Façade Optimization Through BIM Technology Based on LEED Assessment of Existing Building Energy

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ABSTRACT

Building sustainability in architecture has become a significant concern, especially for building energy since it is one of the most important aspects to be considered. In architecture, the sustainable building includes different areas such as daylight, airflow, ventilation, solar performance, etc. These areas have different effects regarding building sustainability, energy consumption, and human comfort, which have been considered recently. Daylight is the primary natural source that affects the building energy in terms of visual comfort. This lets the architects pay attention to the need for daylight consideration. Building façade is one of the most important considerations to enhance the daylight performance since it introduces the sunlight to the building interior. Regarding this, the research aims to test a method to enhance the building daylight performance regarding visual comfort by optimizing an existing building façade based on LEED criteria through BIM technology. In order to achieve that, the research explained the important data of daylight parallel to LEED daylight criteria in an office building in Jordan, which is in the climate zone of the middle east. In addition, the research focused on the BIM technology in different manners to help the architects connect all building drawing, data, and energy performance linked to each other to test and accurately produce different solutions.

Keywords: Façade Technology, BIM, Building Daylight, LEED Assessment, Façade Optimization

ÖZ

Mimaride yapı sürdürülebilirliği, özellikle bina enerjisi söz konusu olduğunda dikkate alınması gereken en önemli unsurlardan biridir. Mimaride sürdürülebilir yapı; Gün ışığı, binadaki havalandırma ve hava akışı, güneş enerjisi vb. gibi farklı alanları içerir. Bina üzerinde birçok etkisi olan, enerji tüketimi ve insan konforu son zamanlarda ele alınan başlıca etkilerdir. Gün ışığı, bina enerjisini farklı dönemlerde etkileyen birincil doğal kaynaktır ve bu da mimarların gün ışığı ihtiyacını mimari tasarımlarda dikkate almalarında büyük önem taşır. Bina cephesi, gün ışığı performansını arttırmak için, ışığın bina içerisine alınmasında en önemli unsurlardan biridir. Bununla ilgili olarak yapılan bu araştırmada, mevcut bir bina cephesi incelenip, BIM teknolojisi ile LEED kriterlerine göre optimize edilerek, görsel konfor açısından bina günışığı performansını artırmak amaçlanmaktadır. Bunu elde edebilmek için yapılan araştırmada, LEED gün ışığı kriterlerine paralel olarak, Ortadoğu ikliminde bulunan Ürdün'de bir ofis binasının cephesi incelenerek, gün ışığı verileri doğrultusunda bu bina cephesi üzerinde çalışma yapılmıştır. Bu bağlamda yapılan araştırmada, mimarların farklı çözümleri doğru bir şekilde test etmek ve üretmek için tüm mimari bina çizimlerini, buna bağlı verileri ve bina enerji performansını birbirine bağlamalarına yardımcı olmak için farklı yaklaşımlarla BIM teknolojisine odaklanıldı.

Anahtar Kelimeler: Cephe Teknolojisi, BIM, Bina Gün Işığı, LEED Değerlendirmesi, Cephe Optimizasyonu

To My Family and Loved Ones……

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I would like to extend my heartfelt gratitude to you all…

“We were born of light. The seasons are felt through light. We only know the world as it is evoked by light …… To me natural light is the only light, because it has mood – it provides a ground of common agreement for man – it puts us in touch with the eternal. Natural light is the only light that makes architecture architecture”

Louis I. Kahn

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

3D	Three-Dimensional
AEC	Architecture Engineering Construction
AGC	The Associated General Contractors of America
BIM	Building Information Modeling
CD/M2	Candle Per Square Meter
DA	Daylight Autonomy
DF	Daylight Factor
DGP	Daylight Glare Probability
FDD	Fault Detection and Diagnostics
GBA	Green Building Assessments
GBS	Green Building Studio
GUI	Graphical User Interfaces
HSA	Horizontal Shading Angle
IES	Illuminating Engineering Society
IES-VE	Integrated Environmental Solutions-Virtual Environment
IPD	Integrated Project Delivery
LEED	Leadership in Energy and Environmental Design
LUX	Unit of illuminance
NBIMS	The National Building Information Modeling Standards
PMV	Predicted Mean Vote
PPD	Percentage of Dissatisfied
PV	Photovoltaic
SDA	Spatial Daylight Autonomy

SI	International System of units
UDI	Useful Daylight Illuminance
VSA	Vertical Shading Angle

Chapter 1

INTRODUCTION

The architecture development has considered building sustainability as one of the significant aspects in building design due to the overloaded activities on the planet resources. To save the natural resources and the ecosystem, the architecture comes here to create an eco-friendly mass that shapes our districts, cities and countries (Williamson et al., 2003). Sustainable architecture considers many aspects to be achieved, such as material usage, renewable energy system, energy consumption and many other aspects. Each aspect depends on different working areas, such as building orientation, building façade, interior organization, etc. (Ander, 2003). The studies approved that building exterior has the maximum effects of building sustainability. The building energy highlights important aspects such as daylight, ventilation, air flow, and many other aspects that mainly affect interior space (Gupta et al., 2014).

For this reason, architects have started to pay attention to building energy. One of the main aspects to be considered is the building daylight performance due to the huge effect on thermal and visual comfort of the building. Therefore, architects need to pay greater attention to the factors to obtain a better building daylight performance during earlier design stages. The building façade design is the main factor that affects building daylight since it is the boundary between the natural exterior factors and the building interior (Villela, 2014).

Visual comfort is one of the main aims of daylight goals since it affects the human perception inside the building and reduces the artificial lighting usage inside the building to reduce the building energy consumption. These aspects are usually disappearing when it comes to real building applications for different reasons, mainly the lack of information to enhance façade daylight regarding visual comfort and lack of correct usage of technology, which may sort incorrect results. This gap lets the research focus on daylight façade performance by sorting out the daylight importance, factors, metrics, standards and problems. Besides building façade daylighting strategies regarding visual comfort and focusing on appropriate technology usage, Building Information Modeling (BIM) will be employed correctly by understanding the technology with their usages, importance, risks, and benefits and methods in architecture and daylight façade enhancement.

Nowadays, architecture development is trying to solve the existing building problems regarding building daylight aspects, optimizing the existing building façade to match the international standard (Council, 2009). The Middle East has a different climate ranging from hot sun to moderate climate where the research aims to optimize an office building façade there. In addition, the region has started to consider an international American building sustainable standard called leadership in energy and environmental design (LEED). The research will be applied to an existing office building in Jordan to enhance the daylight façade performance through BIM technology based on LEED criteria by creating a method to compare different studied solutions through BIM simulation.

1.1 Problem Statement

Sustainability has become important in architecture day by day since it has different aspects of building sustainability. Daylight is one of these aspects which can affect the building sustainability through the façade, which allows many architects to consider it during earlier design stages. But when it comes to a real building application, the daylight consideration starts to disappear due to different reasons or incorrect applications, leading to many existing buildings that need to be optimized due to the natural energy. Away from the building construction cost, two main architectural reasons affect the problem: the lack of daylight information and international standards and the lack of correct usage of appropriate technology. This gab will help the research assess the existing buildings façade regarding certified international standards, which leads to creating different optimized solutions for an existing building façade or in a new building design by a developed technology.

1.2 Research Aim and Objectives

The research aims to assess and analyze the building façade regarding daylight visual comfort standards and LEED criteria through BIM technology to optimize the building façade. The research will produce a method and technique based on BIM technology to manipulate different façade solutions and test them to develop the best solution that can enhance the daylight performance through the building façade. In addition, the research focus on enhancing the usage of BIM technology in architecture in a correct manner, which allows the architects to have all drawings and data linked to each other to manipulate the façade solutions to achieve accurate results that may help considered in their early design stages or for existing building enhancement.

1.3 Research Methodology

The research is based on a mixed type of quantitative and qualitative research. The approach of research study is divided into three methods: a descriptive method by desk work studies to collect appropriate data and standards from different resources. The second one is the observation method from the field study. To produce qualitative research based on numerical outcomes. A simulation method will be applied to investigate the building façade daylight performance of a selected case study using BIM technology regarding daylight LEED criteria. Later on, these outcomes will lead to optimizing the existing façade by manipulating the variables of different simulations to produce an accurate quantitative analysis regarding daylight which will allow the research to end up with a comparative method to enhance the daylight of building façade by proposing different solutions based on daylight LEED criteria.

1.4 Research Limitation

The research will be focused on how the façade can enhance the daylight inside the building due to the visual comfort based on daylight LEED criteria without considering the material usages. To perform that, the research will be done on a high-rise office building in Amman, considering the exact location and weather data in a clear sky through different simulations. Due to the building conditions, the research will provide a daylight simulation that considers the occupied area by the users that have an opening without considering functions that have no openings such as stairs, storage, WC, etc., constructed based on mechanical solutions. In addition, the simulation will consider one typical plan at a high level since it is the typical high-rise plan and does not affect any surrounding factors. Another limitation regarding BIM technology is that the research will focus on how BIM technology can be used accurately in architecture to produce all working drawings and data. Besides, evaluating the daylight façade performance together with based drawings, and since it is a technology, the research will conduct digital data, numerical reports, and simulation plan figures instead of letters done in the long term and specifications of BIM behind the scene.

1.5 Employed Software Programs

Several software has been employed for different purposes to conduct the research goals and outcomes, which will be explained below, regarding their aims to serve the research target.

1.5.1 Autodesk Revit 2020

The Revit software is a BIM software based on parametric objects and can be used by all engineers, architects and others to produce all building drawings and data connected in one file. The software has been used as a BIM platform to produce all accurate architecture drawings of the case study besides a 3D modeling of the exact building measures. Besides, offering the flexibility of usage with different software plugs in.

1.5.2 Autodesk Insight

The software is used to conduct energy analysis by Autodesk clouds, such as solar and lighting analysis. The software has been used as a plug-in connected to Revit, which allows for a different daylight simulation on the case study in Revit. In addition, the software produced a resulting daylight simulation on the plan view, 3D views and numerical report, all exported to Revit. In addition, Autodesk Insight is qualified by LEED, which produces a result and direct LEED points.

1.5.3 Climate Consultant 6.0

Climate Consultant is software that produces all climate and weather data and their effects of an exact location based on different standards. The software has been applied based on (ANSI/ASHRAE/IES Standard 55-2021) standard in the exact location of the case study, which allows producing average monthly temperatures of weather data to be exported into solar sun path diagram for calculating the shading angels (HSA and VSA), due to the weather data.

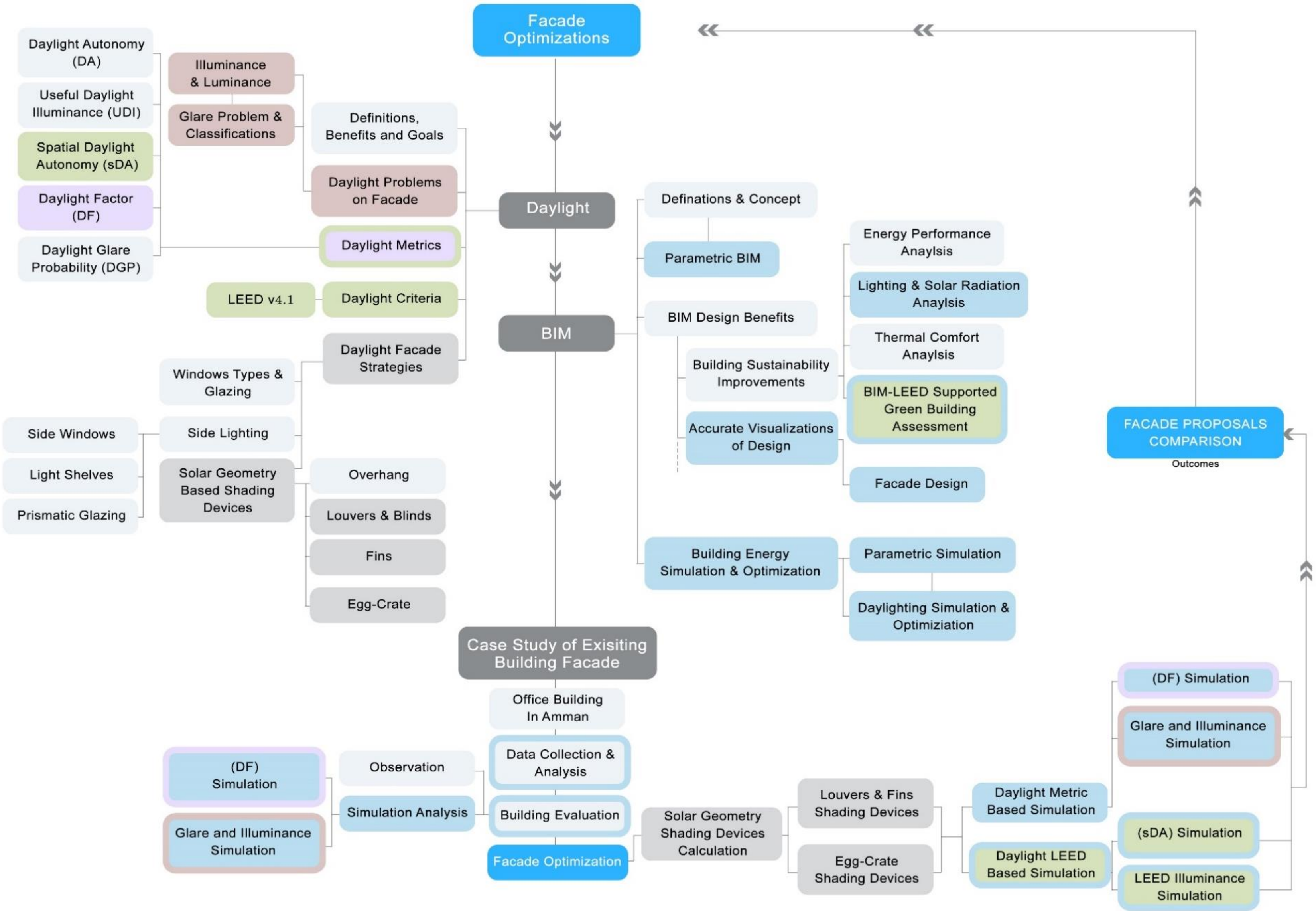
1.6 Thesis Structure

The research is divided into three sections, which are daylight, BIM and case study, to completing each other to reach the goal of optimizing an existing building façade regarding daylight based on LEED criteria through BIM

The daylight chapter collected the main data of daylight: the definitions, benefits and goals, and the problems of daylight. To control these factors, the chapter sorted out the daylight metrics beside LEED v4.1 criteria to be based on, which allows setting the metrics and manipulating them according to daylight standards. In the end, the chapter explained the daylight strategies that can be used to enhance the façade, which focuses mainly on the shading devices based on solar geometry.

Secondly, the research explained a highly demanding technology in the architecture and engineering world, which is BIM. The chapter of BIM focus on exploring the need of this technology for architecture in a different manner which lets the study explain the concept and definition of it to reach the main feature based on which is parametric BIM in addition to the benefits of BIM to have a clear way into the usage that the research needs. The benefits connected BIM to the building energy, allowing the research to reach the daylight importance based on LEED standards. The chapter explained the technology that can enhance the building façade by daylight simulation and optimization through parametric BIM.

The last section aimed to measure and apply the daylight data collection through BIM technology on an existing office building in Amman, Jordan, which choose for two reasons which are the effective climate condition in the middle east regarding daylight and the building function which has the most users who are affected from the daylight regarding visual comfort. The chapter figured out the location and climate data of the case study to evaluate it by an observation through the field and a simulation analysis through BIM technology based on daylight metrics standards. Later on, the research proposed two façade solutions of shading devices based on the calculation of solar shading angels. The research applied a BIM method to these solutions to achieve the best performance enhancement to the façade by defining two simulation methods: manipulative simulations and LEED simulations. In the end, the research compared the results of the façade shading devices solutions to choose the best alternative to optimize the existing building façade.



Facade Optimizations
Daylight Autonomy (DA)
Useful Daylight Illuminance (UDI)
Spatial Daylight Autonomy (sDA)
Daylight Factor (DF)
Daylight Glare Probability (DGP)
Illuminance & Luminance
Glare Problem & Classifications
Definitions, Benefits and Goals
Daylight Problems on Facade
Daylight Metrics
LEED v4.1
Daylight Criteria
Daylight Facade Strategies
Daylight
Windows Types & Glazing
Side Windows
Side Lighting
Light Shelves
Prismatic Glazing
Solar Geometry Based Shading Devices
Overhang
Louvers & Blinds
Fins
Egg-Crate
BIM
Definations & Concept
Parametric BIM
BIM Design Benefits
Building Sustainability Improvements
Accurate Visualizations of Design
Energy Performance Anaylsis
Lighting & Solar Radiation Anaylsis
Thermal Comfort Anaylsis
BIM-LEED Supported Green Building Assessment
Facade Design
Building Energy Simulation & Optimization
Parametric Simulation
Daylighting Simulation & Optimiziation
FACADE PROPOSALS COMPARISON
Outcomes
Case Study of Exisiting Building Facade
Office Building In Amman
Data Collection & Analysis
Building Evaluation
Facade Optimization
Observation
Simulation Analysis
(DF) Simulation
Glare and Illuminance Simulation
Solar Geometry Shading Devices Calculation
Louvers & Fins Shading Devices
Egg-Crate Shading Devices
Daylight Metric Based Simulation
Daylight LEED Based Simulation
(DF) Simulation
Glare and Illuminance Simulation
(sDA) Simulation
LEED Illuminance Simulation

Chapter 2

DAYLIGHT AND FAÇADE PERFORMANCE

Daylighting is a term that refers to the deliberate utilization of natural light within and around structures (Reinhart, 2014). The Illuminating Engineering Society's (IES) Lighting Handbook's tenth edition describes daylighting as "the process of facilitating the supply and distribution of daylight from the sun and sky to the inside of a structure." In an ideal world, the duration and intensity of this lighting would meet the building's occupants' and biological and visual requirements (Subramaniam, 2018).

In office buildings, daylight is widely acknowledged as a critical energy-saving design approach, but it requires an architectural design to obtain full advantages (Johnson et al., 1985). The quantity of daylight that enters a structure is mostly governed by the window openings, which have a dual purpose of bringing light into the interior environment, creating a more appealing and pleasant ambiance, and allowing people to keep direct contact with the outside environment (Li and Tsang, 2008). It is commonly recognized that daylighting strategies may help reduce electrical energy use, and there is a rising demand for daylight-efficient building design. Apart from reducing energy usage, daylighting affects the interior environmental quality. Additionally, sunshine entry is critical for increasing occupant productivity. A recent investigation (Dogrusoy and Tureyen, 2007) undertaken to validate the advantages discovered that most residents prefer natural light over artificial light, with natural sunlight and natural ventilation being the two most essential features. Another research found that people working in daylight completed around 10% more tasks properly, were quicker, and were less exhausted than those working in artificial light. Thus, while designing a building with daylight consideration, it is necessary to consider the amount of daylight and the residents' well-being and health (Ko et al., 2008).

2.1 Daylight Formation

Sun is the primary light source that forms the daylight, considered an energy source for buildings. Daylight is a composite of all indirect and direct sunlight that occurs during the day. The optimal lighting in the majority of situations is a blend of diffuse and direct light, as seen in Figure 1. In office buildings, sufficient natural light contributes to creating a visible interior environment that enables occupants to be more effective in their duties. On the other hand, direct sunlight may introduce undesirable thermal and optical discomfort into the work environment due to overheating and glare problems. Discomfort occurs with decreasing or increasing light intensity, which may be quantified as illuminance over a grid-based region of a work plane (Tabadkani et al., 2021).

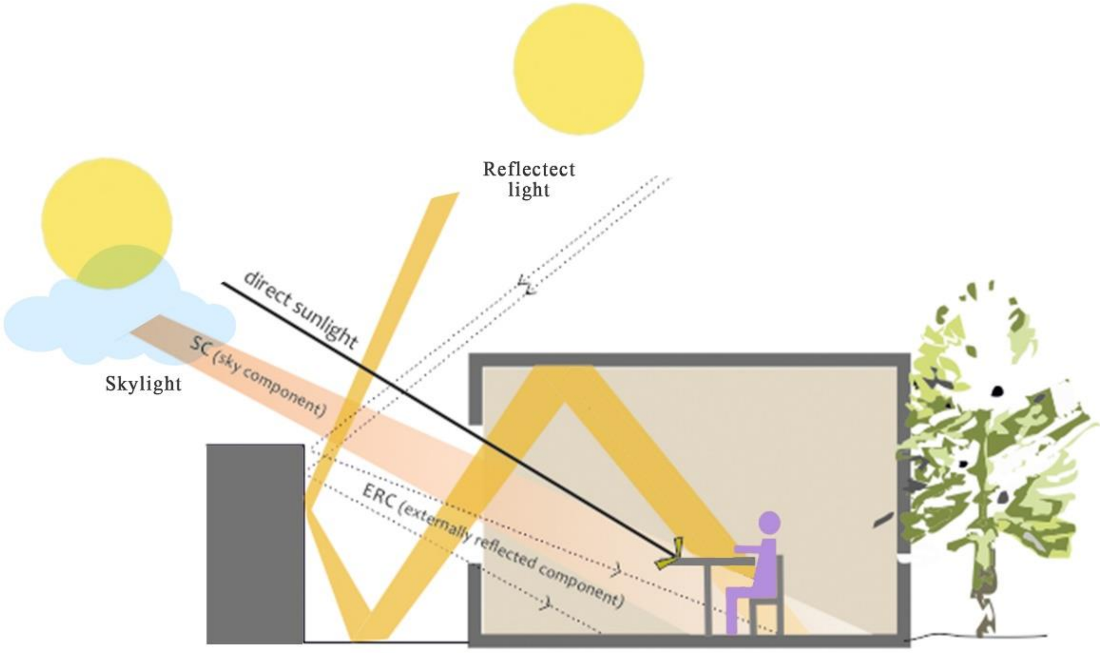


Figure 1: Daylight Components (Author, 2021)

2.2 Daylight Benefits

The two primary reasons for delivering daylight in the workplace are energy savings and psychological advantages associated with visual comfort. Proper daylighting has been shown to benefit building occupants' circadian rhythms, overall health, well-being, and contentment. Additionally, appropriate daylighting in office buildings can boost worker productivity and minimize absenteeism. On the other hand, appropriate daylighting can lead to huge energy savings by reducing associated cooling and lighting demands (Thanachareonkit et al., 2021).

2.3 Daylighting Performance Goals

It is critical to tackle daylighting design comprehensively and effectively. Providing daylighting while keeping an outside view is one of the primary goals of designers when building work environments. Visual comfort is another factor to consider when designing a workplace. For example, working environment inhabitants are frequently tempted to block off distracting glare by closing window shades (Suk, 2014). The following paragraph lists the overall daylighting goals that incorporate effective daylighting design features.

Quality encompasses the control of direct sunlight and the uniform distribution of daylight to alleviate uncomfortably high brightness ratios. Usability, the provision of views and connections to the outside environment and the confirmation of suitable daylight for all space occupants. Quantity entails meeting ambient lighting requirements and demands during the majority of the year's daylight hours. Building Integration refers to the process of fully integrating the outside and interior look of the building and the construction, electrical, mechanical, and lighting systems, in addition to the Cost-Effectiveness, which refers to obtaining significant energy savings through reductions in lighting energy prices and cooling energy costs (Abdollahi, 2021).

2.4 Glare Definition and Classifications

"Glare is visible noise which interferes with visual performance" (Lechner, 1991). Glare is a visual perception created by an abnormally bright and uncontrolled illumination that might be debilitating or merely inconvenient. The glare occurs by artificial or natural light when the illumination is exceeded. Additionally, it can be the reflection of light on a surface seen by the human eye, resulting in glare and a variety of other problems. Glare is classified into two categories: the impacts on the user and spectator and the consequences of glare owing to the position of the light, as seen in Figure 2. The first one, directed at the spectator, is classified into two types: discomfort glare and disability glare. On the other hand, the second one, which concerns light placement, is classified into two types: direct glare and veiling reflection, as well as reflected glare (Hamedani et al., 2020).

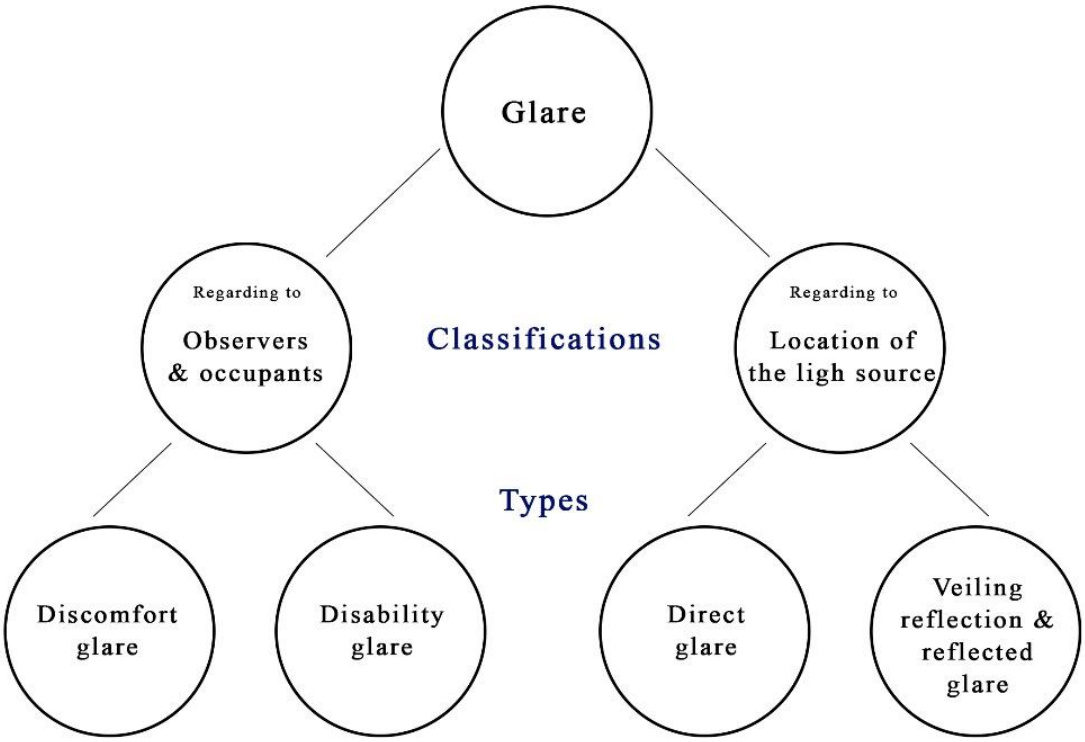


Figure 2: Glare Classification and Types (Author, 2021)

2.4.1 Discomfort Glare

Discomfort glare frequently happens in enclosed spaces or at night when ambient lighting is dim, and the viewer perceives another bright light source (Figure 3). For instance, sunshine streams through the building's apertures in the afternoon. This sort of glare impairs visual comfort by causing pain and strain to the eyes (Quek et al., 2021).

2.4.2 Disability Glare

Disability glare happens when a large amount of bright light is seen by the eye and is powerful enough to cause the eye to avoid staring at it. Additionally, it causes harm to the eyes (Figure 3). It may occur when the contrast between the backdrop and the glare source is significant, which indicates the intensity of the brilliant and the number of lightings in a very dark region (Abdelwahab et al., 2019).

2.4.3 Direct Glare

Direct glare happens when the observer is directly in front of a bright source of light (Figure 4). Additionally, it may occur when the light source is close to the observer's central vision (Mashaly et al., 2021).

2.4.4 Veiling Reflection and Reflected Glare

Veiling reflection and reflected glare are two types of glare that arise in relation to the location of the light source, which occurs when light strikes a surface and creates an undesired mask of light on it as a reflection of the light from the eyes (Figure 4). It is frequently observed while reading a book or staring at a computer monitor (Tabadkani et al., 2020).

