Design of a 3D Parametric Facade System for Given structures to Enhance Indoor Visual Comfort

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Abstract

The goal of the building sector of the German government's climate policy, Climate Action Plan 2050 (2016), is reducing carbon dioxide emissions as part of universal moral obligation against the global warming. This aim can be realized by improvement of optimization of facade design as one method.

This research proposes optimal daylight performance for the facade of an existing building, which helps designers improve daylight generating optimized design options and understand the relationships between design variables and performance metrics. This can be provided by parametric design through facilitating model-based analysis and simulations with Revit, Dynamo (the visual programming add-in for Autodesk Revit), Honeybee and Ladybug environmental plugins.

The analysis discovered the new facade model with improved daylight performance through comparing with average and standard deviation of solar irradiance between the early model and the new model. The results were reasonable, but could be improved through detailed analysis and simulations by more parameters and development of daylight environmental plugins.

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1 Introduction

The Paris Agreement is a United Nations Framework Convention on Climate Change (UNFCCC) agreement on mitigation, adaptation and financing of greenhouse gas emissions, adopted by consensus on 12 December 2015. Beginning in April 2019, 185 Parties have ratified the Convention from 197 Parties. The agreement aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius (UNFCCC, 2018).

The EU has been leading the way in tackling the fundamental causes of climate change and reinforcing a coordinated global response under the Paris Agreement. The European Commission (2018) set to maximize the energy efficiency profits including buildings with zero emission. Energy efficiency will play a central role in decarbonizing industrial processes but much of the reduced energy demand will occur in buildings, in both the residential and services sectors, which today are responsible for 40% of energy consumption. Given that most of the housing stock of 2050 exists already today, this will require higher renovation rates, fuel switching with a large majority of homes that will be using renewable heating (electricity, district heating, renewable gas or solar thermal), diffusion of the most efficient products and appliances, smart building/appliances management systems, and improved materials for insulation (European Commission, 2018).

Furthermore, Climate Action Plan 2050 (2016), Principles and goals of the German government's climate policy, has set a target of reducing CO_2 emissions by around 67% in the building sector by 2030, through being improved energy efficiency in buildings (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), 2016). Table 1.1 (next page) gives a summary of CO_2 emissions for building sector.

Area of action	1990 (in million tonnes of CO_2 equivalent)	2014 (in million tonnes of CO_2 equivalent)	2030 (in million tonnes of CO_2 equivalent)	2030 (reduction in % compared to 1990)
Energy sector	466	358	175 – 183	62 – 61 %
Buildings	209	119	70 – 72	67 – 66 %
Transport	163	160	95 – 98	42 – 40 %
Industry	283	181	140 – 143	51 – 49 %
Agriculture	88	72	58 – 61	34 – 31 %
Subtotal	**1,209**	**890**	**538 – 557**	**56 – 54 %**
Other	39	12	5	87 %
Total	**1,248**	**902**	**543 – 562**	**56 – 55 %**

Table 1.1 Emissions from areas of action set out in definition of the target (Climate Action Plan 2050 of the Federal Government, 2016)

The majority of the total energy utilization of a building is lighting, heating and cooling. HVAC is the main end use with a weight close to 50%, lighting follows with 15% and appliances with 10% (Pérez-Lombard, Ortiz & Pout, 2008). The amount of energy consumed through heating, cooling or lighting in a building is mainly influenced by its fenestration system (Lee et al., 2013). Of several products in the system, windows, which can provide light, view and fresh air to the resident, play the most important role in a building's energy consumption (Lee et al., 2013). Thus, one of the most essential strategies for energy efficiency of a building is the design of facade.

Modelling and energy simulation with parametric tools, such as Revit and Dynamo, have supported this facade design. Dynamo-Revit presents an especially powerful combination, allowing an unbroken flow of information that integrates into the later stages of the design process (Baker, 2017). The newly enabled integration of parametric design, energy simulation tools, and optimization algorithms opens up a new realm of possibility to create a variety of new forms and optimized components that are generated to provide maximum environmental performance (Glassman & Reinhart, 2013).

1.1 Motivation

The motivation for this project is to analyze on how the sunlight performance of the building of the Institut für Bauinformatik in Technische Universität Dresden can be enhanced. The research will generate a new facade design of this building and investigate potential high performing solution in the renovation strategy.

Decreasing CO_2 emissions is the first goal of the building sector in Germany related to Climate Action Plan 2050 (2016). This building of the Institut für Bauinformatik uses electricity to generate light and hot water, resulting in higher energy costs. Using daylighting to cut reliance on artificial light can reduce the electricity used to power the lighting, and additionally reduce cooling loads induced by the waste heat created by lighting fixtures (Bodart & De Herde, 2002). To participate in the global plan, the new facade system will be designed for maximization of the visual comfort during winter season utilizing Revit and Dynamo.

To summarize, this study aims to generate a 3D parametric facade for the building of the Institut für Bauinformatik, analyze the daylight assessment, generate a new skin of this building, evaluate the skin's daylight performance, and search for the best solution using Revit and Dynamo.

2 Literature Review

2.1 Facade

The facade means the front of a building or any face of a building given special architectural treatment (Merriam-Webster Inc., 2019) as well as curtained element in front of one or more stories of a building (Aßmus, E., 2018). It is the first impression of a building to people but it must not be taken into account only the appearance of the skin. Therefore, in design, the functionality of the façade also should be considered. “A successful facade system is one that combines both the beauty of the architect’s vision and the practicality of being energy efficient” (Spohn, 2008). Fig 2.1 displays requirements of modern facades.

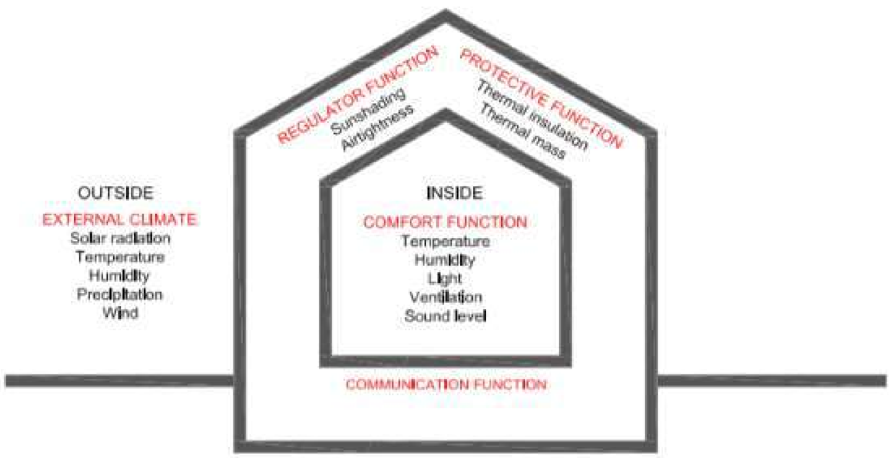

Figure 2.1: Conditions and Requirements of a Facade as Illustrated by Arch. G. Paoletti (Giovanardi, 2012)

Johnsen & Winther (2015) explains the main role of the facade "to protect the indoor environment from the outdoor environment and the optimization of this function includes control of (leaving out many other functions as noise, security, etc.):

- Heat transmission from inside to outside
- Solar load from outside to inside

- High utilization of passive solar gains
- High utilization of daylight
- Protection against glare from outside
- Air flows between inside and outside (both ways)
- Allow for a view to the outside
- Allow for privacy

2.2 Daylight

Daylight influences users' health such as visual and mental comfort, productivity, and saving energy and improving energy efficiency for buildings. There are also specific advantages of daylight in various buildings.

- Users' health and productivity : Blue light (wavelength 460-480nm) absorbed by photoreceptors in the eye, has been shown to regulate endocrine, behavioural and physiological responses, including melatonin suppression, alertness, mood, performance, heart rate and gene expression (Beaven & Ekstrom, 2013). The effects of natural light on building occupants, and summarized that daylighting was found to be associated with higher productivity, lower absenteeism, improved mood, reduced fatigue, and reduced eyestrain (Edwards & Torcellini, 2002).

- Saving energy for buildings : Daylight on its own can not result in saving energy. Cost and energy savings are achieved through lighting control strategies and photo sensors, when artificial lighting can be dimmed or switch off when daylight is sufficient (Wong, 2017). Lee and Selkowitz (2006) performed a 9-month field study in the mockup of a commercial building in New York, and found 20.23% and 52.59% energy savings in two areas of the space through automated roller shades and daylighting controls.

- Improving energy efficiency for buildings : Alrubaih et al. (2013) reviewed that artificial lighting systems consume about 25%-40% of the total energy consumption of buildings, and daylighting as an alternative to artificial lighting is considered to be one of the simplest method to improve energy efficiency. Good use of daylight also reduces energy demands for artificial lighting, as well as cooling loads due to sensible heat gains from artificial lighting (Baker, 2017).

- Specific advantages of daylight in various buildings :
  - In hospitals and assisted-living communities, daylight can improve the physiological and psychological states of both patients and staff (Edwards & Torcellini, 2002). Proper lighting environment can ease pain, reduce depression of patients, decrease length of stay in hospitals, and lessen agitation among dementia patients (Joseph, 2006). A significant relationship between indoor daylight environments and a patient's average length of stay (ALOS) in a hospital, and the ALOS of patients in rooms located in the southeast area was 16% - 41% shorter than that in the northwest area (Choi, Beltran, and Kim, 2012).
  - The benefits of daylight in office environments include reduced absenteeism, increased productivity, financial savings (Edwards & Torcellini, 2002). Leather, Pyrgas, Beale, and Lawrence (1998) found the area of sunlight penetration is significant positively related to job satisfaction, and negatively related to intention to quit.
  - The benefits of daylighting in school environments include improved health, student attendance and academic performance (Edwards & Torcellini, 2002). The scores of students from schools using daylighting to schools using artificial light, and found students from daylit schools have higher scores in reading and math tests (Nicklas and Bailey, 1997).

2.2.1 Daylighting Performance Metrics

Researchers defined a range of performance metrics to assess how much natural light is present on work surfaces inside of the buildings. At the scale of everyday objects light can be treated as a flow of energy and defined by human vision; in this case the normal physical units of energy do not apply and thus another set of units are defined (Tregenza & Wilson, 2011).

Illuminance

Illuminance is the most commonly used metric to evaluate the brightness of the indoor environment and measures the amount of light on a surface per unit area, and its unit is lux (Fang, 2017). The candela (cd) is the unit of luminous intensity, which is the quantity of luminous energy flowing from a source in a particular direction that gives way to luminance, measured in cd/m2, which is the measureable brightness of a given surface (luminous intensity per unit area) (Baker, 2017). Recommended levels of illuminance are defined by the Illuminating Engineering Society (IES) according to the space type, the type of visual tasks, the age of occupants, etc. Table 2.1 shows some examples of the recommended illuminance values for different building types and seeing tasks (DiLaura, Houser, Mistrick, & Steffy, 2011).

Building types	Area and seeing task	Recommended Illuminance values (lux)
Residences	General lighting	50-100
	Noncritical kitchen duties	200-500
Office	Lobbies	100-200
	Reading	200-500 or 500-1000 or 1000-2000 depending on the reading material types
Restaurants	Kitchen	500-1000
	Dining	50-100
Stores	Merchandising areas	500-1000
	Feature displays	1000-2000
	Stockroom	200-500
Hospitals	Patients' rooms	50-100
	Emergency rooms	500-1000
	Operating rooms	1000-2000

Table 2.1 Recommended Illuminance Values of Building Types

Daylight Factor (DF, static metric)

Daylight Factor (DF) is the ratio of light on a specific interior work floor to the global horizontal illumination of the sky, calculated as a percentage. In other words, It is the proportion between indoor luminous flux and outdoor luminous flux under overcast sky conditions. The factor was developed for manual calculation before computers, but aptly represents the apparent brightness of a room by capturing the contrast between interior and exterior (Tregenza & Wilson, 2011). DF is a static daylight metric, which means it does not change with the building location or orientation, and many daylighting design problems cannot be detected by DF (Reinhart, Mardaljevic, & Rogers, 2006).

CIE Standard Overcast Sky

CIE Standard Overcast Sky is an internationally adopted standard sky formula that is commonly used to demonstrate compliance with standards and regulations (Baker, 2017). It is the sky circumstance primarily used in the calculating the daylight factor. It is designed to represent the lowest levels of steady daylight occurring in temperate climates, where the sky is grey, overcast and the sun's location is indeterminable (Tregenza & Wilson, 2011). There is no sunlight, only diffuse daylight and the sky's luminance is constant with changing azimuth, but increases with altitude from horizon to zenith, where the luminance is 3 times greater than that at the horizon (Baker, 2017).

Daylight Autonomy (DA, Dynamic Metric)

Daylight Autonomy (DA) is the percentage of time during the year which a point is illuminated above a certain threshold, by daylight alone (Reinhart, Mardaljevic & Rogers, 2006). Daylight autonomy as well as Useful daylight illuminance (UDI, see below the following paragraph) are dynamic daylighting metrics. Dynamic daylight metrics are based on time series of illuminances, which are based on annual solar radiation data for the building site (Reinhart, Mardaljevic, & Rogers, 2006). Dynamic daylight metrics are based on time series of illuminances, which are based on annual solar radiation data for the building site (Reinhart, Mardaljevic, & Rogers, 2006). The primary advantage of dynamic daylight performance metrics over static metrics is that they consider the quantity and features of daily variations of daylight together with irregular meteorological events (Reinhart, Mardaljevic, & Rogers, 2006).

Useful Daylight Illuminance (UDI)

Useful Daylight Illuminance (UDI) is the ratio of the number of hours in the year when illuminance provided by daylighting is within a useful range, to the total number of occupied hours in a year (Nabil & Mardaljevic, 2005). UDI has a spectrum of 100-2000 lux, which suggests that daylight is practical. Outside of this range, the illuminance is either too low to be useful, or too high, introducing problems with overheating and glare (Reinhart, Mardaljevic & Rogers, 2006). Light under 100 lux is perceived so dark, and light over 2000 lux is considered too shiny.

Continuous Daylight Autonomy (cDA)

Continuous Daylight Autonomy (cDA) is similar as DA, but it provides partial credit to the times when the illuminance is below minimum requirement (Rogers, 2006). The lowest lighting criterion of a room, for instance, is 500 lux, and the lighting is 100 lux at one time. It would be taken 0 credit by the Daylight Autonomy, whereas 0.2 by Continuous Daylight Autonomy.

Spatial Daylight Autonomy (sDA)

Spatial Daylight Autonomy (sDA) is the percentage of area that meets the minimum daylight illuminance for a specified percentage of hours in a year (Heschong et al., 2012).

Annual Sunlight Exposure (ASE)

Annual Sunlight Exposure (ASE) is the percentage of area that exceeds specified illuminance for more than a specified percentage of hours in a year (Heschong et al., 2012). Generally, sDA and ASE together assess the daylight condition of the space.

2.3 Parametric Design

The term of "parametric" originates from mathematics, and refers to using certain parameters or variables, which can be amended in order to manipulate with the equation results (Frazer, 2016)

And "parametric design" is the process where a description of a design problem is created to be controlled by some variables and by changing it. A range of solutions can be generated, then based on some criteria a final solution is selected (Hudson, 2010, Aish and Woodbury, 2005). Cordoso, C. G. M., (2017) describes an example of parametric design, "A parametric model of a tree could be based on a subdivision process where each new branch has half of the size of the previous one, and each branch produces two new branches. The parametric model would accept as parameters the length of the initial branch and a value n, representing the number of subdivisions of the tree. By exploring values for parameter n, a wide variety of results can be achieved: if n=0, the tree would only produce the trunk; if n=1, the trunk would have two branches; if n=2, there would be two new branches coming from each of the previous ones, and so on" (Figure 2.2). Another example of parametric design is shown in Figure 2.3

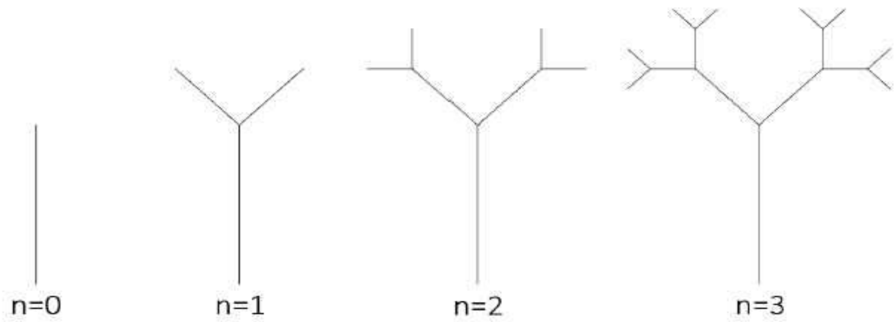

Figure 2.2 Example of a Parametric Design (Cordoso, C. G. M., 2017)

Figure 2.3 Dongdaemun Design Plaza (DDP), Zaha Hadid Architects, Samoo Architects and Engineers Construction : Samsung C&&T Corporation (source:http://www.ddp.or.kr/board)

According to Lee & Lee (2013), "the advantage of parametric design is that it's not necessary to reproduce the entire model. It is possible to automatically modify the characteristics of the model components based on the basis. Examples of such rules or numbers include structural loads, environmental data (sunshine, solar angle, wind speed, etc.) or simply changes in dimensions. The differentiated advantage of parametric tools is that they can be useful for specific complex and time-consuming design tasks."

Fang, (2017) refers to 2 disadvantages of parametric design. "First one is that the modeling of the initial parametric model takes longer time than conventional methods. But as the number of design alternatives grows, parametric modeling method will quickly show advantage. Another disadvantage is that the design alternatives generated by a parametric model still follows the same design concept, and have lots of similarities."

Touloupaki & Theodosiou, (2017) describes that the focus on parametric 3D modeling is performed for various reasons:

- New generations of architects are becoming increasingly accustomed to digital processes of design generation and representation, demonstrating a global trend on algorithmic or parametric design in architectural practice and academic environment.
- New software tools have been developed that exploit powerful synergies, making it possible for building design simulation and optimization to be seamlessly integrated in digital representation software, thus allowing instantaneous feedback for the ongoing process of synthesis.
- The need to address multiple, contradicting objectives at the same time, during all stages of the design process, is becoming more and more imperative, making the establishment of a holistic approach for sustainable building design an urgent request.

