FAÇADE SYSTEM

Sustainable and comfortable architecture by optimizing the Façade

XIAOMIN GUO
University of New South Wales, Sydney, Australia
Z5158014@ad.unsw.edu.au
Nayukiguo@Gmail.com

A façade system denotes a building's complements or structural components, often connected to a building's surroundings to improve its aesthetics. An optimized façade framework would require an analysis of the weather and climate of the site, the recognition of the user community, the enhancement of architectural materials, and the efficiency of construction to achieve sustainable growth. Construction mapping and the use of the instrument for environmental analysis are important for the analysis of environmental impacts in the digitised architecture industry. They may also affect design and construction performance through visualization. This research adopted the case study of two difform architectures and a comparison analysis between parametric façade architectures and conventional non-gradient façade architectures, explores the use of environmental analysis techniques to create a safe and relaxed façade architecture in the early design and design testing phases. The optimized parametric façade raises the percentage of time for pleasant temperatures, boosts the comfortable amount for tenants, according to the study diagram and performance data of LADYBUG. As a result of HONEYBEE, this plugin for daylight analysis recognizes the optimized parametric façade that increases daylight relative to conventional architecture. Furthermore, the optimized façade device has a heat storage effect, decreases the time of too cold, but still faces problems in the too hot time. Therefore, with the aid of environmental analysis tools, this research created an automated and streamlined façade method, this energy reduction system assistance, achieving sustainable growth. Also, the façade system's structural technological assistance will prolong the long-life cycle of architecture, façade review, and maintenance management that are essential to sustainable growth.

Keywords: Façade Systems; Environment Analysis Tools; Sustainable Building

1. Introduction: Research Aims and Motivations

Façade refers to an architecture's out-wall, a façade system perceived to be a system that complements building organization in accordance with the world around it. Façades are essential for the comfort and performance of the user (Aktaş 2018). Carlow (2014) suggests that the study of on-site weather and the surrounding environment, the recognition of the primary user group and the procurement of relevant materials will accomplish an integrated façade scheme of sustainable growth. Roudsari (2013) defined that software capable of evaluating environmental impacts can dramatically affect the results of design and construction efficiency. Furthermore, to achieve sustainable design, façades are intended to control the exchange of heat and light and reduce energy consumption. Through customizing façade device parameters, architects conform to various climatic regions, helping them to achieve 30-50 per cent reduced energy consumption relative to conventional buildings (Kothari 2016). A façade system has the potential to improve energy quality and increase the level of comfort for tenants, which improves the overall building output.

LADYBUG is a plug-in application for environmental design applications in the Grasshopper program. The LADYBUG tool is capable of importing and questioning Energy Plus Weather (EPW) files. By having adequate sun direction, as well as radiation maps to visualize the manipulation that the geometry produces with the sun, it can also produce customizable graphical outputs and impact façade design. The LADYBUG method can also be paired with other environmental plugins, such as HONEYBEE, to conduct sunshine, solar heat benefits, measurements of thermal losses and simulations. The LADYBUG capability is implemented in this analysis in the early design process and in the production of environmental situation data. These findings from the site will assist architects in designing the preliminary design and development. It may also allow the architect to monitor the façade's building, change the plan, or repair found problems later on. LADYBUG Techniques may be used to re-test environmental adaptation and environmental status in the final design processes.

As a result of case studies and contrastive analysis, the advantages and disadvantages of gradient façades are addressed by the optimized façade method using environmental analysis techniques. Enhance the user's relaxed level with the integrated façade scheme, decrease energy usage, to achieve sustainable architecture.

2. Research Objectives

An automatic façade system that involves an environmental measurement modelling system, temperature and daylight testing. Improving the Façade's Heat Retention, evaluating the residents' relaxed degree. Also, the nature of aesthetic and logical façade and adaptive façade connections, connectivity testing and viability of construction. Explore the ability of the Façade System in the future, relative to standard architectures with parametric Façade architectures. Extending the architectural long-life cycle, achieving convenient and sustainable development.

3. Research Question(s)

What are the characteristics of the Façade Device Optimizer?
How can architectural analysis techniques be used to optimize the façade to achieve a more environmentally-friendly and comfortable architecture?
What plugin should be used in the construction phase of the Façade? What are the advantages of these plugins and their limitations?

4. Methodology

Action analysis (AR) is adopted in this research initiative, which applies to the plurality of techniques in evaluative, investigative and empirical research for current issues. Participating in the three main phases of successful study, including studying and identifying priorities and direction; integrating theory and experiences; reviewing short and long-term strategies and objectives. According to Hearn (2005), the Intervention Program should concentrate on the needs of the customers, an in-depth investigation of techniques, integrating the experience during service and academic research to evaluate the implementation probability of this method, modifying the strategy inadequately.

