuable because:

•Performance-driven architectural design, while emphasizing on performance optimization, must simultaneously consider space and shape, two of the major design considerations that architects will never neglect. Rhinoceros/Grasshopper is such a program.

•The powerful modeling capability of Rhinoceros/Grasshopper makes it an adaptable platform for performance-driven design since it can handle various conceptual designs from linear to non-linear and from simple to complex.

For these reasons, the selected program is Rhinoceros/Grasshopper as the modeling program to study the performance-driven design technique.

Lighting analysis is done with DIVA, a plug-in for both Rhino and Grasshopper. It works together with Daysim and Radiance. DIVA is developed by Christoph Reinhart, J. Alstan Jakubiec, Kera Lagios, Jeff Niemasz and Jon Sargent.

5.2 Framework of the Design Process

As mentioned before in this thesis the aim is to design a performative, responsive façade, using parametric modeling tools in such a way that it responds to the sun exposures, while entering the adequate daylight penetrartion into the sapce, blocking the undesired sun beam. There are lots of performance criteria which can be considered during the design of the facade. Figure 5.1 presented some of the expected performance criteria for the facade designing.

Performance criteria should require demand and need of the Human. Human needs and demands refer to the human perception of complex factors, and the formulation of architectural requirements. But architectural performance does not depend only on the human demands, but is also directly related to its natural and surrounding environment. Environmental conditions have a significant role on the accomplishment of the architectural requirements, and need to be taken into account when assessing architectural performance.

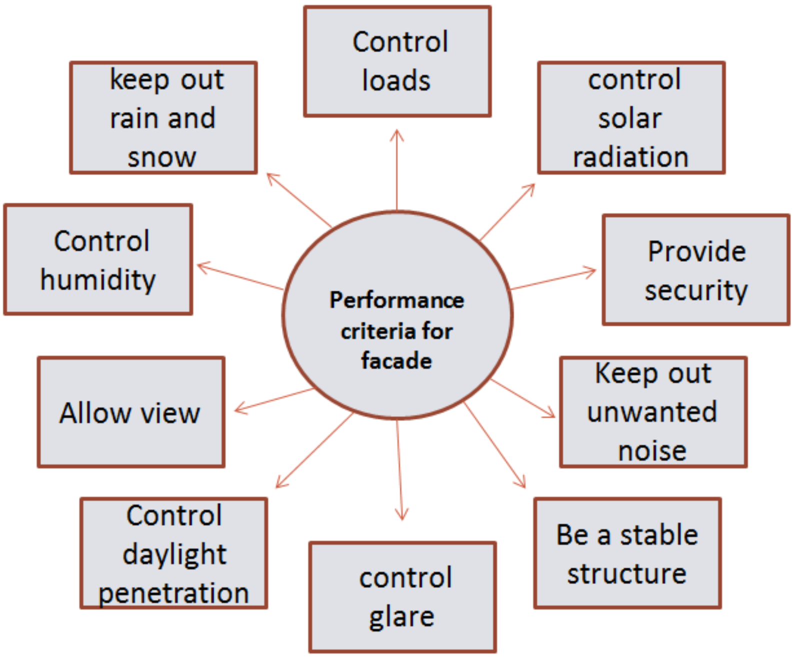

Figure 5.1 : Expected performance criteria for the façade.

Changing environmental factors affect the performance of the building: daily and seasonal climatic conditions impact daylight and thermal performance.

In this thesis just the lighting criteria is considered as a performance measure.

The general framework of the performative facade design process:

1) Simulate the existing building in the Revit program.

2) Import the 3D model from Revit to Rhino to do the lighting analysis.

3) Doing lighting analysis with DIVA on Rhino for the model.

4) Creating the sun path and sun exposures of Istanbul with Ladybug.

5) Designing the Façade which respond to the sun exposures with Grasshopper.

5) lighting analysis with DIVA after covering the existed building with the new performative facade.

6) Compare 2 analysis results with each other and get the conclusion.

The case study is a office buidling located in the city of Istanbul, Turkey. Simulation was conducted using the DIVA v3.0.0.6, a plug-in for both Rhino and Grasshopper. It was used to interface Radiance and Daysim for simulation and illuminance computation (Reinhart et al., 2011). Simulation was conducted for 21 of July at four time zones; 9am, 12pm, 15pm and 18pm, a typical working time in Turkey that is usually starts from 9am to 18pm. The last floor (12th floor) of the buidling was chosen as the analysis surface. The choosen space was assumed to have a 6 mm double glazed window that is 3.60m wide and 1.80m high. The reference plane on which daylight performance was simulated contained 6910 measuring points. Measurement that were in he range of 300-1500 Lux were cnsidered ‘adequate’. At first, the base case was modeled and its illuminance values for specific date and time was observed and analyzed with DIVA plug-in for Rhino. Afterwards, the parametric façade which was designed in Grasshopper was added as second façade with 1 meter distance of existing one and again we did the same analyses to observe the difference and compare the results.

