MULTI OBJECTIVE OPTIMIZATION OF FAÇADE GLAZING

Exploring the impact of glazing on the internal conditions of a space

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Abstract. The necessity for making sustainable design choices has risen and introducing a workflow that allows for a greater understanding of certain decisions such as the impact of glazing choice, has the potential to influence the likelihood of achieving sustainable design outcomes. It is generally understood that windows significantly impact the thermal loads of a building, particularly the thermal performance of an internal space. But there are still limited ways that a designer can understand more specifically how glazing choices can contribute to the energy performance of a building. This research aims to address this issue in two key stages: simulation and optimization using Grasshopper (GH) a visual scripting environment, that utilises various energy and optimization plugins. The simulation stage reveals the impact of glazing choice through visualizing the thermal and lighting conditions of the internal space through microclimate maps. This energy simulation also outputs various results regarding, temperature, comfort, sunlight hours, etc, which are then transferred into the second stage of optimization. The results are extracted and used as fitness objectives for the multi-objective optimization engine. This system uses parameters of elements such as the window sizing and shading arrangements to perform a mass iteration according to the objectives set. This system can be controlled to run according to the users desired intent as a longer run time will reveal a more resolved final output. Overall, this paper investigates how these forms of testing address the issue through leading the user to a greater understanding in a shorter amount of time. This is though using the tool to visualise the impact of glazing choice and then delivering the most refined solution.

Keywords. Façade glazing analysis, Solar energy analysis, Multi-objective optimization, automation, parametric design

1. Introduction: (Research context and motivations)

There are many design decisions made throughout a projects design development lifespan, with a large degree of decisions that are conducted with pure intuition. This intuition gained through education and experience will validate decisions that impact the cost and performance of the projects final form. Assistance in this process through data driven input would improve the accuracy and understanding of design decisions in early stages of design to deliver a final form that has been refined therefore generating more confidence in cost and performance. This form of development is a segment of the integration process for computational design into the AEC (Architecture, Engineering and Construction) industry. This notion formats the statement of how designers can "progress from intuition to precision" (Aish 2005, p10) through adapting an understanding of geometry, composition and algorithmic thought to establish a sustained workflow with computational tools. These tools do not attempt to make intuition redundant, it's intention lies within the designer engaging in design logic within a design system where intuition and precision are integrated into the same artefact. (Aish 2005, p12) This research project highlights this engagement through generating the "precision" element into the combined artefact, it represents an improvement on an existing workflow through the integration of a computational tool.

This papers particular integration of this concept highlights the demonstration of building performance through allowing the designer to select the material based on intuition and then use the computational tool to effectively evaluate that decision through visualizing the impact and performance of that material. This process introduces human error into the earliest stages of design, ultimately saving on financial and physical impact which in this case is environmental impact. It investigates the design decision of glazing, a decision that is predominantly backed by intuition and material research, important factors, but the inclusion of computational assistance integrates these two forms of knowledge into one combined tool. This collaboration between human experience and computational accuracy delivers a tool that increases the value of the final product through refinement.

This research also delivers refinement through multi objective optimization, a format that utilises the results drawn from energy simulation to mass iterate the geometry and find the most optimal outcome. This entire tool is delivered through a Grasshopper script using the environmental simulation plugins Ladybug and Honeybee which take EPW weather data and mask that onto geometry. The optimization component is also integrated within the same script using a Multi- Objective Optimization (MOO) plugin called Wallacei. This form of refinement delivers a higher valued outcome as it uses an algorithm that follows the multiple gene objectives to deliver results. This form of computational integration represents a skill that is impossible for the human mind to calculate, it reduces a task that would typically take a few days for a human into a few hours for the tool. It breaks down a tedious task that would require basic intuition of trial and error, into a calculated precise alteration process following a set of objectives.

2. Research Aims

The integral aim of this project is to develop a tool that provides an insight and understanding into how the internal thermal performance of a space is impacted by glazing choice. The process to achieve this form of tool integrates energy simulation and multi-objective optimization to visualize a refined set of results. Therefore, this form of testing is intended to support early stage design decisions about façade glazing through a streamlined approach of integrating internal thermal performance simulation into those decisions. To develop this tool a Grasshopper script will be produced that is able to quickly test and analyze the impact of glazing choice through energy simulation plugins. This script will also include a multi-objective optimization component that is run through another plugin, that will extract the results from the energy simulation to mass iterate the geometry to find the most optimal set of variations that align with the objectives set.