According to Hearn (2005), the Intervention Program should concentrate on the needs of the customers, an in-depth investigation of techniques, integrating the experience during service and academic research to evaluate the implementation probability of this method, modifying the strategy inadequately.

5. Background Research

Façade refers to the front exterior of architecture. However, in the recent times, the term façade is regarded with a new context due to the digitalization of the design field, the emergence of novel construction techniques, and usage of new materials in the architecture industry. It is now more common to use the term façade to refer to the combining of functional requirements and architectural design aspects to facilitate improved architecture material and construction performance. Furthermore, façade is also regarded as a system that complements building organization in association with the surrounding environment. Façades are significant for user comfort and performance (Aktaş 2018).

Architects can use data analysis tools to manage the entire project, which includes exploring the construction and materials in three-dimensional views and improving the design scheme. Moreover, the architects are also able to manage and coordinate the integrating task of providing a sophisticated freeform façade in a façade system (Leon 2012).

5.1 ENVIRONMENT ANALYSIS & SIMULATION SYSTEM

According to (Carlow 2014), sustainable development can be achieved in numerous ways, such as analysing on-site weather and surrounding environment, identifying the primary user community, and selecting suitable materials. With regards to the environmental adaptation of architectures, the architects can develop a design plan before commencing the project. The plan can be based on the analysed site results and extensive re-testing of the environmental adaptation and environment status after modelling.

In this manner, the tools of site analysis and construction analysis highlight the significances in the digitized architecture industry. LADYBUG is an environmental design software plug-in tool in the Grasshopper software. In addition to allowing architects to export the data and diagram of architecture, the LADYBUG Plugin also allows architects to import and analyse the weather and environment. Furthermore, LADYBUG is also useful for shadow studies and analysing wind energy and radiation.

Roudsari (2013) described that software capable of analysing the environmental effects can significantly influence the outcomes in the performance of designing and building. During the initial design phase, the architects can make effective design decisions to improve the sustainability of the schematic by visualizing the environmental effects via the software used for environmental analysis. LADYBUG offers three types of diagrams for radiation, the architect has the option of choosing the time and location in the EPW files of LADYBUG, such as import Los Angeles in February. Following the selection, LADYBUG generates differently coloured lumps to represent the weather conditions from all the directions, it also shows the sun-path (Dickinson 2016). As a building environmental analysis software, LADYBUG has the potential to develop further, the architect could observe the effects of modifying the design and fix or improve existing issues. However, the architecture should find an appropriate equilibrium between the results from calculations, digital simulation, and the requirements of the resident.

Furthermore, Subhajit Das (2012) investigated the optimization design techniques of a tower in Central China with a hotel and offices. A sustainable design solution was proposed by the design group. Moreover, it was also stated that the architectural design has to confront diverse user-interaction and the climate of the locality. To adapt to the tropical humid weather whilst maintaining the original architectural aesthetic, the design scheme adopts a responsive façade system with hundreds of panels in the external wall. These panels connect the entire façade framework, the panels are transformed, scaled, and rotated independently. The aim is to evaluate various patterns and behaviours of the transformation in the panels via a programmed simulated environment which comprises of embedded logic and trends. Therefore, this design optimization satisfies user requirements and preserves the original aesthetics.

5.2 MAINTENANCE COSTS & MATERIAL

Based on the Energy Information Administration, around 20 to 60% of the energy consumption and electricity usage in buildings is affected by the methodologies adopted in designing and constructing the building envelope (International Energy Agency 2013).

Importantly, sustainable measures should be used to satisfactorily address the thermal and aesthetic requirements of occupants in buildings. To achieve this, a responsive façade system was proposed as a sustainable response to environmental stimuli. However, owing to the limited ability to control passive systems, Negar Heidari Matin (2019) aimed to combine the integrating passive and active systems. A comparative study was conducted to highlight that technological functionality incorporated in responsive façade systems, such as sensing, actuating, and controlling, these are integrated into the framework of advanced hardware and materials. However, this method increases the costs associated with the construction stage and maintenance, it also increases project duration.

A façade system should be continually and proactively maintained, which includes the systemized technical support, inspection of façades, and maintenance management. This maintenance system should consider the fact that initial costs and maintenance costs will impact the global cost, which also includes the cost of corrective/preventive techniques. These solutions must fulfil the requirements of the façade coatings, aesthetics, and cleaning ability associated with certain levels of performance and quality (Colen 2002).