The Daysim results presents three evaluation criterias:

1. “Daylit areas”, which are the spaces that receive at least half the time sufficient daylight.
2. “Daylight Factor:”, that is a ratio that represents the amount of illumination available indoors relative to the illumination present outdoors at the same time under overcast skies.
3. “Daylight Autonomy”, that is a percentage of annual daytime hours that a given point in a space is above a specified illumination level.

Figure 5.2 stated the optimization methodology of the simulation process.

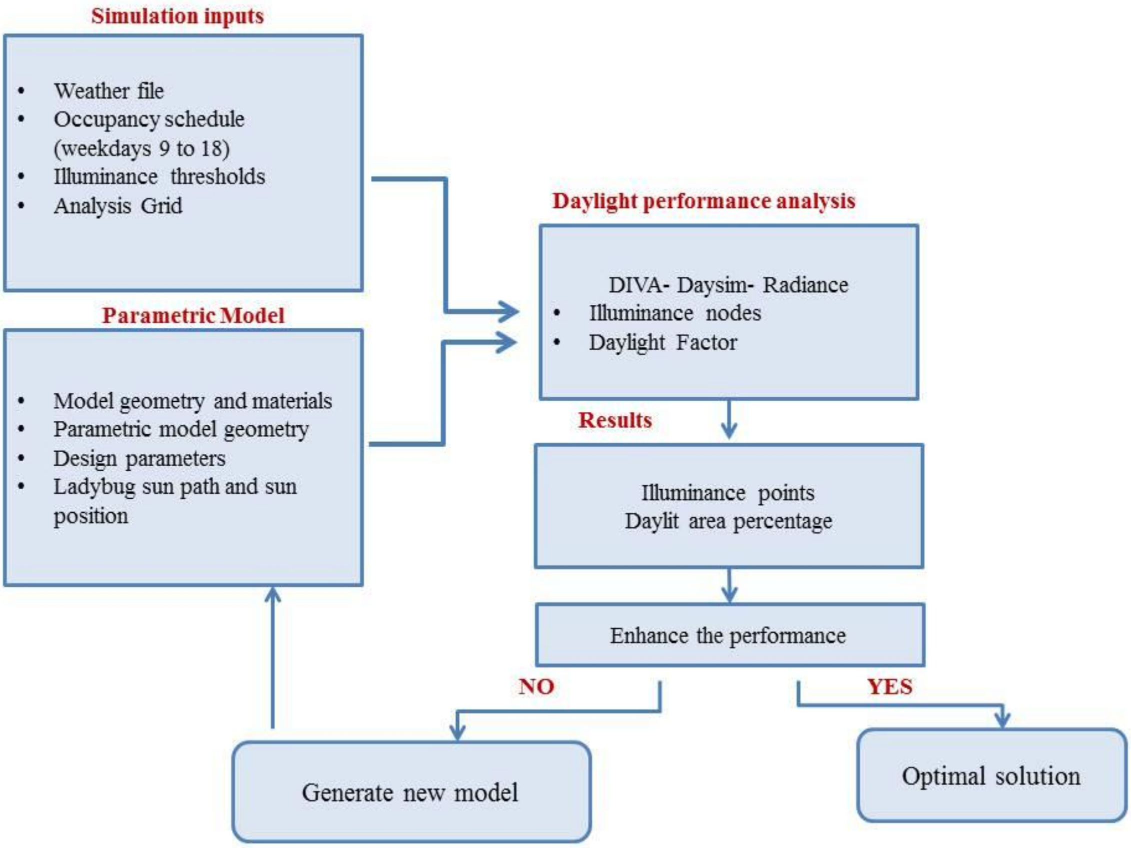

Figure 5.2 : Optimization Methodology Diagram.

If with performance simulations we get the desired result so it is the optimal design, if not we should consider and adjust other conceptual design. Figure 5.3 shows a diagram of the performance-based design workflow.