3. Research Questions

Based on the previously introduced aims of this project, this research investigates:

- How glazing choice decisions impact the thermal performance of an internal space?
- How can computational tools assist in this decision process through environmental simulation and multi-objective optimization?

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4. Methodology

This research project more so accommodates itself to a design action research methodology, Robert Cole's (2005) paper commands this prospect through defining the similarities between Design Research and Action Research through synthesizing that if both combined it would approach with "a problem definition, intervention, evaluation and reflection and learning" (Cole, R 2005). Whilst design research focuses on an artifact and action research focuses on a change in process, both being implemented where an artifact is design and explored through a change in process is what best describes the outlook of this project. This project explores the change of an artifact, through a change within a process, in this case manipulating a building form using a specific process that has limited investigation in the current academic landscape. This project highlights the integration between artifact and process, it integrates this through using the methods of action research of plan: act, observe the results and reflect throughout the process to deliver an artifact. The results are unknown, but a plan is in place with expectations of a result, and that result will inform the next progression leap of this investigation through a controlled repetition of the process to create this formation of iteration. This project heavily integrates iteration through using multi objective design, using computational calculation to mass test geometry repeatedly within a short timespan to discover the most optimal result. This method is the computer repeatedly running through every possible result, it goes through several stages that continuously fine tune the result to skew down evaluations. The user has planned the script and calculated what parameters are being changed by the evolutionary solver, the script is run which represents the act process, where finally the results of that is observed and a reflection is made to determine how successful the process was. A basic example of this process is David Newton's paper (2018) where he discusses the process of implementing qualitative optimization within Multi-Objective Optimization in architectural design. There is a segment where he discusses the process, and ten versions of a geometric form was generated, this process would involve action research methodology, there was a planned approach to manipulate a form, a result was observed and a reactive iteration was created.

5. Background Research/Literature review

In the AEC industry multi-objective optimization is currently being implemented into early design stage workflows, it is a process of computational calculation where inputs are controlled via parameters which gauge the limitations of what is explored. This process conducts a simulation of mass variation where parameters are changed to explore all potential options, this process skews all these variations until the most optimal solution is discovered. A multi-objective optimisation process also requires an understanding of what generative design is and how that process of optimization can be applied to testing glazing properties for resolved façade design. This research will investigate multi-optimisation on processes more specifically in relation to their application in façade design and glazing characteristics.

Optimization within material and environmental analysis is important as the common methods used for analysis are typically tedious and often involve a process of trial and error (Carpo 2015, p26). Optimization ultimately stems from automation, which is an essential component of the computational design practise. It is a process of relying on the computer to do the calculation, leaving more opportunity for humans to be creative as computers "simply cannot design" (Cardoso 2009, p289). This concept of allowing "the perfect slaves that are to perform the dirty work" (Cardoso 2009, p289) allows time for the designer to work harder on the design, whilst providing the most optimal solutions. This process of iterative digital simulation embodies that original method the traditional artesian would use in a fraction of the time, using huge variations where eventually the most refined solution can be established (Carpo 2015, p26). Multi- objective optimisation within a computational design context employs genetic algorithms to "rapidly generate and evaluate multiple design solutions" (Ashour and Kolarevic 2015, p356), this process of testing is effectively the computer conducting a mass simulation of "trial and error" (Carpo 2015, p26). This process finds the most "optimal" solution through testing multiple variations under controlled parameters to achieve a single objective, or within this research project multiple objectives, hence "Multi Objective Optimization". Many software solutions provide this testing ground, in this case Grasshopper3D can implement systems called evolutionary solvers such as Galapagos, Wallacei and Octopus into its framework where the user is able to explore and make critical evaluations on designs within a small time frame, this process can have a "significant" impact in the early stages of a project (Ashour and Kolarevic 2015, p356).

An example of multi-objective optimisation is demonstrated in Ryan Johan's research project (2019). Here he investigates material-based constraints on a generative framework to determine if bamboo can be used as a building material in non-planar based truss systems (Johan 2019, p372). This research used Grasshopper to test generative simulation with material and form for structural performance, and the paper revealed novel outcomes representing the beginning of inspiration to start further design development, and in its current state it would still require further more reputable structural analysis software (Johan 2019, p372). However, it did demonstrate that bamboo can achieve the same UoS as steel which represents potential for the material, as it aligns with the drive to achieve the more sustainably conscious building design ethos.