Also, the maintenance requirements of building facilities partly depend on the choice of materials, this is because of the capacity to resist defects through natural deterioration changes from one material to another. Moreover, the choice of material also influences the ease of maintenance and improves maintenance costs throughout the life cycle (Kanniyapan 2015). Furthermore, Kanniyapan (2015) analysed dozens of façade materials and tested the performance of these materials, including durability, material sustainability, functional performance, thermal performance, etc. It was concluded that the architecture industry should maintain the long-life cycle of constructions by adopting environmentally sustainable materials.

5.3 SUSTAINABLE FAÇADE

A façade system can enhance energy efficiency and raise the level of comfort for the residents, which boosts the overall performance of the building. By analysing the climate and sun-path, and exploiting the glazing and shading aspects of a façade makes the monolithic architecture of sustainable façades reach exemplary performance.

Façades are intended to regulate heat and light exchange and reduce energy consumption to achieve sustainable architecture. The architects adapt to different climatic regions by customizing parameters of the façade system, which enables them to achieve 30-50% reduced energy consumption compared to traditional buildings (Kothari 2016).

In conclusion, the LADYBUG tools help architects analyse the characteristics of the local climate and sun-path. Following this, design tools can be applied to optimize the façade and construct a façade system to maintain building facilities and reduce energy consumption. Lastly, selecting suitable façade materials, improving the comfort of residents, and the lifecycle of the building are important design goals.

6. Case Study

This research project covers initial test and study of the environment; façade design and re-test façade; performance and comparison of the test data results; simulation system evaluation and heat retention system evaluation. Later, the constraints and possibilities of this method are addressed in the performance of an automated façade system.

6.1 ENVIRONMENT ANALYSIS & AUTOMATIC EPW-FILES EXTRACTION

As far as environmental analysis is concerned, LADYBUG is an open-source module for GRASSHOPPER for environmental analysis. Only LADYBUG is capable of importing and interrogating Energy Plus Weather (EPW) files that correspond to simulation weather data, including weather, temperature, humidity, radiation, sunlight, and direction of the wind.

GRASSHOPPER may create customizable graphical outputs with the work of LADYBUG and have adequate sun direction, develop radiation maps to visualize the manipulation. For daytime, solar heat benefits, thermal loss measurements, and simulations, LADYBUG may be paired with other environmental plugins, such as HONEYBEE.

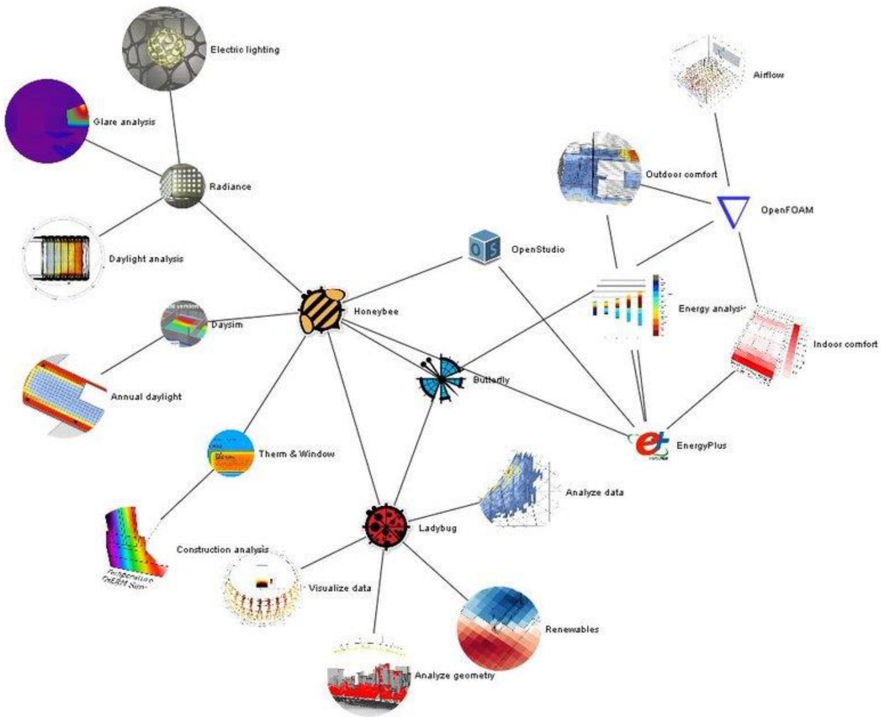

Figure 1. Building Performance Simulation (BPS) tools (Bazafkan 2017)

Formerly, architects have to scan the EPW-Files on the internet and download these files to import LADYBUG, reference the Rhino model, pick the performance set, such as weather, temperature, solar and radiation analysis indices. The visualization charts seen in the GRASSHOPPER and RHINO viewports are shown after importing weather data and choosing the output. In the early design stage and in the production of environmental condition data, LADYBUG potential is implemented. These findings from the site will assist architects in designing the preliminary design and construction.