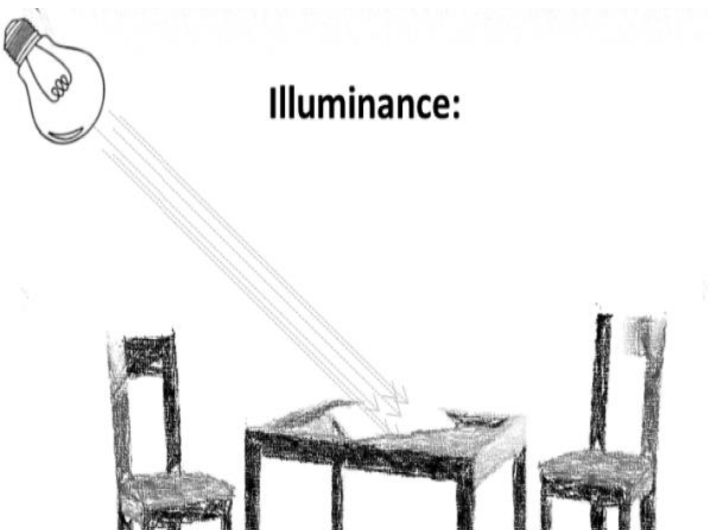
Figure 3: (Left to Right); Discomfort Glare (URL, 1), Disability Glare (URL, 2)

Figure 4: (Left to Right); Direct Glare, Veiling Reflection (URL, 3)

2.5 Illuminance and Luminance

2.5.1 Illuminance

Illuminance is the most frequently used in literature to refer to the amount underlying visual comfort needs. In addition, illuminance is the quantity of light radiating from a unit of surface-expressed lux unit, as seen in Figure 5. The recommended minimum illuminance at the work plane for regular office writing, typing, and reading operations range from 200 to 600 lux for office buildings. However, the recommended range for computer-based operations is between 100 and 300 lux, much less than the recommended range for paper-based work. Additionally, guidelines for maximum illuminance levels on the work plane between 1280 and 1800 lux are included, meaning glare is likely to occur above those levels. (Correia et al., 2012).

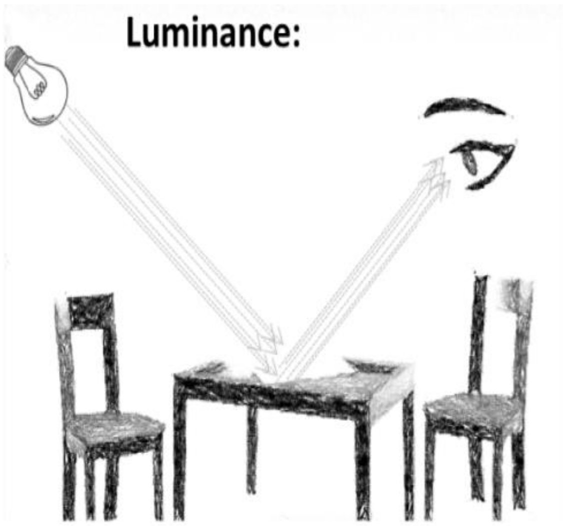


	Units	Symbol
Illuminance	LUX (SI), Foot candle (I-P) 1 fc =10 lux	lx(SI), Fc(I-P)

Figure 5: Illuminance Effect and Units Usages with Their Symbols (Abdollahi, 2021)

2.5.2 Luminance

Luminance is a measure of the amount of light reflected off the surface of an item and reaching the eyes. It is expressed in the international system of units (SI) by candela per square meter, as seen in Figure 6. Thus, luminance is a measure that is mostly used to quantify glare, whereas illuminance is primarily used to quantify light levels within buildings (Fathy et al., 2020).



	Units	Symbol
Luminance:	Candela per square meter (SI) Candela per square foot(I-P)	cd/m2 cd/ft2

Figure 6: Luminance Effect and Units Usages with Their Symbols (Abdollahi, 2021)

It is critical to do a brightness study since it affects visual comfort. Figure 7 illustrates the relationship between the luminance of an item (cd/m2) and the luminance of adaptation or perception (cd/m2). The discriminating range is a term that refers to the average brightness of objects within a direct visual range (Kischkoweit-Lopin, 2002).

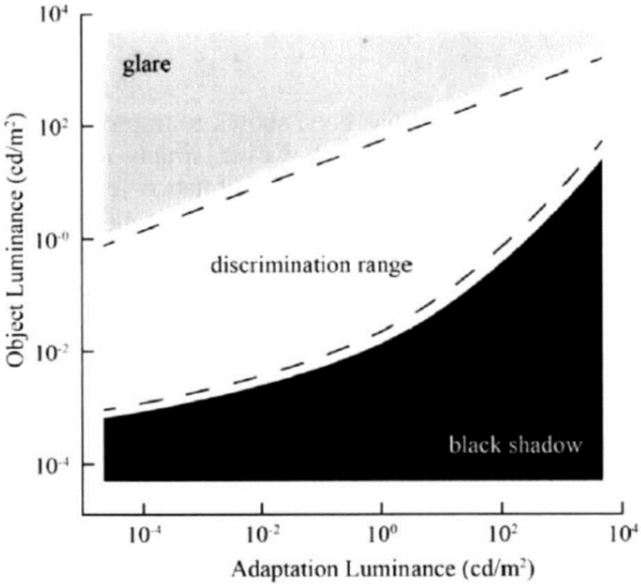


Figure 7: The Relation Between Object Luminance and Adaptation Luminance (Jakubiec, 2014)

Given the relationship between luminance and brightness, it is critical to evaluate the brightness ratio. Essentially, the brightness ratio is the quantity of light that enters an area due to the opening size that results in a particular brightness level within the space. If the opening size is excessively large, there is a significant contrast between outside and inside light since human eyes cannot adapt to extreme brightness levels. This is most noticeable while gazing out a wide window since the degree of light obscures the external area, as seen in Figure 8 (Mohammed, 2014).

Figure 8: Brightness Ratio by the Windows (Author, 2021)

2.6 Daylight Metrics

Daylight metrics are used to enhance daylight harvesting systems and estimate the amount of daylight harvested in a specific area (Mangkuto et al., 2016). This article discusses a few daylight metrics mainly used as measurement tools explained in the following paragraphs (Mardaljevic et al., 2011).

2.6.1 Daylight Autonomy (DA)

Daylight Autonomy (DA) refers to annual daylight measurements. It displays the percentage of yearly daylight hours to determine if a particular place got sunlight over a predefined level. The building function determines the defined degree of illumination. For example, the threshold for office buildings is between 350 and 750 DA (IES, 2021).

2.6.2 Useful Daylight Illuminance (UDI)

Useful daylight illuminance (UDI) calculates the percentage of time during which a particular point got a range of illuminances that met a goal range of illuminances. This is provided as a maximum threshold to prevent glare and overheating. The recommended thresholds are 100 lux and 2000 lux, where 100 lux is considered too dark, and 2000 lux causes optical and/or temperature discomfort. In the office building, the UDI between 100 to 300 lux is regarded as effective in combination with artificial lighting. It is desirable or tolerable to be perceived in the range of 300 to 3000 lux (Majeed et al., 2019).

2.6.3 Spatial Daylight Autonomy (SDA)

Spatial Daylight Autonomy refers to the percentage of a place that receives adequate daylight, which must be at least 55% of a total floor area for residential spaces (SDA 300 lux / 50% of the yearly occupied hours) upon LEED criteria. It has no upper limit on the amount of luminance. It determines the proportion of analysis points that surpass a defined illumination level (300 lux) for at least 50% of the total occupied hours between 8:00 am and 6:00 pm throughout the year. In contrast, the percentage of SDA is at least 55% or 75% to earn 2 to 3 LEED points, as shown in Table 1.

Table 1: LEED v4.1 points for daylight floor area (LEED v4.1, 2021)

(sDA) for regularly occupied floor	Points
55%	2
75%	3

2.6.4 Daylight Factor (DF)

The daylight factor determines the amount of natural light in an area. It specifies the ratio of outdoor illuminance to that of interior areas. A higher value of DF indicates that more natural light is available in the space (IES, 2021). Electric illumination is required for most of the year in spaces with a DF of less than 2%. Spaces with an average DF of between 2% and 5% offer a good balance of thermal and lighting factors. However, an area with more than 5% DF electric lighting is seldom necessary. Still, it is more likely to have thermal difficulties due to overheating in the summer and heat loss in the winter (Mavridou & Doulos, 2019).

2.6.5 Daylight Glare Probability (DGP)

The Daylight Glare Probability is a measure for evaluating glare based on the brightness and illuminance in a field of vision. The probability of Daylight Glare is classified into four categories: Disturbing Glare is between 35% and 40%, Intolerable Glare is less than 35%, Perceptible Glare is between 40% and 45% Imperceptible Glare is greater than 45% (IES, 2021).

2.7 Daylight LEED Criteria

The Leadership in Energy and Environmental Design (LEED) standards are the most extensively used system for evaluating green buildings in the world. This green rating system aims to promote the development of sustainable and environmentally friendly buildings that do not harm people or the environment. LEED establishes a framework for building owners, operators, and design teams to follow when adopting practical and quantifiable green building design, construction, and operation (LEED v4.1, 2021). Credits for LEED V4.1 are assigned to eight categories: (i) Location and Transportation, (ii) Sustainable Sites, (iii) Water Efficiency, (iv) Energy and Atmosphere, (v) Materials and Resources, (vi) Indoor Environmental Quality, (vii) Innovation, and (viii) Regional Priority. It features a total of 110 points that may be earned by completing all of these categories. The LEED v4.1 BD+C Scorecard requirements related to daylighting are included in the section on Indoor Environmental Quality, shown in Table 2 with their points (LEED v4.1, 2021).

Providing enough daylighting has a number of benefits, including reduced power usage, increased productivity, and decreased lethargy and sadness. The daylight standards are intended to decrease reliance on electrical lighting, maximize the benefits of natural light, and create a link outdoor environment and the interior space of the building. The quality of daylighting has specified credits in LEED criteria. They are based on simulations in the study and measurement of daylight to determine daylight quality (Yasinci, 2020). LEED offers three options: (i) Simulating Annual Sunlight and Spatial Daylight Autonomy, (ii) Simulating Illumine Calculations, and (iii) Measuring the daylighting quality using the precise standards and points which will be mentioned for each purpose regarding daylighting in this research (LEED v4.1, 2021).

Table 2: LEED v4.1 BD+C daylight-related point (LEED v4.1, 2021).

LEED v4.1 BD+C **Indoor Environment Quality**	**110 Points** **16 points out of 110 points**
Thermal comfort-related points	1 point
Daylight	3 points

2.8 Daylight Strategies

Facades with high performance are building coverings that integrate and manage exterior environmental elements to provide inhabitants with energy-efficient, comfortable, healthy and productive indoor environments. The US Department of Energy has been maintaining a database of designing efficient, high-performance buildings since 2012. Climate-conscious building design, climate-responsive design, green buildings, bioclimatic architecture, and sustainable design are all terms that precede the use of high-performance buildings (Rao et al., 2017).

In all climates, daylight use is accomplished by appropriately sizing daylight apertures and utilizing control mechanisms such as static and light shelves and moveable shade devices to maintain acceptable light levels during daily and seasonal fluctuations in sun position. These buildings' aesthetics are inspired by their surroundings, and their material selections are made from easily accessible local resources. What makes these structures sustainable is that they let sufficient sunshine, air, solar energy and moisture into the interiors when required and prohibit them when they are not. Environmental factor control and usage patterns are extremely climate-dependent and are developed with factors such as building type, materials, building, orientation geometry (Shi et al., 2020).

To better understand the process of constructing high-performance buildings, it is necessary to analyze the primary source of light: the sun, its movement, and its location in the sky. Solar energy reaching the earth's atmosphere averages 1367 W/m2 (433 Btu/ft2) throughout the year. However, the length of the atmosphere through which the sun's rays travel, the amount of cloud cover, and the degree of turbidity in the atmosphere all substantially affect the quantity of diffuse and direct solar radiation reaching the earth's surface. The direction and slope of a surface and the presence of nearby buildings that block or reflect sun rays all affect the quantity of radiation received on a particular surface (Stein et al., 2006).

The building has many parameters to enhance daylighting performance. Climate, latitude, site obstacles and reflections, glazing size, windows and skylights, geometry, glazing transmittance, and shading affect daylighting performance. The following strategies below consider the façade only since the research aims to enhance the façade performance regarding the daylight.

2.8.1 Windows Types and Glazing

The primary function of glass is to let daylight into interior areas and connect the indoor spaces to the outdoor environment. However, human nature values the natural surroundings, with all their variations in color, light, and shade, through the use of glass to windows or facades. Glazing is classified into three main types: Clear Glazing, Tended Glass, and Miscellaneous Glazing. The miscellaneous glazing includes wired glass, glass blocks, patterned glass and laminated glass (Phillips, 2004). They affect the building daylight in different terms, such as their transparency percentage, which allows a specific amount of daylight to enter the building, their reflection on daylight and their daylight distribution effect.

2.8.2 Side Lighting Strategies

Side lighting is performed mainly to enhance the daylight towards the interior environment and avoid related problems such as glare and unreachable daylight to the interior space. Besides, acting as a shading device by limited types since the side lighting system is considered a non-shading device. There are many different side lighting strategies (Ko et al., 2008). The main commonly used to enhance the daylight towards the interior spaces are side windows, light shelves, louver system and prismatic glazing, which are explained in the following paragraphs

2.8.2.1 Side Windows

Side windows regulate the amount of sunlight that is admitted under various circumstances and conditions. The effective window sizes and position on the wall, in addition to sky overcast and direction, define the function of daylight in the area. Regarding the size of the windows, the height of the window has a major effect on maximizing the daylight inside the building (Obradovic & Matusiak, 2020). Figure 9 shows the effective relation between the window's height and daylight. In addition, the window's width has the same effect since it is related to the sizes shown in Figure 10.

In general, daylight from a single side window in space causes eye discomfort due to the stark contrast between the window's strong light and the darkness deep within the room. However, it is advisable to locate windows correctly to minimize glare and balance the amount of light in the area, as seen in Figure 11 (M. Liu et al., 2019).

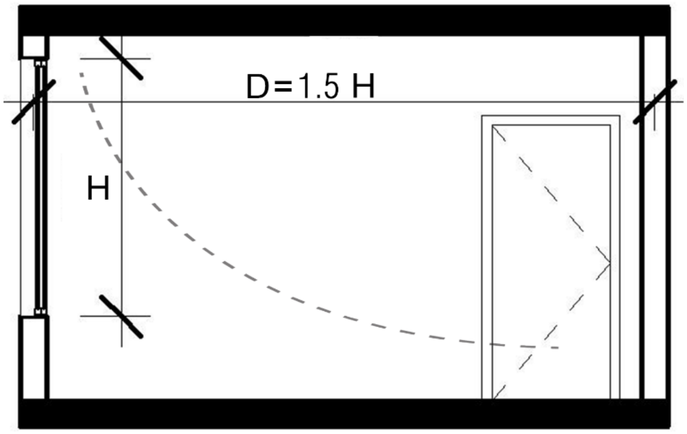


Figure 9: Effective Depth of Daylight (D) When Penetrated via Side Window (H) Height (Author, 2021)

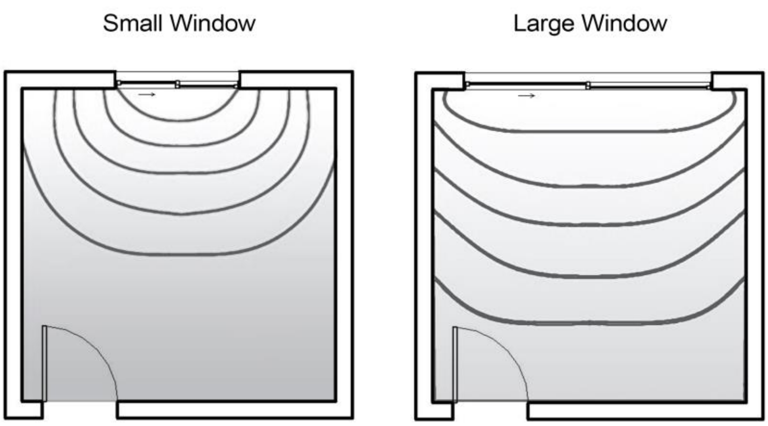


Figure 10: Iso contour Curves Representing the Pattern of Lighting Passing Through Large and Small Windows (Author, 2021)

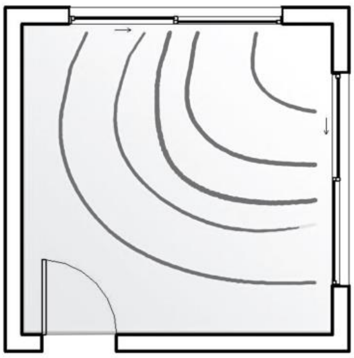


Figure 11: Two Adjacent Side Windows Distribute Daylight Equivalently (Author, 2021)

2.8.2.2 Light Shelves

Light shelves are regarded as shade devices, solar collectors, and redirector devices that affect the area. The light shelves are positioned horizontally above the eye levels, dividing the glazed into two sections. The higher ratio of glaze shapes the first section. In contrast, a clerestory window shapes the second section above the light shelf, which provides indirect daylight and allows the light shelf to redirect the light through it via a reflection done with the light shelves for the deep area, as is seen in Figure 12 (Mangkuto et al., 2018). Additionally, the light shelf may be used to reduce glare and maintain the exterior brightness through shade features.

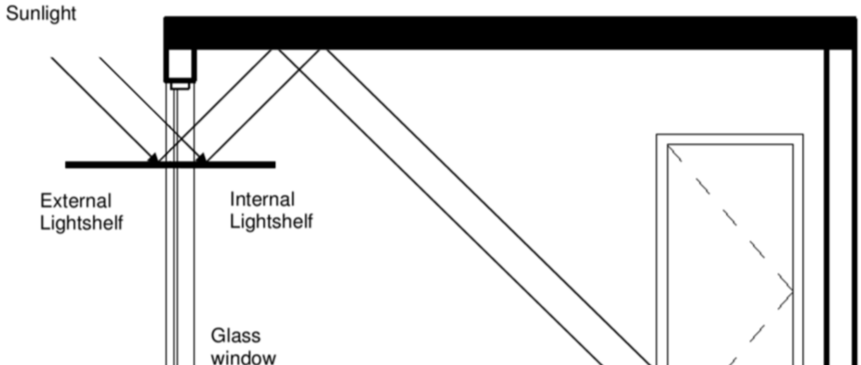


Figure 12: Light Shelf Strategy on Building Daylight (Author, 2021)

2.8.2.3 Prismatic Glazing

This technique has been used for centuries to dilute solar radiation that enters a building as the system reflects direct light. It demonstrates that it is possible to increase the amount of sunshine inside buildings throughout the winter, particularly in greenhouses. Essentially, prismatic glazing adheres to the norms of light refraction by spreading the direction of the light, as is seen in Figure 13. Figure 14, in which a portion of the sunlight is reflected on the ceilings and the remainder remains close to the opening, which may be altered according to the amount of light that has to be reflected by changing the number of prismatic glazing at the top. Additionally, it contributes to the building's energy efficiency and thermal comfort, where studies indicate that it might account for up to 10% of total energy usage. However, the prismatic glass will work inefficiently under an overcast sky. In this situation, the prismatic parts must be sandwiched between two pieces of clear glass at the opening's top (Gago et al., 2014).

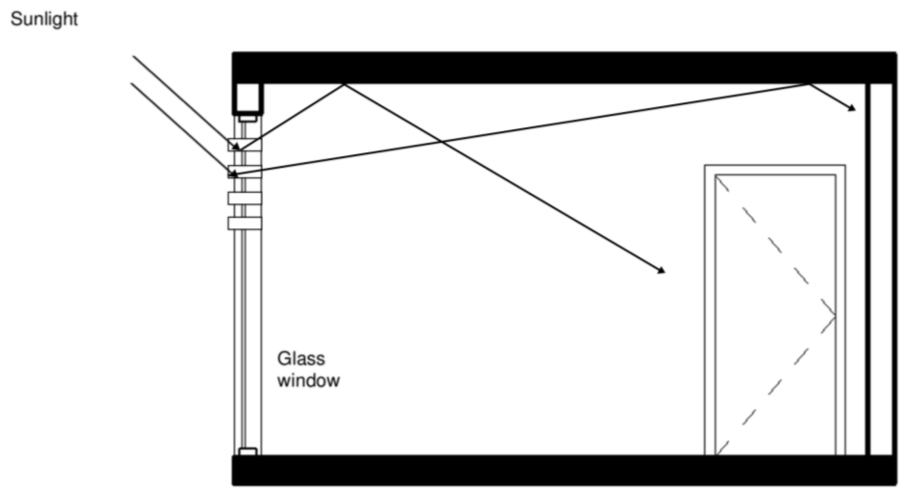


Figure 13: Prismatic Glazing Daylight Strategy on Building Daylight (Author, 2021)

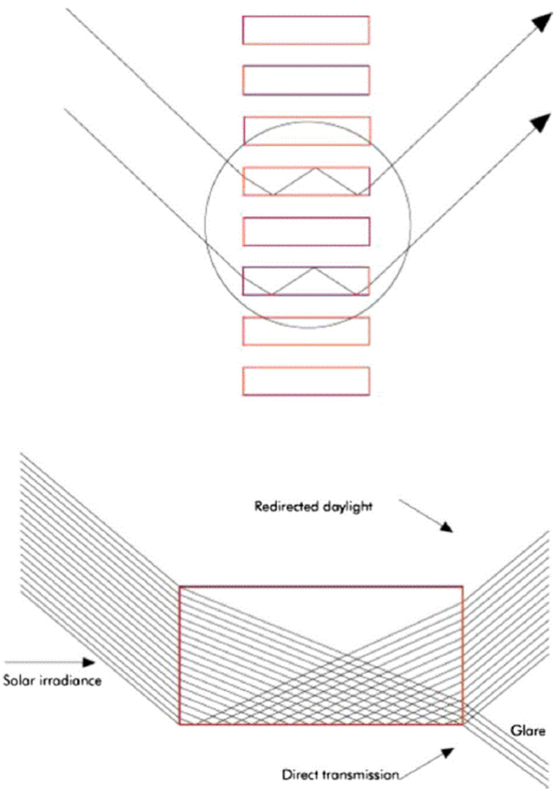


Figure 14: Prismatic Glazing Detailed Strategy (Gago et al., 2015)

2.8.3 Solar Geometry-Based Shading Devices

A thorough grasp of the sun's movement and the local climate helps designers create high-performing facades. Shading systems are the single most successful technique for achieving thermal and visual occupant comfort while also increasing the energy efficiency of a building. Solar geometry-based shading device design is a simplified technique. This approach processes only two pieces of data: the location's latitude and the window's orientation (Villela, 2014). Altitude, azimuth and zenith are the most useful components for introducing solar beams (Figure 15). Zenith angle is the angle between the sun and vertical direction, which creates different angles to be measured; Altitude is measured vertically, and azimuth is measured horizontally.

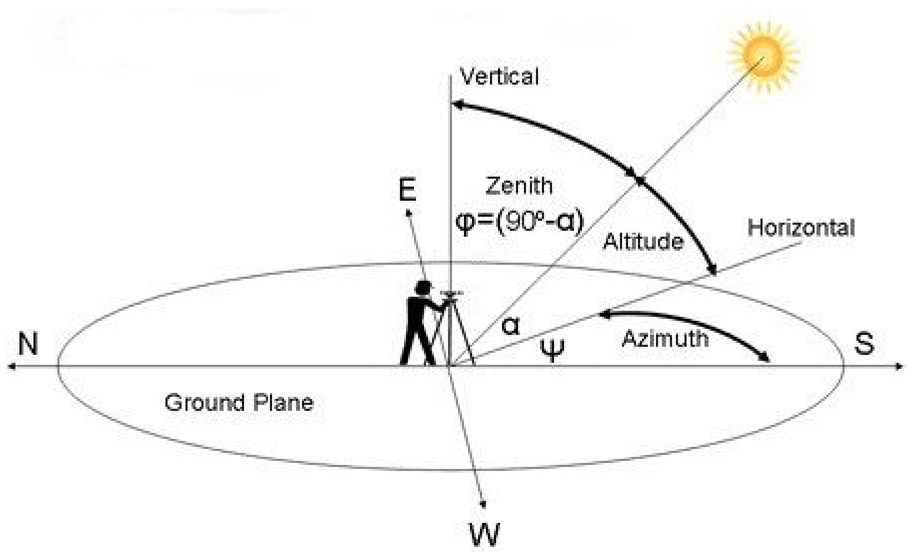


Figure 15: Zenith, Altitude and Azimuth Angels by the Sun (URL, 4)

Thus, the sun path has the main priority to be studied to enhance building daylight through the façade. Sun path diagrams may provide a wealth of information about how the sun will affect the building at a specified location throughout the year by figuring out the solar azimuth and altitude according to the building location. Figure 16 shows a stereographic sun path chart for a studied location, which is a diagram that allows to figure out the solar azimuth and altitude for a particular location, that used to define the sun position at any time of the year, which is the main factor in finding out an accurate angle of the shading devices. Figure 17 highlights the relationship between the shading devices and sunlight radiation angles towards the façade to create a shading mask by calculating the horizontal shading angle (HSA) and vertical shading angle (VSA) where the shading devices will be placed according to these angels as it is seen in Figure 17 (Abugrain, 2017).