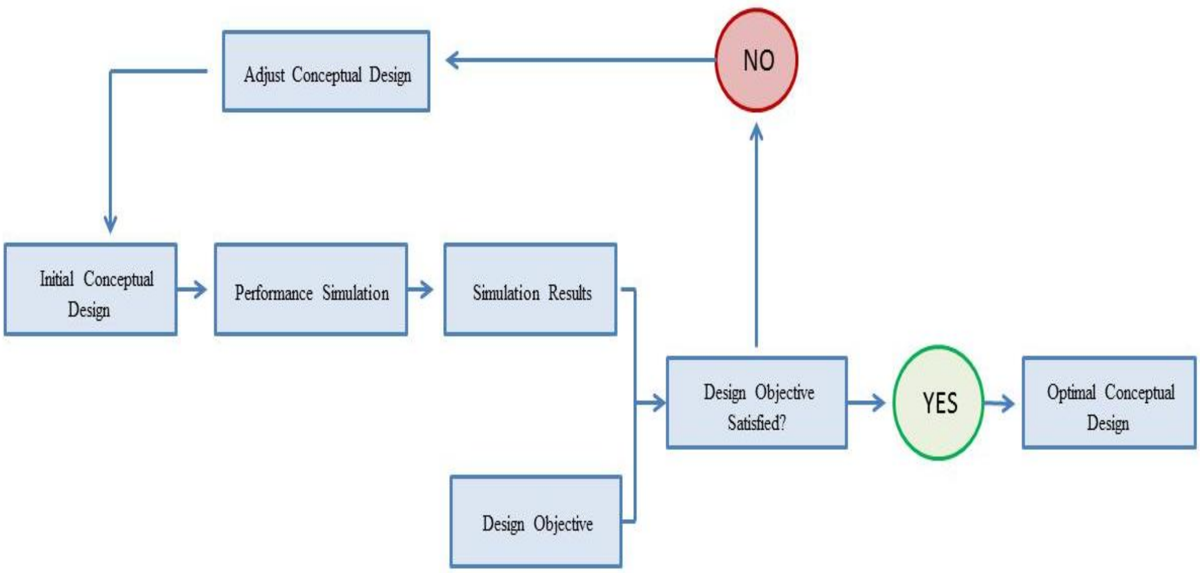

Figure 5.3 : The workflow of Performance Driven Conceptual Design.

6. CONCLUSION AND RECOMMENDATION

With the development of various digital tools, designers are able to deal with problems that are more complex. It allowed dealing with problems one at a time. Computer calculations are generally fast and reliable. Computers are capable of performing continuous calculations with minimized flaws. Using computers usually reduces the man-hours spent on a project and makes it more cost effective**.** With the aid of computer simulation, it is possible to understand the interaction between design features, climate, mechanical and electrical system and occupants.

In the early design stage, the building environmental simulations have significant role in the architectural design process, to determine the best building performances. To implicate these simulations, an advanced simulation software packages required. However, these simulation engines are based on trial and error approach in which this made the simulation to be scenario based process. Consequently, the need have been arisen to develop a computational tool which capable to create design alternatives automatically.

Since the facade is a significant contribution to the energy budget and also through an efficient design of the facades we can improve the indoor comfort and reduce the amount of air conditioning in summer, so focusing more on designing performative-adaptive facade which can respond to the environmental conditions is important.

Parametric design opens up a novel set of opportunities. It enables architects to study causes of problems and their relationships to, and dependencies on, other elements directly. Grasshopper for Rhino, an advanced parametric modeling tool, allows changing the entire model without redrawing any part of it. The geometry in Grasshopper is created with dragging and dropping components, which these components represent data, function and relationship between the geometries. With the DIVA plug-in for Rhino and Grasshopper we can simulate and analyze the model for the lighting performance. In this study three different design techniques were connected together. The Revit program has been chosen for simulating the existed building. Rhino/Grasshopper interface has been chosen for designing the desired performative façade. The DIVA is chosen for daylighting analysis. DIVA is chosen because it is working user friendly with Grasshopper and Rhino. The use of these tools has provided good guidance for architects in the conceptual design, they are able to optimize any element of the building. However these tools are relatively new and have some limitations. In some stages of design or analysis they are time-consuming processes.

The aim of this thesis was to design a performative façade for the existed office building of ARI3 in Istanbul, Turkey, which has glazing facade, to prevent the direct beam of sun and glare during the work time to make a pleesent working space for the occupants and workers. The study also attempted to explore parametric design tools in order to determine the advantages of parametric design in studying real-time changes in building design, the significance of manufacturing tools and technologies in parametric design, the necessity of functionality and efficiency in complex form generation, and the effects of environmental data on building envelopes. Since daylighting is a crucial asset in office spaces we take into account just the lighting parameter as it increases the productivity of workers, enhances their morale, and maintains their health.