To simplify the operation and achieve an automated method, the Initial Environment Analysis is executed by integrating the functions with PYTHON. The user should enter the place name and country name, this system would automatically remove EPW-Files from the Internet or the hard drive of the user. Due to the repetition of the placename, it is important to validate the correct positions by entering the name of the country. For example, if the location of the project is Sydney, Australia, the user only enters the location name, but there is another Sydney in Nova Scotia, Canada. The EPW-Files Extraction Device cannot differentiate these two cities, leading to crashes. Thus, after entering the name of the location and the name of the country, the user could observe the visualization performance of LADYBUG to locate the positive space of the façade. If the project location is Sydney in Australia, the sun sets in the north, the good aspect of this architecture is the north side.

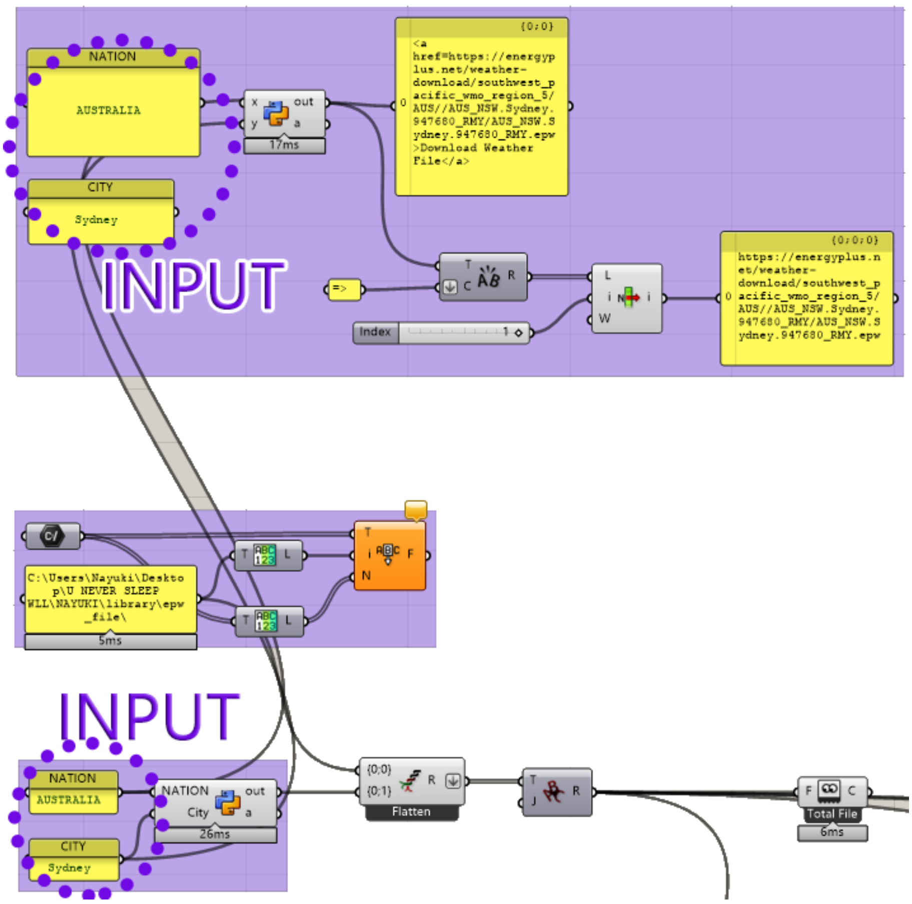

Figure 2. Input Location to Extract EPW-Files

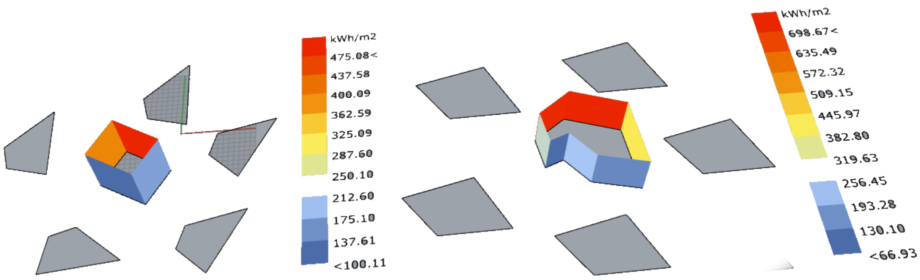

Figure 3. The positive side of architectures

An optimized façade framework is considered connected to the surrounding setting for surrounding forms, reflecting the surrounding architectures. The surrounding architectures affect sunshine, radiation, and temperature in the contemplation in real-life circumstances. Both visualizations are modified automatically for any modifications to input environment data or surrounding models. Architects may change the course of the façade design models and design strategies based on climatological evidence.