Another example of genetic algorithms being implemented through Multi-Objective Design is Michela Turrins paper (2012) where he discusses the implementation of parametric modelling and particularly the use of genetic algorithms to optimise roof structures, to develop performative skins. In this paper it concludes with stating that implementing these strategies into the early design workflow benefited the process and “solution space” through “allowing further generalizations of the parametric model by enlarging the solution space being explored” (Turrin 2012, p49). Caldas and Santos (2012) used genetic algorithms for urban patio optimization to achieve optimal design solutions for thermal and lighting conditions while adhering to the formal structure of a coherent Corpus of Design (Caldas and Santos 2012, p459). The paper confirmed its use case through successful implementation of the software being used “GENE_ARCH”, but more significantly it provided the finding that it was able to decrease energy consumption levels by 60% (Caldas and Santos 2012, p470). Although both these papers discussed the use of Multi-Objective optimization, there was no opinion formed through a critical perspective, it was only attributed to its positive contributions to the projects rather than mentioning its limitations.

Within the last 10 years sustainability has been an evolving major concern for the world and the construction industry, with the increase in global warming, there has never been a more urgent time to design buildings in more sustainable ways. “The most common problem to achieve a sustainable outcome is the absence of appropriate information to make critical decisions” (Zanni 2016, p102), applying an optimization process has been done before, but the use of these tools within early stages of design makes the goal of achieving sustainable outcomes an easier process through the speed at which potential solutions are able to be tested, and the accurate information Grasshopper tools can provide by multiple disciplines within a company. Alec Saguinsin (2019) discusses in his paper the use of Ladybug, a sunlight simulation tool within Grasshopper to test solar access compliance through genetic algorithms, this projects ambitions do not specifically align with sustainability, but still apply the same principles within this project using the same toolset for simulation and implementation of optimization. The project turned out to be a success in terms of the what Alec was trying to achieve, it mentions further development would involve window testing

(Saguinsin 2019, p19), which is the approach that this project is taking. Aiden Ackerman (2019) takes an approach at addressing the importance building sustainability through tackling the landscape design sector through using various simulation processes including Ladybug, Honeybee and Butterfly to simulate and measure landscape environments to mitigate the effects of changing coastlines, raging wildfires and hotter cities (Ackerman 2019, p125). The success of this paper was able to demonstrate the changes the environment was undergoing, but similar to Ryan Johans (2019) paper, expert advice is required to analyse and judge the validity before any information is released to the public, therefore once again inflicting this issue of interdisciplinary issues (Ackerman 2019, p144), where it is difficult to collaborate with separate fields, a common problem with being on the forefront of computational architecture where multidisciplinary practises are becoming a more common circumstance.

There are still limited examples of computationally driven research that focuses on multi-object optimisation in relation to façade glazing properties. Therefore, the goal with this project is to develop an optimization script that is able simulate the effect that glazing's with different thermal properties would have on the internal thermal and lighting conditions. This would also require an investigation into Window to Wall Ratio (WWR) and Shading, a study conducted in Italy determined that through a consistent layout of window to wall of about 40-60% there was no major difference, between the buildings tested in the different environments (Marino 2017, p181). Other studies that exist such as the Peter Lyons (2004) which discusses rating systems for glazing's, giving insight on how various glazing properties work, such as glazing's being measured by their thermal transmittance (U-value), Solar Heat Gain Coefficient (SHCG). It demonstrated that glazing's which are able to maximise light transmission while minimizing solar heat gain are more effective for daylighting, other factors such as the frame being used impacts the U-Value more than the Glazing itself (Lyons 2004, p1). This research is important as these factors need to be considered from an intuitive designers perspective as previously demonstrated through other papers above, external factors outside of the computer's constraints must also be considered in the end game perspective.

The process of choosing Glazing is often an overlooked process and implementing a system that optimises these factors into façade design can change the way architects start to think about designing a façade as the importance of sustainability rises. The goal of this paper is to use multi-objective optimization in conjunction with GH environmental simulation tools to determine how effective various glazing's are at reducing heat and improving lighting conditions within an internal space.