The facade was designed by using the parametric method. The model was conducting 925 hexagon panels which are rotating in response to sun position to stop the direct beam. Panales' material is ETFE which is light and even if the panels are closed you can see through it. The screen is supported in an independent frame sited 1 meter outside of the existed facade. Panels are programmed to respond to the movement of sun that are controlled via the building management system. Next step was analyzing the building for the illminance level with DIVA program after and before the implementation of the designed adaptive facade to compare the results. The best illuminance level for office buidlings is between 300 and 1500 lux and achieving to these levels is optimal and adequate.

The analyses were done in four time zones for 21st of July. Average daylighting illuminance during the four measurement periods (9:00am, 12:00pm, 15:00pm and 18:00pm), before impelemnting the facade were 4700, 5952, 1941 and 3226 Lux which are so high illuminance values for the office space. After implementing the adaptive façade the average daylighting illuminance for the same time zones were 1001, 518, 888 and 972 Lux which we can see the enhancement in the illuminance level that is completely optimal and proper for the office spaces. Percent of nodes which their illuminance levels were higher than 1500 Lux before implementing the façade in four measurement periods were 31%, 56%, 54% and 28%, which these percentage after implementing the façade were 8.5%, 7.6%, 8.7% and 12%, that there is a large difference difference. Therefore the parametric adaptive facade , that respond to the sun radiation has prevent the direct sun beam and also reduce the glare. The mean illuminance level with implementing the adaptive façade is between 300 and 1500 lux which is a proper and adequate illuminance level for the office spaces so this cause for less reliance on artificial lighting which also results in a reduction of CO_2 emissions.

With the use of parametric design it was possible to design a performative-responsive façade that was not easy possible with conventional CAD progrmms. Parametric modelling allows for easy editing the model in any stage of the design process. In parametric design it was possible to produce the exact sun path and sun position of the desired location and connect the sun position with each panels, so that they could respond to sun exposures. Designers have better dominance on the design with the established relationships between parameters in parametric design.

The use of parametric tools has provided a good guidance for the architects in the conceptual design process. However, these tools are still relatively new and it has limitations. One of the limitations is that analyzing that is very time-consuming process, and the performance of the process is based on the performance of the used computers.

For the future researches, it is possible to set photovoltaic material for the panels and do thermal analyse to calculate the total energy of the buidling.

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APPENDICES

APPENDIX A: Daysim schedule file

APPENDIX A

A part of Daysim schedule file (occupied hours: 3650)

month	day	hour	occupancy [0=absent...1=present]	
1	1	0.5	0	0
1	1	1.5	0	0
1	1	2.5	0	0
1	1	3.5	0	0
1	1	4.5	0	0
1	1	5.5	0	0
1	1	6.5	0	0
1	1	7.5	0	0
1	1	8.5	1	0
1	1	9.5	1	0
1	1	10.5	1	0
1	1	11.5	1	0
1	1	12.5	1	0
1	1	13.5	1	0
1	1	14.5	1	0
1	1	15.5	1	0
1	1	16.5	1	0
1	1	17.5	1	0
1	1	18.5	0	0
1	1	19.5	0	0
1	1	20.5	0	0
1	1	21.5	0	0
1	1	22.5	0	0
1	1	23.5	0	0
1	2	0.5	0	0
1	2	1.5	0	0
1	2	2.5	0	0
1	2	3.5	0	0
1	2	4.5	0	0
1	2	5.5	0	0
1	2	6.5	0	0
1	2	7.5	0	0
1	2	8.5	1	0
1	2	9.5	1	0
1	2	10.5	1	0
1	2	11.5	1	0
1	2	12.5	1	0
1	2	13.5	1	0
1	2	14.5	1	0
1	2	15.5	1	0
1	2	16.5	1	0
1	2	17.5	1	0
1	2	18.5	0	0
1	2	19.5	0	0
1	2	20.5	0	0
1	2	21.5	0	0
1	2	22.5	0	0

CURRICULUM VITAE

Name Surname: Delara Razzaghmanesh

Place and Date of Birth: Iran 13/08/1989

E-Mail: delara.rz@gmail.com

EDUCATION: Tabriz Azad University

B.Sc.: Architecture