6.2 FAÇADE DESIGN & COMFORTABLE DEGREE

According to Figure 3, two separate architecture shapes, square box architecture and irregular architecture are assembled in this project, comparing these outputs with temperature, daylight and comfortable degree data of users. In conjunction with conventional non-gradient façade architectures and parametric façade architectures, the potential of the Façade Method will also be examined in the future.

The temperature on the whole side is normal, and nearly unanimous, in agreement with Figure 3. These façades all used gradient style on the positive sides, scaled-down the pattern and raised the number pattern from the ground to the roof to contrast the façade pattern. This style lets the artist analyze the effects of the evaluation and compares with the conventional and non-gradient façade.

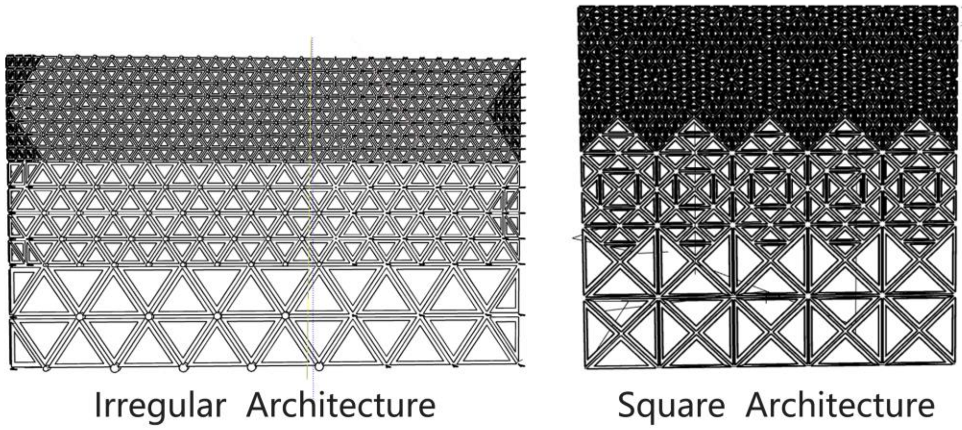

Figure 4. Gradient Façade Design

Prefabricated construction is a method of installing several architectural materials, moving those components to the site, forming a building. According to Ranghino (2020), prefabrication construction will increase productivity and improve the quality of the final project, which could help dramatically enhance the environmental impact and promote sustainable development. Prefabricated construction cuts 35 per cent-55 per cent in construction time, reduces 15 per cent-30 per cent in construction costs, lowers 40 per cent-90 per cent in construction waste than the conventional construction process.

As far as the façade connections are concerned, the 'Sandwich' manufacturing phase has benefited from prefabricated construction and maintenance. The links were assembled by 4 stages (Figure 5), the connection of the foundations, the connections, the façade and the connection caps. Thus the entire façade has been completed, the characteristics of production as a means of renewable comparative advantage relative to conventional methods, reducing energy consumption to promote sustainable development. In maintenance, homeowners could replace the broken façade components instead of rebuilding the entire façade. Furthermore, owing to lower original building costs and maintenance costs, this façade method further lowers the running costs of landowners and leads to the expansion of the life cycle architecture.