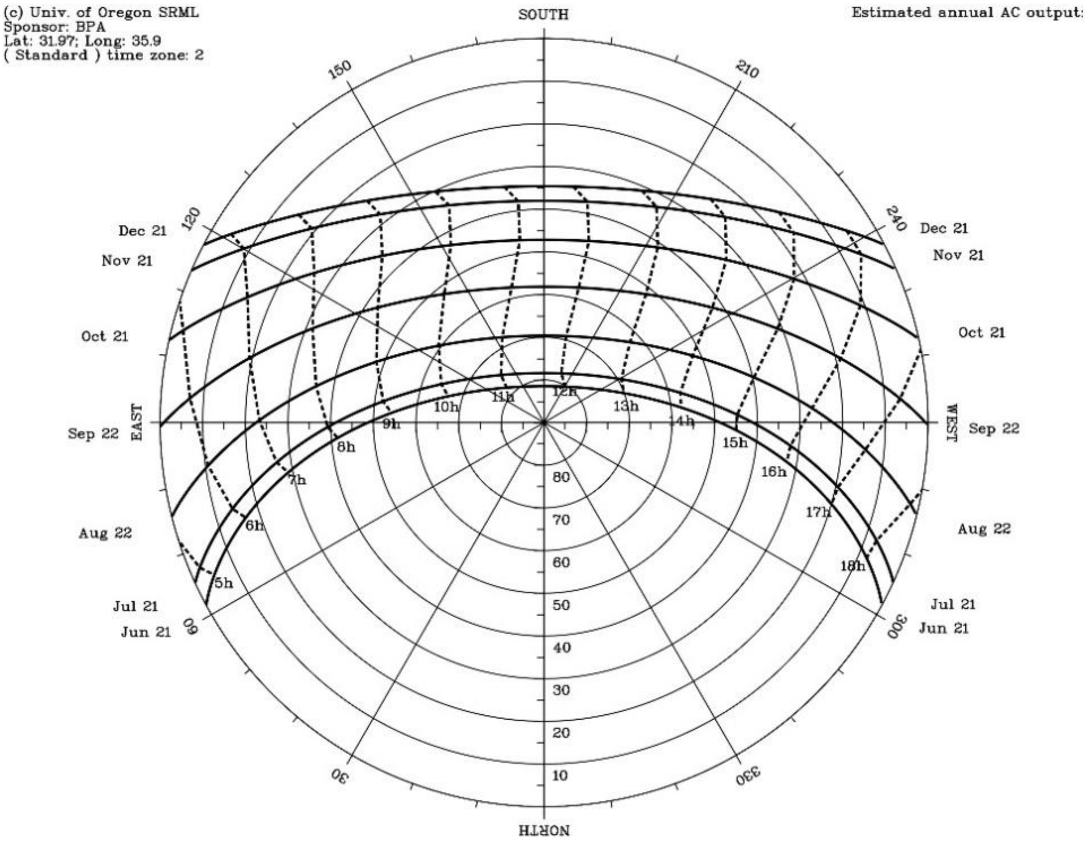


Figure 16: Stereographic Sun Path Chart Showing the Sun Path in The Summer of Amman (URL, 5)

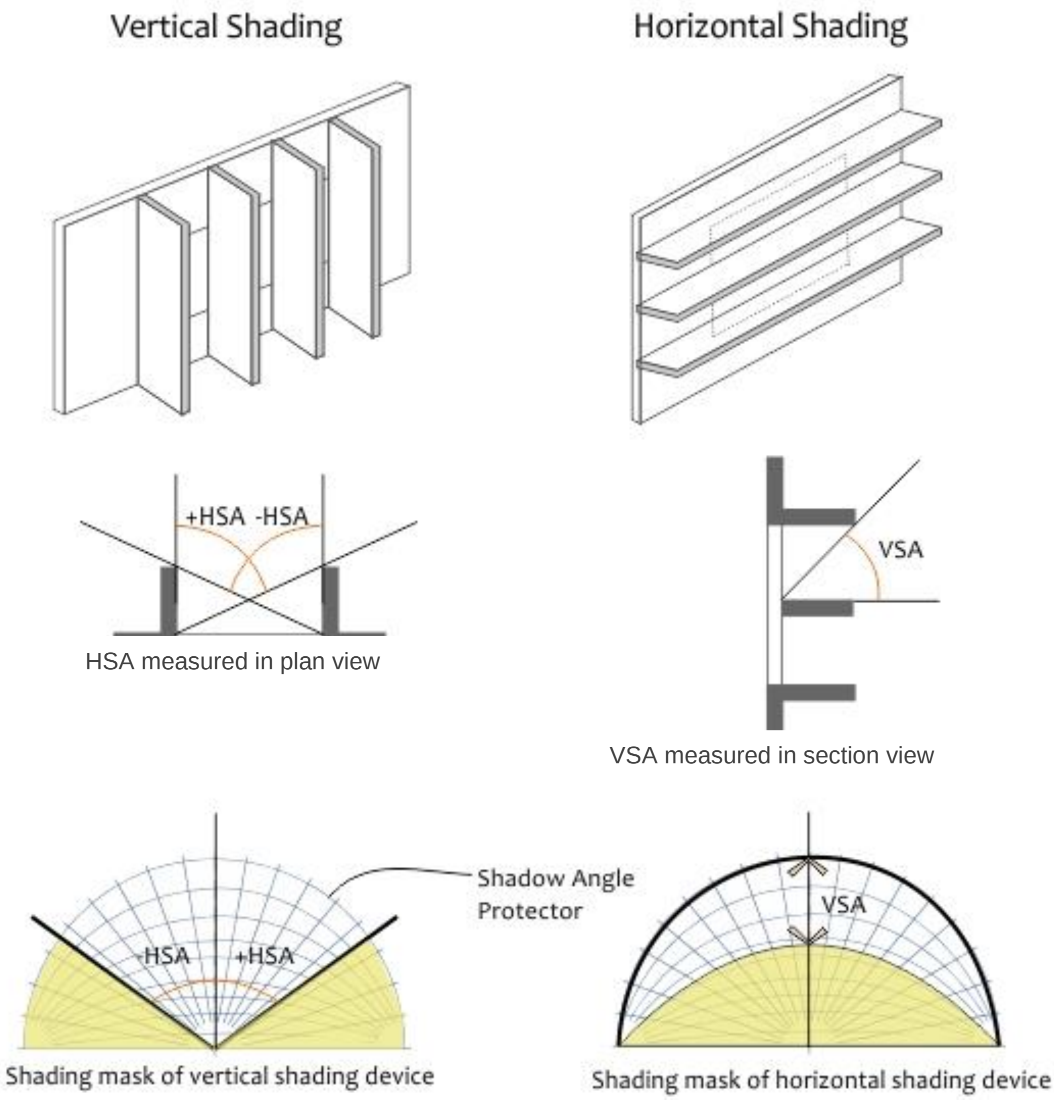


Figure 17: Horizontal and Vertical Shading Devices (URL, 6)

Horizontal and vertical shading devices form different types of fixed shading devices on the façade according to their direction: overhang, louvers, fins and egg-crate as the combination of them. These types are explained in the following sections regarding their main daylight performance towards the space.

2.8.3.1 Overhang

The overhang is typically used to block sunlight when the sun is traveling in a higher direction, such as in the south direction during the summer. The automated design of the overhang is partially successful since it creates an effective vertical shading angle. The overhang can be formed as an extension of the floor slab or attached to the façade, as shown in Figure 18, with its main effect on building daylight through the façade facade (Czachura, 2021).

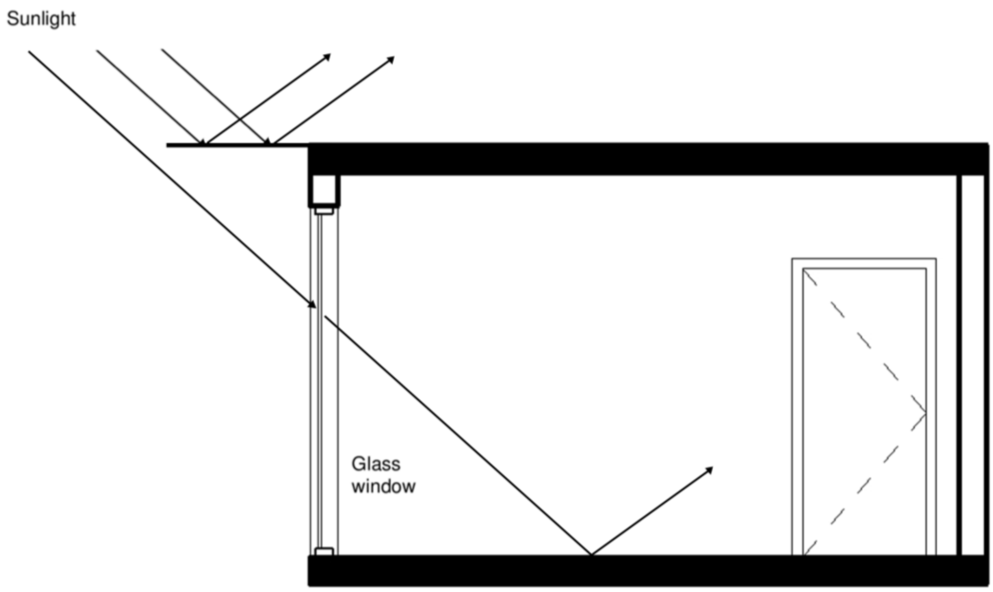


Figure 18: Overhang Shading Effect on Building Daylight (Author, 2021)

2.8.3.2 Louvers and Blinds

The louvers and blinds are used to balance lighting levels by directing sunshine to darker areas of the space and lowering glare near the windows as side lighting systems behaviors (Figure 19), in addition to their usages to block a specific amount of daylight since the angles of the components can be adjusted according to the angle of the sun to perform vertical shading angle in most of the time as an overhang. The lovers and blinds have two types: dynamic and fixed elements, and they can be installed on the facade's exterior or interior (Heidari Matin & Eydgahi, 2021).

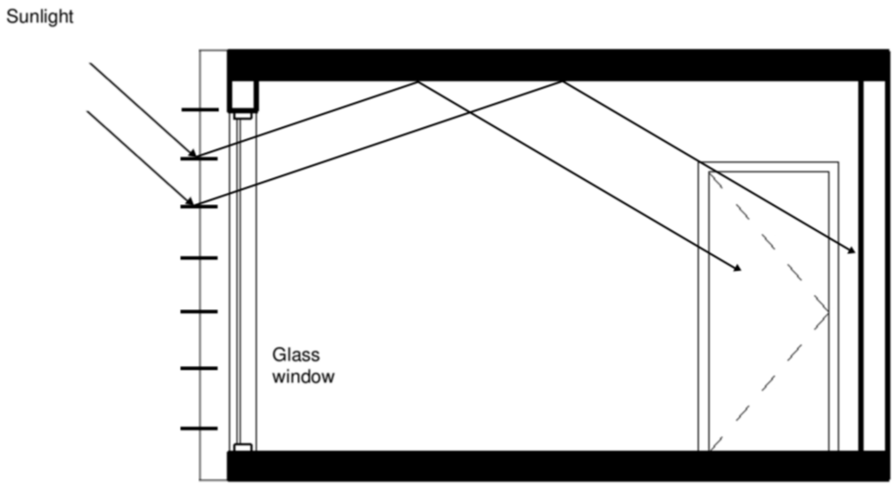


Figure 19: Louvers and Blinds Strategy on Building Daylight (Author, 2021)

2.8.3.3 Fins

Fins are generally considered vertical louvers since it provides the same louvers behaviors to the sun vertically, which prevents direct horizontal solar beams, as seen in Figure 20, from preform horizontal shading angle. Thus, the fins work well in East and West directions. Regarding that, the fins are placed on the façade by defining the HSA in the plan to prevent an amount of sunlight in a specified location (Brzezicki & Regucki, 2020).

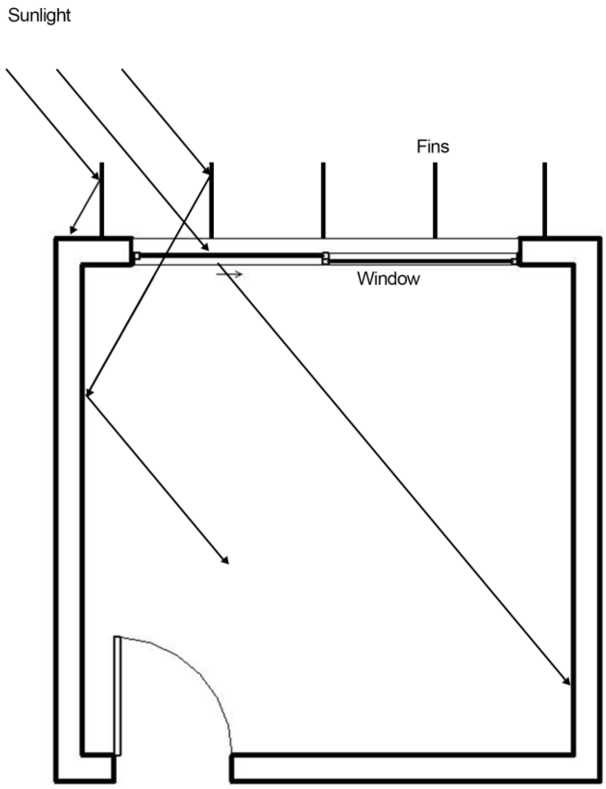


Figure 20: Fins Effect on Building Daylight (Author, 2021)

2.8.3.4 Egg-Crate

Eggcrate is horizontal and vertical shading devices combined, as seen in Figure 21. This creates an effective shading term in all solar beams directions since it shapes both VSA and HSA, making it stiff constructions that are only used under high heat climates (Alsharif, 2017). There are different developed façades based on the same terminology of Eggcrate, such as Perforated screens, adaptive façade or other integrated façade components, on the other hand, which are more prevalent in modern architecture (BAANGOOD et al., 2018).

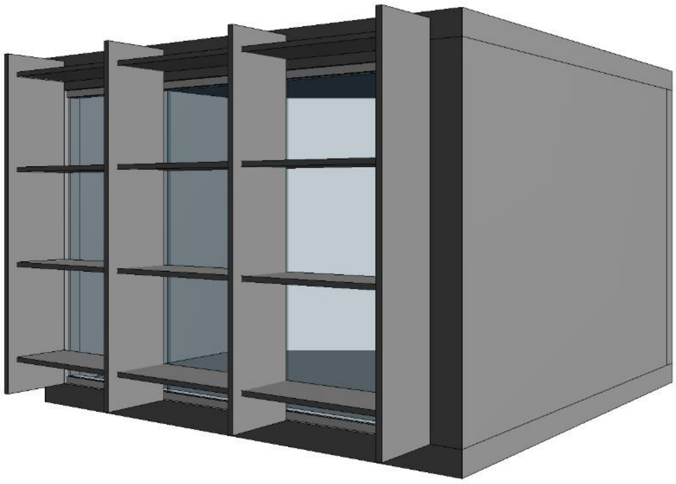


Figure 21: 3D view of Egg-Crate Shading Devices (Author, 2021)

2.9 Chapter Summary

To enhance the daylight of building façade, it is important to understand the daylight primary source and information of daylight. The research explained the primary information such as daylight formation, benefits and goals. Later on, to solve the daylight problem regarding the visual comfort of an existing façade, the research highlighted the glare problems with their classification and the illuminance and luminance, which are the essential factors of daylight that affect the visual comfort through the façade. Therefore, to control the daylight effect, it is necessary to explore the metrics of daylight which are sorted out. These metrics allow manipulating the daylight enhancement according to the daylight standards and criteria. LEED v4.1 daylight criteria have been considered in the research as the main criteria to be based on to perform accurate daylight strategies that serve the façade.

The daylight strategies in the research are categorized into three parts: windows types and glazing, side lighting strategies and shading devices based on solar geometry, which the research focused on by explaining the method of calculating the shading device regarding the sun radiation angles. The figure shows the workflow of the chapter as a summary, where the highlighted ones represent the chapter's main results to match the research aims.

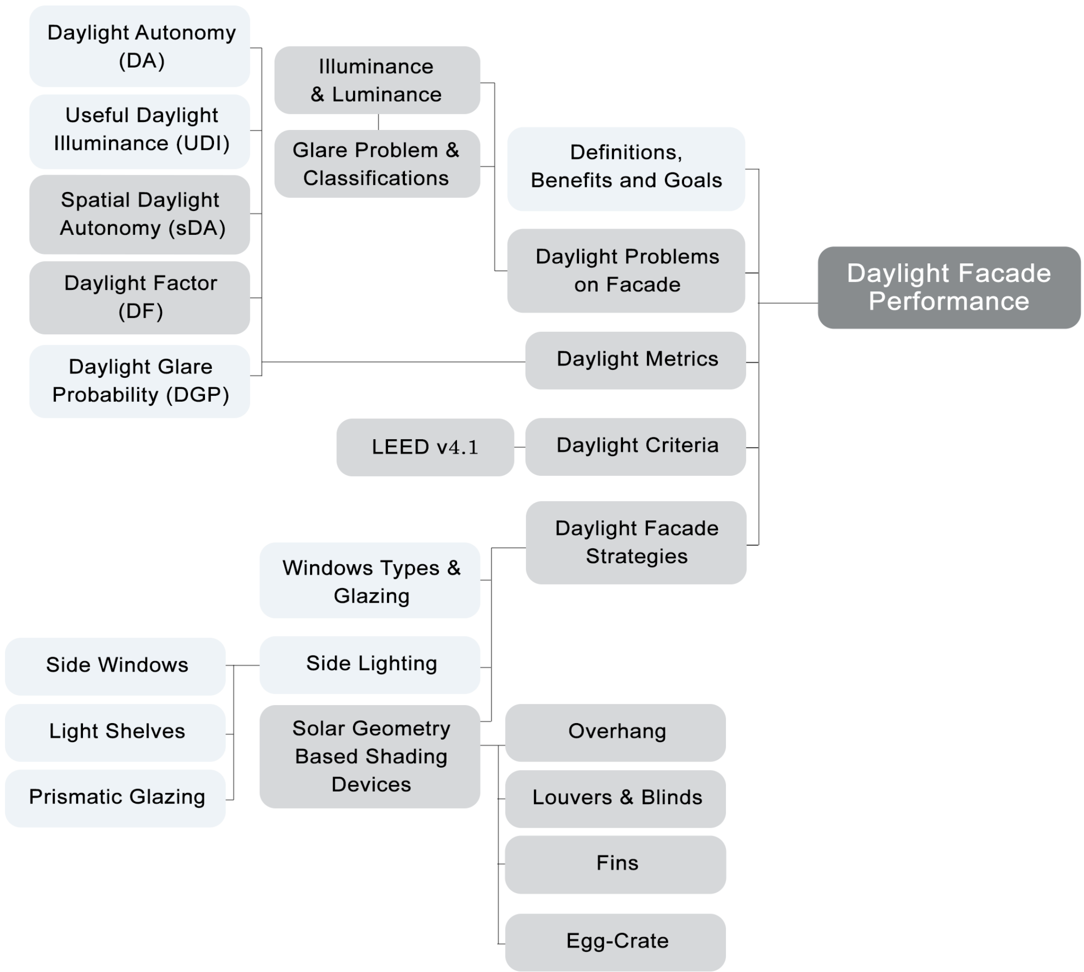


Figure 22: The Workflow of Daylight Façade Performance Chapter (Author, 2021)

Chapter 3

BUILDING INFORMATION MODELING TECHNOLOGY (BIM)

Building Information Modeling (BIM) is a ground-breaking approach and technology that has revolutionized the way buildings are envisioned, designed, constructed, and operated considerably. Although the beginnings of BIM can be traced back to the late 1970s and early 1980s parametric modeling research in the United States and Europe, it was not until the mid-2000s that the Architecture-Engineering-Construction (AEC) industry began using it in projects. In the last seven years, BIM has developed from a buzzword to the focal point of AEC technology. (Hardin, 2015).

3.1 BIM Definition and Concept

BIM is described as a digital representation of a building's functional and physical properties by the National Building Information Modeling Standards (NBIMS) organization in the United States of America. A building information model (BIM) is a shared knowledge source of information about a building that serves as a reliable foundation for decision-making across its life cycle, defined as conception to demolition. Collaboration between stakeholders at various phases of a building's life cycle to input, delete, update, or edit information in the BIM to improve and reflect each stakeholder's role is a basic idea of BIM (Makenya & Ally, 2018).

According to the Associated General Contractors of America (AGC), BIM is developing and utilizing a model based on computer software to simulate the construction and operation of a building. That produces an oriented object, intelligent, data-rich, and parametric digital representation of the project, from which data directly related to the needs of different users can be extracted and analyzed to generate a wealth of data that can be used to enhance the building delivery process and make decisions (AGC, 2005).

As the above two definitions illustrate, BIM is neither software nor a process; it is both. Not only does BIM require the use of sophisticated 3D models, but it also necessitates significant changes to the process and project delivery practices. BIM represents a paradigm change in the AEC sector, supporting the integration of all stakeholders' roles on a project. It has the potential to boost efficiency and collaboration among parties. Additionally, BIM promotes the concept of Integrated Project Delivery (IPD), a ground-breaking approach to project delivery that brings together business structures, systems and practices in a collaborative process aimed at optimizing efficiency and minimizing waste throughout the project's life cycle (Hardin, 2009).

3.1.1 BIM as a Technology

From a technological standpoint, a BIM is a project simulation comprised of 3D representations of the building’s components, linked to all necessary information for design, management, operation construction, as seen in Figure 23 (Khemlani, in Eastman et al., 2011). Failure to include one of these parts will collapse the system, as stated in the figure. BIM is a technique that originated from object parametric modeling. The term "parametric" refers to a technique in which an element and a nearby element or assembly are updated simultaneously. For instance, a door connected to a wall is automatically adjusted to maintain an established connection (Stine, 2012).

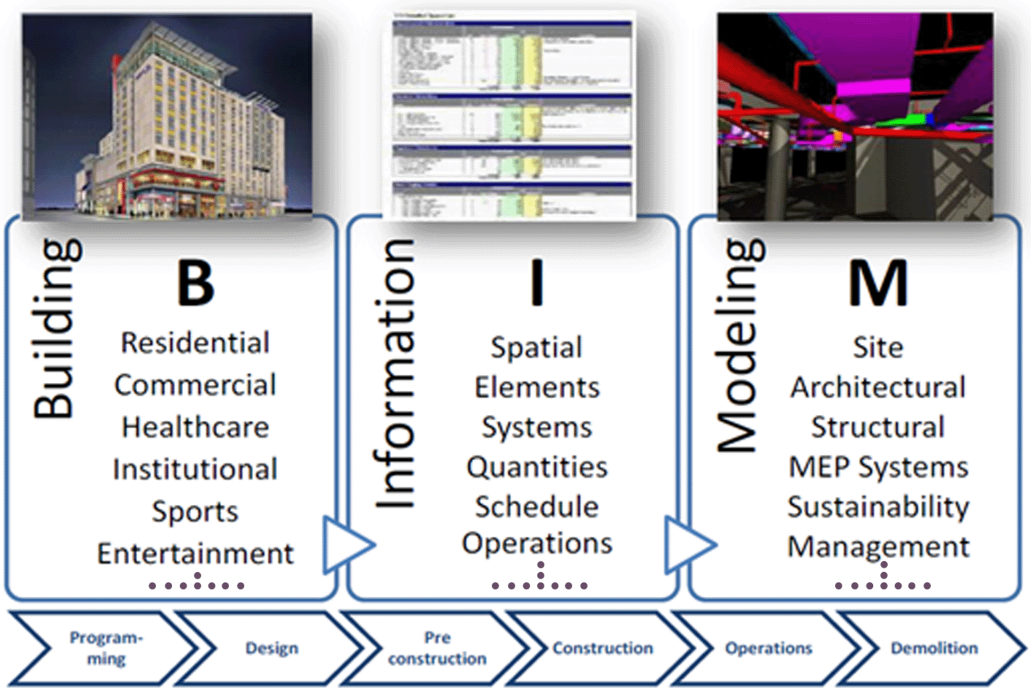


Figure 23: BIM Concept (Azhar et al., 2012)

The fundamental difference between BIM and conventional 3D CAD technology is that the latter represents a structure using discrete 3D perspectives such as plans, elevations, and sections. Editing one of these points requires reviewing and modifying all other views besides the waste of time consumed by approaches that largely contribute to poor documentation. Additionally, the data in these 3D drawings are restricted to graphical entities such as lines, arcs, and circles, in contrast to the rich contextual semantics of BIM models, which define things related to architectural elements and systems such as spaces, columns, beams, and walls. In a series of smart objects, BIM contains all data about a structure, including its functional and physical features and information about the project's life cycle. For example, a BIM model of an air conditioning unit may include information about the unit's provider, operation and maintenance procedures, flow rates, and clearance requirements, all of which are connected in the event of a modification (S. Liu et al., 2015).

3.1.2 BIM as a Process

BIM is a virtual procedure that includes all elements, professions, and systems of a building into a single digital file, allowing all building users such as architects, engineers, contractors, suppliers and owners to cooperate more precisely and effectively than previous approaches. Team members are constantly updating and amending their segments in reaction to project requirements and design modifications as the model is being developed to ensure it is as exact as possible before the project breaks ground physically (Carmona and Irwin, 2007). BIM is founded on two fundamental principles: communication and collaboration. The early engagement of all project participants is required for successful Implementing BIM. This means that traditional project delivery methods play a minimal role in BIM-based projects. The notion of Integrated Project Delivery (IPD) as a supporting tool to BIM has emerged recently. IPD, early in the cycle, brings together key construction management, manufacturing, suppliers and others with design professionals and the owner to create a design that is enhancement streamlined for aesthetics, quality, constructability, timeliness, affordability, and a smooth transition into lifecycle management solutions. The IPD has become the primary project delivery technique for all large-scale BIM projects in the United States (Ahn et al., 2016).

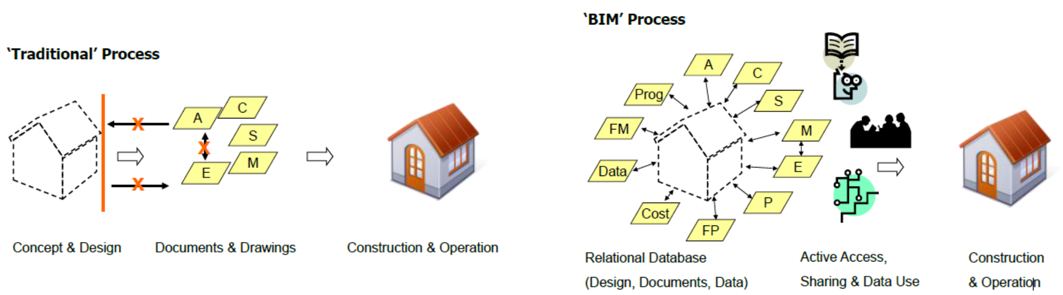


Figure 24: The Differences Between Traditional and BIM Process (Azhar et al., 2012)

3.2 Parametric BIM

Parametric modeling is a generic approach for constructing models with restrictions and changeable parameters. Based on the aesthetics and performance criteria of the building, parametric modeling permits the generation of new forms by using parameters based on changing circumstances. Therefore, that changing object is simply writing the value of a parameter. When the engineers or architects develop numerous solutions instead of just one, they may leverage those various optimization solutions. Building-integrated photovoltaics, for instance, can utilize parametric models and genetic programming to optimize the design of curtain panels that serve as PV and glazing components, influencing daylighting and heat efficiency. BIM is a process that promotes the sharing and exchange of building data due to the physical and functional aspects of the structure. Object-based BIM enables the creation and management of complete building data involving objects and their properties used in the AEC process. The parametric modeling feature of BIM enables rapid, interactive and real-time design adjustments. As seen in Figure 25, when it comes to BIM, parametric modeling and BIM are intertwined (Eastman et al., 2011).

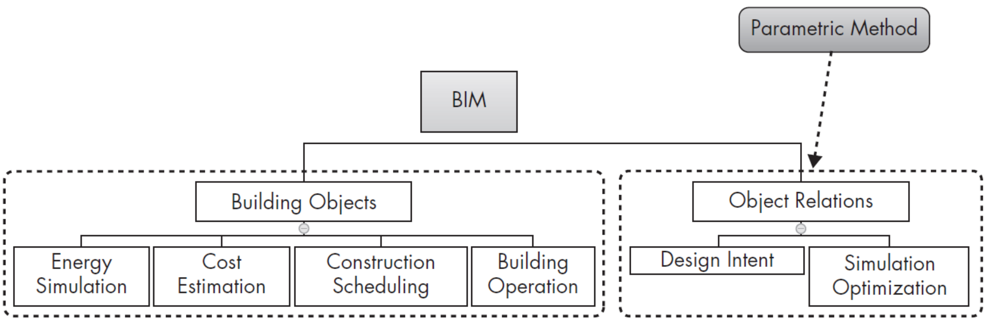


Figure 25: Parametric Method and BIM Relationship (Noble & Karen M, 2014)

In a BIM project, objects are described using built-in and user-defined parameters and data sources such as physical, aesthetic, and functional information obtained via databases or entered using graphical user interfaces (GUI). Figure 26 shows the relationships between external processes and the BIM objects in the parametric BIM structure diagram, explaining the process flow through BIM.

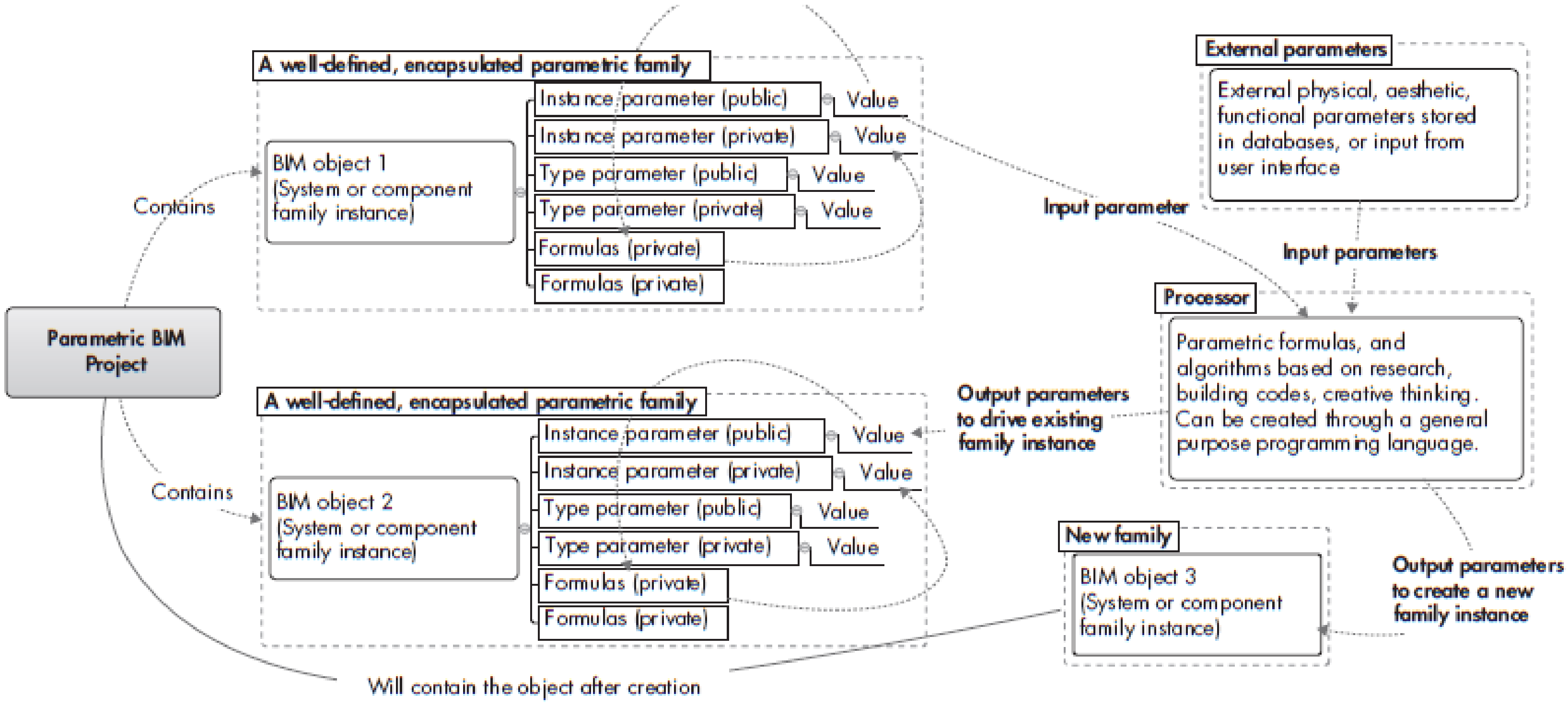


Figure 26: Parametric BIM Diagram Emphasizing the Relationships Between External Processes and BIM Objects (Noble & Karen M, 2014)

In contrast to the process details of BIM, visual programming enables users to develop computer programs through graphic manipulation of program parts rather than word manipulation. A more visual approach to programming might be easier for non-programmers or rookie programmers, which is typically the case for architects. Autodesk Insight is a software used visual programming tool for parametric design integrated into the BIM platform Revit. Additionally, Dynamo is a new product by Autodesk in BIM as a visual programming tool. Many programs work with BIM technology to update with the development, such as Grasshopper and Navisworks (Bellido-montesinos et al., 2019). Figure 27 shows different user interfaces of parametric modeling for BIM.