2.3.1 Parametric Design Software

Parametric design software is the means of defining and controling 3D models with various variables adjusted for researching many kinds of possibilities. This is very powerful when creating and testing variations in a design, as it canreduce drawing time significantly, as well as facilitate optimisation through simulation (Yan, 2014).

The advantage of parametric software is that if the virtual 3D model is set-up appropriately, changes in the parametres generate within minutes complete correct models and consequent bills quantities and 2D sections and then, this makes it possible to adjust the design until the last minute (Hubers, 2010).

Eltaweel and Su (2017) claimed that parametric design software was first developed in 2008, and the prevalent tools include Catia, 3D MAX, 3D Maya, Revit, Grasshopper, Dynamo, Generative Components, Marionette, and Modelur.

2.3.1.1 Revit

Revit is a building information modeling software developed by Autodesk. According to Autodesk, Inc., "Revit is a design and documentation platform that supports the design, drawings, and schedules required for building information modeling (BIM). BIM delivers information about project design, scope, quantities, and phases when you need it. Parametric modeling refers to the relationships among all elements in a project that enable the coordination and change management that Revit provides. These relationships are created either automatically by the software."

2.3.1.2 Dynamo

Baker, (2017) defines "Dynamo is a visual programming editor, developed by Autodesk, for use with Autodesk Revit. It is based on a programming language called DesignScript, created specifically for Dynamo, but also supports Python. Dynamo can be used to manipulate building information and geometry, automate workflows and link to different applications. It is free, open-source and designed to function within a development community. Users can develop their own nodes to extend the basic functionality. These can be grouped into packages and uploaded to the package manager, for use by others."

2.3.1.3 Rhinoceros

Accodring to Wikimedia Foundation, Inc., (2019) Rhinoceros (typically abbreviated Rhino, or Rhino3D) is a commercial 3D computer graphics and computer-aided design (CAD) application software developed by Robert McNeel & Associates, an American, privately held, employee-owned company founded in 1980. Rhinoceros geometry is based on the NURBS mathematical model, which focuses on producing mathematically precise representation of curves and freeform surfaces in computer graphics (as opposed to polygon mesh-based applications).

Rhinoceros is used in processes of computer-aided design (CAD), computer-aided manufacturing (CAM), rapid prototyping, 3D printing and reverse engineering in industries including architecture, industrial design (e.g. automotive design, watercraft design), product design (e.g. jewelry design) as well as for multimedia and graphic design (Robert McNeel & Associates., 2019).

2.3.1.4 Grasshopper

In the thesis of Baker, (2017) "Grasshopper is an earlier visual programming editor, developed by Robert McNeel & Associates, for use with Rhino3D. All .NET programming languages can be used with Grasshopper. Grasshopper provided the inspiration for Dynamo, so the two function similarly on the surface, but they differ in the same manner as Rhino and Revit differ. Similarly to Dynamo, Grasshopper is free and open-source and functions within a development community, where users develop their own components for use by others. Figure 2.4 shows the Dynamo interface and the Grasshopper interface.

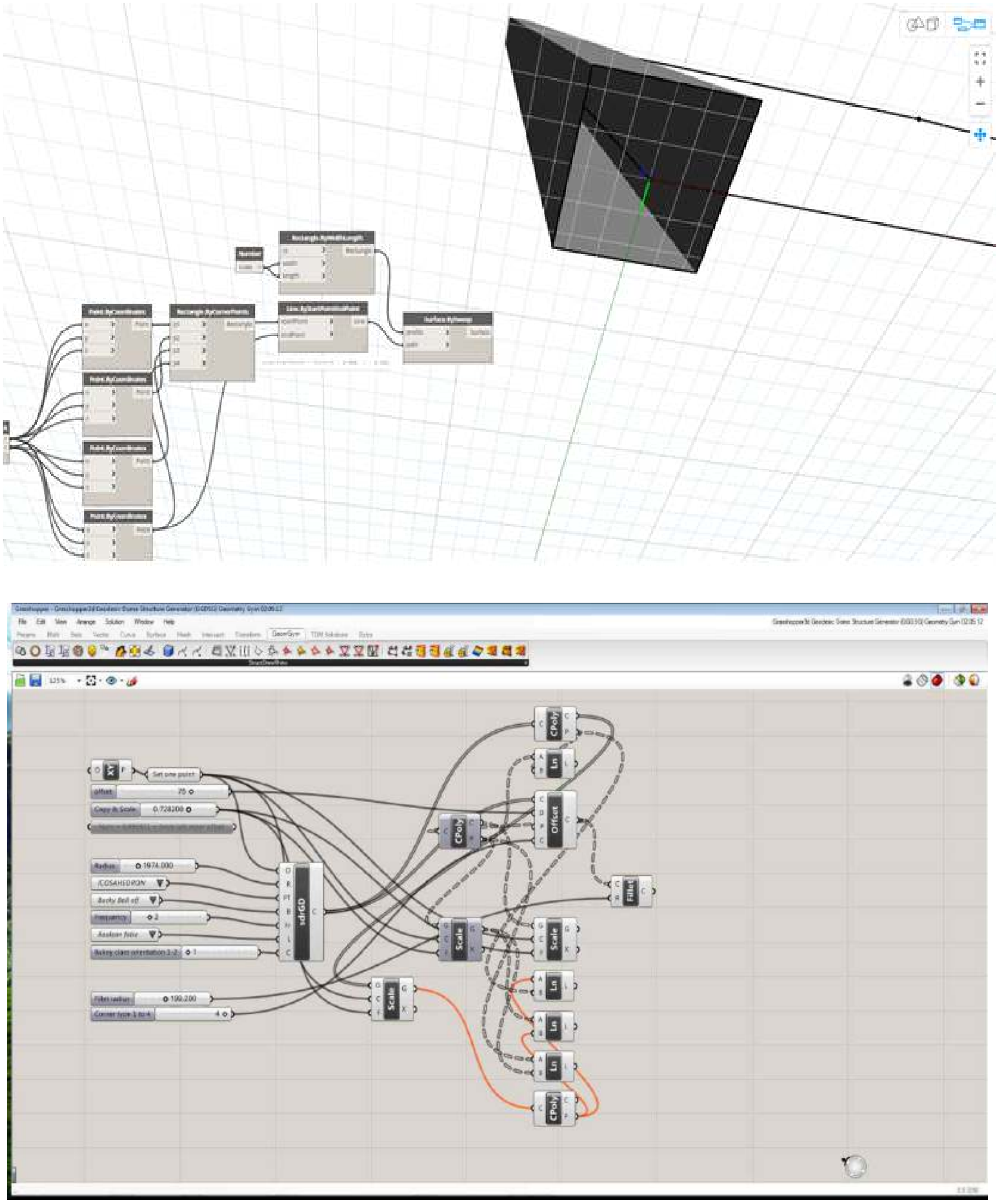

Figure 2.4 Screenshots of User Interfaces from Software Dynamo (a) and Grasshopper (b, online image source https://www.grasshopper3d.com)

2.4 Computer Modelling and Energy Simulation tools

Computer simulation tools are impactful analysis programs for energy efficiency of buildings. Digital tools offer stakeholders a variety of results that can be used to promote and encourage cooperation in the process of both design and construction.

2.4.1 Honeybee and Ladybug

Honeybee and Ladybug, created by Mostapha Sadeghipour Roudsari and others, are free and open-source environmental plugins for Grasshopper and Dynamo. They were initially developed for use in Grasshopper, but have relatively recently been released for Dynamo and the plugins connect the visual programming environments to 4 validated simulation engines; Radiance, Daysim, OpenStudio and EnergyPlus (Baker, 2017).

The developer Roudsari (2019) claims Ladybug Tools "as a collection of free computer applications that support environmental design and education. Of all the available environmental design software packages, Ladybug Tools is among the most comprehensive, connecting 3D Computer-Aided Design (CAD) interfaces to a host of validated simulation engines. Ladybug Tools is built on top of several validated simulation engines: Radiance, EnergyPlus-OpenStudio, Therm-Window, and OpenFOAM."

Honeybee is a free and open source plugin to connect Grasshopper3D to EnergyPlus, Radiance, Daysim and OpenStudio for building energy and daylighting simulation (Roudsari, 2019). According to him, "it supports detailed daylighting and thermodynamic modeling that tends to be most relevant during mid and later stages of design. Specifically, it creates, runs and visualizes the results of daylight simulations using Radiance, energy models using EnergyPlus/OpenStudio, and heat flow through construction details using Berkeley Lab Therm/Window. It accomplishes this by linking these simulation engines to CAD and visual scripting interfaces such as Grasshopper/Rhino and Dynamo/Revit plugins (Roudsari, 2019). It also serves as an object-oriented Application Programming Interface (API) for these engines. For this reason, Honeybee is one of the most comprehensive plugins presently available for environmental design (Roudsari, 2019)."

2.4.2 Radiance

Radiance is open source software for lighting simulation copyrighted and distributed by Lawrence Berkeley National Laboratory in California. Radiance uses a hybrid of Monte Carlo and deterministic ray tracing techniques to calculate radiance values (McNeil & Chadwell, 2012). Direct, specular indirect and diffuse indirect components are calculated in order to trace rays backwards from measurement-point to source (McNeil & Chadwell, 2012).

Radiance is commonly used through other programs, which allow the user a limited input and set-up the majority of the simulation automatically and this is precisely how Honeybee works, allowing the user to set the geometry, sky and material properties, as well as Radiance parameters (Baker, 2017).

3 Methodology

3.1 Research Framework

The overall process of this project is displayed in Figure 3.1. There are 3 main

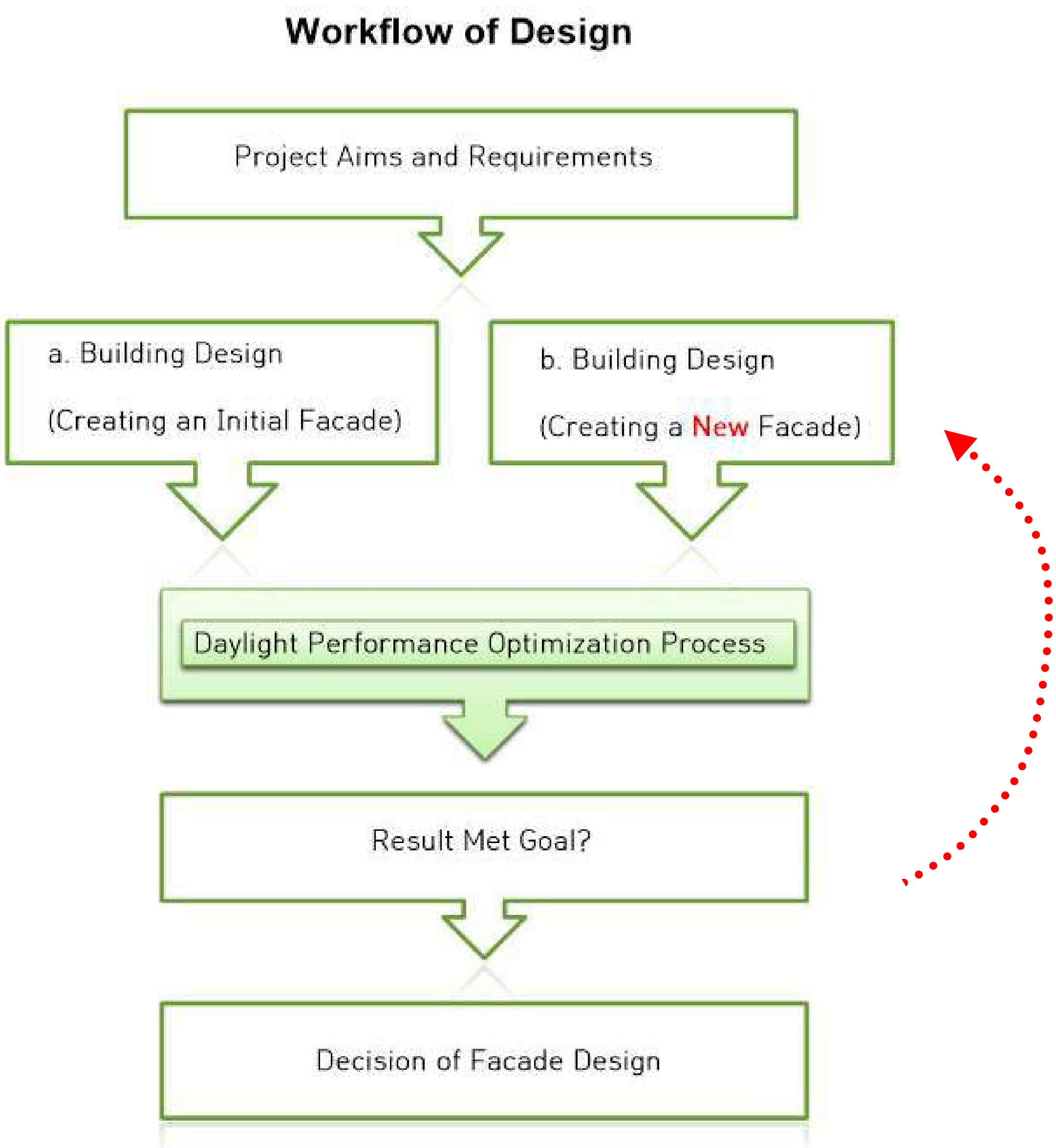

Figure 3.1 Diagram of Project Process

steps.

The first step is to analyze the daylight performance during winter solstice when has the shortest daylight performance after generating an early 3D model for the building of the Institut für Bauinformatik using Revit, Dynamo, and daylight simulation tools .

The second step is to evaluate the daylight performance after designing a new facade system for the same building with the same processes.

The last step is to find out the optimum solution through analysis and evaluation of the simulation results. The 2 facade systems are compared visually, and the settings of each design are compared. The daylight performance improvement and the variables which is the most influence factor for the building performance are also analyzed.

3.2 Case Study Model - Bauinformatik Institut Building

The Bauinformatik Institut Building is shown in Figure 3.2. This is a 8 storey complex building and has 4750㎡– of laboratories, offices, seminar rooms and commercial spaces. The structure is based on low-energy characteristics which include conventional passive solar architectural design, limited levels of infiltration and quality natural lighting and ventilation.

- The front of the building is facing southwest by around 20 degrees.
- There is a existing shading system . fabric blinds situated outside to enable windows to be covered.
- Natural ventilation of any spaces through openable windows.

Figure 3.2 Southwest side of Bauinformatik Institut Building

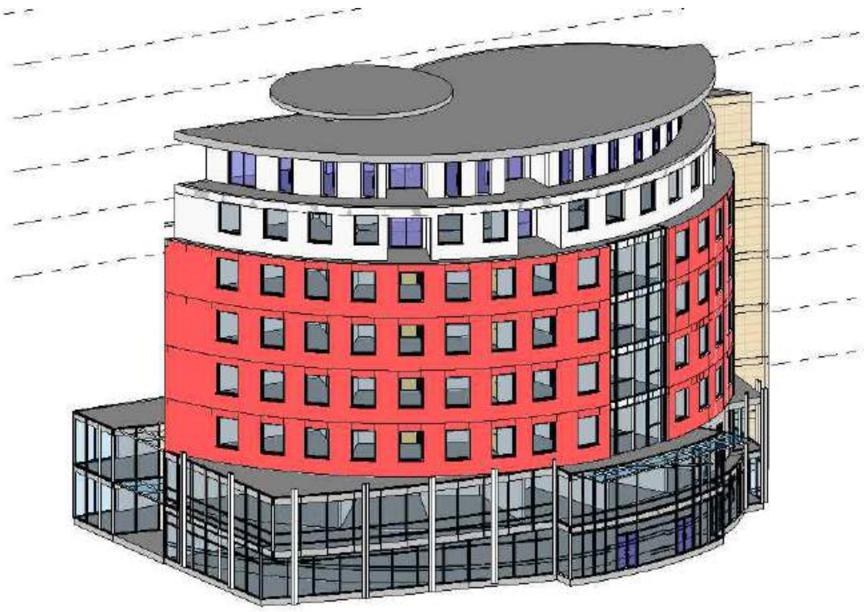

Figure 3.3 Revit Model of Bauinformatik Institut Building

A Revit Model of the Bauinformatik Institut Building is displayed in Figure 3.3 where the southwest facing facade features are focused. This building has two semicircular shapes with different radius in both the front side (southwest) and back one (northeast).

3.3 Daylight Simulation

3.3.1 Workflow

Methodology for daylight simulating is based on a general workflow within Dynamo using Honeybee and Ladybug packages), which is presented below. Figure 3.4 shows an overview of the general workflow that will be used in Dynamo. The alphabet from A to F with red color below is for explanation of following Dynamo definition.