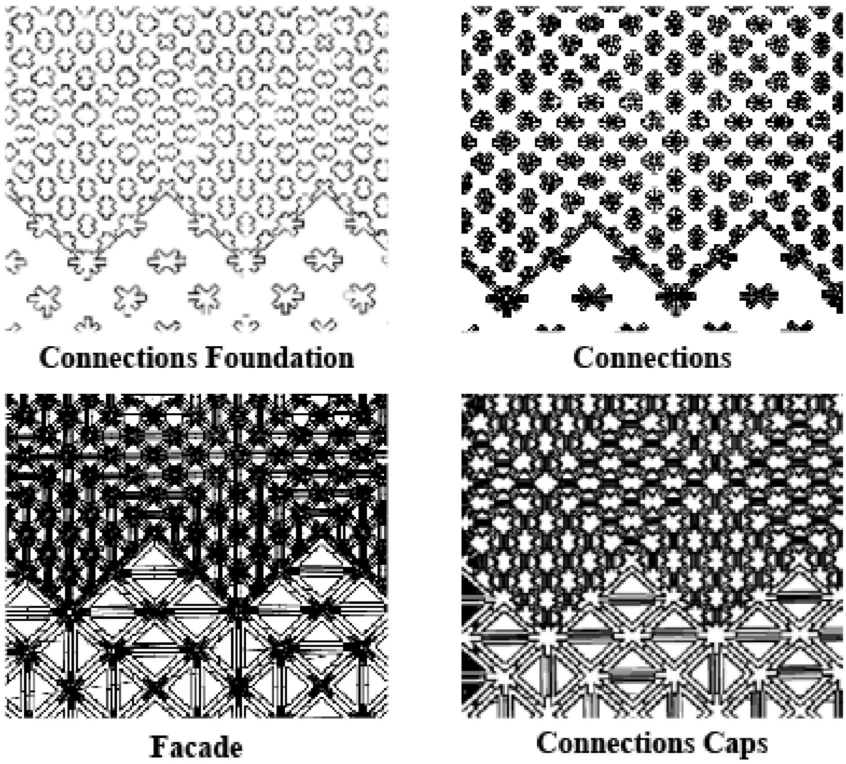

Figure 5. Fabrication Process of Connections

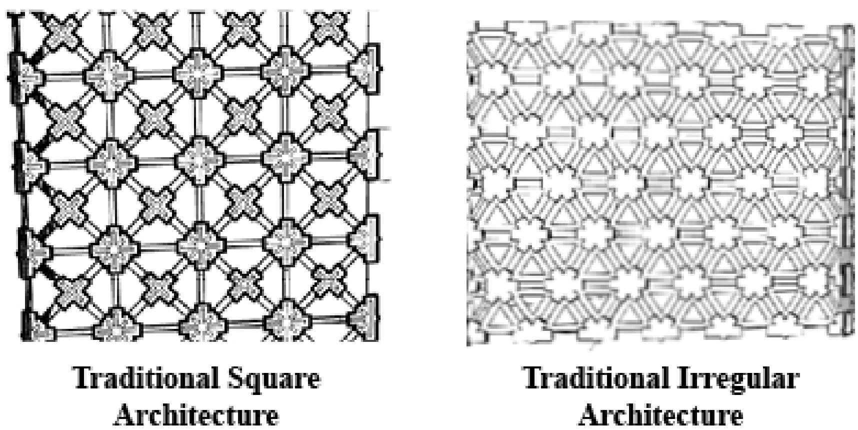

Figure 6. Traditional non-gradient Façade

In comparison to the output of typical non-gradient façade architectures (Figure 6), LADYBUG simulated the environment in January, re-tested the temperature of the entire architect and provided its details. From Figures 7 and 8, the yellow areas, which are the comfortable temperature for residents, the red areas are too hot, while the blue areas are too cold.

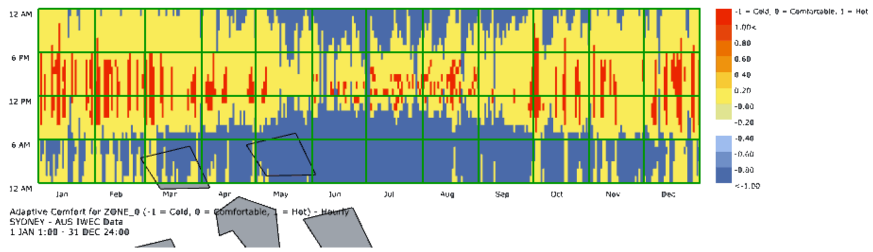

Figure 7. Test Result of Square Architecture

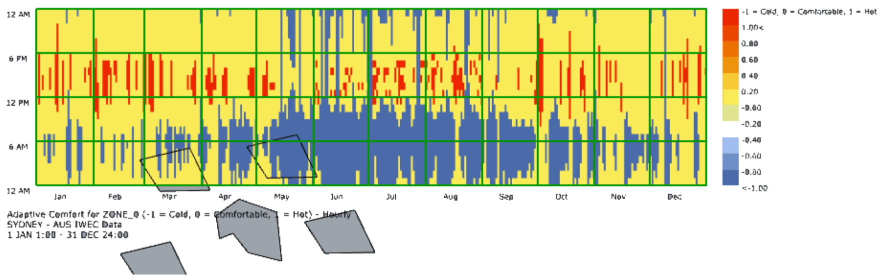

Figure 8. Test Result of Irregular Architecture

According to these study findings (Figure 9), the percentage of the relaxed period for gradient square façade architecture is about 76%, whereas the standard façade architecture is 55%. Similarly, the gradient façade also raises comfort by 20.6 per cent for irregular architecture. The parametric façade may also boost too cold or too hot conditions for irregular architectures. The parametric façade increases the convenience of the tenants. In the case of a square design, the parametric façade led to an improvement in the percentage of time for relaxed and low-temperature conditions. However, the amount of time that is too hot is greater than the conventional square architecture. Thus, the gradient façade cannot enhance the too hot conditions of the square architecture.