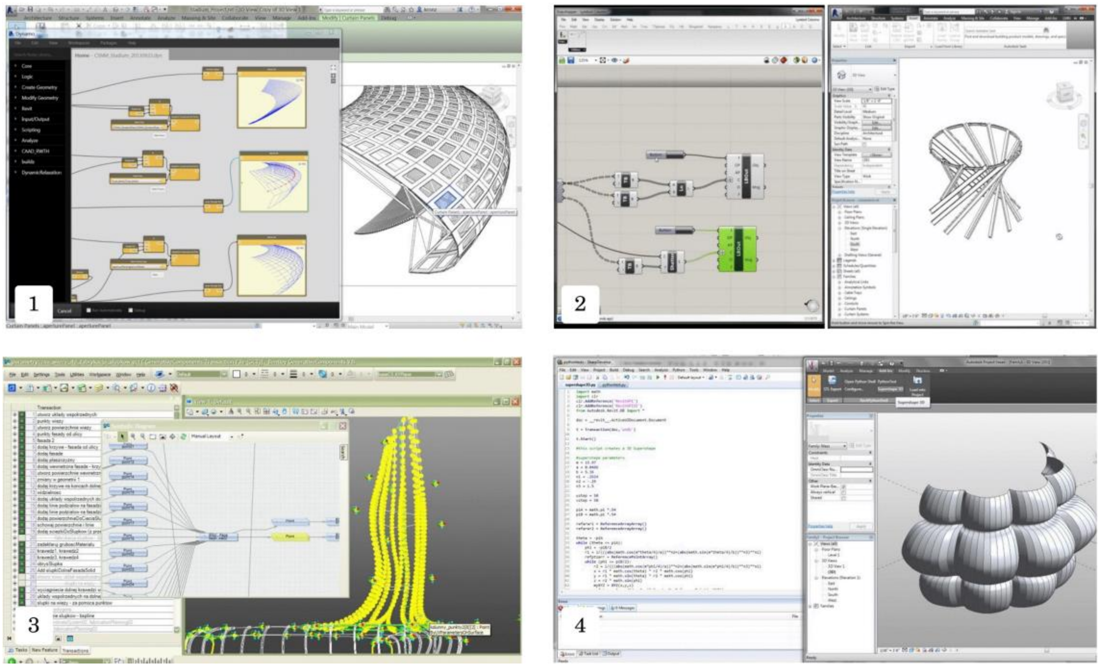


Figure 27: Different BIM User Interfaces for Engineering Usage and Design Integration; (1) Dynamo and Revit, (2) Grasshopper and Revit, (3) GenerativeComponents, (4) Visualizing by Dynamo (Feist, 2016)

Professional parametric modeling and BIM integration examples include the Shanghai Tower and the Hangzhou Olympic Stadium (Figure 28). Grasshopper as a visual programming tool and Rhinoceros as a 3D modeling tool is utilized in both projects to create a parametric design for the building's bulk and skin. The generated shapes are then converted to Revit BIM for detailed design and construction. The projects profited considerably from parametric BIM. For instance, in the Shang Center project, by modeling several possibilities and conducting wind tunnel tests, the design team determined that a 120-degree twist and a 55% taper combination decreased wind loads by 24% and material costs by $58 million (Wujec 2011).

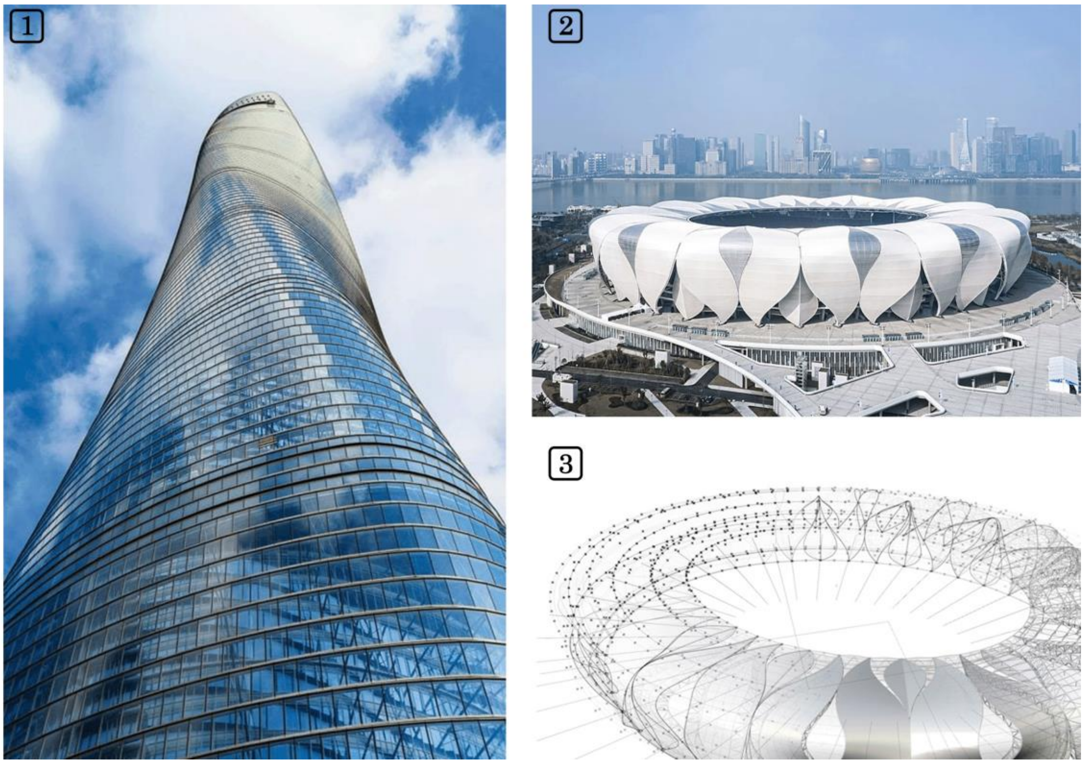


Figure 28: Parametric BIM Applications Used in Built Projects; (1) Shanghai Tower (URL 7), (2) Hangzhou Olympic Stadium (URL 8), (3) Hangzhou Olympic Stadium by BIM Modeling (URL 9)

Regarding the main categories that explain BIM, which is BIM as technology and BIM as a process, the risks will be shaped parallelly, explained in the following sections.

3.2.1 Technology Related Risks

The first technological risk is an absence of BIM standards and administration and incorporation by cross-disciplinary teams. Integrating multidisciplinary data into a single BIM model implies that the BIM model is available to many users. To preserve consistency in formatting standards, information and guidelines must be implemented throughout the project's development process. Because there are no standard protocols, each firm develops its standards. This may introduce discrepancies in the model, which, if not recognized appropriately, may result in an erroneous and inconsistent BIM model. This means the project team should conduct periodic "model audits" to guarantee that such difficulties do not arise (Weygant, 2011).

Licensing issues may arise when project team members other than the engineer/architect and owner add data to the BIM model. For example, suppliers of materials and equipment may give designs associated with their commodities for the benefit of the design director to persuade the designer to specify the vendor's equipment. While this strategy may be advantageous to the firm, licensing issues may arise if the drawings are not generated by a licensed designer in the area where the building is taking place (Thompson and Miner, 2007).

3.2.2 Process Related Risks

The procedure is fraught with contractual, legal, and organizational hazards. The first source of worry is an absence of ownership assessment for BIM data, which necessitates the use of copyrights and other legal means to protect it. For example, if the owner pays for the design, the owner may feel entitled to ownership; yet, if team members provide proprietary information to the building, that information must also be protected. As a result, there is no simple solution to the data ownership conundrum; each building needs a unique response customized to the needs of the participants. The goal is to avoid introducing impediments or disincentives that prohibit participants from fully utilizing the model's capabilities. To minimize arguments over copyright issues, it is important to lay out property rights and responsibilities in the contract documents (Rosenberg, 2007).

The integrated concept of BIM straddles the boundaries of accountability to such an extent that risk and responsibility are likely to grow. Consider the following example: The building owner files a lawsuit citing a design defect. Engineers, architects, and other BIM process players confer to determine who is responsible for the matter at hand. In the event of a disagreement, the lead professional will not only be legally accountable to the client but may also have difficulty demonstrating blame with others. One of the most effective ways to avoid such risks is to utilize collaboration, integrated design, and construction agreements that share the benefits and risks of BIM implementation. The American Institute of Architects recently produced a BIM exhibition to help project participants build a strategy for integrated project delivery using BIM. This display may help project participants identify model management projects, as well as ownership and level-of-development requirements, across the project's many stages (Z. Liu et al., 2019).

3.3 BIM Benefits

BIM is at the core of the construction and building design process and may adapt to growing challenges for faster development, more complexity, cost savings, increased sustainability, and more effective and efficient management and maintenance of structures (Sacks et al., 2018). Figure 29 shows the main categories of BIM benefits, each category has many detailed points that affect the project in beneficial ways. The research focuses on façade design and improvement of building sustainability, highlighted in the figure below, to enhance the building daylight through the façade based on BIM.

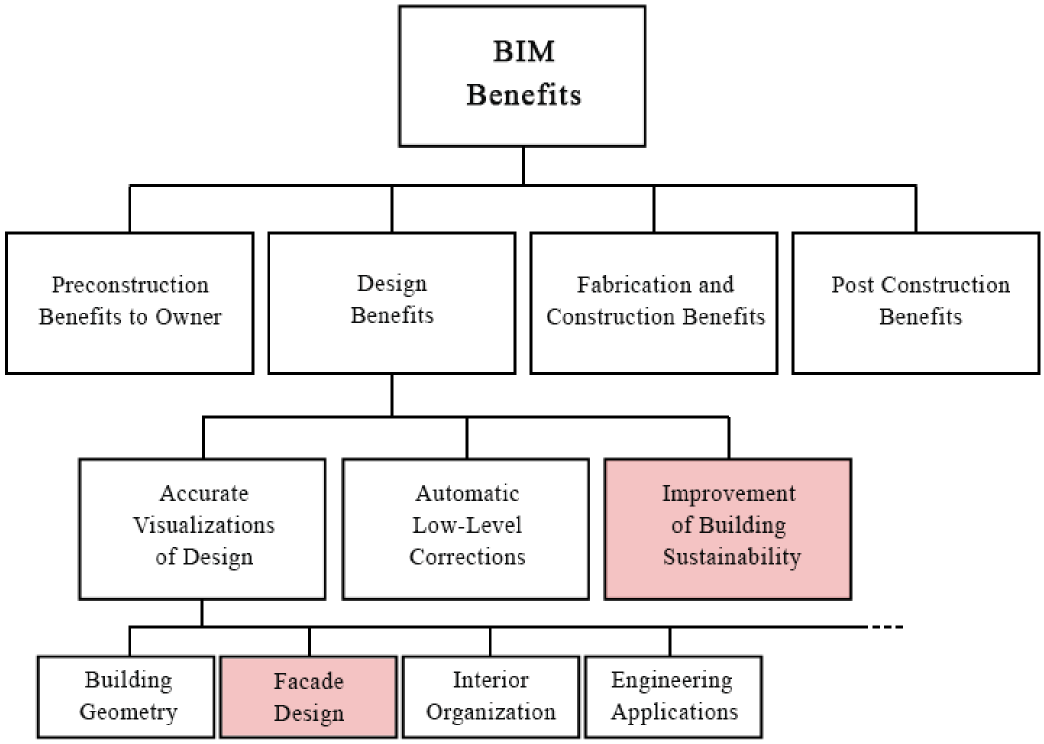


Figure 29: The Main Categories of BIM Benefits (Author, 2021)

3.4 BIM-Based Façade Design Features

In BIM parametric design, all genuine features of façade manufacturing components are simulated and calculated parametrically and associated data statistics. A façade component is not just a virtual geometric component in BIM-parametric design; it also contains additional geometric qualities such as thermal performance, component material and cost, purchase information, weight, and installation number. The BIM visualization is built automatically utilizing the data for entity components. Therefore, when a façade component modifies, all associated views are automatically updated (Luo, 2018). For instance, it automatically generates multi-view sectional and axonometric drawings of a curtain wall model to transfer the information, as seen in Figure 30.

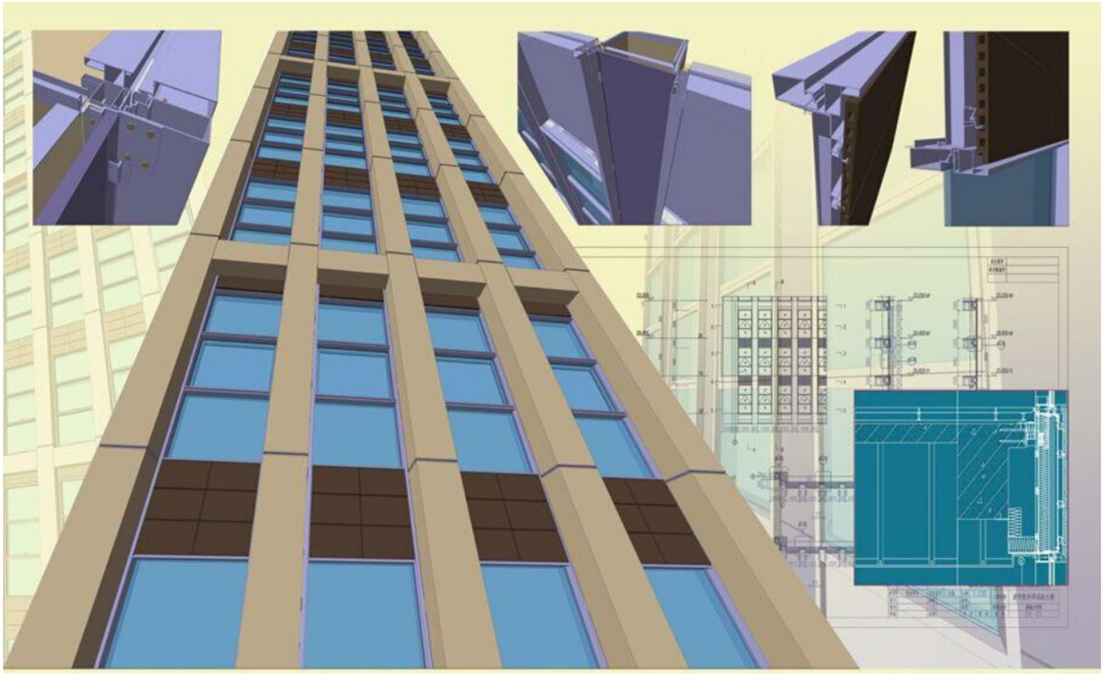


Figure 30: Multi-view Drawings by BIM of CABR Research Building Façade (CABR Technology Co, 2015)

The Barclays Center, seen in Figure 31, strikes a balance between unusual shape and performance. Its intricately designed, weather-resistant steel and glass façade. To ensure that the weather resistant steel's "grille" division accurately reflected the shape of the building, the project implemented an integrated construction process centered on assembly and utilized digital fabrication technology to sequence assemble and deliver 900 large unit panels comprised of 12,000 weather resistant steel grilles of various sizes (CABR Technology Co, 2015).

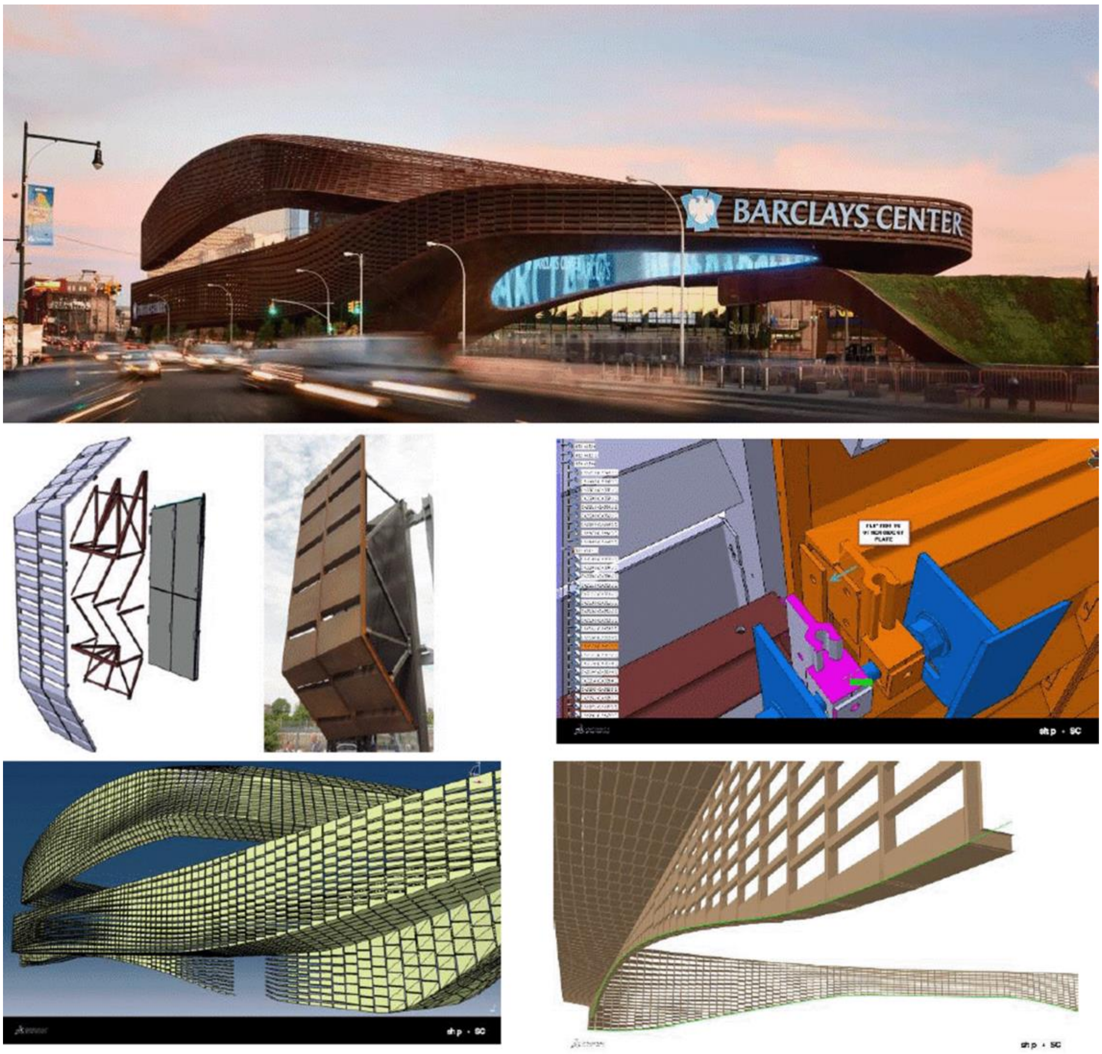


Figure 31: BIM Façade Assessment of Barclays Center (CABR Technology Co, 2015)

The relevance of BIM parametric façade design allows swift calculations and statistical analysis on modeling, layout, energy conservation, and evacuation based on various design factors and then prioritizing the most suited scheme. The enhancement of building sustainability takes a big place in the importance to design an efficient façade. The following section has explained the effect of BIM on building sustainability which helps to design an appropriate façade regarding that (Akkoyunlu, 2018)

3.5 BIM-Based Building Sustainability Improvements

BIM plays an important role in enhancing building sustainability accurately and efficiently. It is important to consider certified standards assessments to enhance building sustainability. Green Building assessments (GBA), such as the LEED framework, are very important to the "Sustainability characteristics" since they may give a comprehensive evaluation of the numerous green features (Olawumi et al., 2021).

Three dimensions create a triangle, where green buildings and BIM interact, as seen in Figure 32. The interactions can be divided into two groups: BIM attributes project phases, which explain how BIM can support the various stages and lifecycles of green buildings, and BIM attributes-green attributes, which explain how it can be used to assist the various sustainable building elements. The green arrow in Figure 32 illustrates these BIM-related effects on green buildings (Lu et al., 2017).

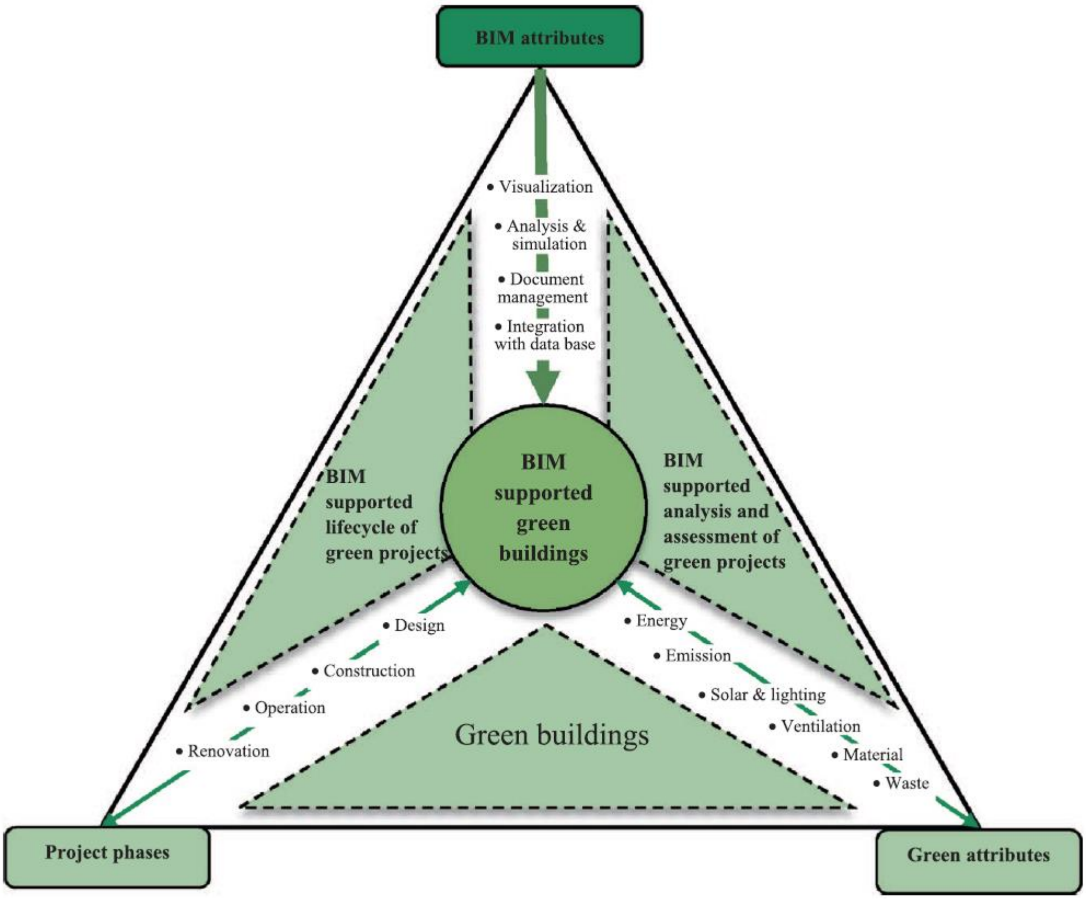


Figure 32: BIM and Green Buildings Interactions (Lu et al., 2017)

BIM capabilities for significant green concerns provide a comprehensive overview of various forms of BIM technology and how they may aid sustainable buildings efforts in seven categories such as energy use, carbon emissions, natural ventilation, lighting and solar radiation, acoustics, water usage, and thermal comfort (Jung & Joo, 2011). The following sections highlight three categories that deal with daylight: energy performance, lightning and solar radiation, and thermal comfort.

3.5.1 Energy Performance Analysis

BIM software serves four essential activities in the analysis and evaluation of energy performance: (1) an actual energy assessment of the whole building, (2) systematic analysis of alternative energy-saving measures, (3) a clean energy feasibility assessment, and (4) more effective identification and diagnosis of energy problems (Lu et al., 2017).

1) To begin, by utilizing common methods and parameters, BIM software enhances the usefulness of the entire building's energy computation. Traditional techniques for analyzing and assessing energy performance are based on CAD solutions, which require substantial modeling time and effort. On the other hand, BIM software uses a standardized technique to calculate the energy usage of a whole structure depending on a range of criteria such as the geometry of the building, its material composition, its usage patterns, and environmental conditions (Subramaniam, 2018).

2) BIM software allows for comprehensive studies of various energy reduction strategies. Building energy simulation tools incorporate occupant effects into the energy analysis process, allowing for the estimation of energy savings under various scheduling situations. The application considers aspects affecting occupants, such as occupancy and equipment scheduling. The users of BIM technology can enhance the initial solution by comparing the results of the program's numerous energy-saving measures. (Huang et al., 2021).

3) Some BIM tools can analyze the possibility of implementing renewable energy sources (solar, water energy, wind circulation, etc.). The majority of BIM tools can only predict the co-effects of shelters surrounding the building to a limited extent. For example, it has been discovered that nearby buildings may greatly influence the energy performance of a structure via mutual shading and reflection (Jung & Joo, 2011).

4) BIM software may provide real-time Fault Detection and Diagnostics (FDD), enabling more efficient energy power performance management throughout a building's life cycle. Such a BIM-based FDD technique establishes a scalable and adaptable data infrastructure that can be used in conjunction with other building energy analysis and simulation methods to accelerate the information exchange process. (Lu et al., 2017).

3.5.2 Lighting and Solar Radiation Analysis

Evaluating lighting effects on the interior and exterior of buildings is incorporated in BIM software. Additionally, BIM has a comprehensive radiation analysis module in grasping and optimizing the influence of sunlight on a building. Firstly, BIM technology can analyze and visualize the sun's movement and position relative to a building model at any location and time, which allows the users to optimize the location and orientation of the project in the early design phase. Secondly, BIM software enables the assessment of solar gain and radiative transfer across the surfaces and facades of the building. The assessment outcomes may be shown and distributed at any stage throughout the building's thermal research. Thirdly, several BIM software applications, such as Revit, can simulate the effect of interior and external solar shading and compare the simulated results to the desired design. Following that, the comparison may aid designers in picking appropriate shade schemes. To replicate the external conditions more completely, BIM software such as Autodesk Insight Simulation enables users to manually select unique properties such as the luminance level (Khan, 2019).