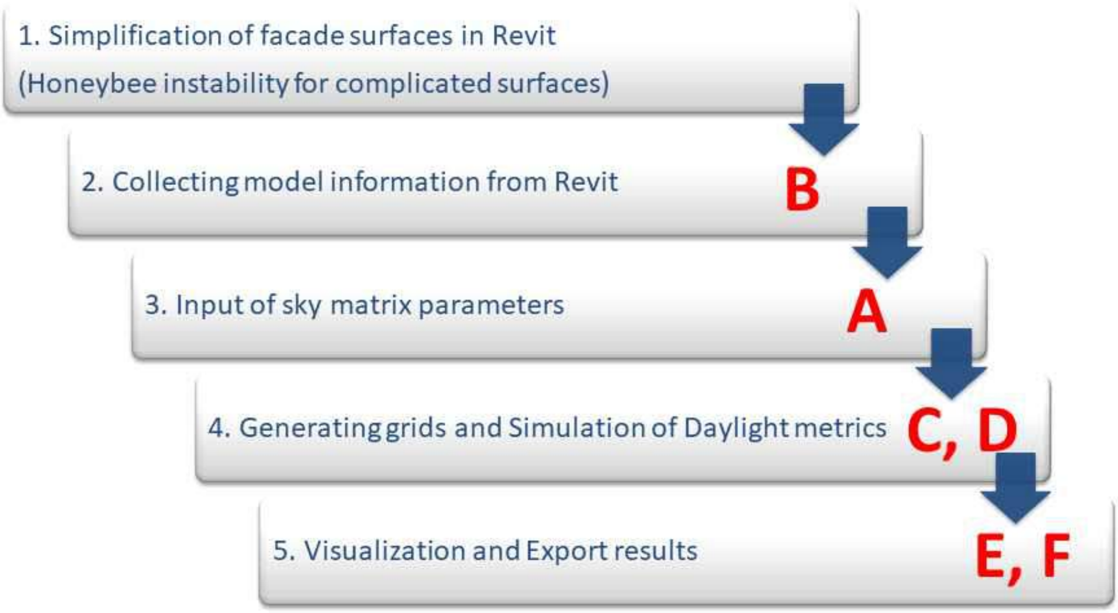

Figure 3.4 Workflow for Daylight Simulation

Firstly, facade surfaces in Revit are simplified to polygons from the semicircular geometry of the existing building due to instability of Honeybee component when Honeybee zones are converted. And then Dynamo collects model information with windows and walls as well as properties of them. For simulations of daylight, input of sky matrix parameters is used for daylight metrics. Eventually the results are visualized with grids and colors in the rooms as well as data in Excel.

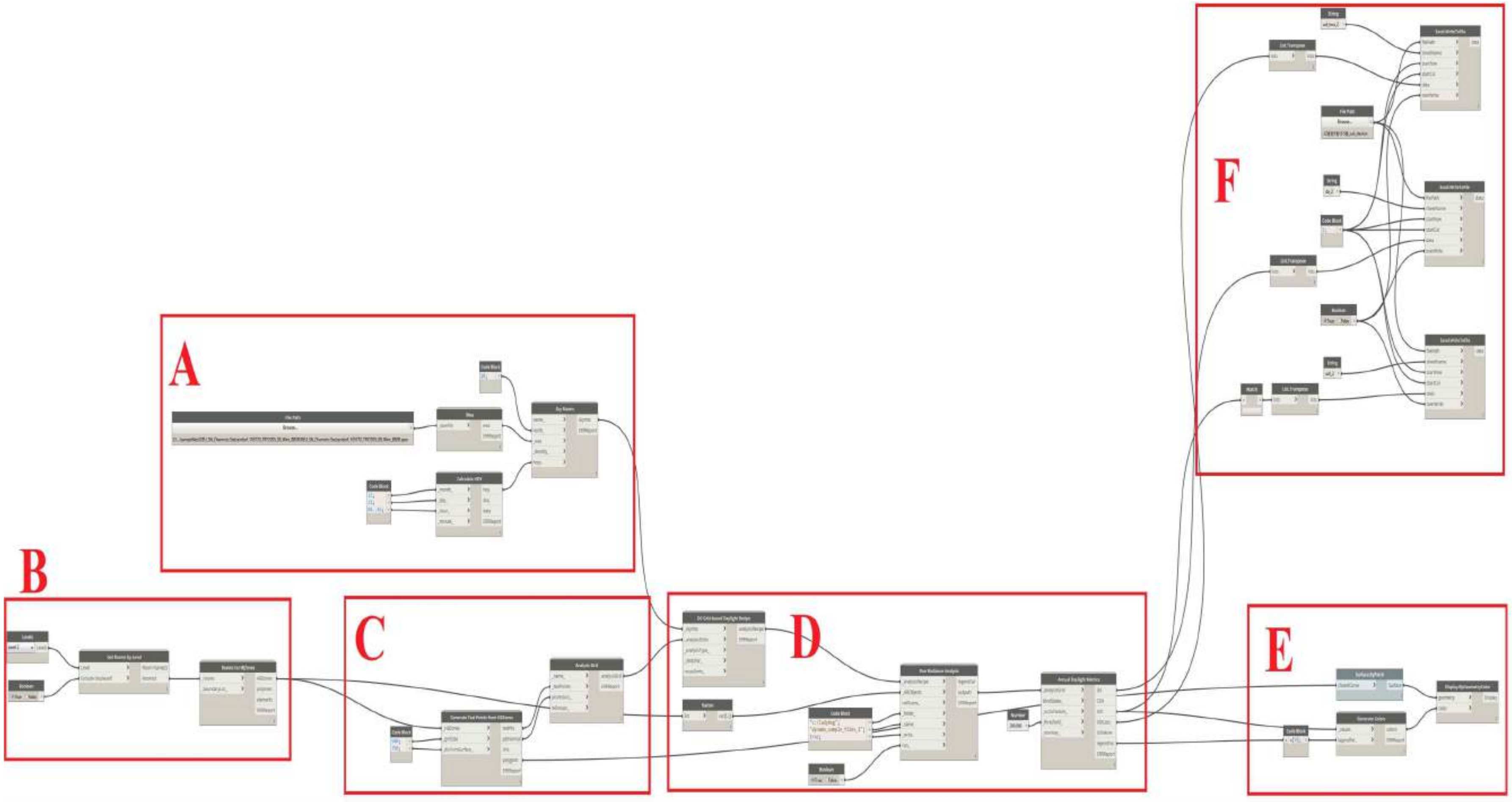

Figure 3.5 Overview of the Dynamo definition for Daylight Simulation

Figure 3.5 (on the previous page) shows the completed daylighting simulation. The procedure begins in Dynamo with the geometry of the building and a few kinds of parameters. Ladybug and Honeybee have the functionalities of daylight, which The geometry in the daylight modeling method is linked to the radiation materials element by setting transparency and reflectance of the material, and then to weather files and other simulation settings. Eventually Ladybug and Honeybee export the result of the simulation results.

Group A is the components for sky matrix information. The geometry is linked to Group B components for information being read. Group C generates text points and grids in the rooms. Calculations and simulations are conducted through Group D. Group E makes colors in the grids for showing the results after daylight simulation. The last components of Group F export the data into Excel.

Parameter	Values
Sky type	CIE Overcast Sky
Test grid size	500mm
Height of test points	750mm
Glass material visual light transmittance	0.62
Floors of simulation model	Level 2 ~ 5

Table 3.1 Parameters and Values for Daylight Simulation

Daylight simulation uses parameters and values of Table 3.1. The sky type is the common default for daylight packages in Honeybee and Ladybug. Test grid size is 500mm selected for simulation speed and specific results and height of test points is 750mm. The value of 0.62 is default of used windows in Revit. Floors of simulation model are from 2nd floor to 5th floor whose exact floor plans are known via CAD file.

3.3.2 Daylight Simulation with Dynamo

3.3.2.1 Simplification of Facade Surfaces in Revit

First of all, facade surfaces are simplified to polygons from the semicircular geometry of the existing building. That's because Honeybee in Dynamo is instable for the complicated geometries when rooms in the building are converted to Honeybee zones in order to be used for generating test points and grids. One of the developers of Honeybee and Ladybug, Roudsari (2017) claims that the Room To HBZones component for Dynamo is doomed to fail for complex cases. Figure 3.6 displays that the facade geometry is changed to polygons from the round surfaces for making Honeybee zones in this room.

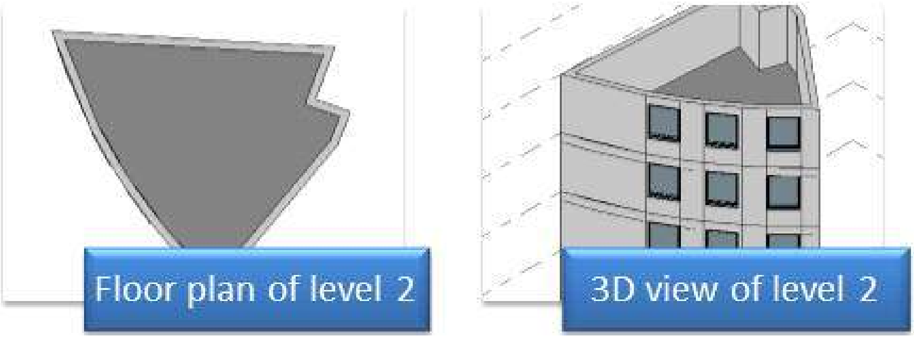

Figure 3.6 Simplification of Facade Surfaces in Revit

3.3.2.2 Collecting Model Information from Revit

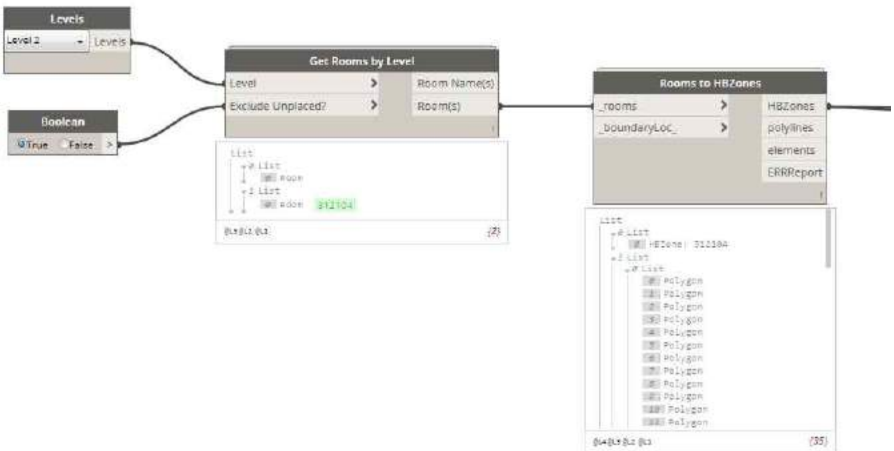

Figure 3.7 Collecting Model Information from Revit

The first room on the 2nd floor from the left of the building is collected through the definition above Figure 3.7. And then it is converted as a Honeybee zone which is regardes as a medium for daylight simulation and it automatically separates a few dozen polygons for test points of the next step. The node **Rooms to HBZones** recognizes only polygons of the facade geometry when round surface of the room is set. Therefore the narrow piece of round shape is not included when it is simulated for daylight performance.

3.3.2.3 Input of Sky Matrix Parameters

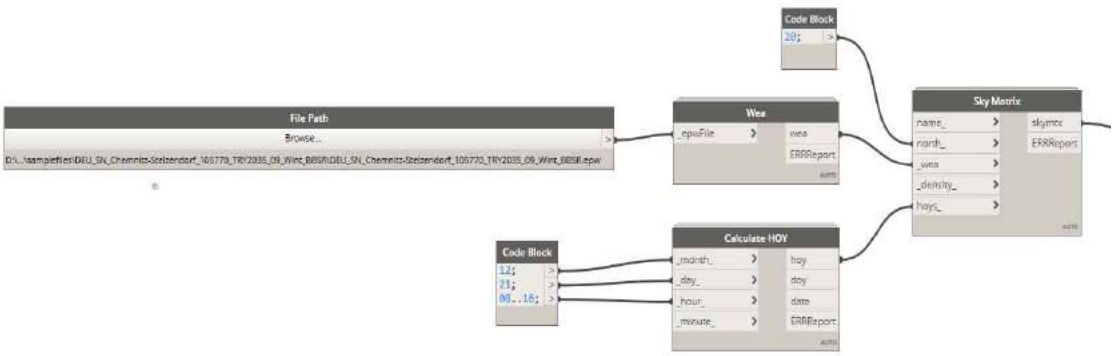

Figure 3.8 Input of Sky Matrix Parameters

Sky Matrix node for radiance step needs input of variables such as weather file, angle of the case model from north, and date and time. Sky type is CIE Overcast Sky. **File Path** conducts with EPW file which is weather data file saved in the standard EnergyPlus format; used by EnergyPlus energy simulation software, developed by the U.S. Department of Energy (DoE); contains weather data that is used for running energy usage simulations (Fileinfo, 2019). Dresden weather file does not exist in the weather data file so Chemnitz weather file is input as one of the nearest and the same climate zone. Next angle of the building from north is around 20 degree. **Calculate HOY** is for input of date and time of simulations. The range of date and time is winter solstice and from sunrise to sunset between 8 and 16 for this simulation.

3.3.2.4 Generating Grids and Simulation of Daylight Metrics

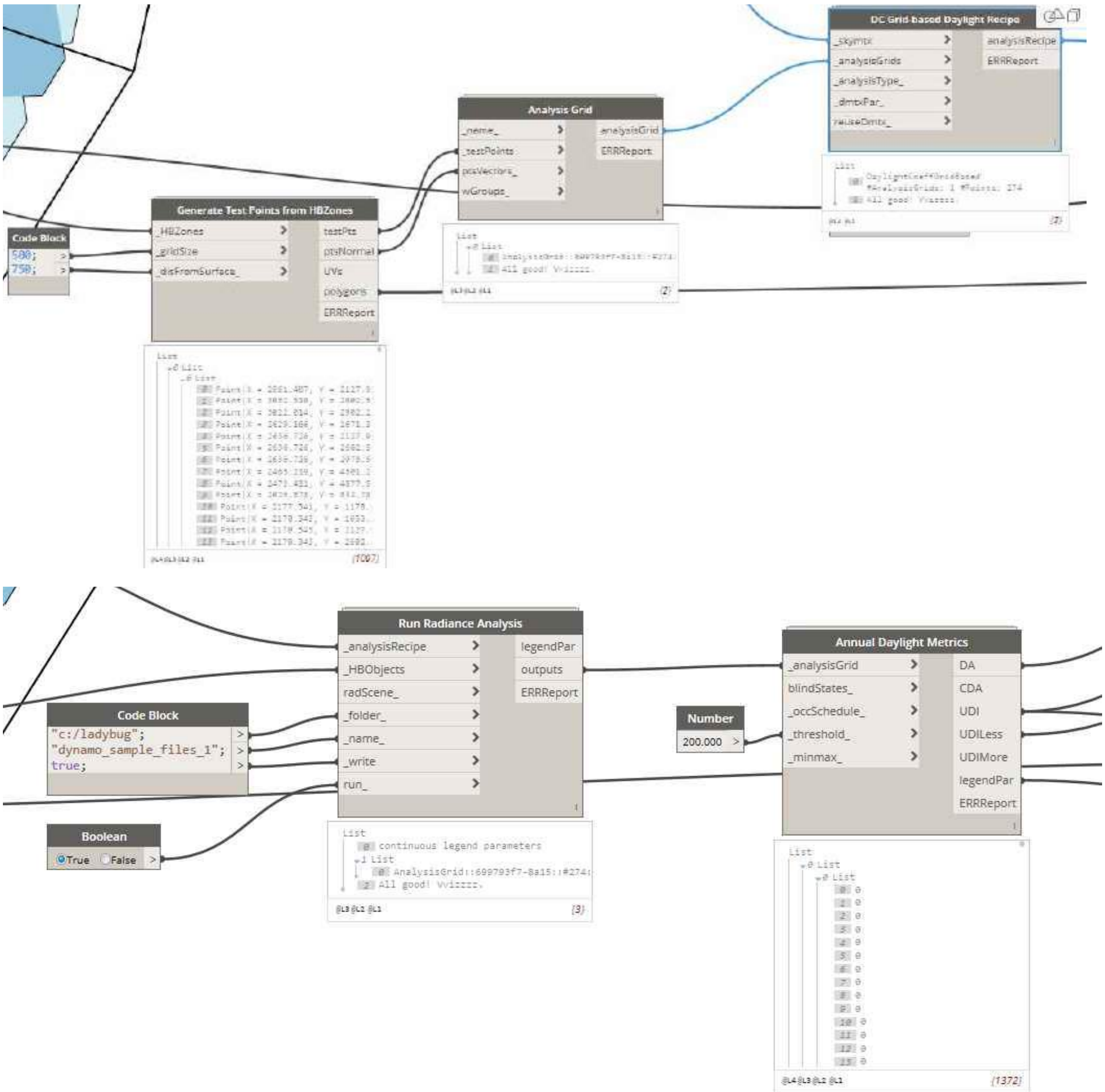

Figure 3.9 Generating Grids and Simulation of Daylight Metrics

Figure 3.9 shows the process of generating test points through polygons in the previous Honeybee zone and grids using the points as well as daylight metrics. **Generate Test Points from HBZones** conducts to make test points by input of grid size and distance from the floor surface. 500mm is used for grid size and 750mm is for general height of the desk in the room (Figure 3.10). **Run Radiance Analysis** traces rays in order to calculate radiance values. **Annual**

Daylight Metrics calculates outputs during period set in the early step. The results are Daylight autonomy (DA) which is the percentage of time during winter solstice which a point is illuminated above 200 lux in this simulation and Useful daylight illuminance (UDI) which the percentage of the number of hours during the same period when illuminance is between 100 lux and 2000 lux.