	Square Architecure		Irregular Architecure	
Type	Gradient Facade	Traditional Facade	Gradient Facade	Traditional Facade
Percentage Times of Comfortable	75.93%	55.18%	87.78%	67.15%
Percentage Times of Too Hot	16.29%	7.80%	0.74%	3.29%
Percentage Times of Too Cold	7.78%	37.00%	11.48%	29.56%

Figure 9. Test Result of Comfortable Degree & Too Hot/ Too Cold Situations

Figure 10, on the other hand, is the contrast between the gradient façade and the regular façade. With the aid of HONEYBEE, daylight output data reveals that the gradient façade also advances architecture's natural daylight. The enhancement of the irregular architecture's daylight is greater than square architecture, which may be due to the adjacent architectures, solar rays and façade of self-shading. The gradient façade thus encouraged visual convenience for people, increased the quality of sunlight to minimize the use of electric lamps for electricity and accomplished sustainable architecture.

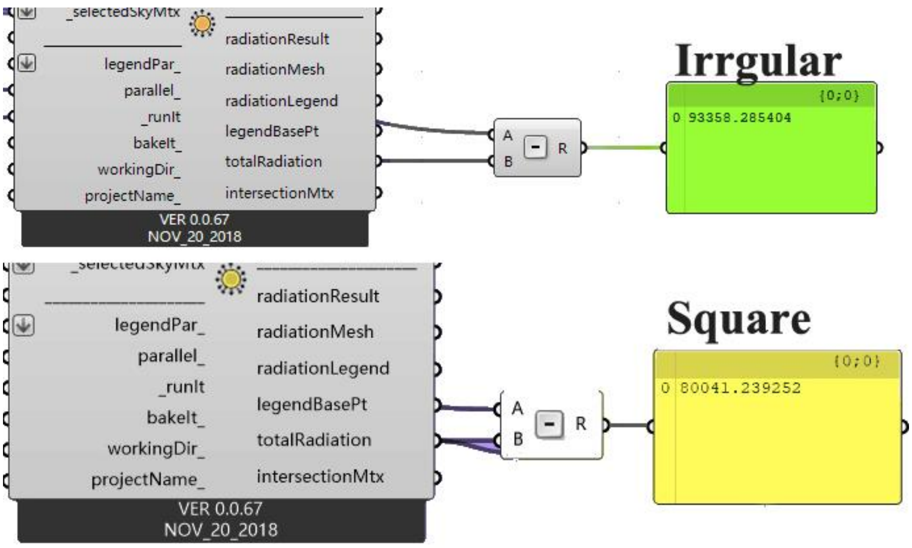

Figure 10. Test Result of Daylight

7. Evaluation and Conclusion

This study attempts to investigate how environmental analysis techniques are used by optimizing the Façade to create a safe and comfortable architecture? What is the hallmark of an automated and integrated finished façade system? The Modeling Method of the Façade System based on context studies, lets architects more intuitively analyze and modify their designs. In the early design process and re-test phase, LADYBUG and HONEYBEE were used to help architects observe the ambient atmosphere and the relaxed project stage.

The LADYBUG tools aid architects evaluate the local climate and sun-path characteristics. In order to maximize the façade and create a façade scheme to manage building infrastructure and reduce energy usage, construction tools will then be implemented. Finally, the selection of acceptable façade materials, enhancement of occupant satisfaction and the lifecycle of the building are significant design priorities.

It is clear that the gradient façade raises the comfortable degree of the inhabitants, including the comfortable temperature and visual comfort, according to the contrastive analysis of the gradient façades. The user's relaxed degree of Irregular gradient façade architectures is higher than Square architectures, greater than square architectures as well as the daylight of the irregular architectures.

The gradient façade has used prefabricated architecture to decrease construction time and building waste, increase construction efficiency and achieve sustainable growth. What is more, the enhancement of the exterior wall's sunshine and heat preservation scheme is the advantage of energy reduction, the development of sustainable construction, the transport of green ecological residential buildings.