3.5.2.1 Thermal Comfort Analysis

The Integrated Environmental Solutions-Virtual Environment (IES-VE) organization demonstrates how thermal simulations evaluate the buildings with comfort challenges, such as overheating and underheating and pinpointing the source of comfort issues. In addition, BIM applications include various sensors that can help with thermal comfort optimization during the design stage. Similarly, by utilizing Revit models, IES-VE has the power to simulate Fanger's predicted mean vote (PMV) and to predict the percentage of dissatisfied (PPD), both of which are commonly used to quantify thermal comfort, allowing for the assessment by comparing the simulation results to the standards' comfort requirements such as LEED (Sacks et al., 2018).

The BIM applications described above were built and developed for various sustainability evaluations, including lighting analysis and energy performance. Figure 33 shows the functionalities of BIM for green analysis (Jung & Joo, 2011). However, most of these apps are optimized for a single sort of study and are incapable of addressing others.

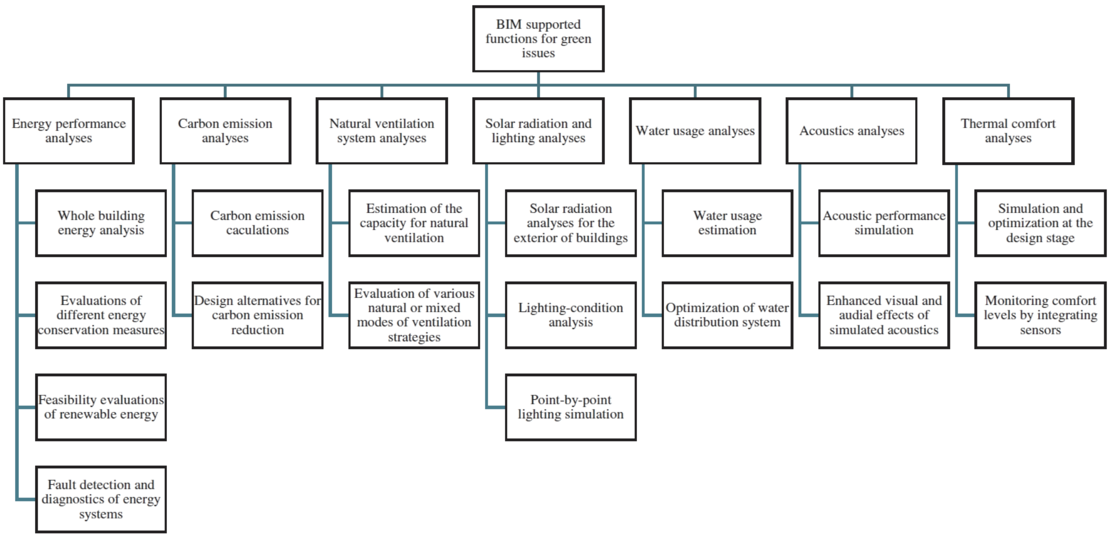


Figure 33: BIM Major Functions for Sustainability Analysis (Lu et al., 2017)

3.5.3 BIM-LEED Supported Green Building Assessments

While the majority of sustainable professionals recognize the value of LEED standards based on BIM calculation technologies for sustainable building design, popularizing these technologies faces several challenges. Current BIM software is insufficient for giving a comprehensive analytical solution for GBA since it cannot examine all green features of buildings concurrently. Due to BIM functionalities' restricted interoperability, certain analytical characteristics are tuned independently. Thus, BIM is currently restricted in its capacity to comprehensively analyze the environmental sustainability of buildings. The BIM software that not support some sustainable credits are mostly included management (for instance, in Green Star), ecological issues (for instance, in BREEAM), developed performance and procedures (for instance, in BEAM Plus, LEED, and Green Star), and transportation conditions such as in BREEAM. For example, it was discovered that BIM had trouble addressing the built environment's influence on ecosystems. (Subramaniam, 2018).

BIM has an important impact on GBA since it allows to simulate and test most of the required criteria on the building. LEED is one of the main systems of GBA that is used to enhance building sustainability. Table 3 shows the minimum support that BIM can provide to score the LEED v4.1 BD+C point. This shows that BIM can support a minimum of 74 points out of 110 LEED v4.1 points in different sections of new construction, which means BIM can support more than 74 points in the LEED v4.1 BD+C Scorecard (LEED v4.1, 2021).

Table 3: BIM – supported green building assessments, LEED v4.1 BD+C related points (Retrieved from LEED v4.1, 2021)

Name of GBA **Country of practices** **Total Points**	**LEED v4.1 BD+C** **USA** **110 Points**
Sustainable sites supported by BIM	Minimum support 8/10 points
Water LEED score supported by BIM	All 11 water credits
Energy and atmosphere or emissions supported by BIM	Minimum support 29/33 points
Materials and resources supported by BIM	All 13 points
Indoor environment quality supported by BIM	Minimum support 12/16 points
Innovation supported by BIM	Minimum support 1/6 points
BIM – supported other related points	Regional priority credit (3.6% of total 4 points)
BIM – supported LEED v4.1 point	**Minimum support 74/110 total points**

3.6 Building Energy Simulation and Optimization

BIM tools contain several functions, such as retrieving geometry directly from the primary model, automatically assigning material characteristics to each study, and saving, updating, and applying loading parameters for each analysis. These characteristics are critical to BIM's fundamental promise of eliminating the need for further data entry for different analyses, permitting the model to be reviewed instantly and with exceptionally short cycle times. The major BIM software vendors have achieved this by including engineering analysis tools such as energy, structural, and so forth into their product suites and offering these capabilities via platform-level programming. Internally, several BIM platforms preserve dual representations. For example, Autodesk Revit augments the actual representation of fundamental structural engineering objects such as walls, beams, columns, and slabs with automatically created idealistic "stick-and-node" representations (Li et al., 2020).

3.6.1 Parametric Simulation

Parametric simulation offers energy solution optimization based on many design parameters. Zhang and Korolija (2010) developed a scripting tool for generating 34,560 simulation test runs using variable insulation, glazing, and climatic data for a building design. The energy performance of all the simulated data may then be compared. This volume of labor is difficult to complete manually (Zhang and Korolija 2010). The simplified modeling approach illustrated in Figure 34 is incorporated into the overall architectural design process, including schematic design, conceptual design, construction documentation and design development through BIM.

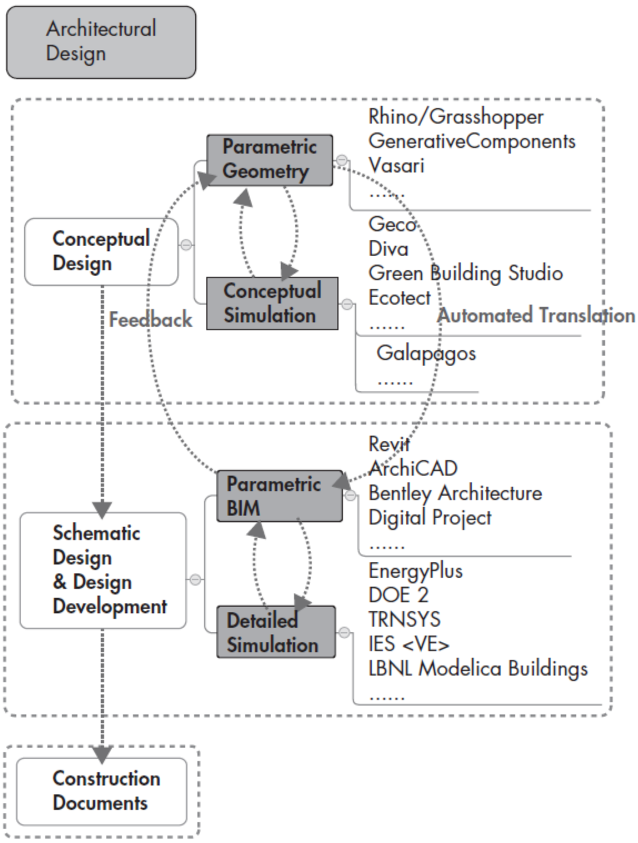


Figure 34: Streamlined parametric BIM and building energy process (Noble & Karen M, 2014)

Several energy simulation programs are available, including Ecotect, Autodesk Insight, TRNSYS, ESP-r, EnergyPlus, IES<VE> and DOE2. These tools provide daylighting, thermal, and/or BIPV modeling functions, as well as shading analysis.

3.6.2 Daylighting and Thermal Simulation Application

The project developed Revit2Modelica—a prototype for mapping BIM to thermal modeling utilizing the Revit API and the LBNL Modelica Buildings library. The prototype can generate a building energy model file in Modelica using BIM data (geometry, location and materials), start the simulation, and output results that include heat flow through each building component, room temperatures, and yearly cooling and heating loads (Wetter 2009). Figure 35 shows these workflows of the BIM process by different BIM programs: Revit, Modelica, and Radiance to achieve the daylighting and thermal simulation.

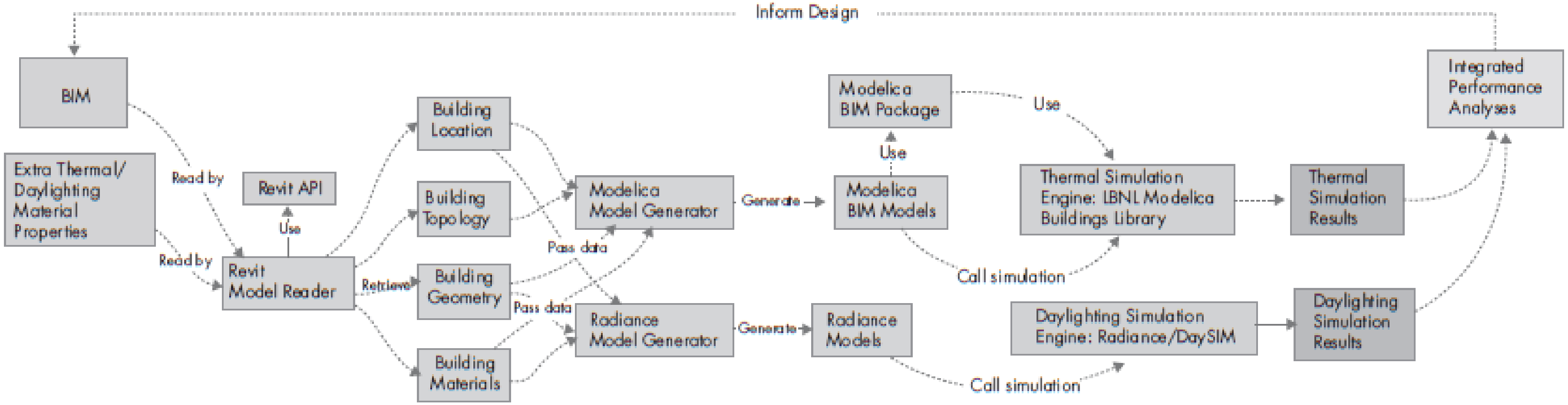


Figure 35: Thermal and Daylighting Simulation Workflow Through BIM (Noble & Karen M, 2014)

Regarding BIM technology, as an example of daylight simulation by BIM, a team developed Revit2Radiance, a BIM to daylighting prototype utilizing the Revit API. The prototype extracts the building surfaces in triangle meshes and other data required to generate Radiance and DAYSIM input files from BIM (geometry, materials, location, date/time, a camera view, and sensor points). After creating the input files, Revit2Radiance invokes Radiance and DAYSIM to perform daylighting simulations (Figure 36). The findings include illumination pictures made by Radiance, isolux contour plots, human sensitivity images, and yearly illumination data provided by DAYSIM. The simulation results are considered ASHRAE standard 140 BESTEST case 600 (Kota et al., 2014).

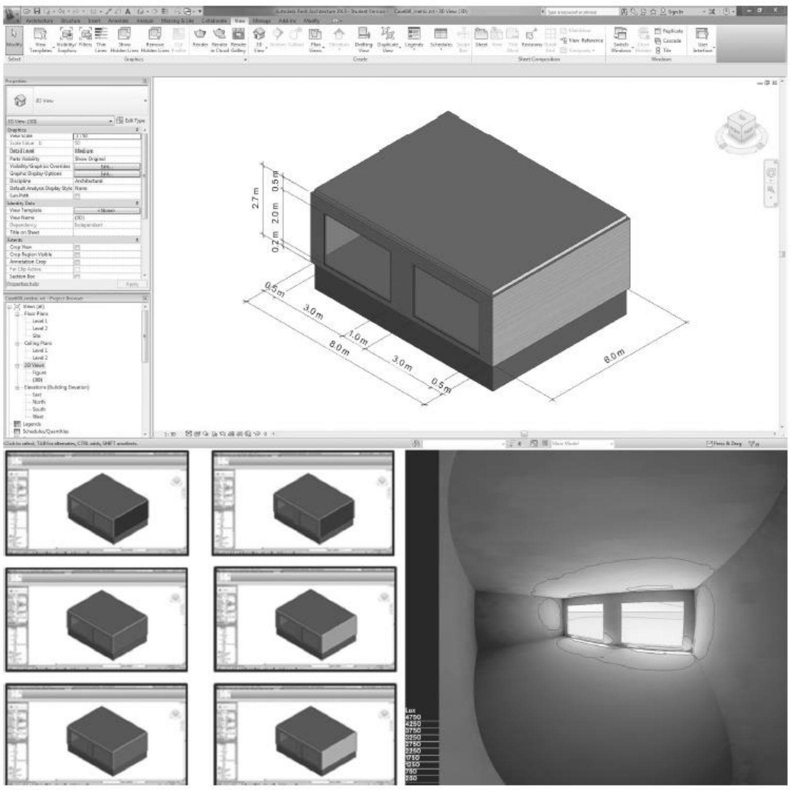


Figure 36: Daylighting and Illumination Simulation Test of a Studied Unit (Kota et al., 2014)

3.6.3 Energy Optimization Application

A parametric BIM-based solution is being developed to enhance building energy performance utilizing cloud resources. It leverages Autodesk Revit for BIM creation and Green Building Studio (GBS) with cloud computing for daylighting and thermal simulations to enhance current functionality in the two applications. The prototype allows the parametric simulation to discover the best answer for the project's many goals. Everything from BIM to parametric simulations is controlled by a single Revit plug-in called Revit2GBSOpt, Revit to Green Building Studio. Revit2GBSOpt generates gbXML files from a BIM model and uploads them to GBS in the cloud through the web to perform efficient energy studies. Then it obtains the energy simulation data and determines the best solution (Asl et al., 2013)

The purpose of this sample seen in Figure 37 is to discover the optimal window size for decreasing building energy use while getting the LEED daylight credit. A parametric window family with width and height attributes is constructed to generate design options. Revit2GBSOpt generates a range of values for these two parameters based on user input. The window's two parameters may be changed to produce 54 design choices. This tool creates gbXML files for all design possibilities. The BIM model's location and type are used to establish a new GBS project. Each design choice has its GBS base run and gbXML file. GBS then simulates in the cloud. Revit2GBSOpt gets the findings from GBS. The optimal window size is determined by building energy expenses and LEED daylight outcomes, written at the bottom of Figure 37. In this situation, increasing the window area raises the building energy cost. The approach is to design with a minimum window size that obtains LEED credit (Asl, 2015).

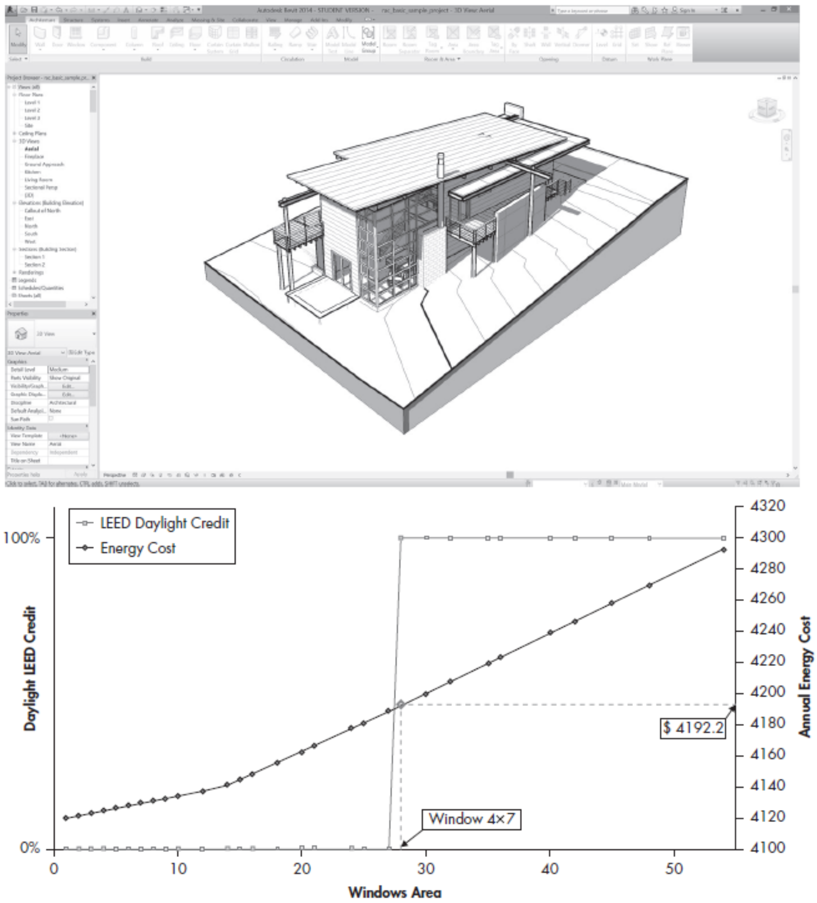


Figure 37: Parametric Windows Sizes Optimization to Minimize the Energy Use Regarding LEED Daylighting Credit by Revit (Retrieved from Asl, 2015)

3.7 Chapter Summary

BIM is a wide term of technology that involves all aspects and professions of the building cycle, which is important to focus on the required areas. The research explained the general definition and concept of BIM from two different terms: BIM as technology and as a process. Later on, the research focused on the main feature of BIM, parametric BIM. Simply, parametric BIM means that all the building data, processes, simulations, and applications are linked, producing accurate building results from all dimensions. To use this feature for the enhancement of façade regarding daylight, the research highlights the benefits of BIM, which allows to figure out two main needs that the research required. BIM design benefits are the building sustainability improvements and accurate visualization of design that serve the façade design by BIM support. The research will use the accurate visualizations of design through BIM parametric to input all building data, climate data, drawing and analysis linked to each other. It will highlight the lighting and solar radiation and, through building sustainability improvements to the BIM-LEED supported GBA. The aim of this approach will let the research result of daylighting simulation and optimization, as seen in Figure 38, through the BIM parametric simulation, which allows optimizing the building façade regarding the outcomes of the first chapter. The highlighted sections in Figure 38 represent the results of the chapter to serve the research aim.

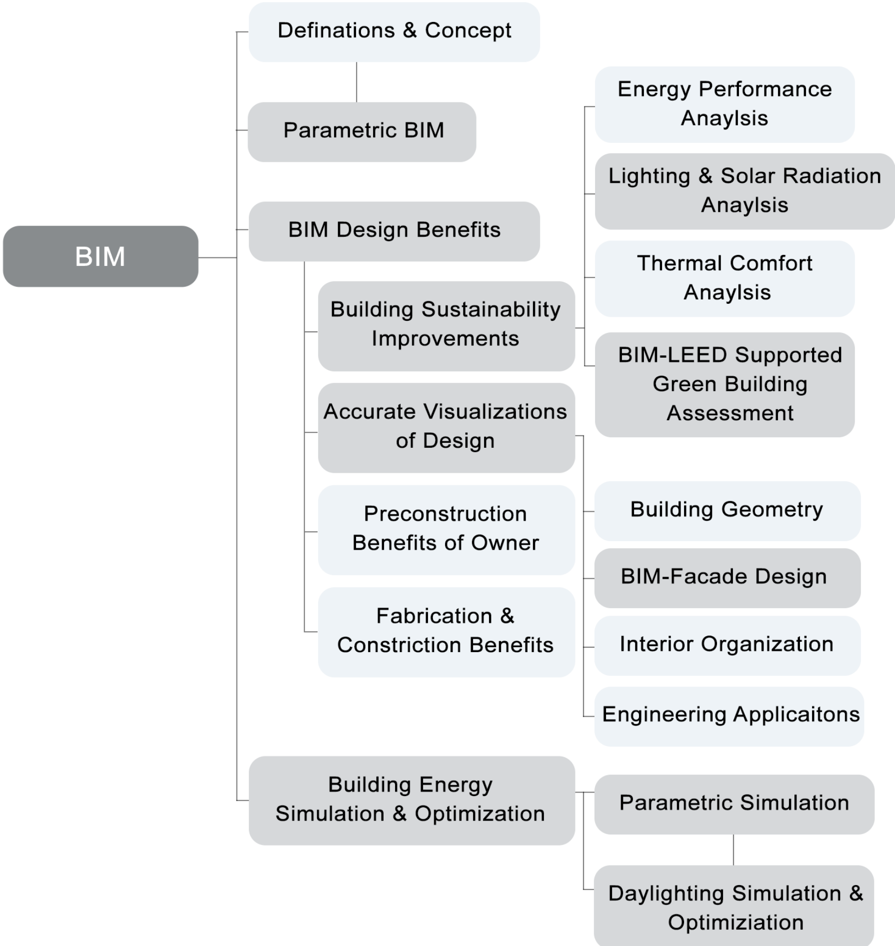


Figure 38: The Workflow of Building Information Modeling (BIM) Chapter (Author, 2021)

Chapter 4

CASE STUDY OF OFFICE BUILDING IN AMMAN, JORDAN

4.1 BIM-Based Data Collecting Method

The evaluation of the case study conducted by observations through the field study with all real measurements beside a computer stimulation to conduct the building performance in digital data, BIM platform has been applied by Autodesk Revit 2020 to have based drawing linked to each other such as plans, elevations, sections and 3-dimensional model. Therefore, small changes in one of the views will create the same changes in the other views. The author draws the case study in Autodesk Revit 2020 based on a working drawing of each floor plan with initial considerations which affect the daylight, such as importing all the climate data, location, orientation, transparent sizes and building envelope characteristics to do accurate analysis, simulation and optimization in one platform only. Therefore, all the following data will be conducted by BIM parametric method through Revit.

4.2 Location Data Findings

Jordan is a small country located in the Middle East of Asia (31° Latitude, 36° Longitude) (Figure 39), where the climate ranges from more Mediterranean climate to desert climate with an arid climate. However, the capital city Amman which is located in a semi-arid climate has temperature rises above 30 °C during the hottest months in the summer season, and temperature decreases to 2 °C during the winter season in

Figure 40. Amman is sunny 82.2% of daylight hours since the sunlight average per year has 3602 hours of a possible 4383 hours (URL 11).

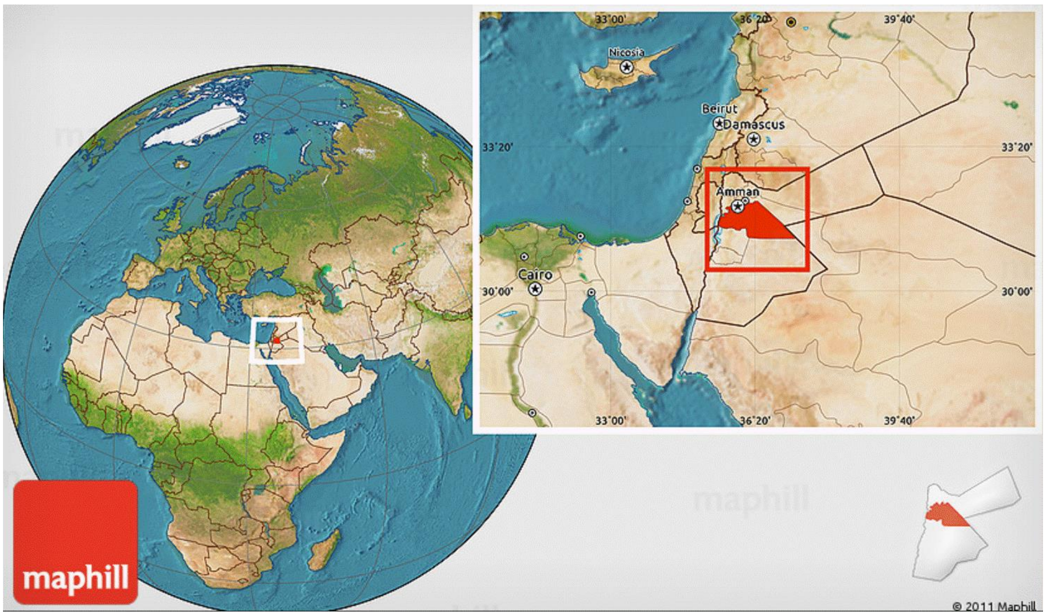


Figure 39: Field Study Location, Amman Jordan (URL 10)

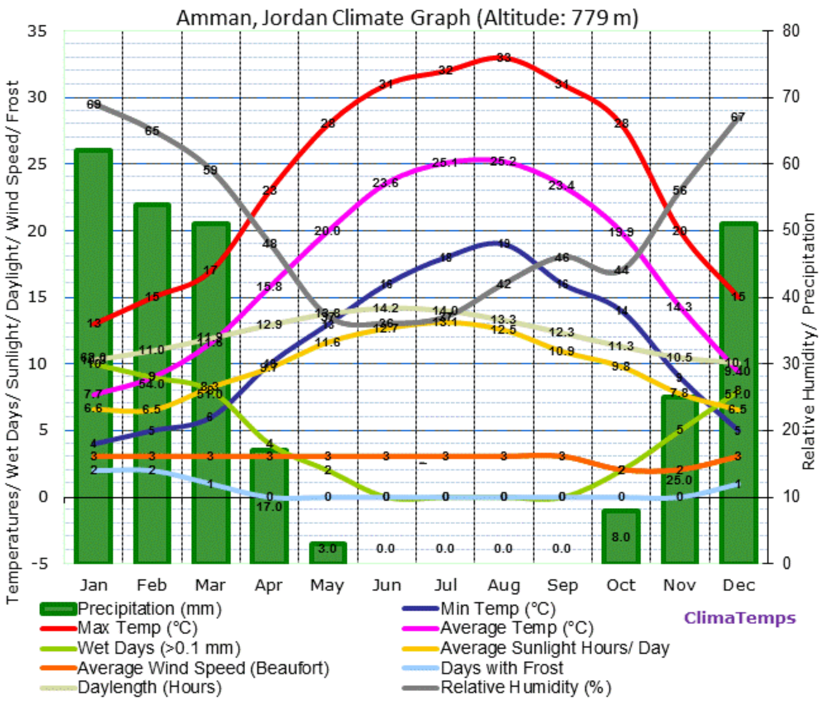


Figure 40: Amman, Jordan Climate Graph (URL11)

4.3 KPMG Office Building

The building is an office building done by the Jordanian Engineers Association as an investment project and rented to KPMG International Limited, one of the big four accounting organizations in the world. The office building is located in Amman at (31.97° Latitude, 35.9° Longitude) and is oriented 7° to the North, as shown in Figure 41. The building is formed by a rectangular plan approach with 5301.39 m^2. In vertical consideration, the building contained a huge core placed on the middle of the east side, and it has the main staircase, shafts, elevators, storage, and WCs. On the other hand, the building has two basement floors followed by a ground floor and eight floors of offices, topped with a service floor.