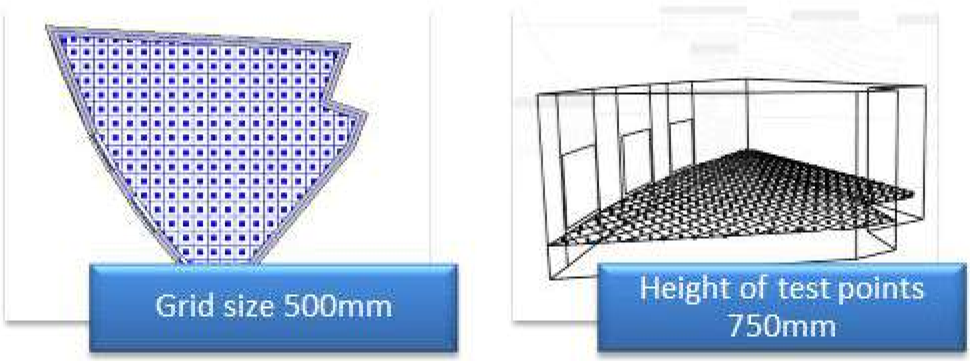

Figure 3.10 Variables for Generating Grids

3.3.2.5 Visualization and Export Results

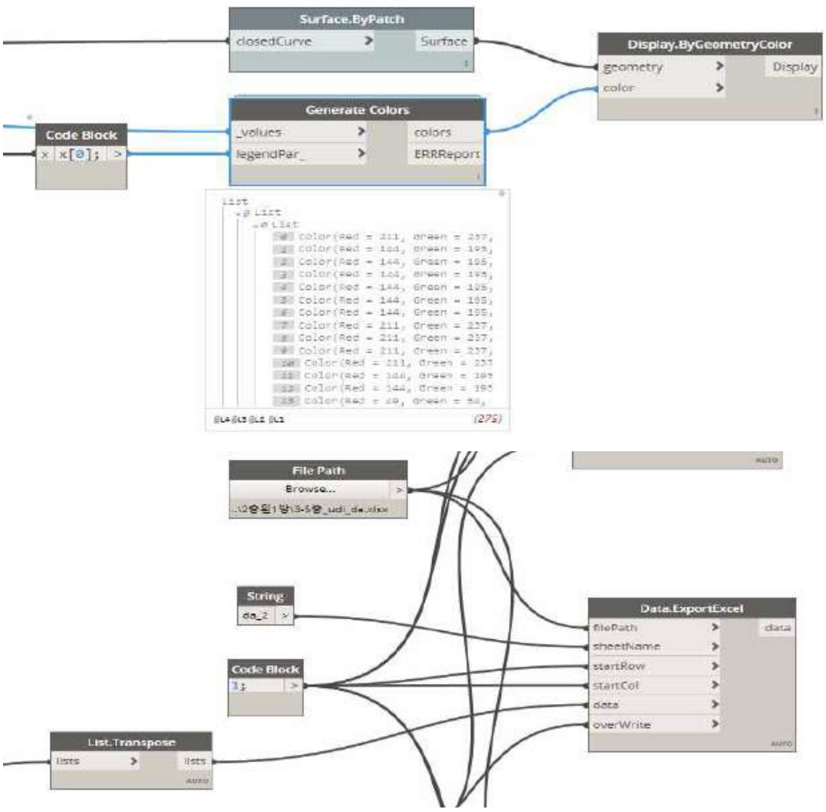

Figure 3.11 Visualization and Export Results

Figure 3.11 displays components for both visualization of the values on the grids and export results into Excel. The geometry used in **Display.ByGeometryColor** is made by surfaces of polygons which is generated from test points in the previous stage. This geometry gets colors according to values from DA or UDI and so on. The last step is to write results of DA and UDI in Excel using **Data.ExportExcel**.

3.4 Parametric Facade Design

A new facade design needs improved daylight compared to the early facade according to a certain criteria. The criteria is winter solstice which is not only the shortest day but daylight is also the lowest in a year. If the new facade gets sunlight more than the previous model on the shortest day, the performance of daylight is improved in winter season. The criteria of period does not include spring, summer, and fall when does not need sunlight more as winter. The another criteria of time for the new facade design is 12:09 p.m. when the sun is the highest on the winter solstice.

The new facade system is designed for more even and better daylight on the each surface on the shortest day. For being realized this goal, 5 non-uniform rational basis spline surfaces which have each different value of parameters and insolation on their grids are taken into account (Figure 3.12 on the following page).

3.4.1 Parameters for Generating New Facades

Figure 3.12 shows the whole process and parameters for finding out the optimal facade geometry which receives better insolation. The early facade system is transformed towards the sun, which is made progress in accordance with parameters.

First of all, the geometry of the initial facade is removed and surfaces of other sides are still left and the all surfaces are simplified to a whole mass for

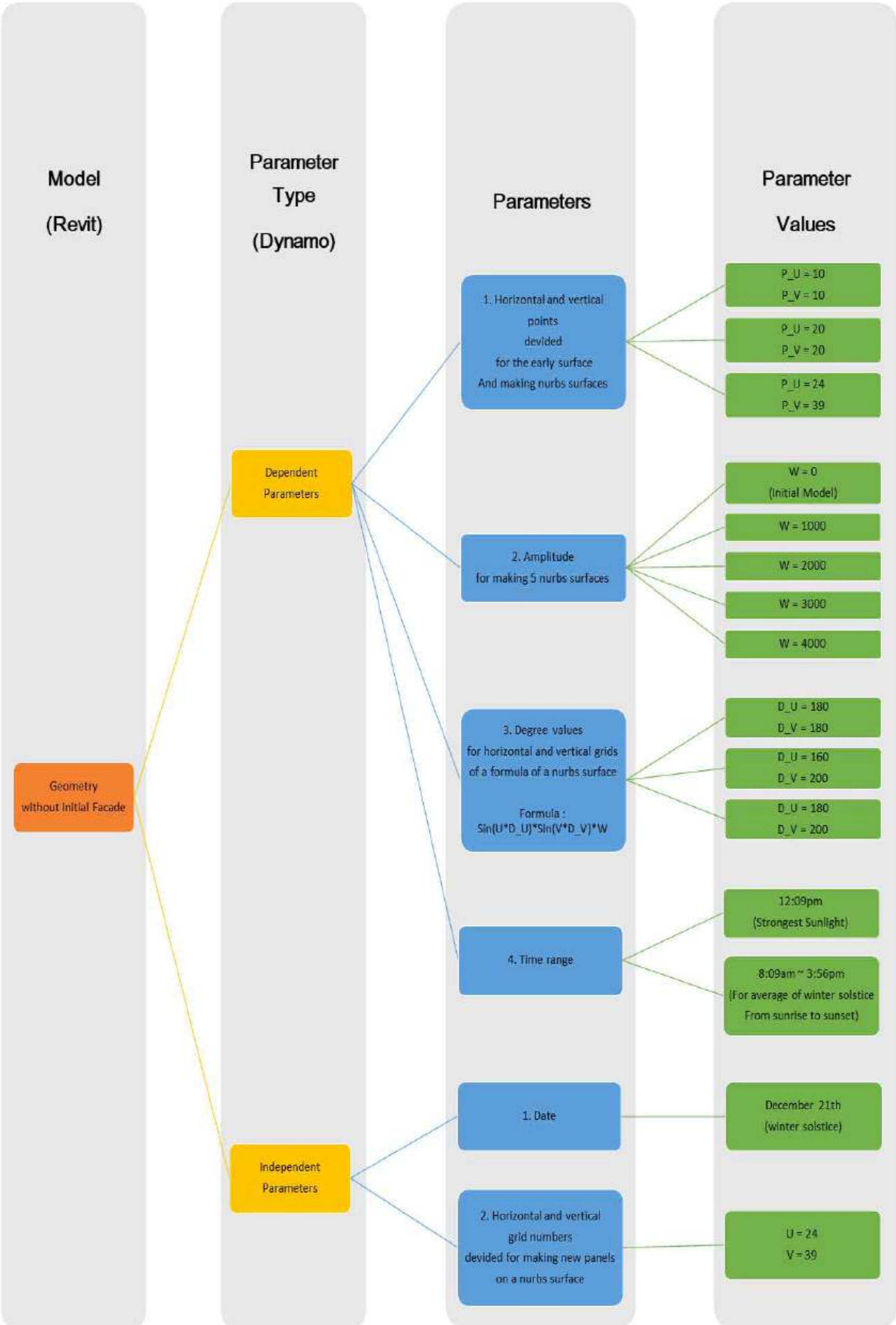

Figure 3.12 Parameters for Generating New Facades

simulations as Figure 3.13. This empty facade geometry is designed after choosing the optimal shape among a few models simulated with parameters and insolation values.

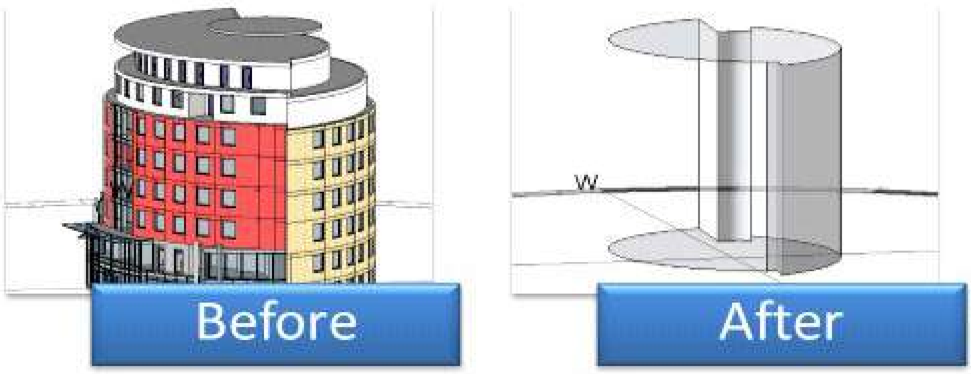

Figure 3.13 Simplification of Initial Facade

Parameter type is 2 kinds of dependent parameter and independent parameter.

- Dependent parameters

- Horizontal and vertical points numbers : the early surface is devided by points and nurbs surfaces is based on these points numbers and transformed. There are 3 sets of values of point parameter which are determined at random but 24 for the horizontal and 39 for the vertical of setting values mean a set of 4 points with around 1000mm of both horizontal and vertical length.
- Amplitude : transformation degree is determined by amplitude. If amplitude value W is 2000, transformation of the geometry is 2000mm from the early surface line (Figure 3.14).

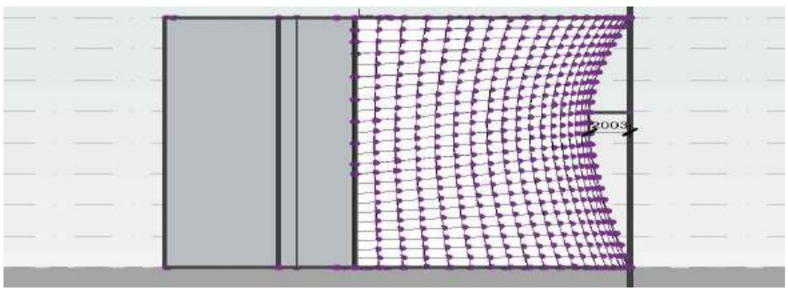

Figure 3.14 Amplitude Parameter

- Degree values in a formula : The formula generates shapes of sine backwards for better insolation. Also degree transforms the round shape.

  Formula : Sin(U*D_U)*Sin(V*D_V)*W
  U : Horizontal grids
  V : Vertical grids
  D_U : Degree for horizontal grids
  D_V : Degree for vertical grids
  W : Amplitude

  The grids of U and V get new values from 0 and to 1 divided by uniform interval by Dynamo definition. Therefore minimum of sine for both the horizonal and the vertical is 0 and maximum of each one is 1 after multiplying 180°
- Time range : First criteria for designing of the surfaces is at noon and then the quantity of solar radiation of all surfaces is calculated during the day between sunrise and sunset.

- Independent parameters

- Date : December 21th is winter solstice, which is the shortest day.
- New grids : horizontal and the vertical grid numbers devided by this parameter values for making new panels on a nurbs surface.

3.4.2 Parametric Design

Figure 3.15 (on the next page) presents an overview of the detailed Dynamo definition for parametric design and insolation. The entire definition is separated into 11 parts (marked in red color), which conducts a different function.

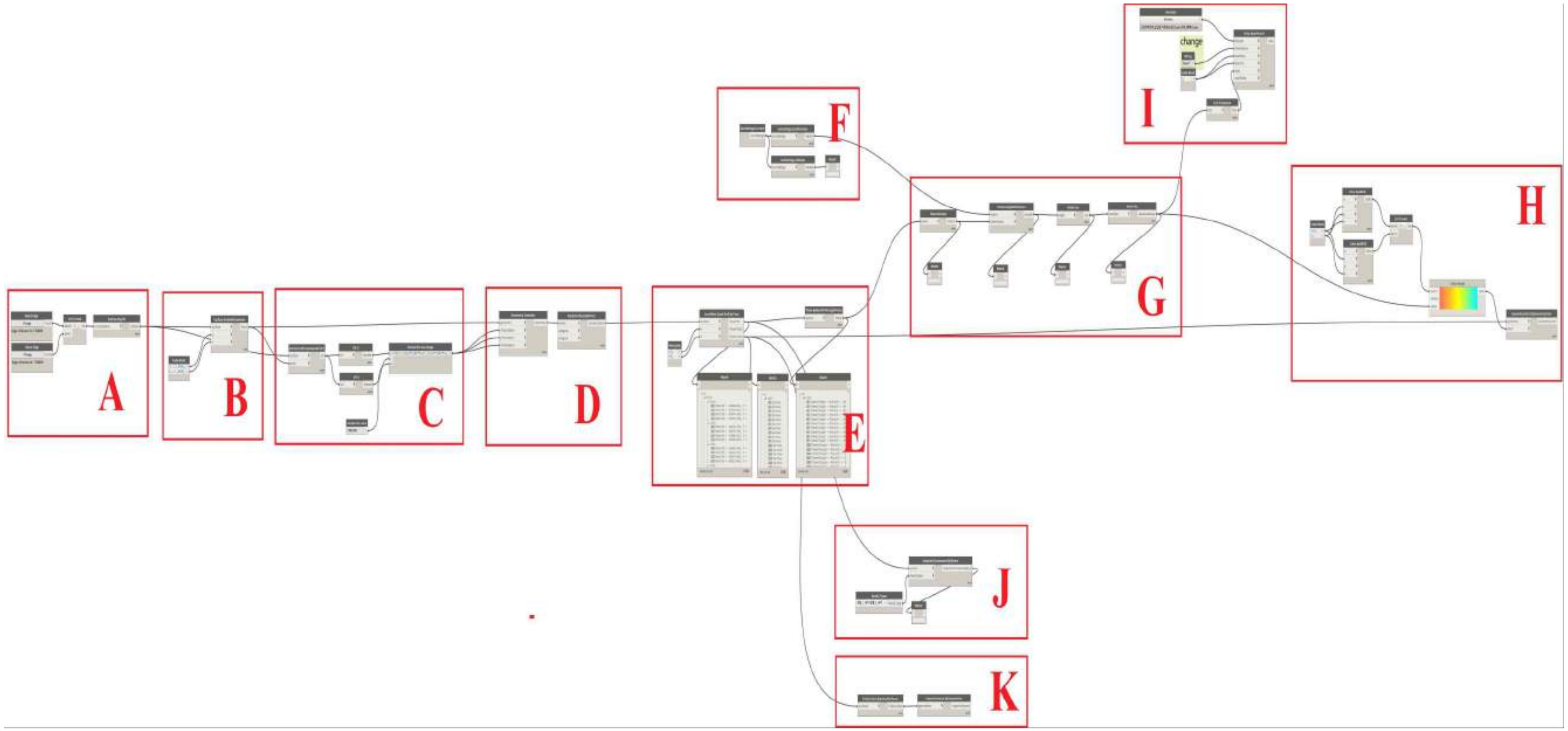

Figure 3.15 Dynamo definition for Parametric Design and Insolation

Group A forms importing the information of the geometry (as Figure 3.16). Specifically, the empty facade deleted the facade geometry as Figure 3.13 is imported into Dynamo through **Select Edge** and 2 semicircle edges up and down are made a surface.

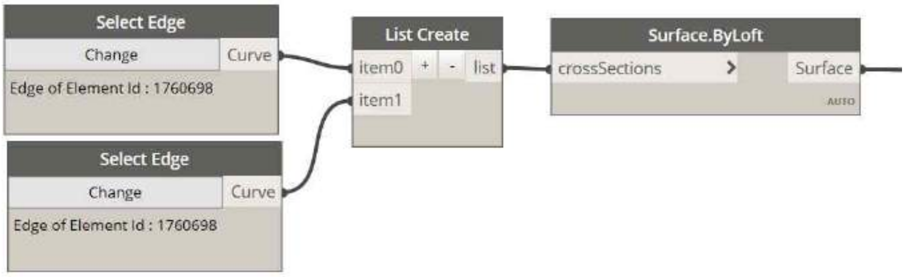

Figure 3.16 Importing Early Surface

Group B shows a component which divides the length and height by values of U and V as the first parameter in Figure 3.17. In detail, 10 of the U value divides the length of the early surface and V value also generates 10 parts of the height. And then the points are made when the parts of both U and V connect.

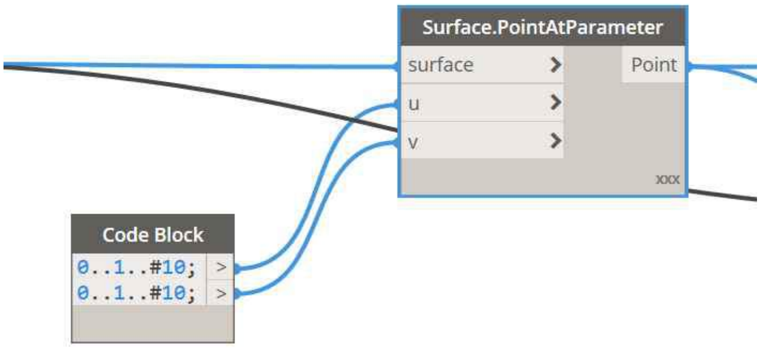

Figure 3.17 Parameter 1 Definition

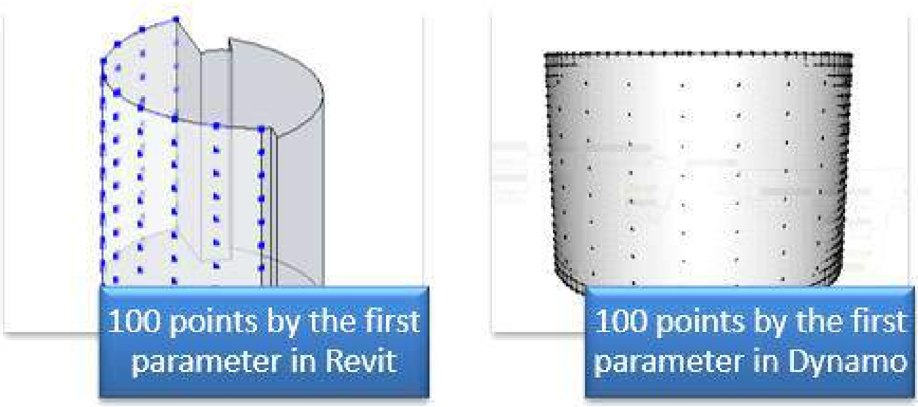

Figure 3.18 Display with Parameter 1

The points generated in the previous node are gathered and separated into each detail for being implemented in the formula in Group C. The formula is used in order to perform a new NURBS surface in accordance with 100 of the previous points and the W value of amplitude. The amplitude has a role of translating the initial surface to the sine shape. When the value is 0, the shape is the early surface which is not transformed at all and the value is from 0 to 4000 for finding out the best performance of daylighting. Figure 3.20 displays the comparison by different amplitude. The third parameter, degree for the horizontal and the vertical is 180° in Figure 3.19. The shapes have different geometries according to degree for U and V.