As for the performance of the automated façade system, current technologies and cases are still limited. For example, LADYBUG considers a positive façade after the Initial Environment Study, but the architects can manually choose the Building Direction. Also, for various architectures, Gradient Façade has a heat preservation effect, reducing the duration of too cold. But the gradient façade does not eliminate too hot conditions for the square architecture, so in excessively hot weather the gradient façade is unsuccessful. In the future, the architecture of the Façade will be changed to conform to hot weather.

In the field of computational design, the façade method progresses to visualized activities and environmental research to meet the need of people, leads to the architecture of the extended lifecycle, builds sustainable architectures. Nevertheless, there are also issues about the façade method. When the comfortable degree knowledge alters, what is the relationship between comfortable degree and degree of heat preservation? What architectural maintenance method could co-operate with this façade system? What materials are available to stretch the length of the building, to accomplish sustainable architecture?

This façade system will be paired with PYTHON in the future, making this Automated Façade System a GRASSHOPPER or REVIT Plugin. The potential of the façade framework is capable of generating comprehensible data, allowing architects and stakeholders to evaluate the probability of implementation and strengthen current problems.

Acknowledgements

First, I would like to thank my tutors, Nicole Gardner, M. Hank Haeusler, and Daniel Yu, for helping me define the purpose of the analysis and solve the research problems. Their feedback is very useful for organizing thoughts and addressing technical issues.

References

Aktaş, B., 2018. Systematic approach to design builds for freeform façade: AFA Cultural Center. XXII CONGRESSO INTERNACIONAL DA SOCIEDADE IBEROAMERICANA DE GRÁFICA DIGITAL, 1 November 2018. p.2.

Bazafkan, E., 2017. Building performance simulation (BPS) tools, [Online]. Available at: https://www.researchgate.net/figure/10-Ladybug-Honeybee-and-Grasshopper-Ecosystem-for-building-performance-simulation_fig22_320931455 [Accessed 20 November 2020].

Carlow, J., 2014. Parametric façade systems performance-driven design for ultra-thin buildings in Hong Kong. Assistant Professor. University of Hong Kong: Hong Kong [Accessed 2 Oct. 2020].

Das, S., 2012. Design Optimization in a Hotel and Office Tower Through Intuitive Design Procedures and Advanced Computational Design Methodologies. Façade design optimization by computational methods, [Online]. 2, 1. Available at: http://papers.cumincad.org/data/works/att/ecaade2012_214.content.pdf [Accessed 3 October 2020].

Flores-Colen, I., 2002. Building façades maintenance support system. Conference: XXX IAHS World Congress on HousingAt: Coimbra, Portugal, [Online]. Available at: https://www.researchgate.net/publication/282913694_Building_façades_maintenance_support_system [Accessed 4 October 2020].

Hearn, G. N. and Foth, M. 2005, "Action Research in the Design of New Media and ICT Systems", in Kwansah-Aidoo, Kwamena, Eds. Topical Issues in Communications and Media Research, pp. 79-94

International Energy Agency, 2013. Technology Roadmap, energy-efficient building envelopes. Available at: https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyEfficientBuildingEnvelopes.pdf[Accessed 3 October 2020].

Kanniyapan, G., 2015. Façade material selection criteria for optimising building maintainability. Jurnal Teknologi, 10, 75.

Kothari, J., 2016. Sustainable Façade for High-Performance Green Buildings: Architecture Update, [Online]. Available at: http://www.conserveconsultants.com/sustainable-façade [Accessed 4 October 2020].

Leon, A., 2012. Two Case-Studies of Freeform-Façade Rationalization Freeform-Façade. PhD. Australia: RMIT University [Accessed 2 Oct. 2020].

Matin, N., 2019. Technologies used in responsive façade systems: a comparative study. Intelligent Buildings International, 19816, 20.

Ranghino, 2020, Ambienta Sustainability Lens. Sustainable construction: the prefabrication opportunity, pp.6-8.

Robert Dickinson, D., (2016). Generating Future Weather Files For Resilience. In 36th International Conference on Passive and Low Energy Architecture. Cities, Buildings, People: Towards Regenerative Environments. Los Angeles, 2016. Los Angeles: PLEA. 11-13.

Roudsari, M., 2013. Ladybug: A parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. Parametric Modeling Strategies for Efficient Annual Analysis of Daylight in Buildings, [Online]. Available at: https://www.researchgate.net/publication/287778694_Ladybug_A_parametric_environmental_plugin_for_grasshopper_to_help_designers_create_an_environmentally-conscious_design [Accessed 3 October 2020].