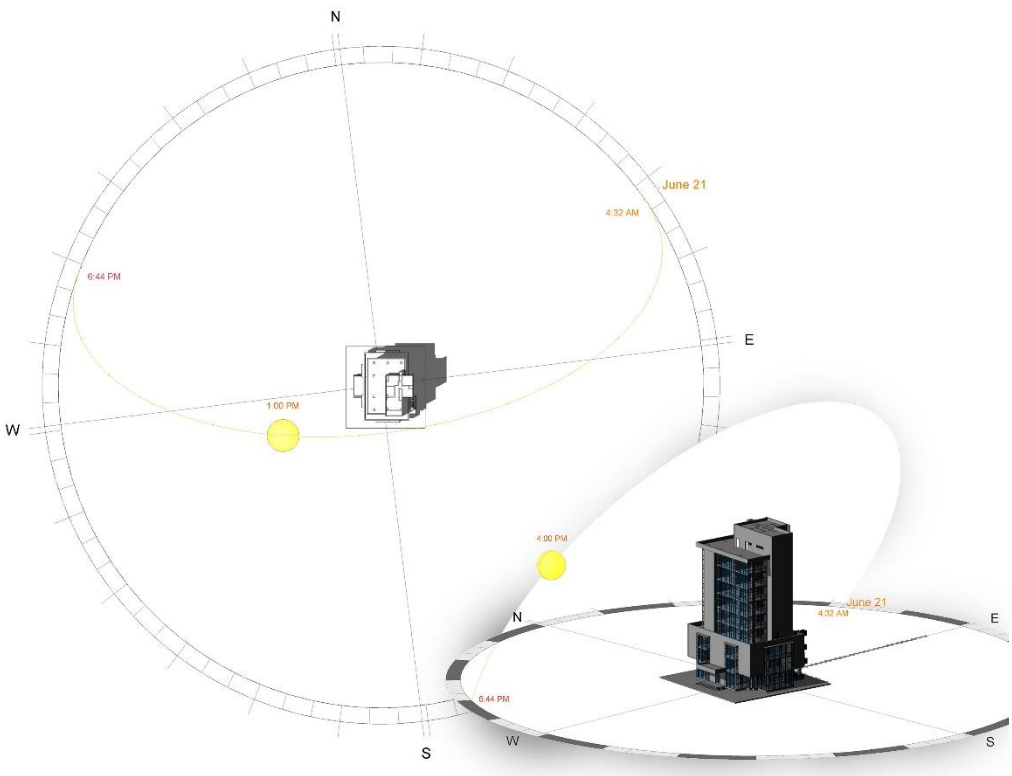


Figure 41: KPMG Building Orientation to the North with Sun Movement (Author, 2021)

The ground floor of 411.92 m2 has the main lobby, and big halls are located, one to the north with a back-entrance door and one at the south side, as seen in Figure 42. In Figure 43, the first, second and third floors share a typical floor of offices and meeting rooms used by the Jordanian Engineers Association and the rest floors from the fourth till the eighth-floor share another typical floor plan of 256.92 m^2 each, of offices, have used by KPMG as shown in Figure 44.

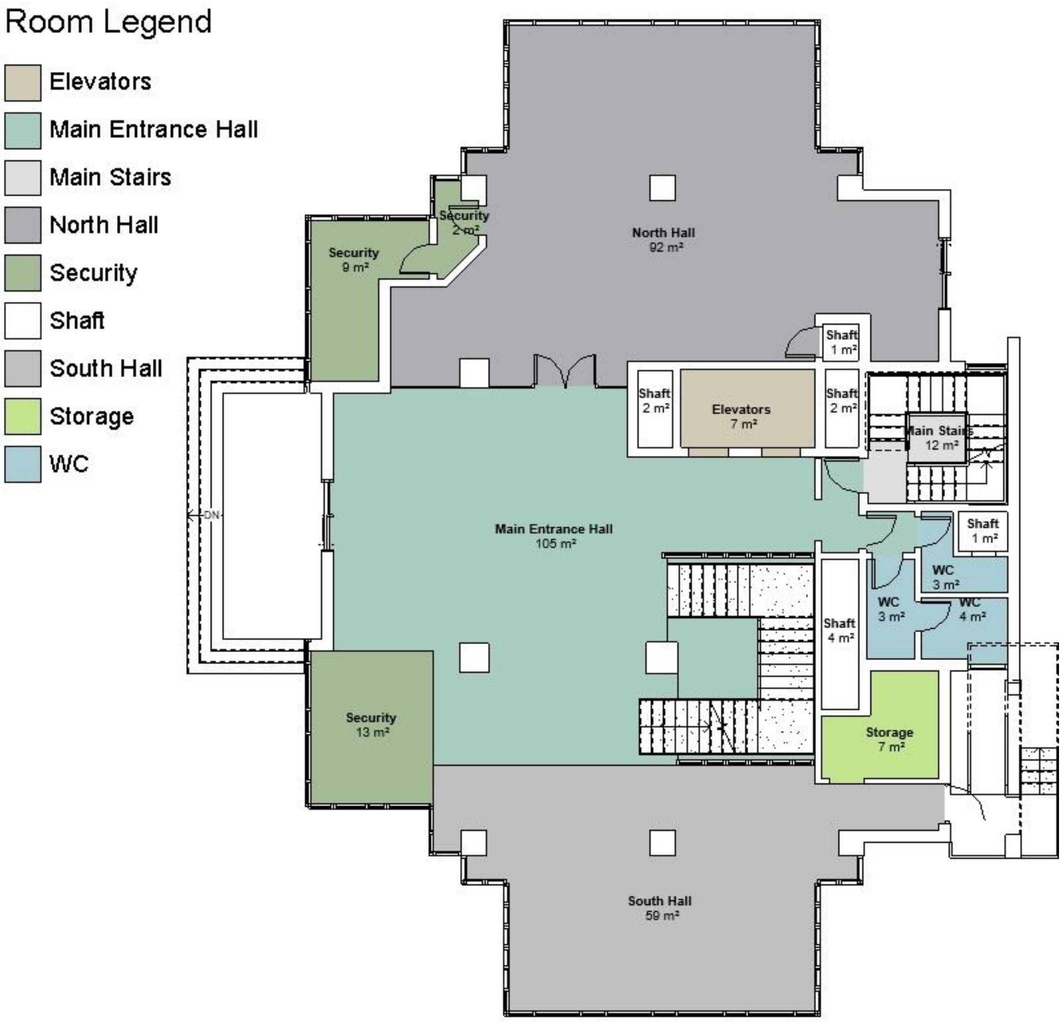


Figure 42: Ground Floor Plan of KPMG Building on Level +0.50 (Author, 2021)

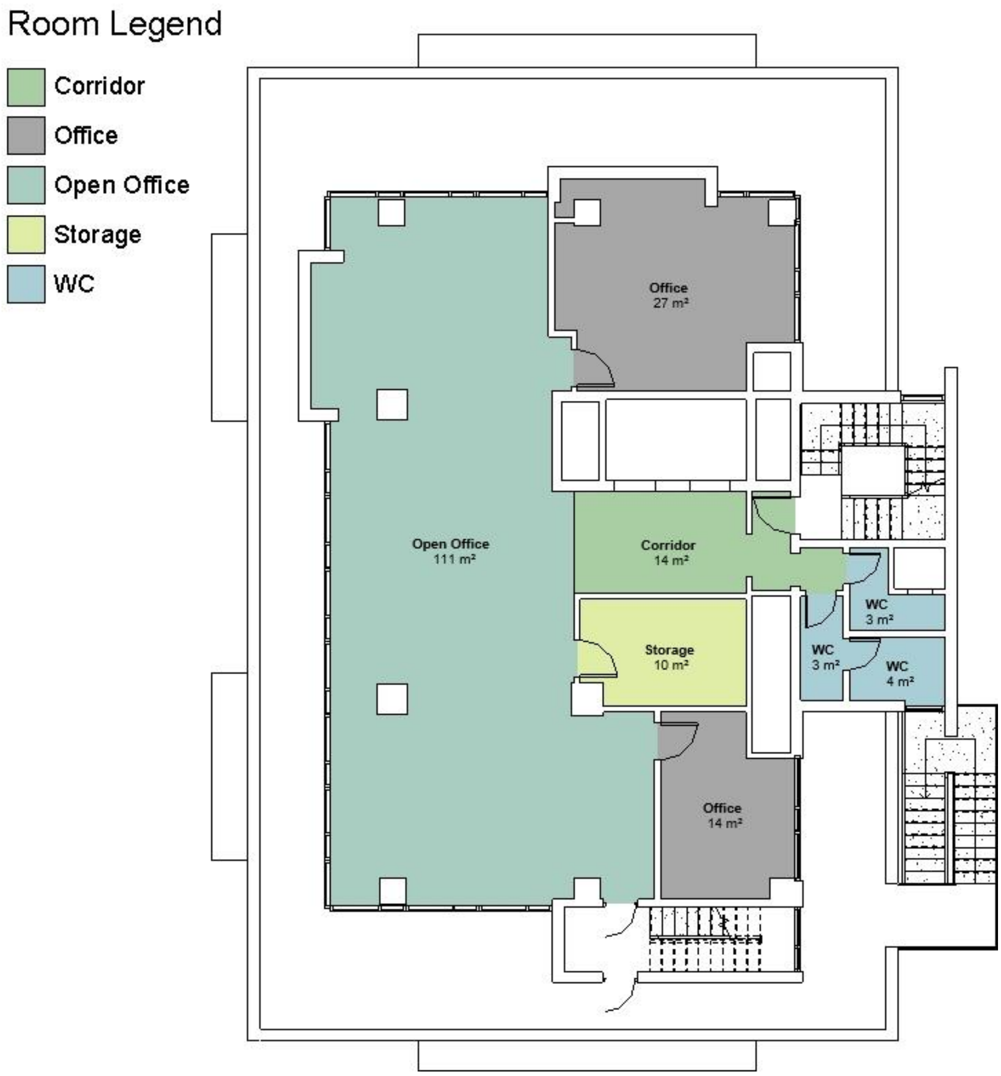


Figure 43: Level +11.81 Floor Plan of KPMG Building (Author, 2021)

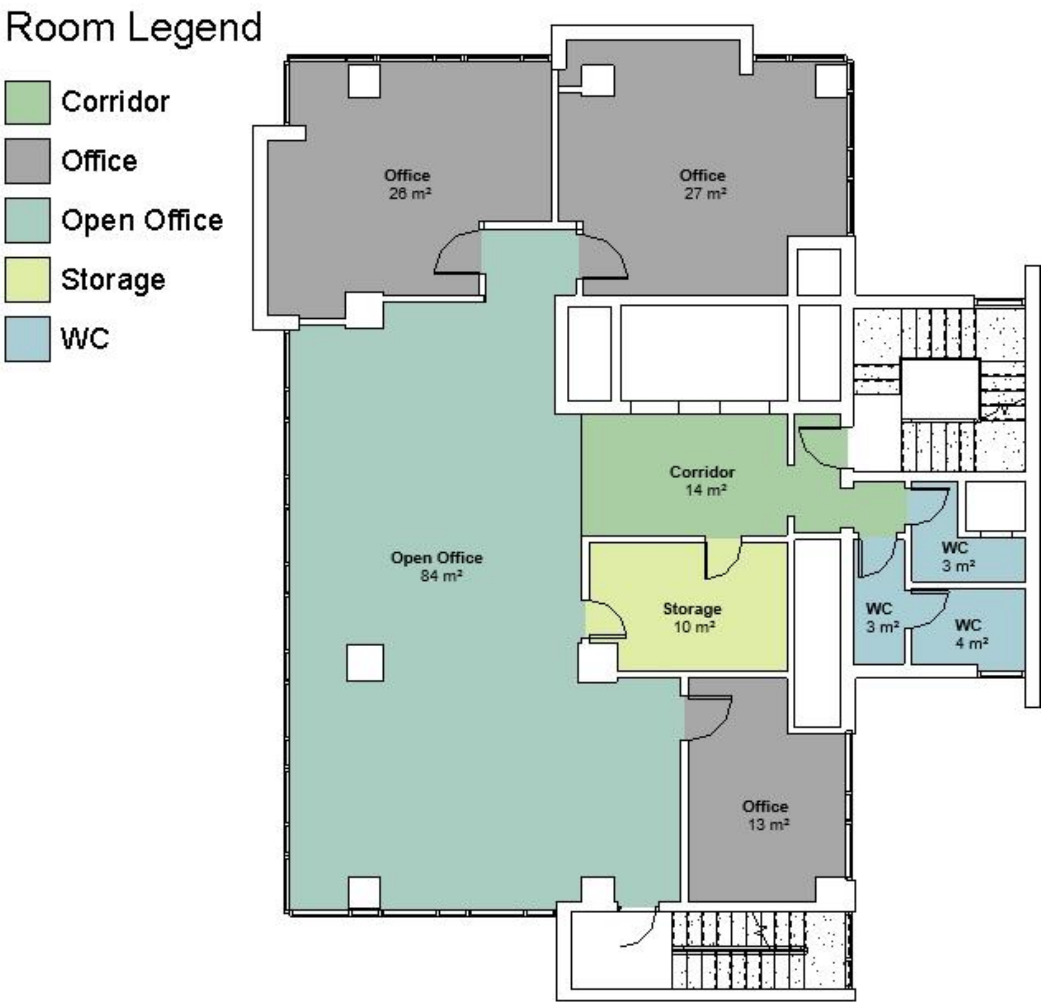


Figure 44: Level +21.95 Floor Plan of KPMG Building (Author, 2021)

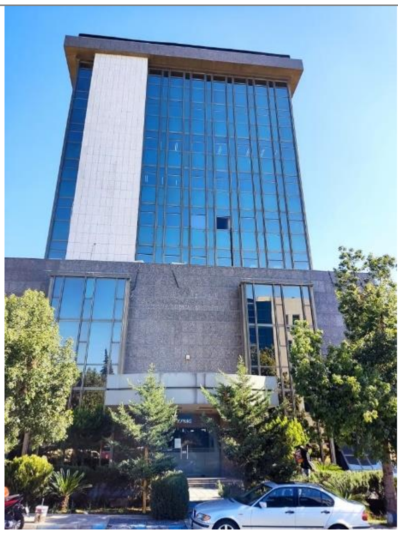
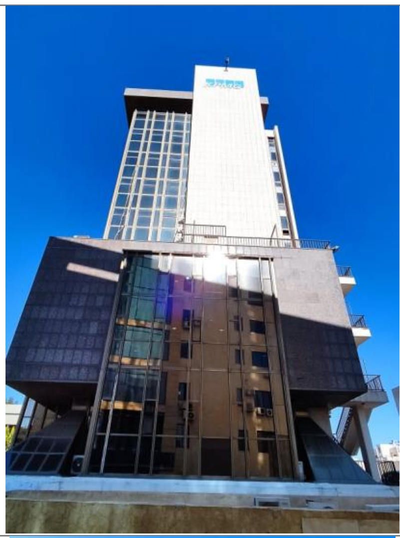
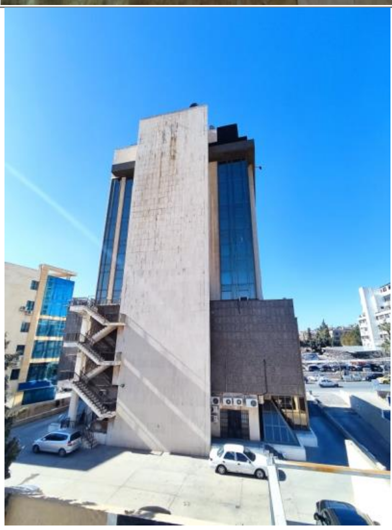
4.4 Evaluation by Field Observation of KPMG Building

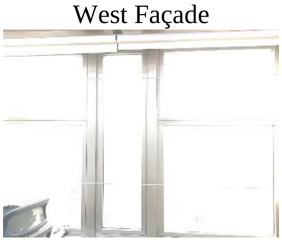
The observation has been done through field surveying by the author to match the study into the realistic condition and understand the main daylight problems. For that, different pictures have been taken to sort out the results, as seen in Table 4. There were some difficulties facing the author from taking more clear pictures from the inside due to the regulation of the KPMG since it is an accounting organization that has private data for many clients.

The results in Table 4 show that there are few shading effects by the surroundings on the façade since only one building is near from KPMG building at the south façade besides a big transparency ratio to the wall without external shading devices. Therefore, most of the daylight is passing into the building, affecting human comfort in terms of daylight, such as high illuminance. In addition, the overheating during the summer and glare problems to the building users and the public by the reflected sunlight of the façade as seen in the South elevation photo.

Table 4: Collected data through observation from a field study

Position	Observation Photos	Observed Facts and Indicators
North Elevation		-Transparency to wall ratio in total is 52% -Transparency to wall ratio over the 3rd floor is 58% -No usage of external shading devices -No shading effect by the surrounding context to the façade -Double glazing used for the windows -Closed offices are located to the façade

West Elevation		-It is the main façade that faces the street -Transparency to wall ratio in total is 51.5% -Transparency to wall ratio over the 3rd floor is 76% -No usage of external shading devices -Drops of shading effect by the trees to the façade below the 3rd floor. -Double glazing used for the windows. -Open offices are located on the façade.
South Elevation		- The lowest usage of façade -Transparency to wall ratio in total is 46.5% -Transparency to wall ratio over the 3rd floor is 44% -No usage of external shading devices -Shading effect by 5 floors height adjacent building -Double glazing used for the windows. -Small side of open offices and fire staircase are located to the façade over the 3rd floor.
East Elevation		-The lowest openings usage -Transparency to wall ratio in total is 30% -Transparency to wall ratio over the 3rd floor is 44.5% -No usage of external shading devices -No shading effect by the surrounding context to the façade. -Double glazing used for the windows. -Services and the core are located to the façade besides 2 closed offices on each side.

Interior	 West Façade at 4 pm  South Façade at 1 pm  West Façade  Brightness ratio	-All sides have the same treatment from the interior side. -Glare problems occur most of the time -Roller blinds with a transparent percentage are used as internal shading devices -A surrounded interior wall of 65cm approximately is placed on the glass which blocks the daylight within its height -A Suspended ceiling with 70cm approximately is blocking the daylight at the top of the floor -High brightness ratio occurs regarding to the size of the opening.

To evaluate the building with an exact result the observation results give consideration to run a realistic simulation as it is shown in the following sections.

4.5 BIM-Based Simulation Method

BIM technology by Autodesk Revit 2020 provided a digital copy of the case study that included all architectural drawings and 3D views as it has existed in a BIM parametric manner, which allows linking all drawings, objects and weather data to each other in one file. The BIM process of the final result is based on entering building envelope parameters and drawing the building geometry and openings sizes according to working drawings provided by Jordanian Engineers Association. Later on, the BIM process through Revit has been continued by entering the exact location (altitude and latitude), original orientation to the north angle and weather file data, and the solar sun path of the studied field to produce an accurate quantitative analysis regarding daylight.

Autodesk Insight has employed the simulation analysis of the case study through the Revit platform as a plug-in that allows the simulation to be done on BIM parametric objects. Therefore, the simulation is connected to each object in Revit, such as walls, windows, and shading devices, to manipulate the elements of shading devices to meet the standards and LEED criteria of daylight without the need to create new files. Autodesk Insight allows many simulations of building energy based on different sittings regarding required standards and criteria.

The daylight simulations that have been applied to the case study are considered two categories by the author based on the research study. The first category is based on manipulating the simulation settings to meet a required threshold. An illuminance simulation was done on the case study by limiting the simulation sitting to have a threshold between (100 lux – 1800 lux) then applied to the building to know where the glare occurs in the building since glare occurs over 1800 lux, as is mentioned in the research before. One more simulation has been done under the first category: daylight factor (DF) simulation with a manipulated sitting by entering a limitation of (2-5%) DF since it is the required threshold for the office building, as mentioned before.

The second category is based on LEED's latest criteria, where the simulation settings are fixed. This category included two simulations: spatial daylight autonomy (sDA) and LEED 2009 IEQc8.1 illuminance stimulation to know how many points the optimization can score regarding LEED. Autodesk insight allows a qualified LEED simulation since it gives the score results by LEED.

BIM as a technology through Autodesk Insight simulations allows importing the outcomes into the same BIM platform (Autodesk Revit) with different views to link all data in the same file. The outcomes imported into 3D view, plan view and scheduled report into the same file which will be shown in the following paragraphs.

4.6 Evaluation by Simulation Analysis of KPMG Building

Since it is an existing building, the research will test the occupied areas and daylight that passes the building through transparent openings on the façade considering a clear sky in the summer season, mainly regarding Jordan climate conditions, excluding the usage of the material. The simulation will take place at the sixth-floor plan on level +21.95 m since it is a typical plan that does not affect the surrounding building and has the highest percentage of transparency compared with the first four floors.

The main consideration is usually taken for any building regarding this topic is to check the availability of daylight inside the building, which KPMG building will not face any problem with it since it has a huge transparent opening which occurs several problems to the human comfort such as glare problems, illuminance problems, overheating and thermal problems.

4.6.1 Daylight Factor (DF) Simulation of KPMG Building

To determine the useful daylight distribution inside the building, daylight factor (DF) simulation will take place regarding the studied data, which shows that DF should be between 2% to 5% to offer a good balance of thermal and lighting factors (Energy, 2012). Figure 45 shows the DF simulation with the same sittings on 32-inch (81.28cm) plane height which meets the useful daylight requirements regarding to an office building user.

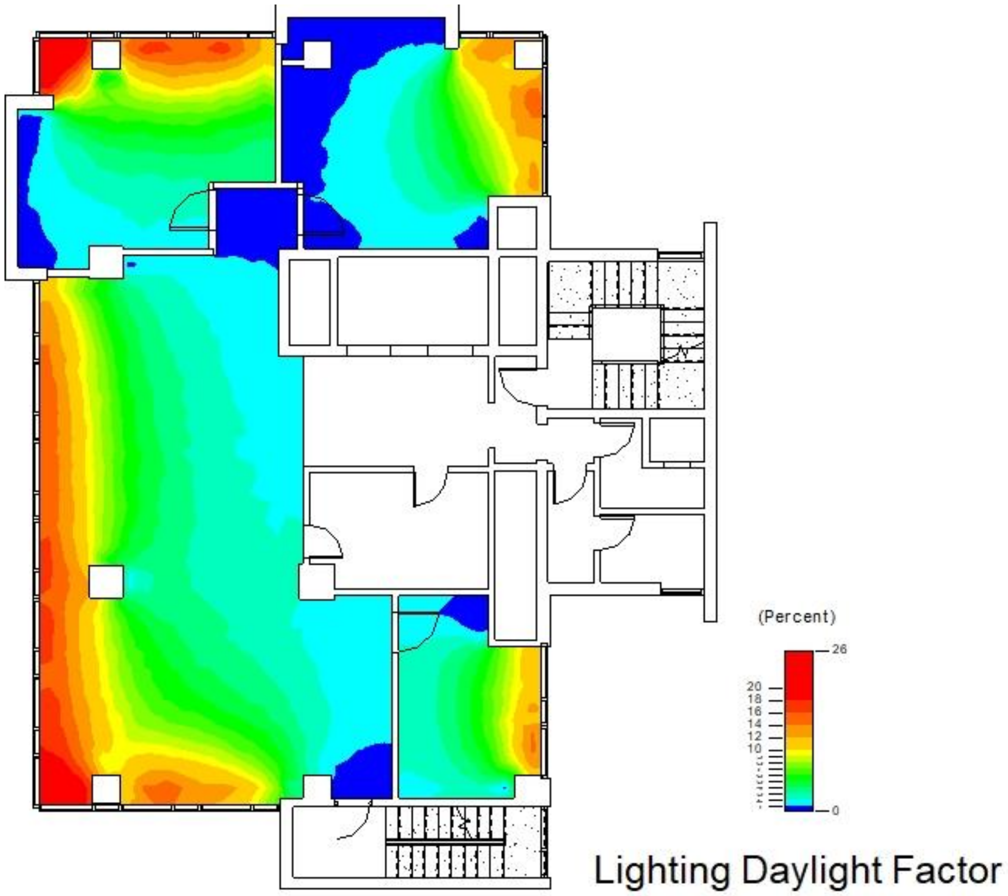
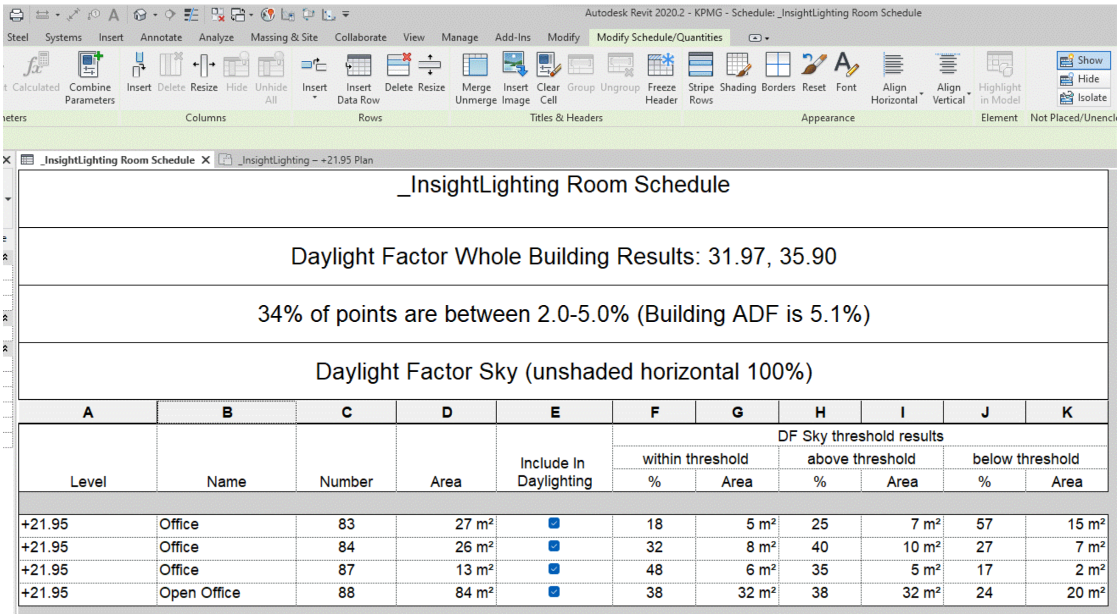


Figure 45: Daylight Factor Plan Stimulation of KPMG Building (Author, 2021)

The BIM technology gives a numerical result in a scheduled report linked in the same Revit file by Autodesk Insight plug-in for each function, as is seen in Figure 46. For instance, the result summary showed that only 34% of the simulated area is passing between 2% to 5% for a standard day. Therefore, 30% is below the threshold and 36% above the threshold. This means the daylight distribution does not meet the balanced percentage of daylight although, it meets the daylight availability percentage.



_InsightLighting Room Schedule

Daylight Factor Whole Building Results: 31.97, 35.90

34% of points are between 2.0-5.0% (Building ADF is 5.1%)

Daylight Factor Sky (unshaded horizontal 100%)

A	B	C	D	E	F	G	H	I	J	K
					DF Sky threshold results					
					within threshold		above threshold		below threshold	
Level	Name	Number	Area	Include In Daylighting	%	Area	%	Area	%	Area
+21.95	Office	83	27 m²	☑	18	5 m²	25	7 m²	57	15 m²
+21.95	Office	84	26 m²	☑	32	8 m²	40	10 m²	27	7 m²
+21.95	Office	87	13 m²	☑	48	6 m²	35	5 m²	17	2 m²
+21.95	Open Office	88	84 m²	☑	38	32 m²	38	32 m²	24	20 m²

Figure 46: Daylight Factor Results Schedule of KPMG Building (Author, 2021)

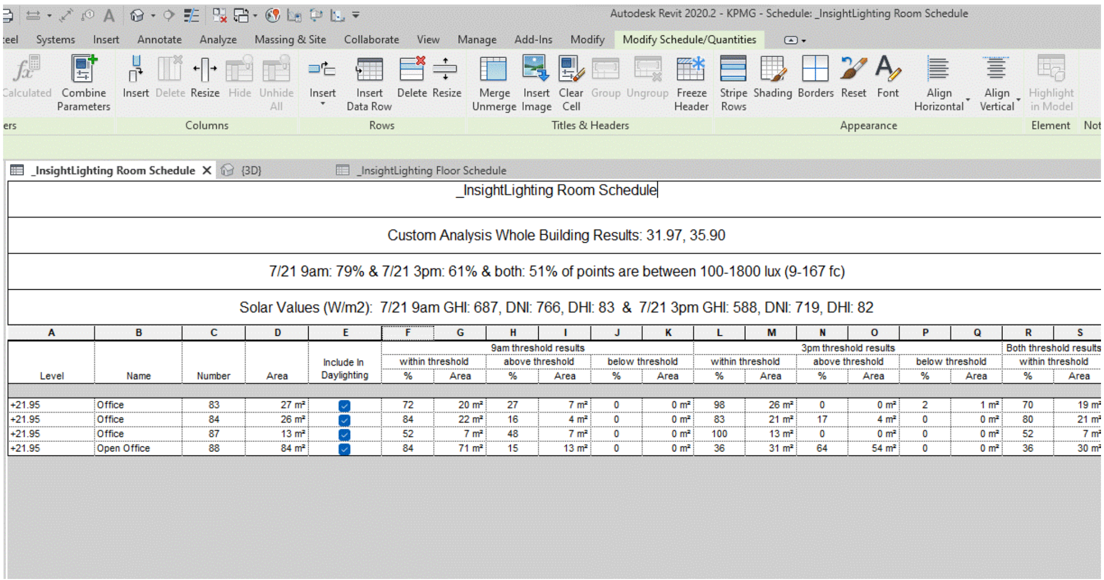
4.6.2 Glare and Illuminance Simulation of KPMG Building

Regarding the studied data, the glare occurs above 1800 lux and between 200 lux to 600 lux is the recommended level of illuminance for offices besides 100 lux to 300 lux for computer-based operation (Correia et al., 2012). Figure 47 shows illuminance plan simulation that done to the existing case on 32-inch (81.28cm) plane height with 100 lux to 1800 lux illuminance range considering two different hours which are 9:00 am and 3:00 pm on 21st of July since the most daylight is passing highly through these hours at the east and west façade which has the highest ratio of transparent opening.