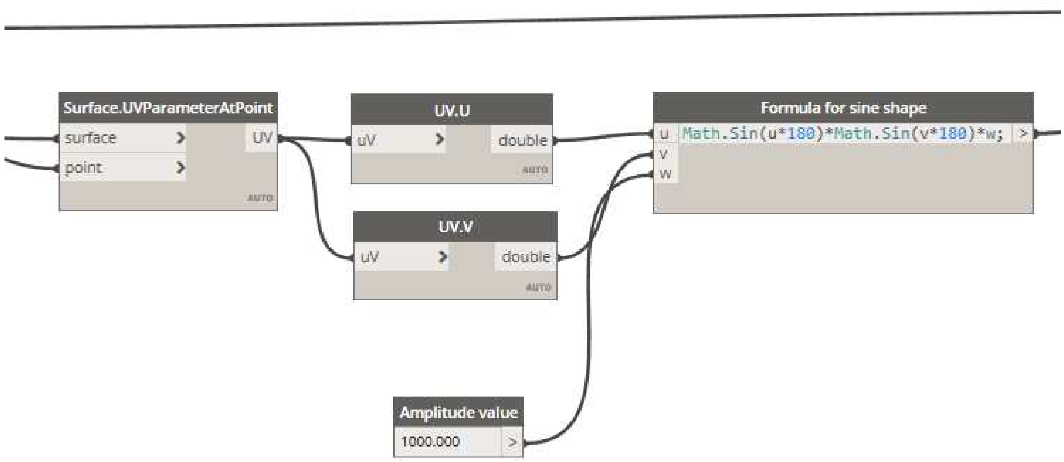

Figure 3.19 Formula with Parameter 2 and 3

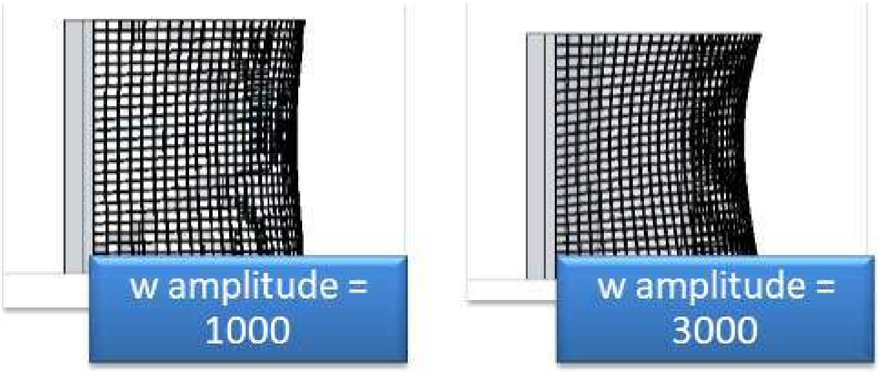

Figure 3.20 Comparison with Parameter 2

Group D forms transformations of the initial surface according to the formula. Non-uniform rational basis spline is shown in the component.

Next step in Group E is to make rectangle grids on the transformed surface and to refine the planes into the best planes which fit with the points translated (Figure 3.21). **New grids** node presents an independent parameter which is not changed in the definition. 24 of the value is for the horizontal and 39 is for the vertical. When the new NURBS surface is divided by the values, a plane has around 1000mm of length and height, which means for understanding the dimension of the geometry simply. All simulations use the fixed values. After implementation of this node, 3744 points are created and 936 planes are produced with the points on the entire building.

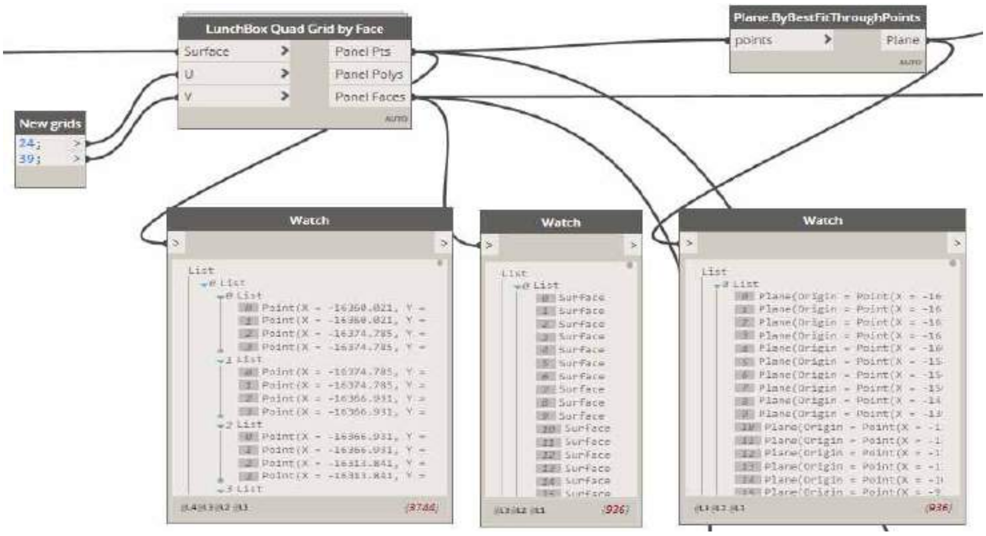

Figure 3.21 New Grids and Planes on the NURBS Surface

In Figure 3.22, Group F presents the sun direction faced on the model. **Sunsettings.Current** component reads the setting of the sun in Revit which is set up in accordance with date and time as well as location of Dresden where the model exists. (Figure 3.23). The appointed date is winter solstice and time is between 8 a.m. and 4 p.m. Through the conditions, the direction of the sun is determined and vector value of the sun and **SunSettings.Altitude** is in order to double check if the definition of reading the sun setting is be corrected.

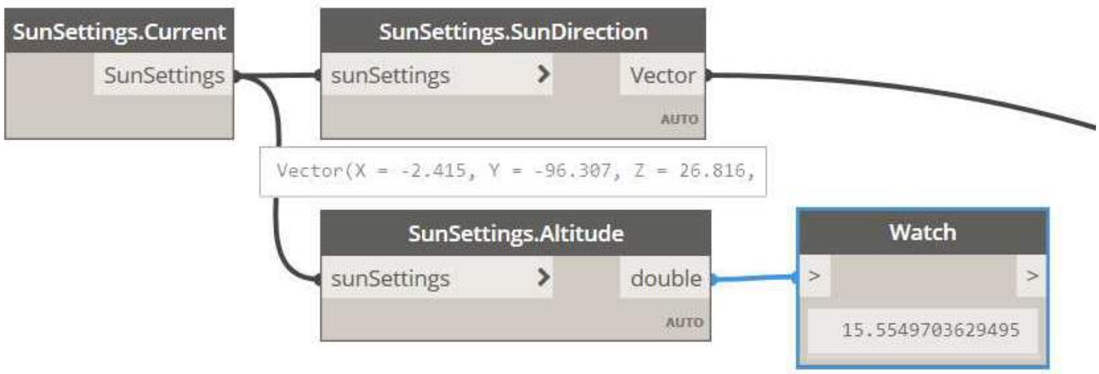

Figure 3.22 Sun setting in Dynamo

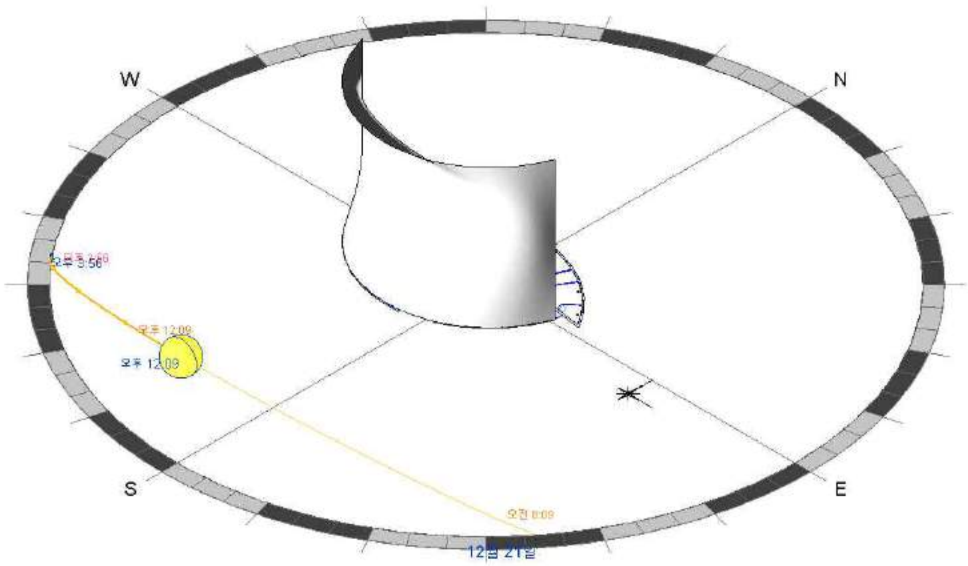

Figure 3.23 Sun setting in Revit

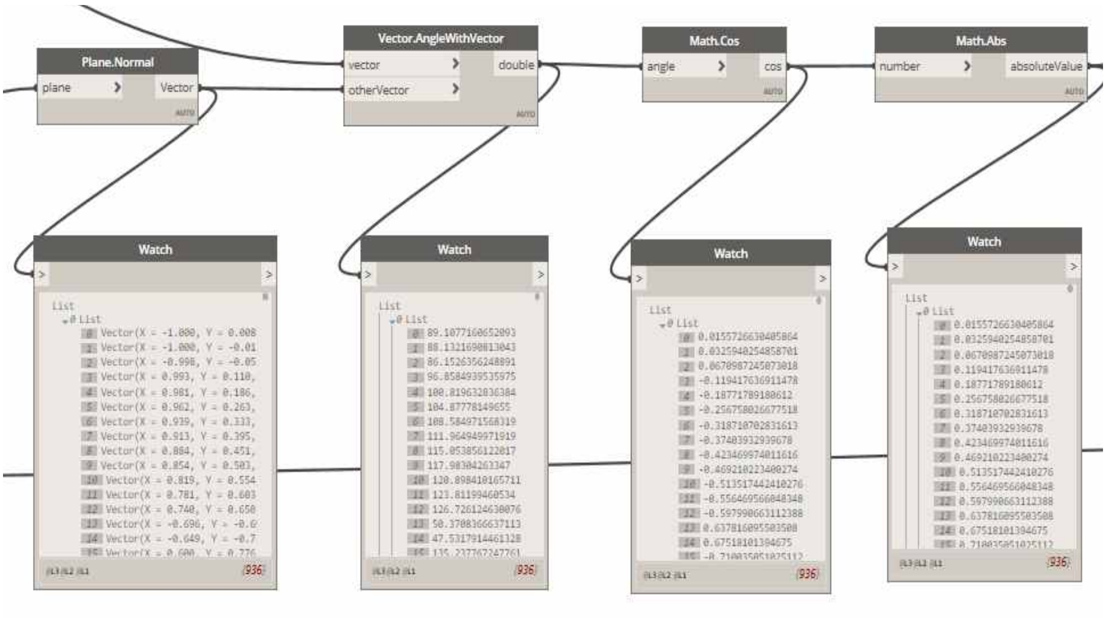

Figure 3.24 Calculating Insolation

Figure 3.24 displays how to calculate the solar irradiance of Group G. Insolation analysis that measures how much thermal energy the building has absorbed from the sun is conducted due to the new geometry which has the better performance of daylighting. Insolation is another standard type of analysis that assesses the relationship between the sun and the structure. The reason why the analysis is used instead of Ladybug and Honeybee daylight simulation is that the new NURBS surface is not simulated with the components. Therefore, insolation analyses of new facade systems are calculated with the definitions of Figure 3.24. The percentage of sun energy absorbed by the surfaces can be calculated as the cosine of angle between the vectors of the normal planes of the new geometries and the sun as Figure 3.25. If the value of angle between the vector pointing to the sun and the surface normal vector is 0, cosine value is 1, which means 100% of the sun energy is absorbed by the plane.

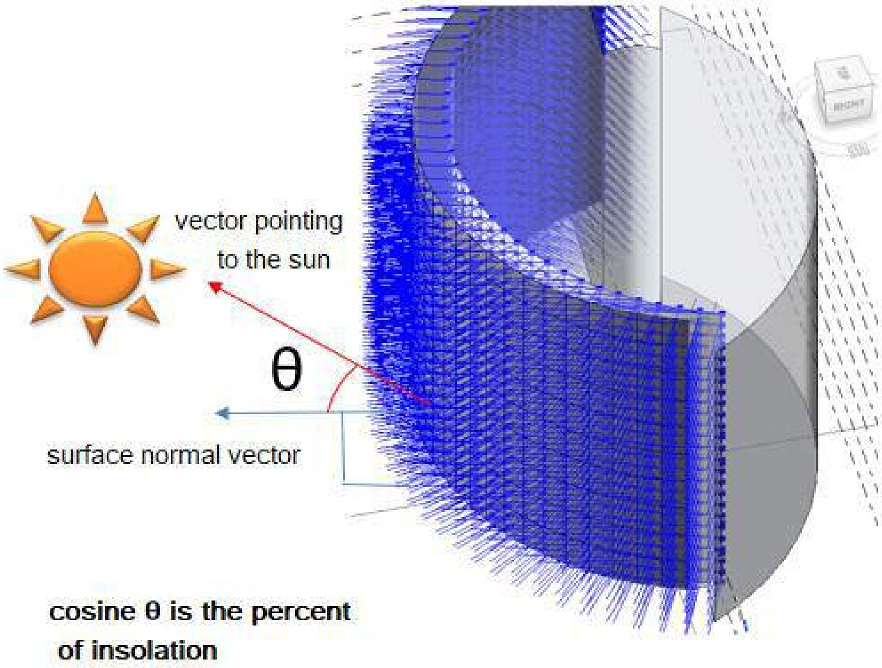

Figure 3.25 Calculating Insolation as Cosine of Angle between Solar and Surface normal vector (Nagy, 2017)

Plane.Normal node computes the normal vectors of 936 planes and the vectors and planes vector pointing from the sun have angles which is calculated by **Vector.AngleWithVector.** The values of angles are converted to cosine values which have 0 of minimum and 1 of maximum. The negative values of cosine are changed to the positive values through the last node in Group G.

Group H displays the colors on the 936 planes of the geometry when it comes to the values of solar irradiance (Figure 3.26). This visualization is helpful both in the understanding and comparison of outcomes and in the verification of simulation mistakes. As the color is closed to blue, the insolation is the maximum, on the other hand, red color means the lowest insolation value.

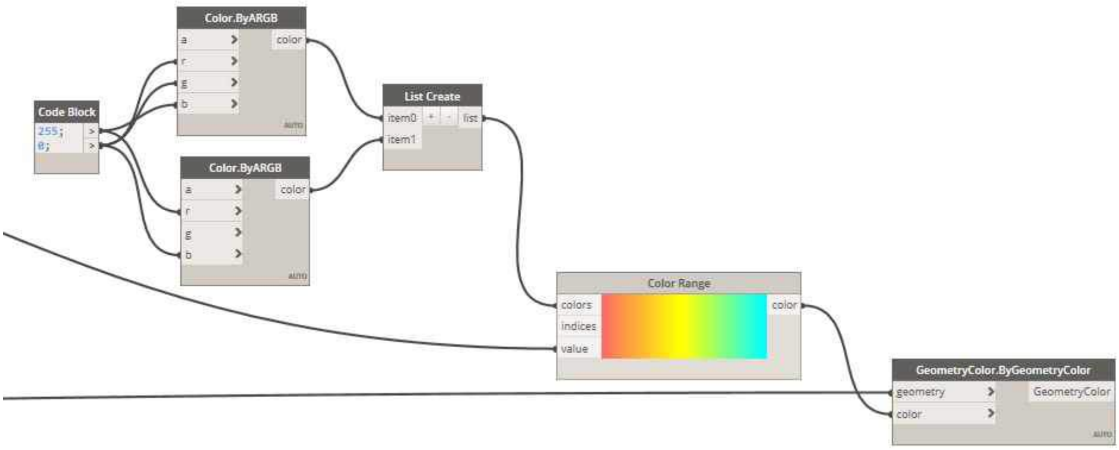

Figure 3.26 Display of Insolation values with Color

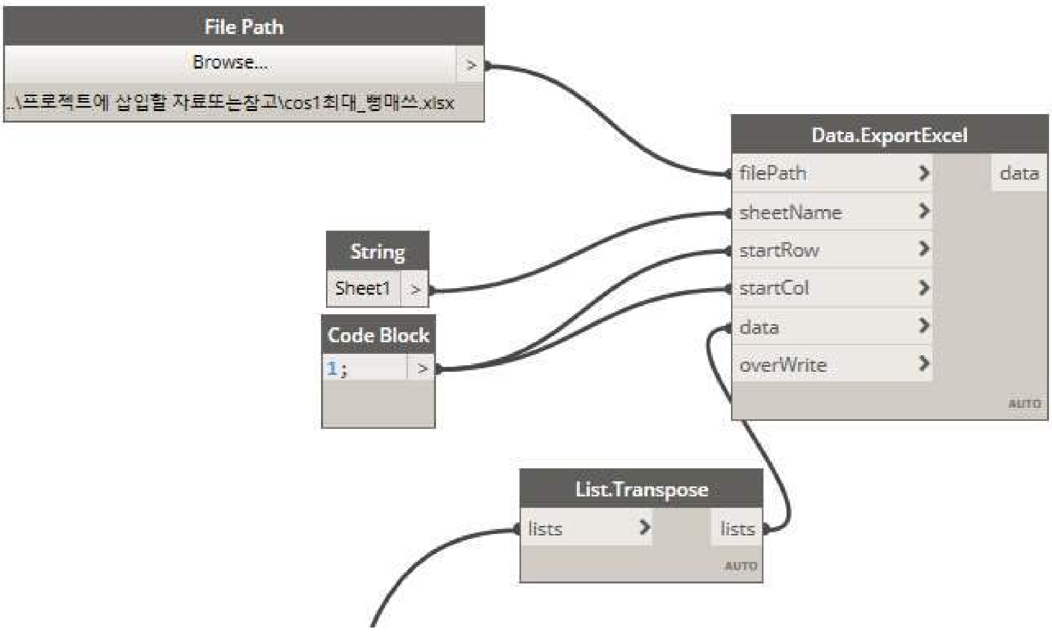

Figure 3.27 Export Data of Insolation values into Excel

Figure 3.27 shows how to export the data after getting the 936 values of solar irradiance in Group I. Data is arrayed along the row in Excel generally so the results can be arrayed in column by **List.Transpose** and are exported into the specific location of a sheet in Excel with above components.