6. Case Study

The research consisted of developing a tool to perform 2 interconnected functions of environmental analysis and multi-objective optimization (MOO). The research develops and tests the computational tool using the case example of the Sunshine Coast University Hospital 3D model in a .3ds file format provided by the industry partner BIM consulting. The next element is the Grasshopper (GH) Script (Figure 1) and this process involves taking Rhino geometry, and applying windows and shaders that are generated within GH to the appropriate window walls. These windows and shaders are controlled by the user through slider input, move the slider will result in dimension parameters of that geometry to change, therefore effecting the performance of the space. This GH script processes geometry information through Honeybee which uses an external database system called EnergyPlus that feeds accurate weather data into Honeybee. This enables Honeybee to project the energy results onto the geometry being analyzed visually mapping the space displaying different colours in various severities of impact. From there the environmental data is transferred into the MOO engine Wallacei.

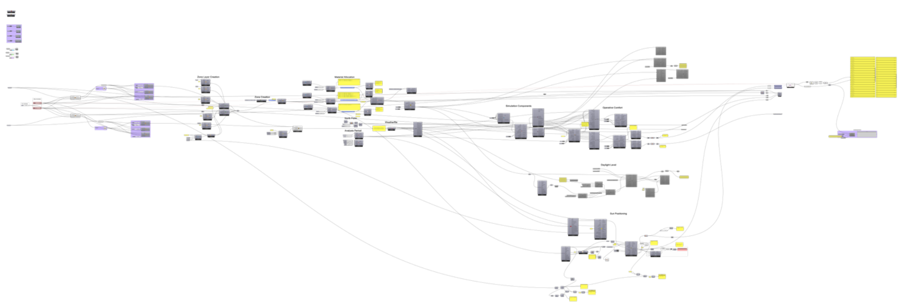

Figure 1: Complete GH Script

6.1 3D Model- Insertion

The project relied on the appropriate setup of the building geometry, which was discovered after several iterations through setting it up. The process of establishing this model involved breaking its elements down into what could be appropriately translated into a GH environment, it was originally a Revit model and therefore had elements such as “blocks” which were difficult and mostly incompatible a GH transfer.

6.1.1 3D Model- Setup

Iteration 1

The work around to the issue of having these "blocks" is by exploding the geometry to unpack it and so that Grasshopper could accurately reference it when in that state. Regardless iteration 1 of this process was referencing the building geometry through directly selecting the model geometry elements in Rhino and then referencing those in Grasshopper. This process was cumbersome and resulted in an incomplete model. With missing elements, the model featured significant inaccuracies leading to the necessity to commence iteration 2 (Figure 2).

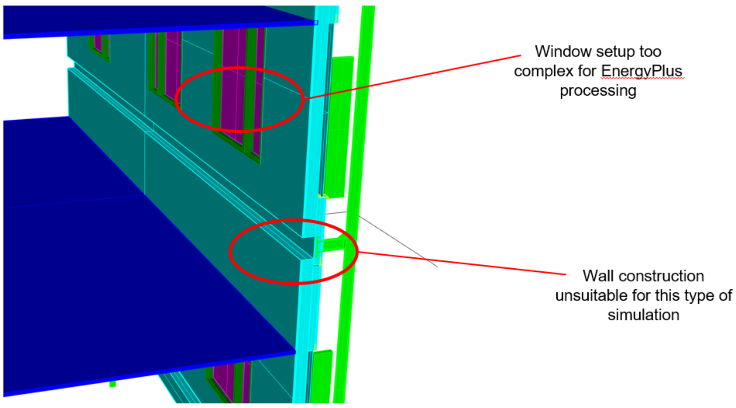

Figure 2: Initial Model Issues

Iteration 2

Consisted of making several rectangular B-reps which are effectively a solid constructed through a collection of surface elements. In other words, it was a collection of rectangular prisms that make up the shape of a basic rectangular room. This method was more effective at removing gaps and inaccuracies, yet it was still cumbersome for Honeybee to test against and process, therefore further reconsideration was required (Figure 3).