The illuminance range near the openings exceeds 5000 lux which causes high glare problems besides discomfort illuminance zone regarding the daylighting levels.

Figure 47: Illuminance Plan Stimulation of KPMG Building (Author, 2021)

The results summary in Figure 48 shows that at 9:00 am, 79% of the simulated area is passing the range (100 – 1800 lux) with no points below the threshold and 21% above it. At 3:00 pm, 61% points are between the range with no points below the threshold and 39% above the threshold. Total both times 51% of the simulated area passes within the threshold, 1% either time below the threshold and 48% or time above the threshold.



_InsightLighting Room Schedule

Custom Analysis Whole Building Results: 31.97, 35.90

7/21 9am: 79% & 7/21 3pm: 61% & both: 51% of points are between 100-1800 lux (9-167 fc)

Solar Values (W/m2): 7/21 9am GHI: 687, DNI: 766, DHI: 83 & 7/21 3pm GHI: 588, DNI: 719, DHI: 82

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
					9am threshold results						3pm threshold results						Both threshold results	
				Include In Daylighting	within threshold		above threshold		below threshold		within threshold		above threshold		below threshold		within threshold	
Level	Name	Number	Area		%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area
+21.95	Office	83	27 m²	☑	72	20 m²	27	7 m²	0	0 m²	98	26 m²	0	0 m²	2	1 m²	70	19 m²
+21.95	Office	84	26 m²	☑	84	22 m²	16	4 m²	0	0 m²	83	21 m²	17	4 m²	0	0 m²	80	21 m²
+21.95	Office	87	13 m²	☑	52	7 m²	48	7 m²	0	0 m²	100	13 m²	0	0 m²	0	0 m²	52	7 m²
+21.95	Open Office	88	84 m²	☑	84	71 m²	15	13 m²	0	0 m²	36	31 m²	64	54 m²	0	0 m²	36	30 m²

Figure 48: Illuminance Results Schedule of KPMG Building (Author, 2021)

Regarding LEED 2009 IEQc8.1 criteria, the building did not score any point since 68% of the area is passing within 10 to 500 food candles (107.64 – 5381.96 lux) in total equinox at the same both times. The building passed the required level at 9:00 am since 93% of the total area is passing within the threshold. Whereas, at 3:00 pm only 74% of the simulated area is passing since 1% below the threshold and 25% above the threshold (Figure 49).

<_InsightLighting Floor Schedule>																
LEED 2009 IEQc8.1 Whole Building Results: 31.97, 35.90																
9am: 93% within & 3pm: 74% & both: 68% within thresholds																
Solar Values (W/m2): 9/16 9am GHI: 594, DNI: 735, DHI: 84 & 9/16 3pm GHI: 420, DNI: 627, DHI: 80																
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
			9am threshold results						3pm threshold results						Both time results	
	Floor Area Included in Daylighting		within threshold		above threshold		below threshold		within threshold		above threshold		below threshold		within threshold	
Name		Total Floor Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area
+21.95	151 m²	151 m²	93	140 m²	6	10 m²	0	1 m²	74	112 m²	25	38 m²	1	1 m²	68	102 m²

Figure 49: LEED 2009 IEQc8.1 Illuminance Stimulation of KPMG Building (Author, 2021)

4.7 Façade Optimization of KPMG Building

Regarding the simulation results of the existing building, the KPMG building needs to be optimized by daylighting strategies to enhance the building performance regarding the studied daylight aspects. This research will propose a fixed shadings device based on solar geometry for different reasons: availability, ease of use and construction, low cost, and research limitation. Later on, the research will test the proposed solution through simulations by BIM technology to compare the results for better building performance.

4.7.1 Shading Devices Calculation Method

The fixed shading devices will be based on a manual calculation by converting the climate date regarding the hours and months of the field study based on (ANSI/ASHRAE/IES Standard 55-2021) from (Climate Consultant 6.0) software program to the summer solar sun path chart of the studied area by University of Oregon sun chart website (URL 10) as shown in Figure 50. Later on, the data was transferred into the shading protractor to determine the horizontal shadow angle (HSA) and the vertical shadow angle (VSA).

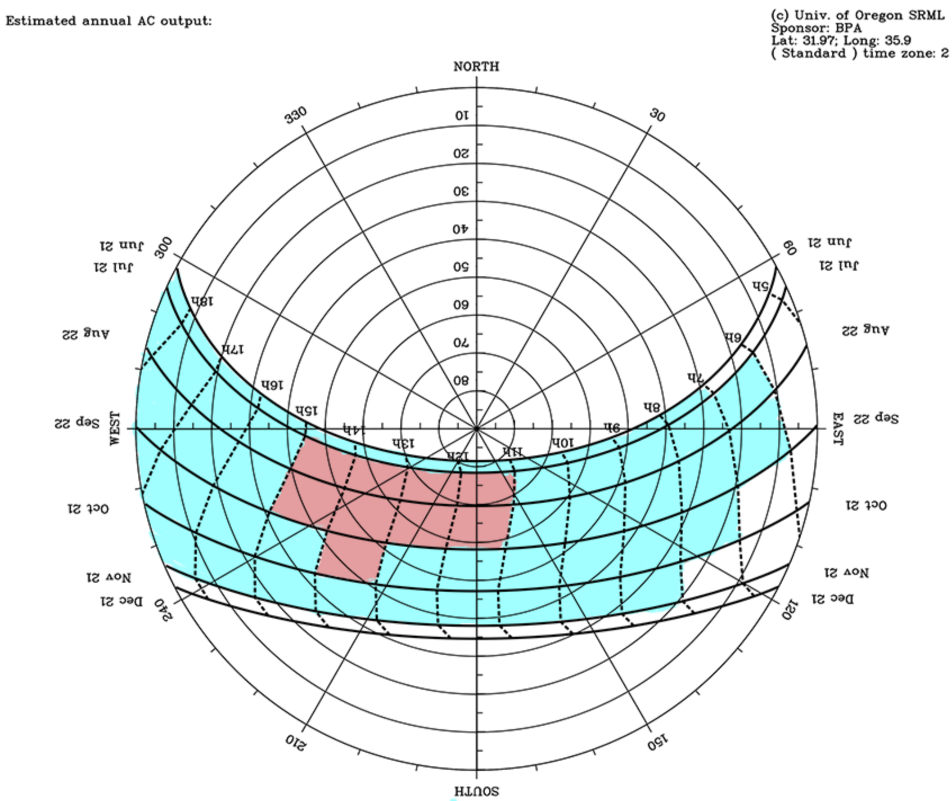


Figure 50: 2D Solar Sun Path Chart of The Summer at The Studied Field in Amman (Retrieved from URL)

4.7.2 Louvers and Fins Shading System Proposal

Based on the outcomes of the shading protractor through the solar sun path chart, the VSA will take place at 75^o degrees to give the shadow angle on the North and South façade by the louvers system, and the HSA will take place at 50^o degrees to support the East and West façade by the fins system (Figure 51).

Figure 51: 3D View of the Louver and Fins system at the West and South Façade (Author, 2021)

The installed shading devices are based on the HSA degree, which gives us the required measurements of the shading devices on the West façade by a plan supported with a detailed drawing. Figure 52 shows us the installed shadings on the South façade by a section view from the Revit program in a detailed drawing.

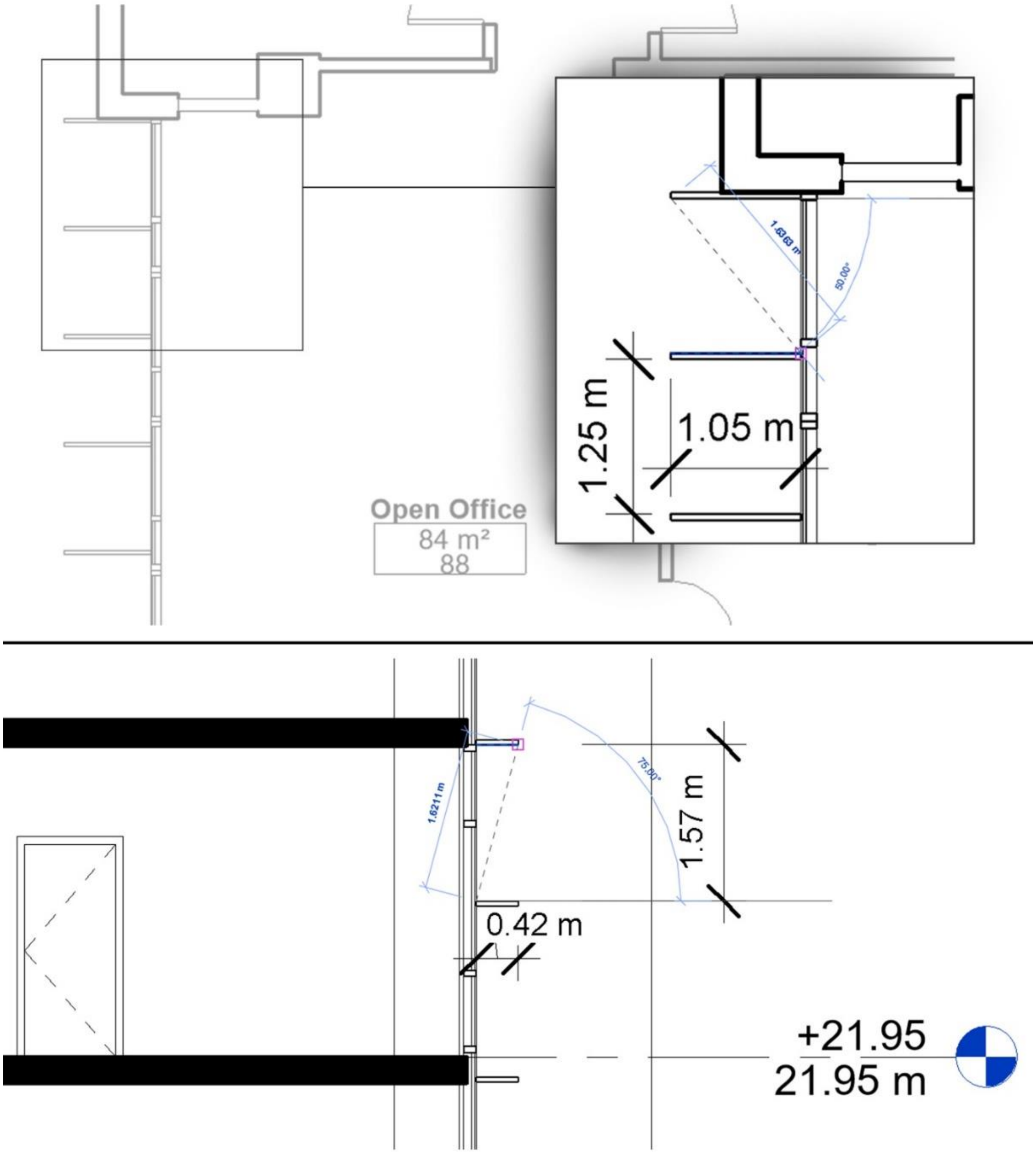


Figure 52:Detail Drawing of Louvers and Fins Shading Devices; (Top) Plan of Vertical Devices, (Bottom) Section of Horizontal Devices (Author, 2021)

4.7.2.1 Daylight Factor (DF) Simulation of Louvers and Fins

Based on the same criteria taken of the existing building simulation, the results showed that 41% of the total area that passes within the threshold was 37% below the threshold and 23% above the threshold. Therefore, the shading systems affected the building mainly by reducing the previous simulation of the KPMG building from 36% above the threshold to 23% above the threshold. In addition, greater daylight distribution is seen in the plan view in Figure 53.

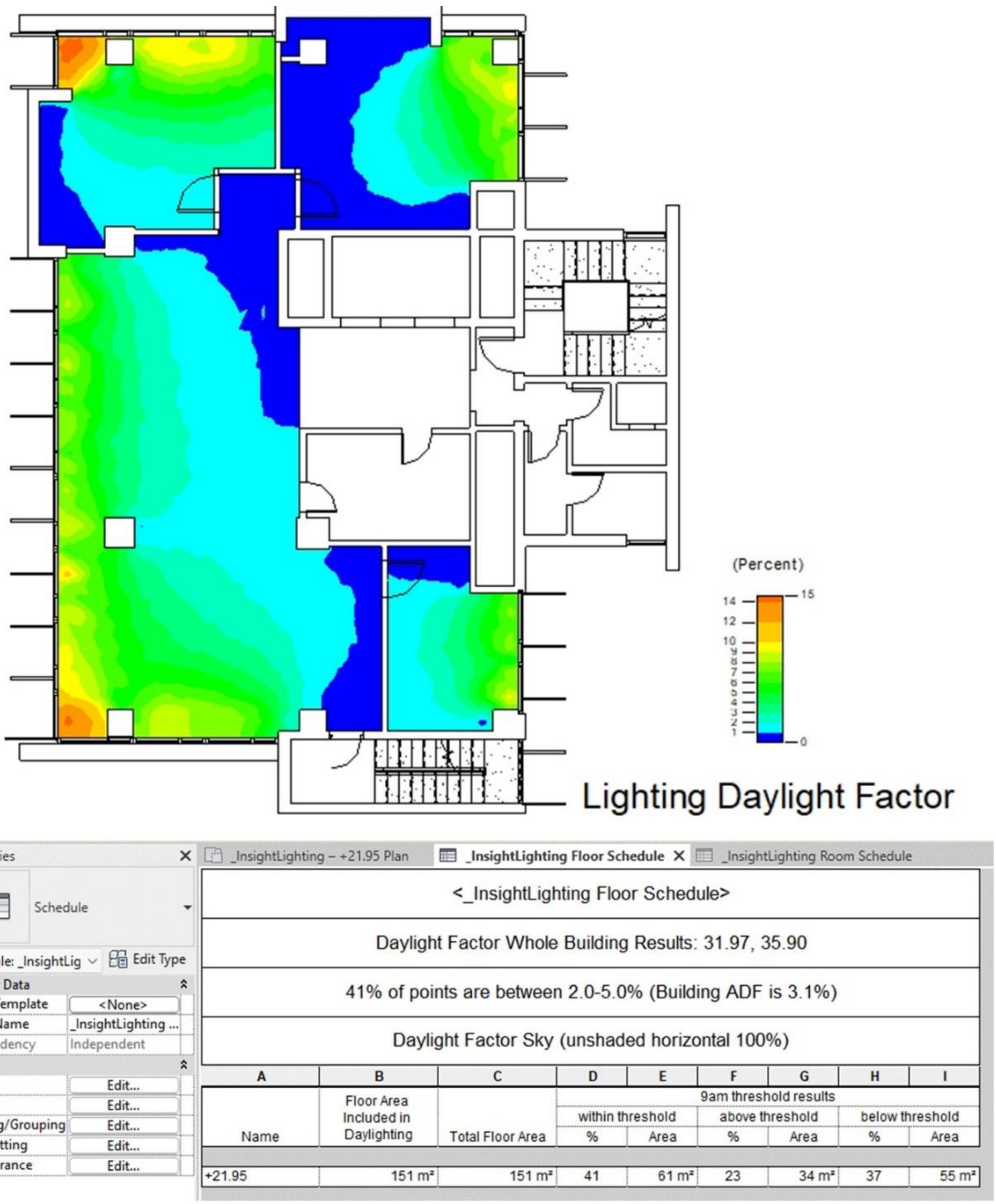


Figure 53: Daylight Factor Stimulation of the Louvers and Fins (Author, 2021)

4.7.2.2 Glare and Illuminance Simulation of Louvers and Fins

Louvers and fins showed a slight change from the simulation of the KPMG building from 51% to 63% of the passing area within 100 lux to 1800 lux in same both times. Figure 54 shows that at 9:00 am, 89% of the area passes within the threshold since 2% below the threshold and 9% above it. On the other hand, 73% of the simulated area passes within the threshold at 3:00 pm by 1% below and 26% above the threshold.

_InsightLighting - +21.95 Plan | _InsightLighting Floor Schedule

<_InsightLighting Floor Schedule>

Custom Analysis Whole Building Results: 31.97, 35.90

7/21 9am: 89% & 7/21 3pm: 73% & both: 63% of points are between 100-1800 lux (9-167 fc)

Solar Values (W/m2): 7/21 9am GHI: 687, DNI: 766, DHI: 83 & 7/21 3pm GHI: 588, DNI: 719, DHI: 82

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
			9am threshold results						3pm threshold results						Both time results	
	Floor Area Included in Daylighting		within threshold		above threshold		below threshold		within threshold		above threshold		below threshold		within threshold	
Name		Total Floor Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area
+21.95	151 m²	151 m²	89	134 m²	9	14 m²	2	3 m²	73	110 m²	26	39 m²	1	2 m²	63	95 m²

Figure 54: Illuminance Stimulation of the Louvers and Fins (Author, 2021)

4.7.2.3 LEED-Based Simulation of Louvers and Fins

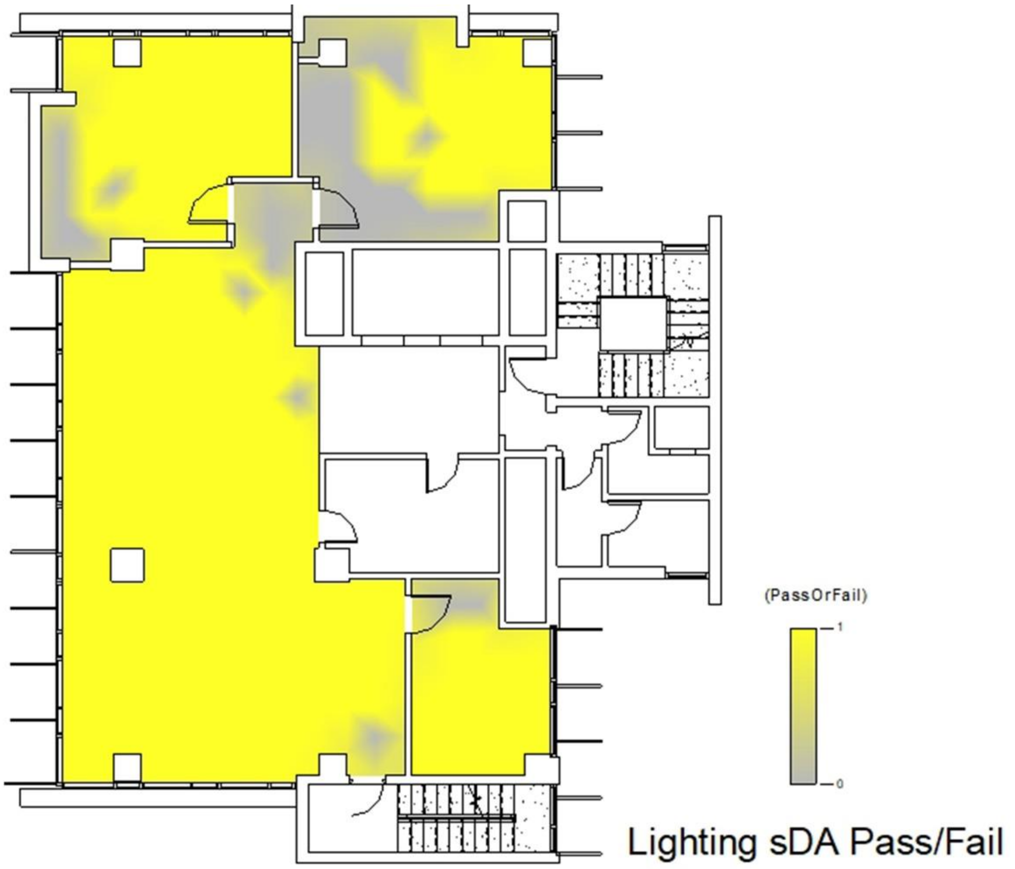
The research will provide two simulations regarding the LEED criteria of the daylight: spatial daylight autonomy (sDA) simulation and LEED 2009 IEQc8.1 illuminance stimulation explained in the following paragraphs.

4.7.2.3.1 Spatial Daylight Autonomy (SDA) Simulation

The studied data shows that the percentage of sDA is at least 55% or 75% of room area to earn 2 to 3 LEED v4.1 points regarding function and floor area (Majeed et al., 2019). The simulation is done through 3650 hours from 8:00 am to 6:00 pm daily, considering that sDA must be over 300 lux for at least 50% of 3650 annual hours.

The simulation results show that 88% of the simulated area meets sDA percentage hours since 100% of rooms meet (sDA > 55% room area), which leads to a score 2 LEED points. In addition, 82% of rooms meet (sDA > 75% room area), which scored 3 LEED points, as is shown in Figure 55.

Regarding LEED v4.1 for qualifying the points of sDA, the simulation should consider the Annual Sun Exposure (ASE) criteria. Therefore, the percentage of the area must receive over 1000 lux for more than 250/3650 annual hours.



_InsightLighting – +21.95 Plan | _InsightLighting Room Schedule

<_InsightLighting Room Schedule>

Daylight Autonomy (sDA Preview) Results Summary: 31.97, 35.90 - 1257552

14% Building area passing thresholds

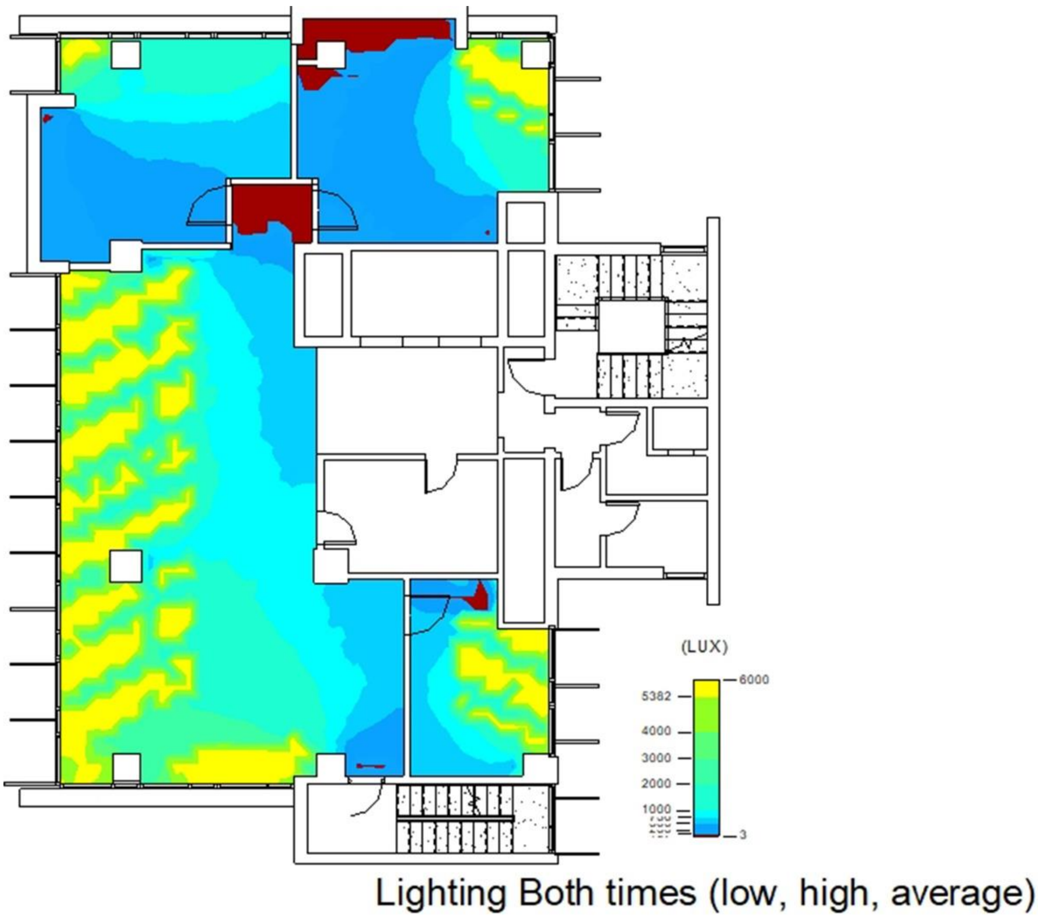
At least 55% must exceed sDA300/50 in Rooms with ASE1000/250 < 20% of Room area

A	B	C	D	E	F	G	H	I	J	K
Level	Name	Number	Area	Include In Daylighting	sDA 300/50 %	sDA 300/50 Points	ASE 1000/250 %	ASE 1000/250 Pass	sDA/ASE %	sDA/ASE Points
+21.95	Office	83	27 m²	☑	61	2 pt	24	No	0	none
+21.95	Office	84	26 m²	☑	85	3 pt	2	Yes	85	3 pt
+21.95	Office	87	13 m²	☑	89	3 pt	68	No	0	none
+21.95	Open Office	88	84 m²	☑	97	3 pt	81	No	0	none

Figure 55: Spatial Daylight Autonomy (sDA) Simulation of Louvers and Fins (Author, 2021)

4.7.2.3.2 LEED 2009 IEQc8.1 Illuminance Stimulation

The required criteria of this simulation are based on weather file data for a clear sky day within 15 days of 21st of September representing the total equinox period of threshold (10 - 500) foot candles. Therefore, 107.64 lux to 5381.96 lux approximately. The simulation shows that the tested area earned 1 point of daylight distribution illuminance due to the criteria since 76% of the simulated area is passing within the threshold at both times, as shown in Figure 56. At 9:00 am, 94% of the area is passing it, which only 2% is below the threshold and 4% above the threshold. On the other hand, 83% of the simulated area passes within a threshold at 3:00 pm since only 3% is below the threshold and 15% above the threshold.



_InsightLighting – +21.95 Plan | _InsightLighting Floor Schedule

<_InsightLighting Floor Schedule>

LEED 2009 IEQc8.1 Whole Building Results: 31.97, 35.90

9am: 94% within & 3pm: 83% & both: 76% within thresholds

Solar Values (W/m2): 9/16 9am GHI: 594, DNI: 735, DHI: 84 & 9/16 3pm GHI: 420, DNI: 627, DHI: 80

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
			9am threshold results						3pm threshold results						Both time results	
	Floor Area Included in Daylighting		within threshold		above threshold		below threshold		within threshold		above threshold		below threshold		within threshold	
Name		Total Floor Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area
+21.95	151 m²	151 m²	94	141 m²	4	7 m²	2	3 m²	83	124 m²	15	22 m²	3	4 m²	76	115 m²

Figure 56: LEED 2009 IEQc8.1 Illuminance Stimulation of Louvers and Fins (Author, 2021)

4.7.3 Egg-Crate Shading System Proposal

Regarding the same calculation of the shading devices according to the solar sun path. Egg-crate can be proposed in the case study since it combines vertical and horizontal elements attached to the highest transparent opening (West Façade), as shown in Figure 57.

Figure 57: 3D View of Egg-Crate Shading System at the West Façade (Author, 2021)

To test different fa < UNK> ade solutions of the façade to enhance the daylight, egg-crate has been manipulated with the HSA and VSA with different measures based on the same method used. Regarding to the shading calculation outcomes, the VSA will take place at 65° degrees and 40° degrees for the HSA. Figure 58 shows a plan of the vertical shading elements in detailed measurements. Whereas shows a section drawing of the horizontal shading elements attached to the same west façade.