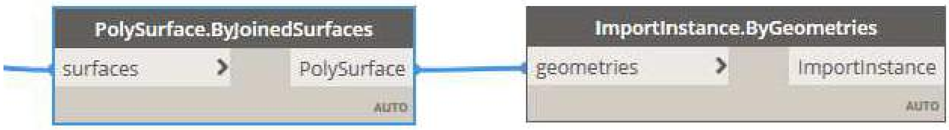

Figure 3.28 Import of New Facade in Revit

Figure 3.28 shows the importing the new facade into Revit in Group J. 936 planes are joined as a poly surface through **PolySurface.ByjoinedSurfaces**. And then it is displayed with 936 planes in Revit.

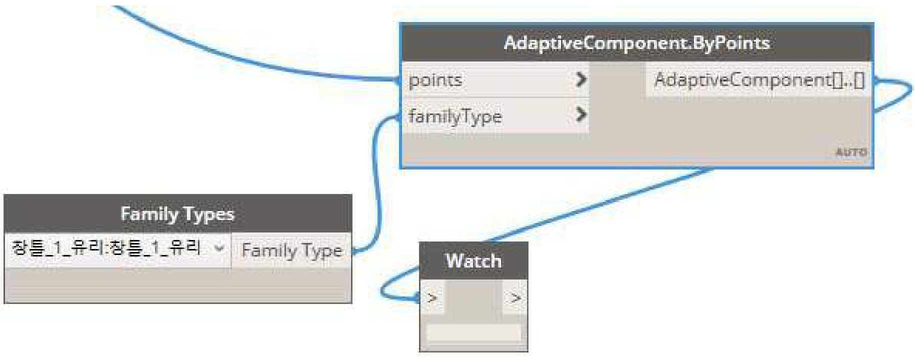

Figure 3.29 Generating Window Family into New Facade

The last step of Dynamo in Group K is to generate the window family which is put on the new facade system (Figure 3.29). Figure 3.30 displays the rectangle window family with 4 adaptive component points which are put on the points of the 936 planes. The window family is transformed along the NURBS surfaces and there does not exist the same window in the new facade system.

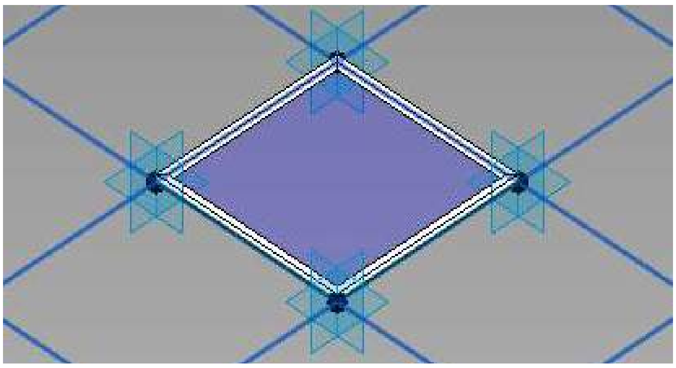

Figure 3.30 Window Family

4 Results of Analysis

4.1 Results of Daylight Simulation

4.1.1 Rooms on the Second Floor

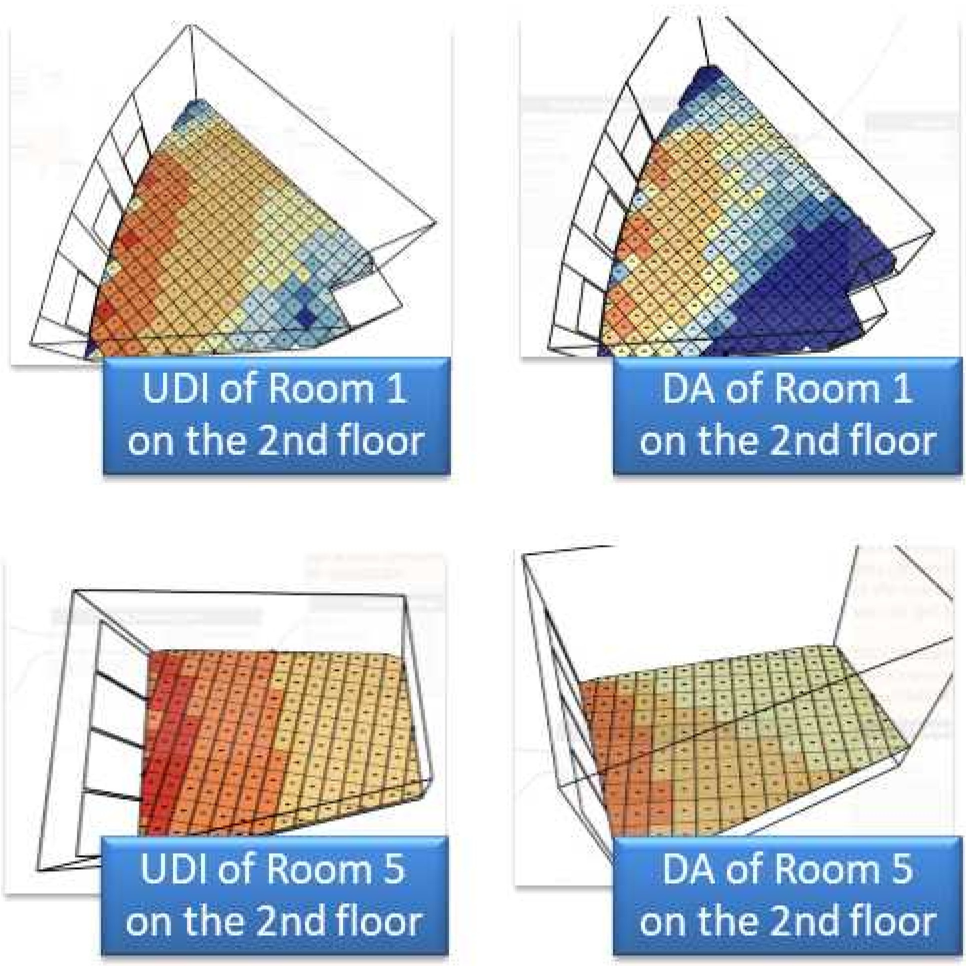

Figure 4.1 Visualization of Room 1 and Room 5 on the 2nd Floor

Figure 4.1 (above) displays the UDI and DA results of Room 1 and Room 5 with colors on the grids for understanding the differency easily. Grids in front of windows has high values on UDI and DA and the farther the grids are from the windows, the lower the values are as expected.

As Table 4.1 and 4.2 indicate that Room 5 has the highest values on both UDI and DA of all 8 rooms on the second floor and Room 8 has the lowest values related to 2 items. Also, Room 1 is the second lowest room with UDI and DA. The reason why Room 5 has the maximum values is that its facade consists of the entire window panels on the front wall and location is in the middle of the building where can get the even insolation from the sun. Room 8 has the only one window and is located in the rightmost side, which is limited to get sunlight. Room 1 from the left is placed to the northwest where can obtain the lowest daylighting but it has 3 windows, which does not lead the minimum values.

Also, Except of Room 8, UDI of other rooms are above 50% on the item between 100 lux and 2000 lux. Furthermore, Room 5 which has the highest value of UDI is only over 70 percentage. The values below 100 lux are around 2 fifths in the most rooms excluding maximum and minimum. The value of maximum on each room is the same with the number 87.50% and minimum is from 0% of 4 rooms to 62.50% of the Room 5. Grids number is related to the area of the room because the grid size is fixed for 500mm. The bigger the room is, the more the grid number becomes.

	UDI_2_1	UDI_2_2	UDI_2_3	UDI_2_4	UDI_2_5	UDI_2_6	UDI_2_7	UDI_2_8
100 LUX < UDI < 2000LUX (unit : %)	55.2464	59.7930	63.0719	63.2353	70.6081	59.7321	59.4262	46.4844
UDI < 100LUX (unit : %)	44.7536	40.2070	36.9281	36.7647	29.3919	40.2679	40.5738	53.5156
MAX (unit : %)	87.50	87.50	87.50	87.50	87.50	87.50	87.50	87.50
MIN (unit : %)	0.00	0.00	0.00	12.50	62.50	25.00	12.50	0.00
Numbers of all grids	274	157	153	153	148	140	122	96

Table 4.1 UDI of Rooms on the 2nd Floor

	DA_2_1	DA_2_2	DA_2_3	DA_2_4	DA_2_5	DA_2_6	DA_2_7	DA_2_8
200LUX < DA (unit : %)	33.4854	39.8089	47.5490	48.1209	62.6689	47.8571	45.9016	31.5104
DA < 200LUX (unit : %)	66.5146	60.1911	52.4510	51.8791	37.3311	52.1429	54.0984	68.4896
MAX (unit : %)	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
MIN (unit : %)	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00
Numbers of all grids	274	157	153	153	148	140	122	96

Table 4.2 DA of Rooms on the 2nd Floor

The chart of Figure 4.2 reveals information about the similar changes in results of DA with UDI table. The maximum value in DA above 200 lux is 62.66% of Room 5 and minimum value is 31.51% of Room 8. The only room which gets the value above 50% is Room 5. The Maximum value on the each room is the same with the number 75% and the minimum of the other rooms is 0% excluding 50% of Room 5. Figure 4.2 shows the total results with bar charts.

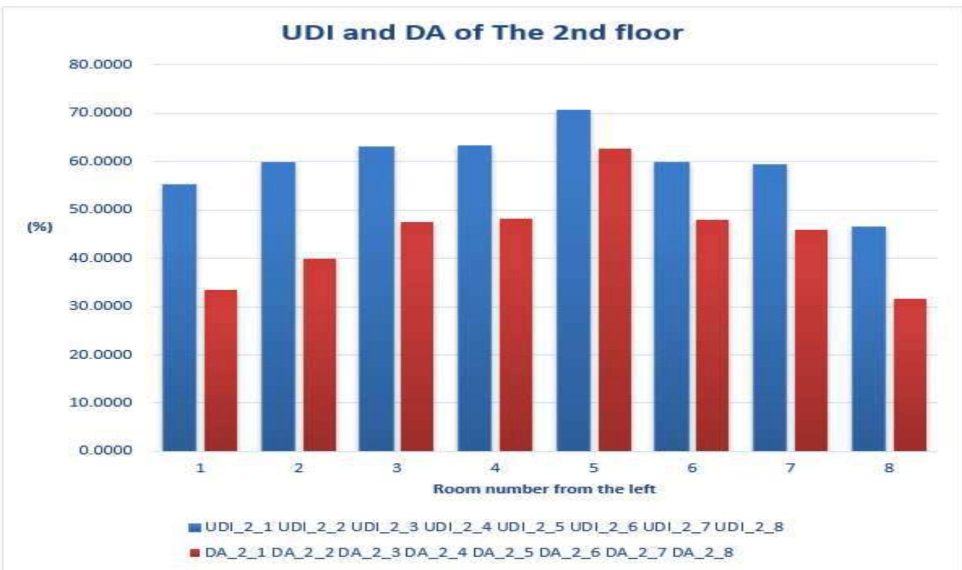

Figure 4.2 Daylighting Performance Metrics of Rooms on the 2nd Floor

4.1.2 Rooms on the Third Floor

	UDI_3_1	UDI_3_2	UDI_3_3	UDI_3_4	UDI_3_5	UDI_3_6	UDI_3_7	UDI_3_8
100 LUX < UDI < 2000LUX (unit : %)	55.3832	60.0318	63.1536	63.0719	70.6926	59.7321	59.4262	46.0938
UDI < 100LUX (unit : %)	44.6168	39.9682	36.8464	36.9281	29.3074	40.2679	40.5738	53.9063
MAX (unit : %)	87.50	87.50	87.50	87.50	87.50	87.50	87.50	87.50
MIN (unit : %)	0.00	0.00	0.00	25.00	62.50	25.00	12.50	0.00
Numbers of all grids	274	157	153	153	148	140	122	96

Table 4.3 UDI of Rooms on the 3rd Floor

	DA_3_1	DA_3_2	DA_3_3	DA_3_4	DA_3_5	DA_3_6	DA_3_7	DA_3_8
200LUX < DA (unit : %)	33.3485	39.3312	47.6307	47.3856	62.5000	47.7679	46.4139	30.8594
DA < 200LUX (unit : %)	66.6515	60.6688	52.3693	52.6144	37.5000	52.2321	53.5861	69.1406
MAX (unit : %)	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
MIN (unit : %)	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00
Numbers of all grids	274	157	153	153	148	140	122	96

Table 4.4 DA of Rooms on the 3rd Floor

Table 4.3 and Table 4.4 present the tabulated results of the daylight for 8 rooms on the third floor. The results follow exactly the same relationships as described for Table 4.1 and Table 4.2. The Data is almost the same and the only differency in MIN of UDI is that 12.5 percentage rises in Room 4. Daylighting performance metrics of the third floor is shown through Figure 4.3.

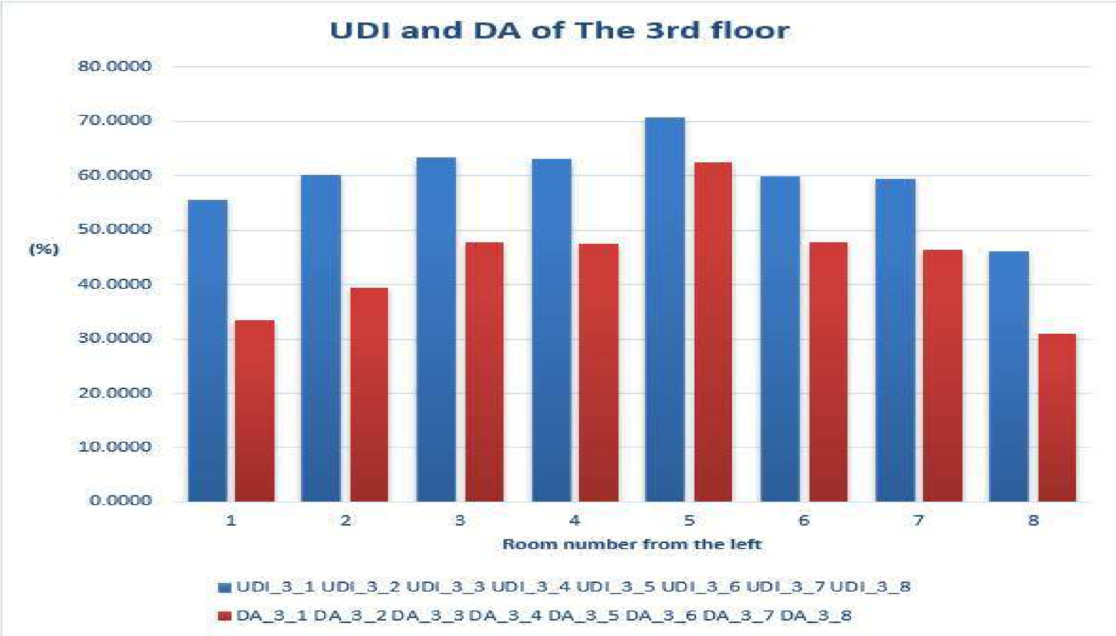

Figure 4.3 Daylighting Performance Metrics of rooms on the 3rd floor

4.1.3 Rooms on the Fourth Floor

	UDI_4_1	UDI_4_2	UDI_4_3	UDI_4_4	UDI_4_5	UDI_4_6	UDI_4_7	UDI_4_8
100 LUX < UDI < 2000LUX (unit : %)	54.9726	59.9522	63.2353	63.3170	70.6081	59.4643	59.5287	46.0938
UDI < 100LUX (unit : %)	45.0274	40.0478	36.7647	36.6830	29.3919	40.5357	40.4713	53.9063
MAX (unit : %)	87.50	87.50	87.50	87.50	87.50	87.50	87.50	87.50
MIN (unit : %)	0.00	0.00	12.50	12.50	62.50	25.00	12.50	0.00
Numbers of all grids	274	157	153	153	148	140	122	96

Table 4.5 UDI of Rooms on the 4th Floor

Table 4.5 and Table 546 present the tabulated results of the daylight for 8 rooms on the fourth floor. The results follow exactly the same relationships as described for Table 4.1 and Table 4.2. The Data is almost the same and the only differency in MIN of UDI is that 12.5 percentage rises in Room 3. Daylighting performance metrics of the fourth floor is shown through Figure 4.4.

	DA_4_1	DA_4_2	DA_4_3	DA_4_4	DA_4_5	DA_4_6	DA_4_7	DA_4_8
200LUX < DA (unit : %)	32.9836	39.8089	47.7941	48.0392	62.5000	47.5000	46.0041	31.2500
DA < 200LUX (unit : %)	67.0164	60.1911	52.2059	51.9608	37.5000	52.5000	53.9959	68.7500
MAX (unit : %)	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
MIN (unit : %)	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00
Numbers of all grids	274	157	153	153	148	140	122	96

Table 4.6 DA of Rooms on the 4th Floor

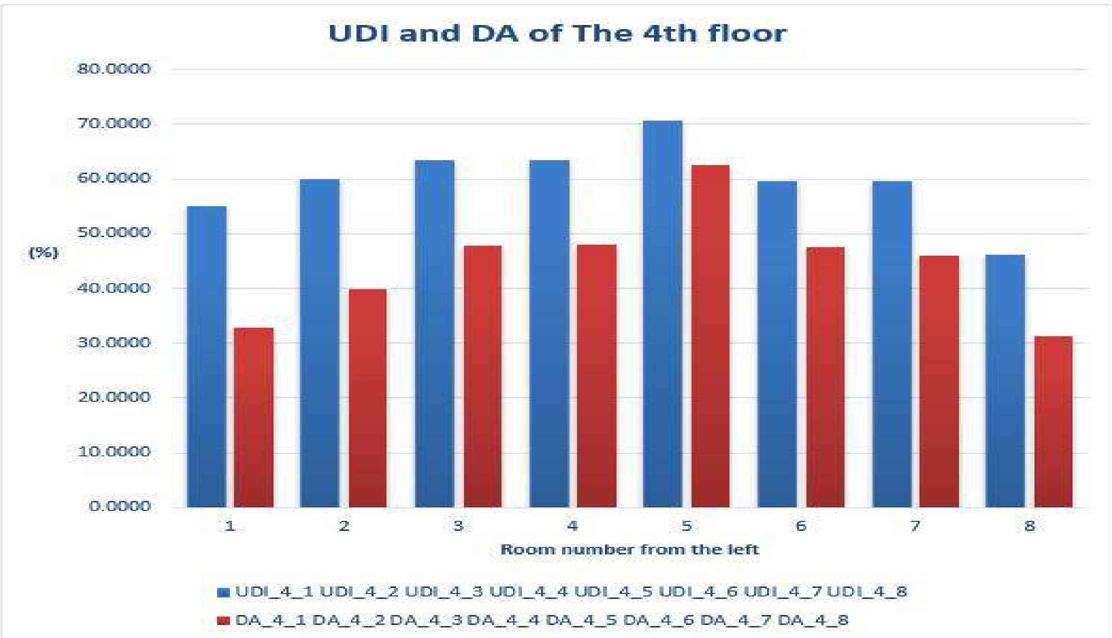

Figure 4.4 Daylighting Performance Metrics of Rooms on the 4th Floor

4.1.4 Rooms on the Fifth Floor

	UDI_5_1	UDI_5_2	UDI_5_3	UDI_5_4	UDI_5_5	UDI_5_6	UDI_5_7	UDI_5_8
100 LUX < UDI < 2000LUX (unit : %)	55.2007	60.0318	63.1536	63.3987	70.6926	59.6429	59.3238	45.9635
UDI < 100LUX (unit : %)	44.7993	39.9682	36.8464	36.6013	29.3074	40.3571	40.6762	54.0365
MAX (unit : %)	87.50	87.50	87.50	87.50	87.50	87.50	87.50	87.50
MIN (unit : %)	0.00	0.00	0.00	12.50	62.50	25.00	12.50	0.00
Numbers of all grids	274	157	153	153	148	140	122	96

Table 4.7 UDI of Rooms on the 5th Floor

	DA_5_1	DA_5_2	DA_5_3	DA_5_4	DA_5_5	DA_5_6	DA_5_7	DA_5_8
200LUX < DA (unit : %)	33.1661	39.4904	47.7124	47.6307	62.5000	48.2143	46.0041	31.5104
DA < 200LUX (unit : %)	66.8339	60.5096	52.2876	52.3693	37.5000	51.7857	53.9959	68.4896
MAX (unit : %)	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
MIN (unit : %)	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00
Numbers of all grids	274	157	153	153	148	140	122	96

Table 4.8 DA of Rooms on the 5th Floor

Table 4.7 and Table 4.8 present the tabulated results of the daylight for 8 rooms on the fifth floor. The results follow exactly the same relationships as described for Table 4.1 and Table 4.2 with almost same data. Daylighting performance metrics of the fifth floor is shown through Figure 4.5.

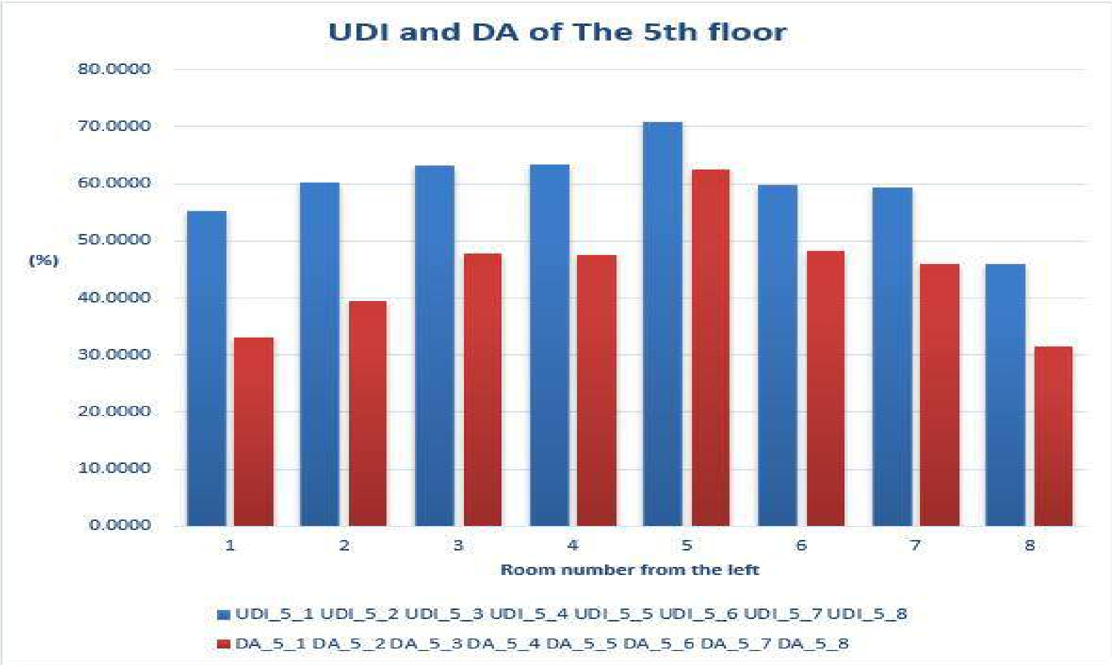

Figure 4.5 Daylighting Performance Metrics of Rooms on the 5th Floor

4.1.5 Comparison of Four Floors

		1st Room	2nd Room	3rd Room	4th Room	5th Room	6th Room	7th Room	8th Room
100 LUX < UDI < 2000LUX (unit : %)	UDI : 2nd Floor	55.2464	59.7930	63.0719	63.2353	70.6081	59.7321	59.4262	46.4844
	UDI : 3rd Floor	55.3832	60.0318	63.1536	63.0719	70.6926	59.7321	59.4262	46.0938
	UDI : 4th Floor	54.9726	59.9522	63.2353	63.3170	70.6081	59.4643	59.5287	46.0938
	UDI : 5th Floor	55.2007	60.0318	63.1536	63.3987	70.6926	59.6429	59.3238	45.9635
200LUX < DA (unit : %)	DA : 2nd Floor	33.4854	39.8089	47.5490	48.1209	62.6689	47.8571	45.9016	31.5104
	DA : 3rd Floor	33.3485	39.3312	47.6307	47.3856	62.5000	47.7679	46.4139	30.8594
	DA : 4th Floor	32.9836	39.8089	47.7941	48.0392	62.5000	47.5000	46.0041	31.2500
	DA : 5th Floor	33.1661	39.4904	47.7124	47.6307	62.5000	48.2143	46.0041	31.5104

Table 4.9 UDI and DA of 4 floors

Table 4.9 shows the tabulated results of the daylight for all rooms of 4 floors. The findings of 8 rooms on the each floor follow precisely the same relationship and according to Figure 4.6, the relationship of 32 rooms is visualized. UDI values are bigger than DA values because the minimum standard value for UDI in the simulations is lower with 100 lux than the number 200 lux of DA value. As expected, Room 5 consisted with glass panels in the middle of the building outstandingly gets solar irradiance the most of all rooms. Furthermore, the farther the room is located from the center of the building and the less the room has windows, the less the quantity of solar radiation is received.

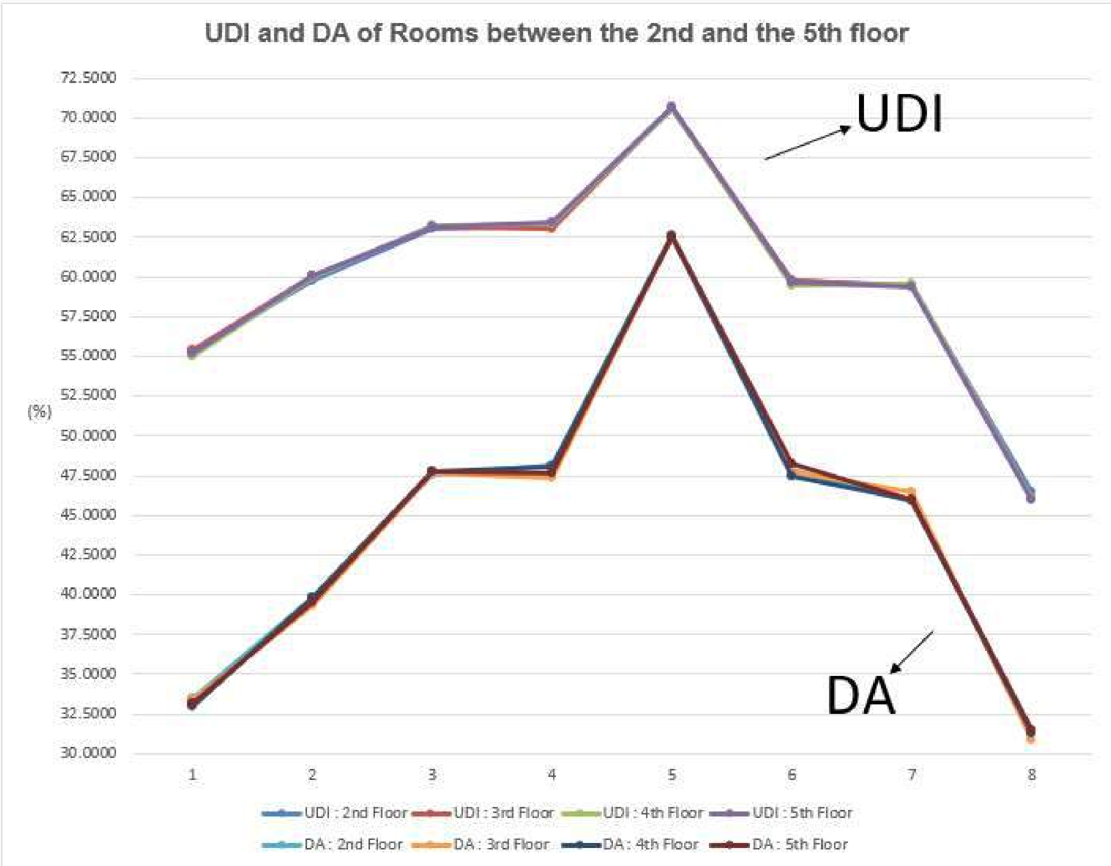

Figure 4.6 Daylighting Performance Metrics of 4 Floors

4.2 Results of Parametric Design Simulations

Formula : Sin(U*D_U)*Sin(V*D_V)*W

	Parameters		Values for simulations				
1	Points for the horizontal and the vertical	P_U	10	20	24		
		P_V	10	20	39		
2	Amplitude for NURBS surface	W	0	1000	2000	3000	4000
3	Degree for the horizontal and the vertical	D_U	180	160	180		
		D_V	180	200	200		
4	Time	Time range	12:09	8:09 ~15:56			

Table 4.10 Parameters for Parametric Design

In accordance with Table 4.10, parameters for the new facades are shown and simulations are conducted with each parameter in regular sequence in the above table and the other parameters which are chosen randomly.

4.2.1 Results of Parameter 1 Simulation

	Parameters		Values for simulations				
1	Points for the horizontal and the vertical	P_U	10	20	24		
		P_V	10	20	39		
2	Amplitude for NURBS surface	W	0	1000	2000	3000	4000
3	Degree for the horizontal and the vertical	D_U	180	160	180		
		D_V	180	200	200		
4	Time	Time range	12:09	8:09 ~15:56			

Table 4.11 Parameter 1 Simulation - 1

2 simulations related to parameter 1 are implemented with 2 different values of the amplitude (Table 4.11 above and Table 4.13 below). Table 4.12 displays the

result of the first case about parameter 1.

	W2000 P_U 10 P_V 10	W2000 P_U 20 P_V 20	W2000 P_U 24 P_V 39
Average	0.695601426	0.695860011	0.695976014
Standard deviation	0.25576786	0.256558887	0.256459591
MAX	0.997053169	0.997057047	0.997061242
MIN	0.019456679	0.00044931	0.004698752

Table 4.12 Results of Parameter 1 Simulation - 1

Table 4.12 shows that the results of the insolation data for the new facade with the number 2000 of the amplitude, 180 degree for the horizontal and the vertical, and 12:09 p.m. As the points become bigger, the average value and standard deviation get slightly bigger. The maximum number is almost similar and the minimum value of 10 points case is the biggest of all. Thus, the larger the points divided on the surface become, the larger the average becomes but all grids on the surface do get irregular insolation values.

Parameters			Values for simulations				
1	Points for the horizontal and the vertical	P_U	10	20	24		
		P_V	10	20	39		
2	Amplitude for NURBS surface	W	0	1000	2000	3000	4000
3	Degree for the horizontal and the vertical	D_U	180	160	180		
		D_V	180	200	200		
4	Time	Time range	12:09	8:09 ~15:56			

Table 4.13 Parameter 1 Simulation - 2

Table 4.14 shows that the results of the insolation data for the new facade with the number 3000 of the amplitude, 180 degree for the horizontal and the vertical, and 12:09 p.m. The data follow the similar relationships as described for Table 4.12.

	W3000 P_U 10 P_V 10	W3000 P_U 20 P_V 20	W3000 P_U 24 P_V 39
Average	0.695823105	0.696304407	0.696432013
Standard deviation	0.244081273	0.245088859	0.245053668
MAX	0.999557731	0.999643656	0.99967399
MIN	0.02365275	0.008683532	0.003420776

Table 4.14 Results of Parameter 1 Simulation - 2

4.2.2 Results of Parameter 2 Simulation

5 simulations are implemented with 5 different values of the amplitude according to Table 4.15 (below). The other parameters are fixed in order to find the relationship as increasing of the amplitude. When the amplitude is zero, it is the initial facade geometry. From the number 1000 to 4000 of the amplitude, the surface is transformed as non-uniform rational basis spline.

Parameters			Values for simulations				
1	Points for the horizontal and the vertical	P_U	10	20	24		
		P_V	10	20	39		
2	Amplitude for NURBS surface	W	0	1000	2000	3000	4000
3	Degree for the horizontal and the vertical	D_U	180	160	180		
		D_V	180	200	200		
4	Time	Time range	12:09	8:09 ~15:56			

Table 4.15 Parameter 2 Simulation

	W = 0 The initial model	W = 1000	W = 2000	W = 3000	W = 4000
Average	0.674540437	0.688267025	0.695601426	0.695823105	0.689133973
Standard deviation	0.289996461	0.27283907	0.25576786	0.244081273	0.244945698
MAX	0.963099611	0.986376921	0.997053169	0.999557731	0.999718212
MIN	0.012251995	0.015572663	0.019456679	0.02365275	0.027756175

Table 4.16 Results of Parameter 2 Simulation

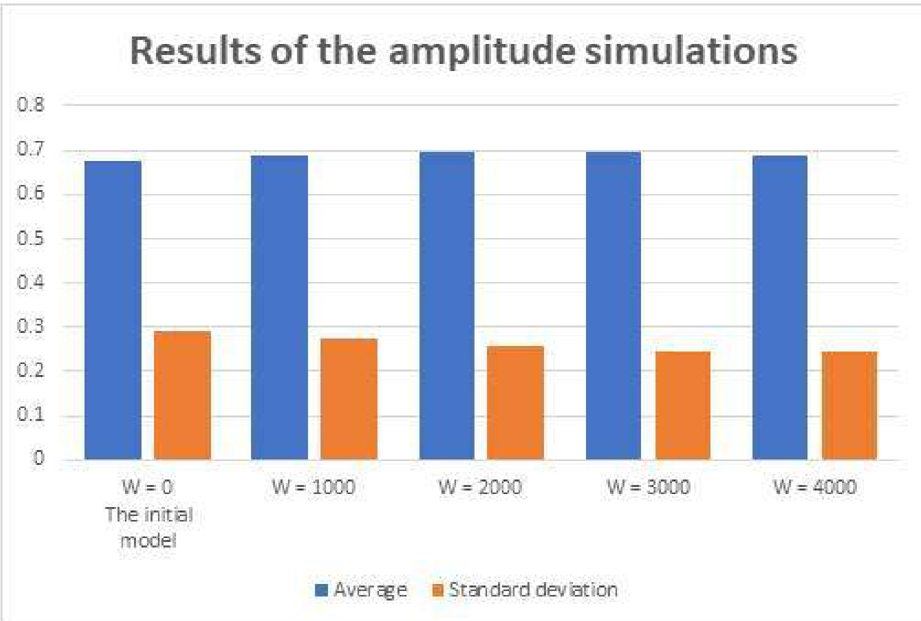

Figure 4.7 Results of Amplitude Simulations

Table 4.16 indicates that the tabulated results of the insolation related to changing the amplitude and Figure 4.7 visualizes the results. In accordance with the table and the figure, when the amplitude value is 3000, the average becomes the highest and the standard deviation obtains the lowest value which means all data is close to the mean value compared to the other 4 models. Thus, the performance of insolation is the highest evenly to all grids on the surface with the number 3000 of the amplitude, points values 10 and degree number 180 for the horizontal and the vertical at noon of December 21th.