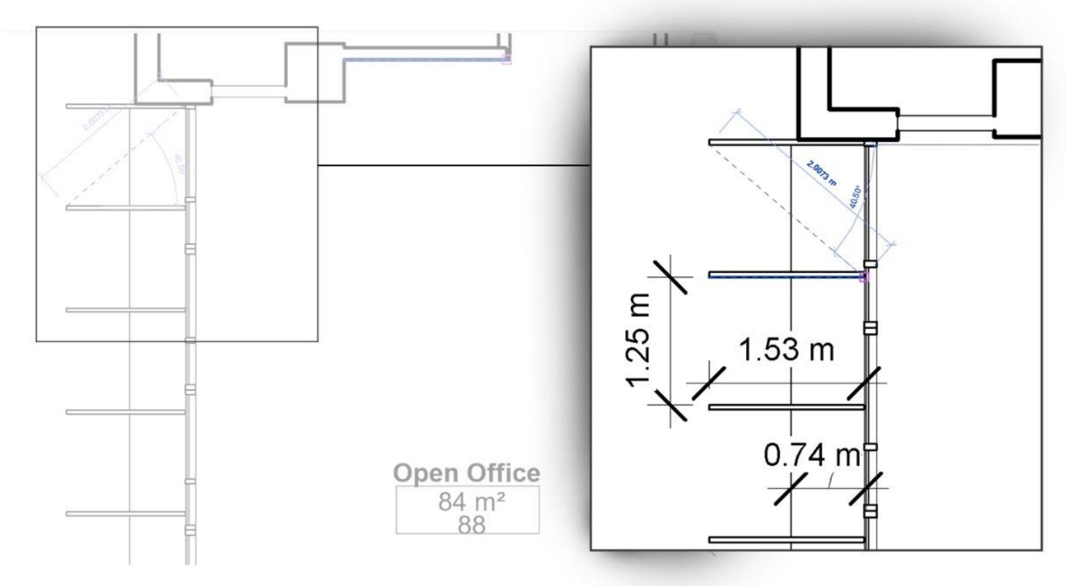


Figure 58: Detail Plan Drawing of Vertical Shading Devices (Author, 2021)

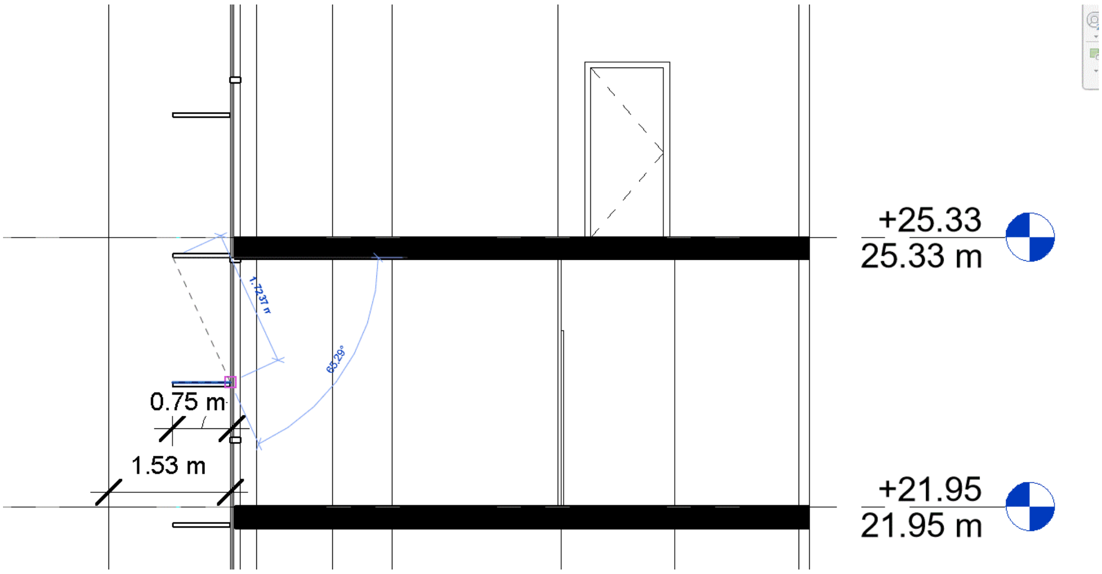
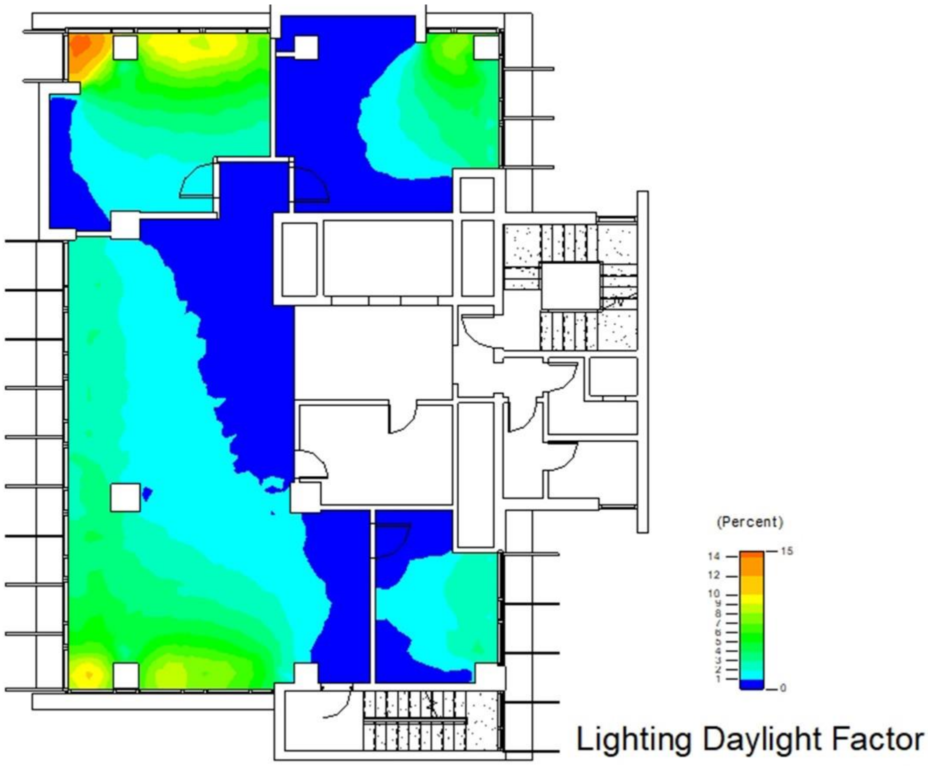
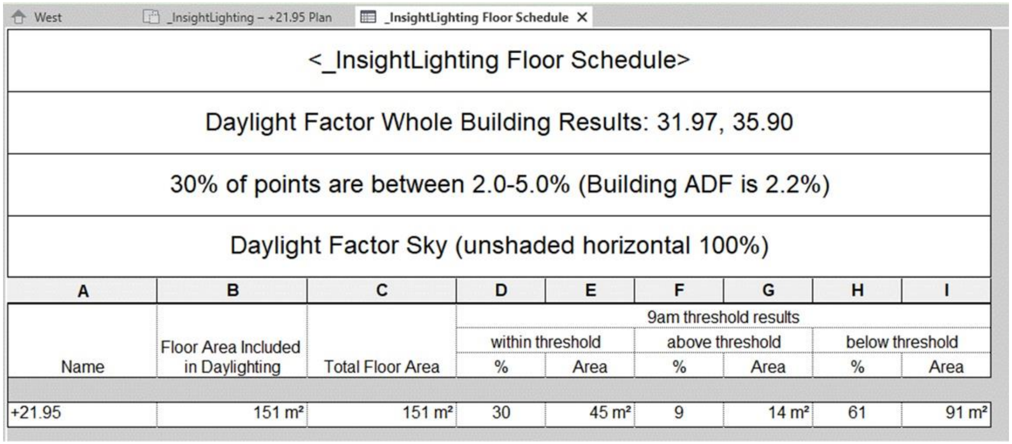


Figure 59: Section Drawing of Horizontal Shading Devices (Author, 2021)

4.7.3.1 Daylight Factor (DF) Simulation of The Egg-Crate

The simulation shows that DF's effect has been decreased compared with the existing KPMG façade and louver and fins system since 30% of the simulated area is passing within 2% to 5% of DF based on the same criteria. The results showed in Figure 60 that 61% below the threshold. Therefore, the egg-crate shading system blocks a huge daylight area compared to the louver and fins system, which is 9% above the threshold.





<_InsightLighting Floor Schedule>

Daylight Factor Whole Building Results: 31.97, 35.90

30% of points are between 2.0-5.0% (Building ADF is 2.2%)

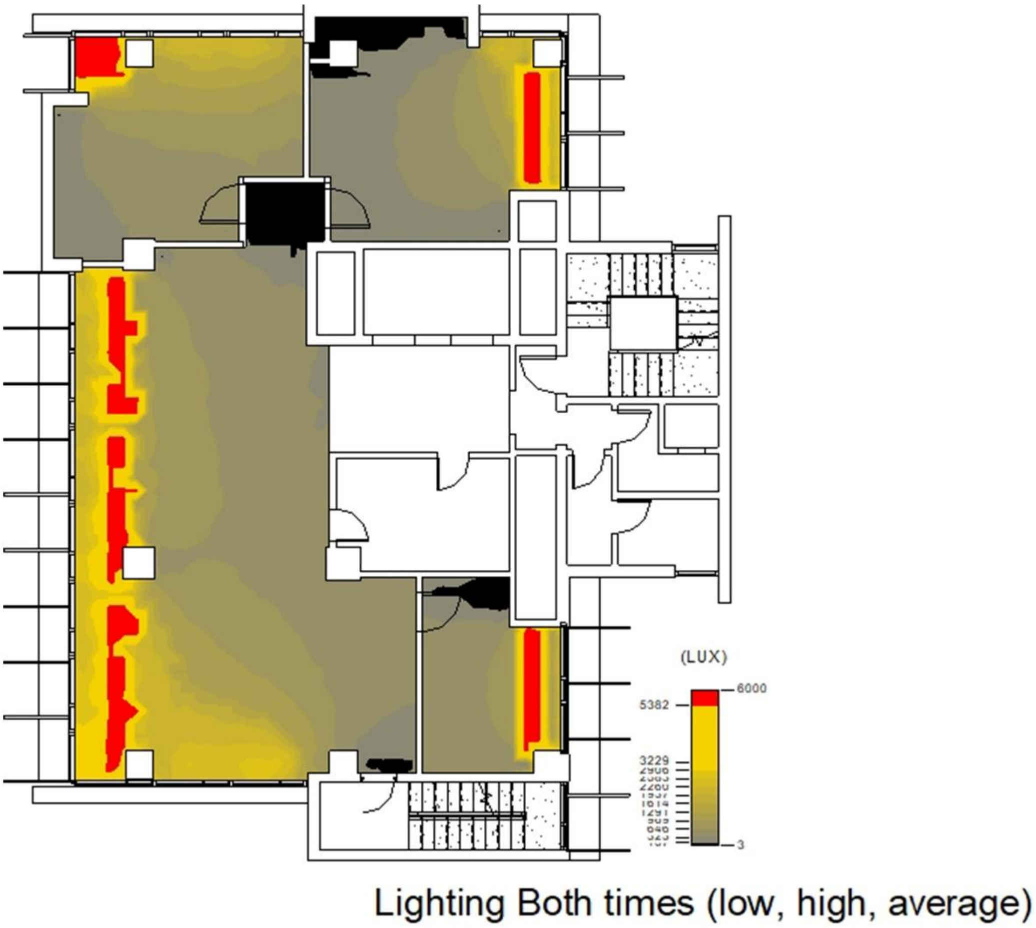
Daylight Factor Sky (unshaded horizontal 100%)

A	B	C	D	E	F	G	H	I
			9am threshold results					
			within threshold		above threshold		below threshold	
Name	Floor Area Included in Daylighting	Total Floor Area	%	Area	%	Area	%	Area
+21.95	151 m²	151 m²	30	45 m²	9	14 m²	61	91 m²

Figure 60: Daylight Factor Stimulation of the Egg-Crate Shading System (Author, 2021)

4.7.3.2 Glare and Illuminance Simulation of The Egg-Crate

The Egg-Crate showed a greater performance due to the illuminance simulation since it reduced the level of illumination, as seen by the plan drawing in Figure 61. The simulation shows that the glare problems have been reduced more than the previous shading system. The results summary in Figure 61 shows that 73% of the simulated area is passing within 100 lux to 1800 lux in both times, based on the same sitting of the other system. In total, 5% above the threshold and 22% above the threshold in both times. At 9:00 am, 92% in total is passing within the threshold since 2% below the threshold and 22% above the threshold. Whereas 80% in total is passing within a threshold at 3:00 pm which is 3% below the threshold and 17% above the threshold.



West | _InsightLighting Floor Schedule

<_InsightLighting Floor Schedule>																
Custom Analysis Whole Building Results: 31.97, 35.90																
7/21 9am: 92% & 7/21 3pm: 80% & both: 73% of points are between 100-1800 lux (9-167 fc)																
Solar Values (W/m2): 7/21 9am GHI: 687, DNI: 766, DHI: 83 & 7/21 3pm GHI: 588, DNI: 719, DHI: 82																
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
			9am threshold results						3pm threshold results						Both time results	
			within threshold		above threshold		below threshold		within threshold		above threshold		below threshold		within threshold	
Name	Floor Area Included in Daylighting	Total Floor Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area
+21.95	151 m²	151 m²	92	138 m²	6	9 m²	2	4 m²	80	121 m²	17	26 m²	3	4 m²	73	110 m²

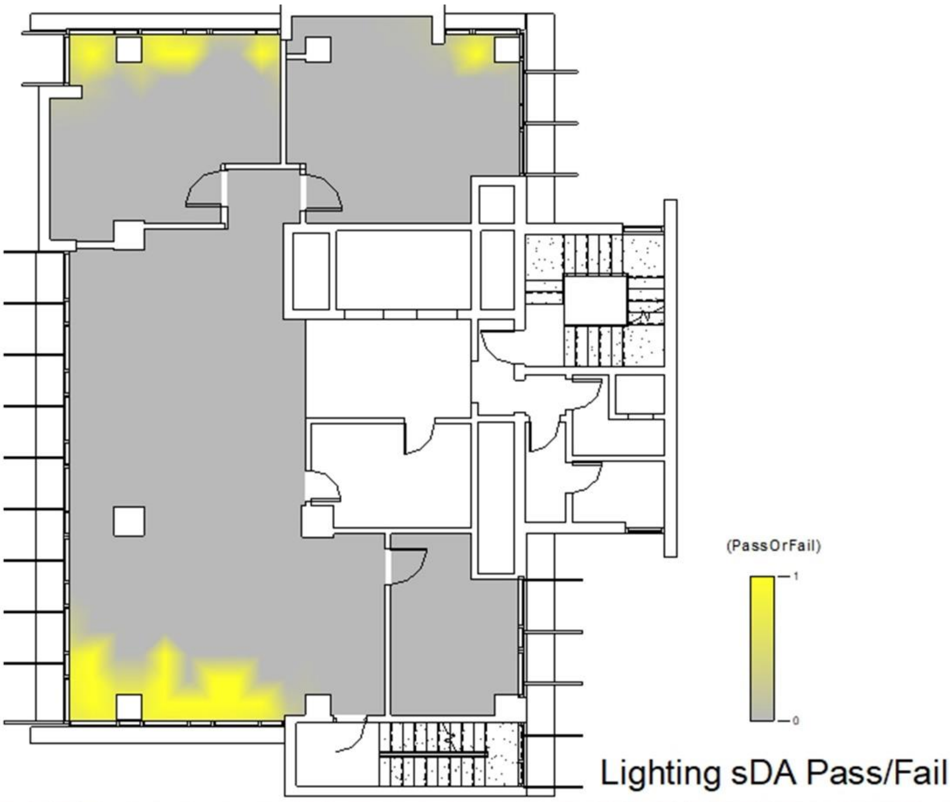
Figure 61: Illuminance Stimulation of The Egg-Crate Shading System (Author, 2021)

4.7.3.3 LEED-Based Simulations of The Egg-Crate

As mentioned for the louver and fins system, the LEED simulations will include two types: spatial daylight autonomy (sDA) simulation and LEED 2009 IEQc8.1 illuminance stimulation, explained in the following paragraphs.

4.7.3.3.1 Spatial Daylight Autonomy (sDA) Simulation

Regarding the annual hours daylight criteria of sDA LEED v4.1, the shading system fails to meet the criteria due to a big amount of blocked daylight, as shown in the plan of Figure 62. The result summary shows that only 6% of the total simulated area meets sDA percentage hours. In addition, none of the rooms has sDA over 55% or 75% of the room area, which means 0 scored LEED points as shown in the schedule in Figure 62.



West | _InsightLighting Room Schedule

<_InsightLighting Room Schedule>

Daylight Autonomy (sDA Preview) Results Summary: 31.97, 35.90 - 1257552

6% Building area passing thresholds

At least 55% must exceed sDA300/50 in Rooms with ASE1000/250 < 20% of Room area

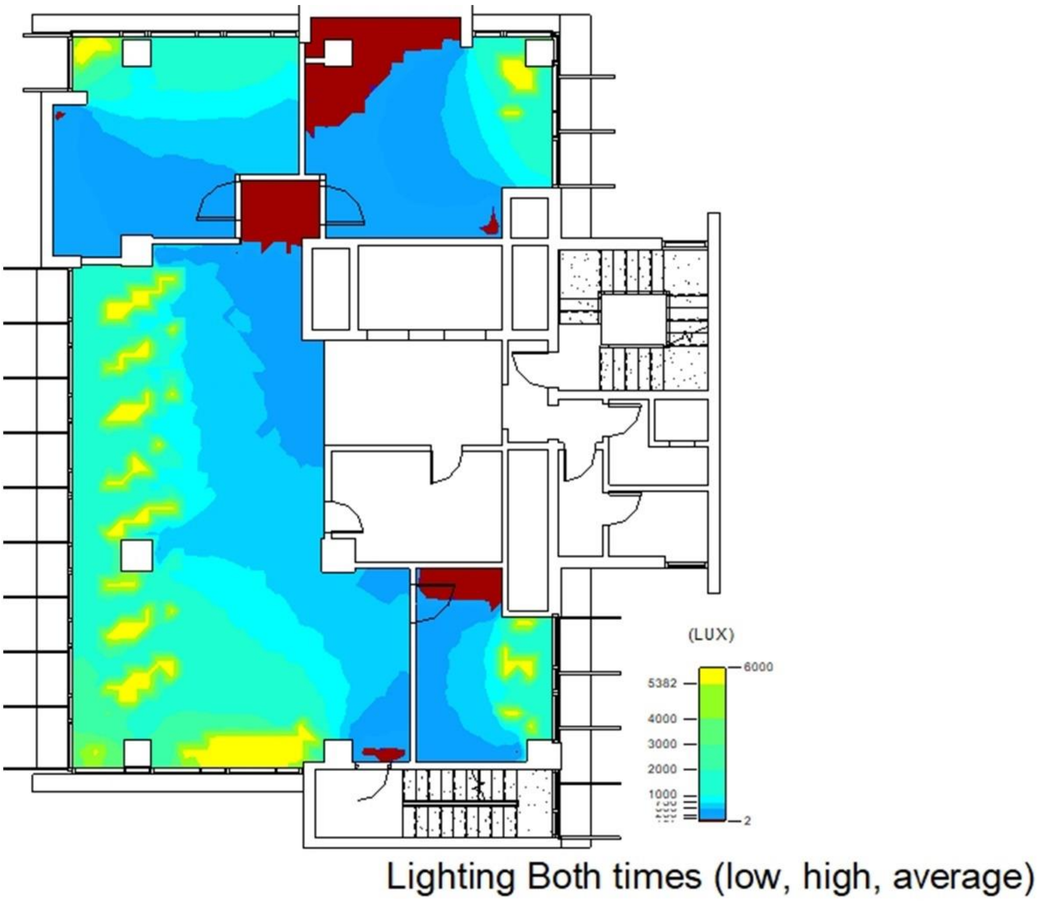
A	B	C	D	E	F	G	H	I	J	K
					sDA 300/50		ASE 1000/250		sDA/ASE	
Level	Name	Number	Area	Include In Daylighting	%	Points	%	Pass	%	Points
+21.95	Office	83	27 m²	☑	2	none	0	Yes	2	none
+21.95	Office	84	26 m²	☑	8	none	0	Yes	8	none
+21.95	Office	87	13 m²	☑	0	none	0	Yes	0	none
+21.95	Open Office	88	84 m²	☑	7	none	0	Yes	7	none

Figure 62: Spatial Daylight Autonomy (sDA) Simulation of The Egg-Crate (Author, 2021)

4.7.3.3.2 LEED 2009 IEQc8.1 Illuminance Stimulation

Regarding the same sitting of weather file data of louvers and fins simulation that meets LEED 2009 IEQc8.1 criteria within 10 to 500-foot candles (107.64 - 5381.96 lux), the results summary in Figure 63 shows that 85% of the simulated area is passing within the threshold in both times since 8% either time below the threshold and 7% either time above the threshold. For the exact simulated time, 96% of the simulated area at 9 passes within the threshold, whereas 89% at 3 pm passes within the threshold.

Regarding the result of the LEED 2009 IEQc8.1 simulation, the tested area scored 1 LEED point.



West | _InsightLighting – +21.95 Plan | _InsightLighting Floor Schedule

<_InsightLighting Floor Schedule>

LEED 2009 IEQc8.1 Whole Building Results: 31.97, 35.90

9am: 96% within & 3pm: 89% & both: 85% within thresholds

Solar Values (W/m2): 9/16 9am GHI: 594, DNI: 735, DHI: 84 & 9/16 3pm GHI: 420, DNI: 627, DHI: 80

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
			9am threshold results						3pm threshold results						Both time results	
			within threshold		above threshold		below threshold		within threshold		above threshold		below threshold		within threshold	
Name	Floor Area Included in Daylighting	Total Floor Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area
+21.95	151 m²	151 m²	96	144 m²	1	2 m²	3	4 m²	89	134 m²	6	9 m²	5	8 m²	85	128 m²

Figure 63: LEED 2009 IEQc8.1 Illuminance Stimulation of The Egg-Crate (Author, 2021)

4.8 Chapter Summary

The research aims to test a method of optimizing the shading devices regarding daylight by applying two different categories of BIM simulation, which are a manual manipulated simulation that based on daylight factor and illuminance metrics due to office building daylight standards criteria, and the second one is LEED simulation that based on sDA simulation and LEED 2009 IEQc8.1 illuminance simulation.

The results showed that the KPMG building does not meet daylight studied criteria, as seen in Table 5. On the other hand, these results allowed to creation of different shading device systems to enhance the façade performance of the KPMG building. Table 5 compares the simulations results between the existed KPMG building and the shading systems, which are louvers and fins shadings and egg-crate shadings.

Table 5 shows that louvers and fins shading device has the best results of daylight factor simulation and spatial daylight autonomy. In contrast, the egg-crate shading device achieved a better result in glare and illuminance simulation and LEED 2009 IEQc8.1 illuminance simulation. Although, louvers and fins success the LEED 2009 IEQc8.1 illuminance simulation since the system passed over 70% of simulation criteria.

Regarding LEED, louvers and fins shading system scored 4 LEED points in both sDA LEED v4.1 and LEED 2009 IEQc8.1 illuminance. The egg-crate shading system scored 1 LEED point from LEED 2009 IEQc8.1 illuminance simulation. Therefore, the louver and fins shading system has the priority to enhance the façade of the KPMG building.

Table 5: Daylight simulations summary of the proposed shading systems for a studied building

		KPMG Building	**Shading Devices System**	
			Louvers and Fins	**Egg-Crate**
	3D view			
Manipulative Simulation	**Daylight Factor (DF)** *Threshold: DF (2-5%) *Standard day	**34% passing within threshold** 30% below threshold 36% above threshold	**41% passing within threshold** 37% below threshold 23% above threshold	**30% passing within threshold** 61% below threshold 9% above threshold
	Glare & Illuminance * Threshold: (100-1800) lux * Data/time: 21st July at 9 am & 3 pm	**51% passing in total both times** 1% either time below threshold 48% either time above threshold	**63% passing in total both times** 3% either time below threshold 34% either time above threshold	**73% passing in total both times** 5% either below threshold 22% either time above threshold
		9 am – 79% passing: - 0% below threshold - 21% above threshold 3 pm – 61% passing: - 0% below threshold - 39% above threshold	9 am – 89% passing: - 2% below threshold - 9% above threshold 3 pm – 73% passing: - 1% below threshold - 26% above threshold	9 am – 92% passing: - 2% below threshold - 6% above threshold 3 pm – 80% passing: - 3% below threshold - 17% above threshold

LEED-Based Simulation	**Spatial Daylight Autonomy (sDA)** *Threshold: sDA>55% or 75% *Data/time: 3650 hours a whole year from 8 am to 6 pm	-	**88% in total meets sDA % hours** 100% of rooms meets sDA >55% room area 82% of rooms meet sDA >75% room area	**6% in total meets sDA % hours** 0% of rooms meets sDA >55% room area 0% of rooms meet sDA >75% room area
		-	(Score 3 LEED points for sDA % hours)	(Score 0 LEED points for sDA % hours)
	LEED 2009 IEQc8.1 Illuminance * Threshold: (10 - 500 fc) = (107.64 - 5381.96 lux) * Data/time: 15 days of 21st of September * Clear sky day	**Total Equinox - 68% passing in both times** 1% either time below threshold 31% either time above threshold	**Total Equinox - 76% passing in both times** 4% either time below threshold 19% either time above threshold	**Total Equinox - 85% passing in both times** 8% either time below threshold 7% either time above threshold
		9 am – 93% passing: - 0% below threshold - 6% above threshold 3 pm – 74% passing: - 1% below threshold - 25% above threshold	9 am – 94% passing: - 2% below threshold - 4% above threshold 3 pm – 83% passing: - 3% below threshold - 15% above threshold	9 am – 96% passing: - 3% below threshold - 1% above threshold 3 pm – 89% passing: - 5% below threshold - 6% above threshold
		(Score 0 LEED points)	(Score 1 LEED points)	(Score 1 LEED points)

Chapter 5

CONCLUSION

Overall, daylight considerations regarding visual comfort are highly recommended to optimize the building façade performance that enhances the building sustainability. Therefore, it is important to explore the impact of daylight on building façade performance. To achieve that, the research explained the daylight, starting with the formation of daylight passing through the benefits that allow solving daylight's visual comfort problems and how it occurs by considering the daylight metrics based on LEED v4.1 criteria. The main outcomes of daylight that serve the research aim of optimizing the façade are, controlling the illuminance and glare problems via the metrics (daylight factor and spatial daylight autonomy) based on LEED v4.1 standard. In addition, highlight the daylight strategies by considering the shading devices based on solar geometry with their calculations and impacts on building façade.

The outcomes of daylight data collection are employed by Building Information Modeling technology (BIM) to optimize the façade of an existing building. BIM has been widely used to optimize the building façade by using a feature of it to achieve specific data without paying attention to the main aim of the technology, which is the Parametric BIM. For that, the research focused on sorting out the BIM concept by explaining the technology and process of it through parametric BIM in addition to two main benefits that serve the research, that are the accurate visualization of building design that allows to input all building data, climate data, drawing and analysis in one file linked to each other and the second benefit is the improvements of building sustainability that allows running a parametric daylight simulation and optimization through BIM connected to the same file, which connects the first chapter to BIM.

To connect these two chapters to optimize the building façade, the research applied the data collection on an office building in Amman by a workflow started with collecting building data and then applying the accurate BIM visualization on it by importing all data to Revit 2020 program as BIM platform. In that stage, BIM technology produced data related to the existing building's climate and location, which allows for an accurate evaluation through simulations analysis regarding daylight on the façade beside the studied field observation to support the evaluation by real measurements. The resulting data supported optimizing the building façade by proposing two different shading devices systems: louvers and fins and egg-crate shadings system by calculating the HSA and VSA based on solar geometry. This allows comparing both systems by applying BIM daylight simulations through Autodesk insight linked to the Revit file of the building. The research applies a comparative method of optimizing the façade regarding daylight visual comfort through BIM by applying manual manipulative simulations based on daylight factor (DF) and the illuminance of the office building. The second is daylight LEED stimulations based on spatial daylight autonomy (sDA) and illuminance simulations. The results showed that louver and fins shading devices have better enhancement on the façade regarding daylight based on LEED criteria than the egg-crate system.

In the end, the research established a method to test the different façade designs regarding daylight by BIM technology. On the other hand, the research opens the ways for further studies to enhance building energy through BIM-based on certified standards for better building sustainability improvements.

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