4.2.3 Results of Parameter 3 Simulation

Parameters			Values for simulations				
1	Points for the horizontal and the vertical	P_U	10	20	24		
		P_V	10	20	39		
2	Amplitude for NURBS surface	W	0	1000	2000	3000	4000
3	Degree for the horizontal and the vertical	D_U	180	160	180		
		D_V	180	200	200		
4	Time	Time range	12:09	8:09 ~15:56			

Table 4.17 Parameter 3 Simulation

	D_U=180, D_V=180		D_U=160, D_V=200		D_U=180, D_V=200	
	W = 2000	W = 3000	W = 2000	W = 3000	W = 2000	W = 3000
Average	0.695601	0.695823	0.693309	0.690848	0.693104	0.690353
Standard deviation	0.255768	0.244081	0.263585	0.255985	0.261532	0.254292
MAX	0.997053	0.999558	0.998683	0.999775	0.998051	0.999961
MIN	0.019457	0.023653	0.004562	0.003576	0.004755	0.007668

Table 4.18 Results of Parameter 3 Simulation

As Table 4.17, the degree number in the formula as the third parameter for the horizontal is changed from 160 to 200 for transformation of the surfaces. When the amplitude value 2000 as well as 3000 are simulated in order to double check of the data relationship.

Table 4.18 presents the results under the condition of Table 4.17 on solar irradiance. The average of insolation with the number 3000 and degree factors 180 for the horizontal and the vertical is the highest and the standard deviation is the lowest as shown for Table 4.16. When the values of degree are 180 for both length and height, the average values with the amplitude 2000 and 3000 are the higher than the other conditions. Hence, degree number for the better performance of insolation is chosen 180 in simulations of Parameter 3.

4.2.4 Results of Parameter 4 Simulation

	Parameters		Values for simulations				
1	Points for the horizontal and the vertical	P_U	10	20	24		
		P_V	10	20	39		
2	Amplitude for NURBS surface	W	0	1000	2000	3000	4000
3	Degree for the horizontal and the vertical	D_U	180	160	180		
		D_V	180	200	200		
4	Time	Time range	12:09	8:09 ~15:56			

Table 4.19 Parameter 4 Simulation

Time standard	12:09 p.m. (at noon of December 21th)					08:56 a.m. ~ 3:56 p.m. (from sunrise to sunset of December 21th)				
Classification	W = 0 The initial model	W = 1000	W = 2000	W = 3000	W = 4000	W = 0 The initial model	W = 1000	W = 2000	W = 3000	W = 4000
Average	0.674540	0.688267	0.695601	0.695823	0.689134	0.653677	0.655898	0.653011	0.644671	0.674540
Standard deviation	0.289996	0.272839	0.255768	0.244081	0.244946	0.288962	0.283701	0.276967	0.271648	0.289996
MAX	0.963100	0.986377	0.997053	0.999558	0.999718	0.982983	0.992913	0.996303	0.997571	0.963100
MIN	0.012252	0.015573	0.019457	0.023653	0.027756	0.072198	0.065338	0.065949	0.067939	0.012252

Table 4.20 Results of Parameter 4 Simulation

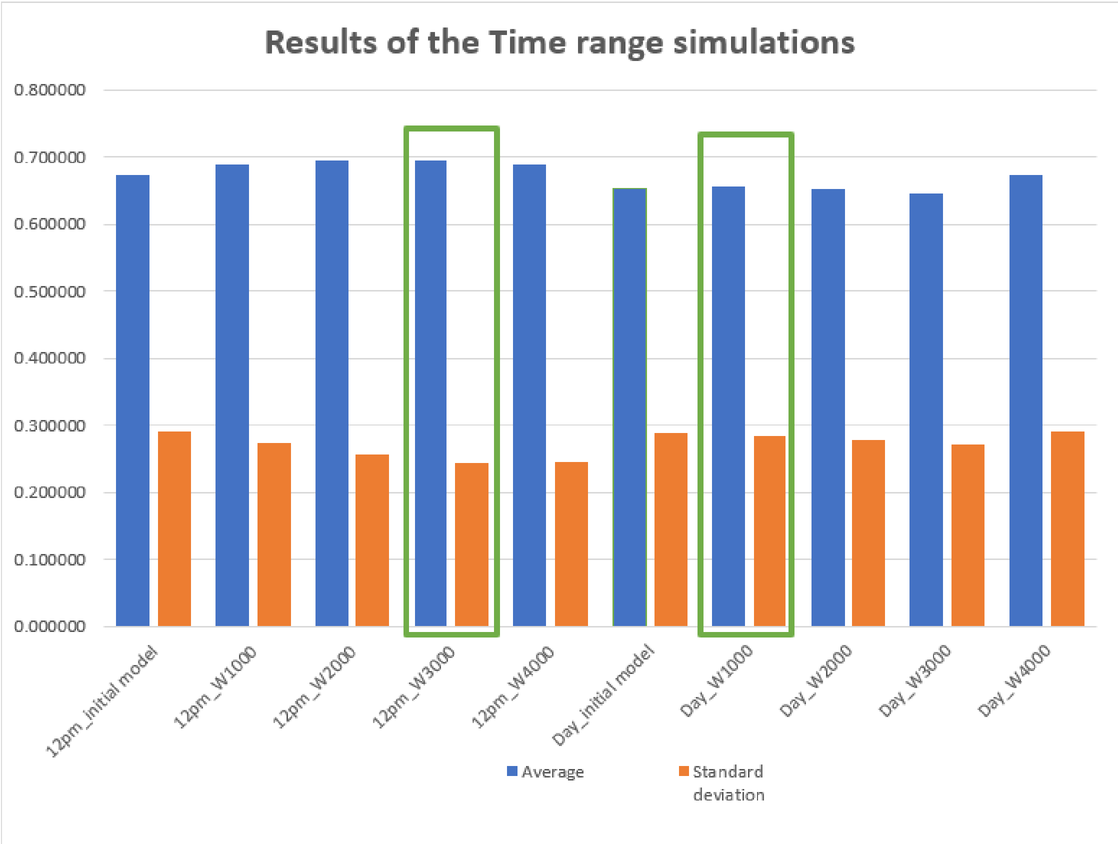

Figure 4.8 Results of Time range Simulation

Table 4.19 displays the total 8 conditions with different time range and amplitude. There are 4 simulations with different amplitude both at noon when the sun is the highest on a day and during the period from sunrise to sunset on December 21th.

As Table 4.20 and Figure 4.8 indicate, in the first time range at noon, the value 3000 of the amplitude obtains the highest average and the lowest standard deviation and in the other case of when the sun is up in the day, the values 1000 of the amplitude uniquely gets the higher average and lower standard deviation of 5 models. Understandably, all of the results conducted in the time range of noon are higher than all of the data for the period between 8:56 a.m. and 3:56 p.m. Therefore, the new model with the amplitude value 1000 during the day is chosen for optimal performance of the shortest day in a year.

4.2.5 New Parametric Facade

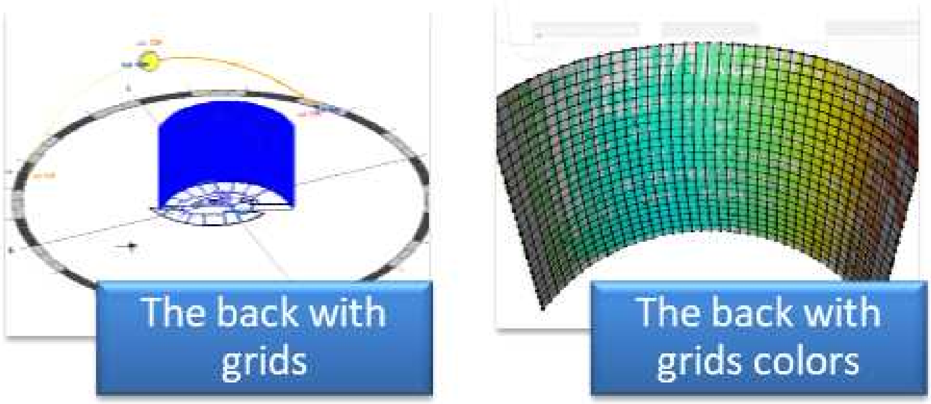

Figure 4.9 New Parametric Facade with Grids and Colors

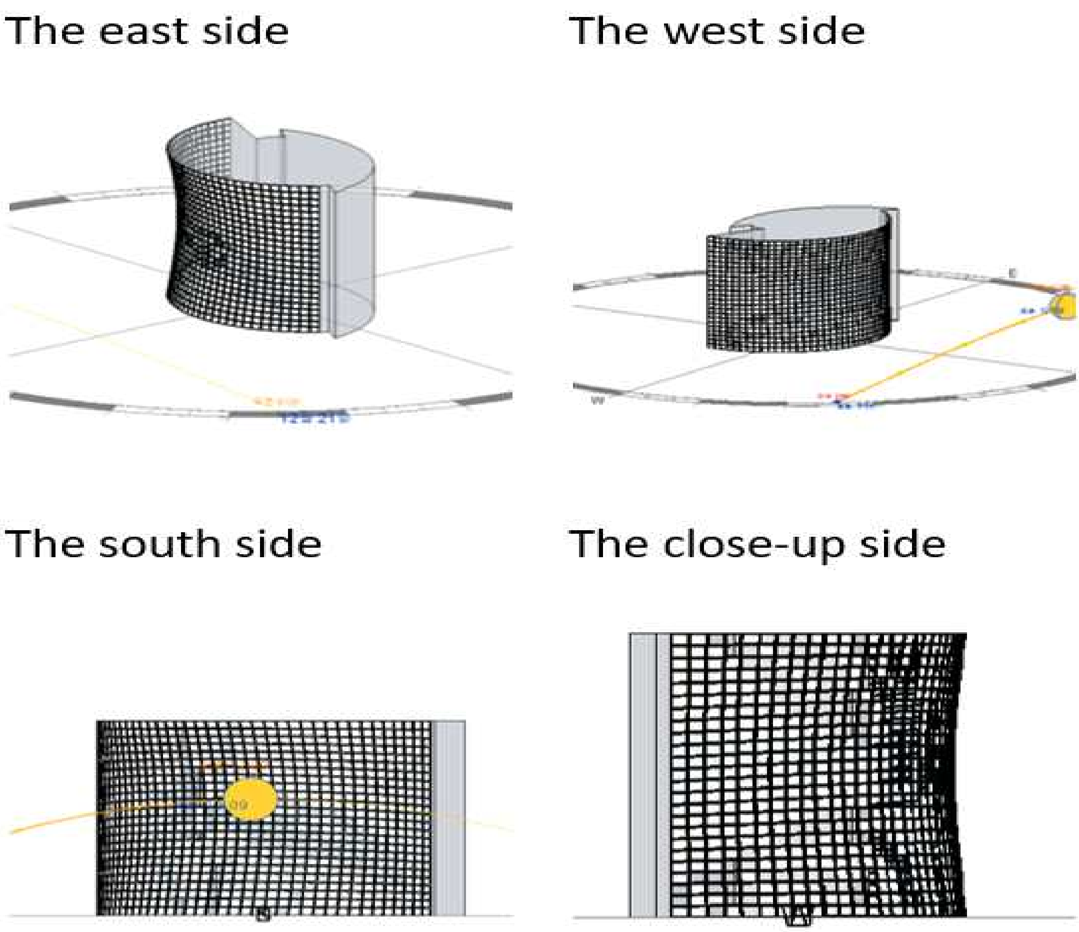

Figure 4.10 New Parametric Facade

Figure 4.9 and Figure 4.10 show the new parametric facade chosen through simulations implemented with dependent parameters. Figure 4.9 especially displays the 936 grids (left) and colors (right) of insolation values on the new surface before generating the window family. Figure 4.10 visualizes the last model from each side with the 936 window family on it.

4.3 Comparison Results of Two Models

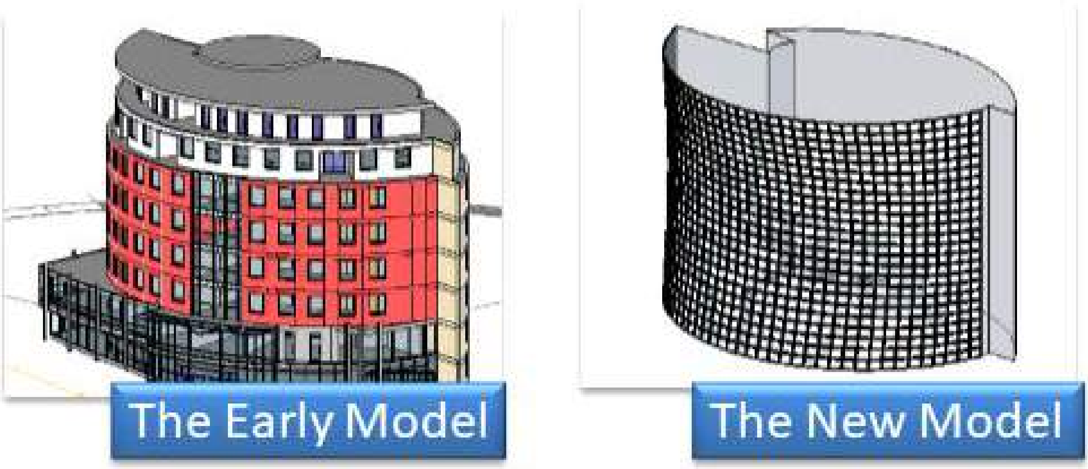

Figure 4.11 Comparison of Two models

Figure 4.11 (above) visualizes the facades of both the early and new model. The initial facade is combined the concrete walls and window panels but the new facade is consisted only with window panels which are generated different shapes.

The comparative outcomes of the two models on December 21th are shown in accordance with Table 4.21 (on the following page). The early model has the values of UDI and DA simulated by Honeybee and Ladybug due to instability of the packages in Dynamo for complicated geometries. The average of UDI between 100 lux and 2000 lux is 59.68% and the average of DA over 200 lux is 44.51% on December 21th. After designing the new facade by 4 sorts of parameters, the performance of insolation increases and improves evenly with reduction value of standard deviation.

Classification		The Early Model	The New Model	Value Change
100 LUX < UDI < 2000 LUX (unit : %)		59.68006895		
200LUX < DA (unit : %)		44.50774986		
Insolation Average (unit : none)		0.65367651	0.65589776	0.00222124
Insolation Standard Deviation (unit : none)		0.28896245	0.28370056	-0.00526189
Parameters	Dividing Points	Horizontal Points : 10 Vertical Points : 10		
	Amplitude	0	1000	1000
	Degree	Horizontal Degree : 180 Vertical Degree : 180		
	Time	8:00 ~ 16:00		

Table 4.21 Comparison of Two Models - 1

Table 4.22 (on the following page) also displays the comparative outcomes of the two models under conditions of different date and time. The time criteria is noon when the sun is the highest of spring equinox, summer solstice, fall equinox and winter solstice. The insolation average of all cases in the new model is higher than the previous model and except of the standard deviation value of summer solstice, other data reduce, which means sunlight is received evenly more.

Classification		The Early Model	The New Model	Value Change
Insolation Average (unit : none)	March 20th (Spring Equinox)	0.53067920	0.53630543	0.00562623
	June 21th (Summer Solstice)	0.31645309	0.31961199	0.00315891
	September 22th (Fall Equinox)	0.53895377	0.54924298	0.01028920
	December 21th (Winter Solstice)	0.67454044	0.68826702	0.01372659
Insolation Standard Deviation (unit : none)	March 20th (Spring Equinox)	0.25051771	0.24846811	-0.00204960
	June 21th (Summer Solstice)	0.14828832	0.15912285	0.01083453
	September 22th (Fall Equinox)	0.23683281	0.22756582	-0.00926699
	December 21th (Winter Solstice)	0.28999646	0.27283907	-0.01715739
Parameters	Dividing Points	Horizontal Points : 10 Vertical Points : 10		
	Amplitude	0	1000	1000
	Degree	Horizontal Degree : 180 Vertical Degree : 180		
	Time	12 p.m.		

Table 4.22 Comparison of Two Models - 2

5 Conclusions

5.1 Conclusions

This project offers an overview of definitions, characteristics, functionalities, daylight and analysis of the parametric facade model for the building of the Institut für Bauinformatik. The main goal was to design and implement the new facade to improve daylighting performance of the building on the shortest day.

The applicability and effectiveness of this parametric design approach using 4 parameters both in Revit and Dynamo were tested through comparison of solar irradiance. According to 4 parameters as well as the formula for NURBS surface, daylight performance is improved evenly. As the results, this approach can be regarded as a valid strategy for optimal daylighting performance.

5.2 Limitations

Daylight performance metrics of the new facade model using Honeybee and Ladybug could not be simulated so the results were not compared with the early model. Also Weather file as EPW file which was needed for Dresden was not exist in Ladaybug epwmap. Therefore, the weather file of Chemnitz where was located close to Dresden was used so UDI and DA results can have errors.

The methodology in Dynamo relies on computational iterations related to each hour of one day for analysis of all cases with 4 parameters. Thus, if the components in Dynamo are optimal for the analysis of all of the cases once, the simple efforts to change the number of each parameter would reduce.

5.3 Further Studies

Further work is needed to be undertaken into expanded time range including more certain days of all seasons or a year for the exact analysis of the geometry.

Further work also is needed on comparison of creating a new facade with window families changed along the transformed geometry and a new model with window families transformed itself.

Finally, more research is needed to be conducted with energy performance including solar heat gains and thermal losses according to the change of the facade as well as comparison of relationship between construction cost of the renovated facade and cost of the electricity consumption is needed.

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