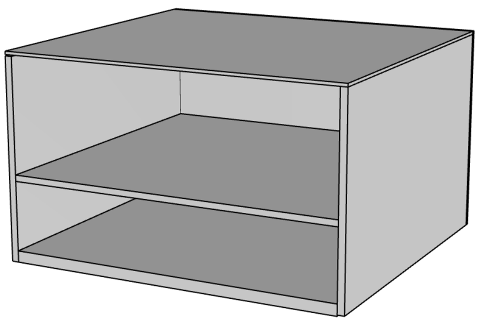

Figure 3: Re-Model with B-reps

Iteration 3

Finally after completing research regarding the manner in which Honeybee prefers to process geometry, it was discovered that it was best if 2D basic surfaces were used as it allows Honeybee to process at a quicker rate , and it is just more appropriate for overall calibration. It was also discovered that using these surfaces allowed EnergyPlus to apply material attributes using its database to allow for accurate energy processing. Therefore iteration 3 was constructed as a simple box that covered the approximate size of the room, where all surfaces were 2D, removing depth classifying them as surfaces rather than B-reps. Overall, this revised approach was more appropriate for calibration (Figure 4).

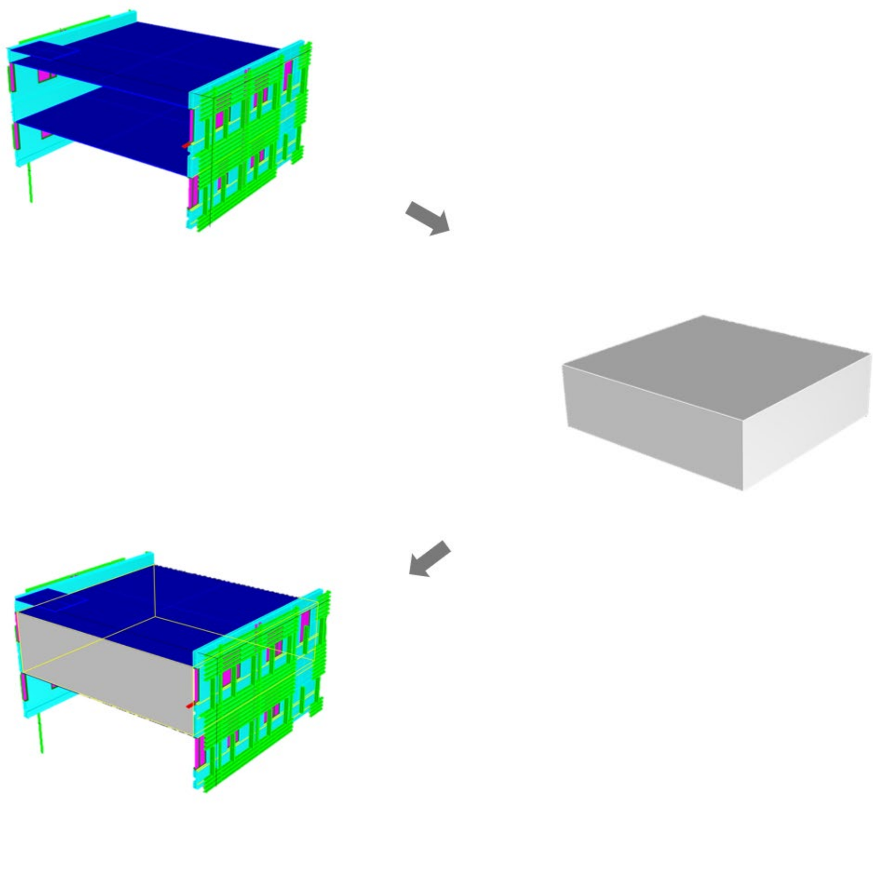

Figure 4: Model Integration

6.2 Grasshopper – Geometry Setup

The geometry setup for Grasshopper was a time-consuming stage of the research project, it was necessary to refer to past examples on the internet using the same tools for different applications through forums, blogs and youtube videos. This was essential to understand how the construction of building and windows in the model had to be setup to enable accurate and effective performance from Honeybee.

Initially the window generation system consisted of using the glazing ratio component which automatically applied windows to every wall on that surface, moving on to physically creating the windows in Rhino. This system also involved energy script that it was later discovered as being poorly setup and therefore delivering inaccurate results, after further exploring how Honeybee works, the final solution was created, delivering its current state. It was discovered that the inaccuracy of results related to the geometry set-up, but also the original script was using "OpenStudio" when as "EnergyPlus" was required as it worked appropriately. The geometry setup relied upon geometry zone allocation in the form of layering, and assigning zone attributes, which were all meant to be utilizing the Honeybee and EnergyPlus' database. The original box in Rhino had to be exploded and broken down and referenced as layers in GH such as roof, wall, floor, etc and then assigned a number as a "SrfType" (Figure 5) so Honeybee could understand and process what type of surface that was.

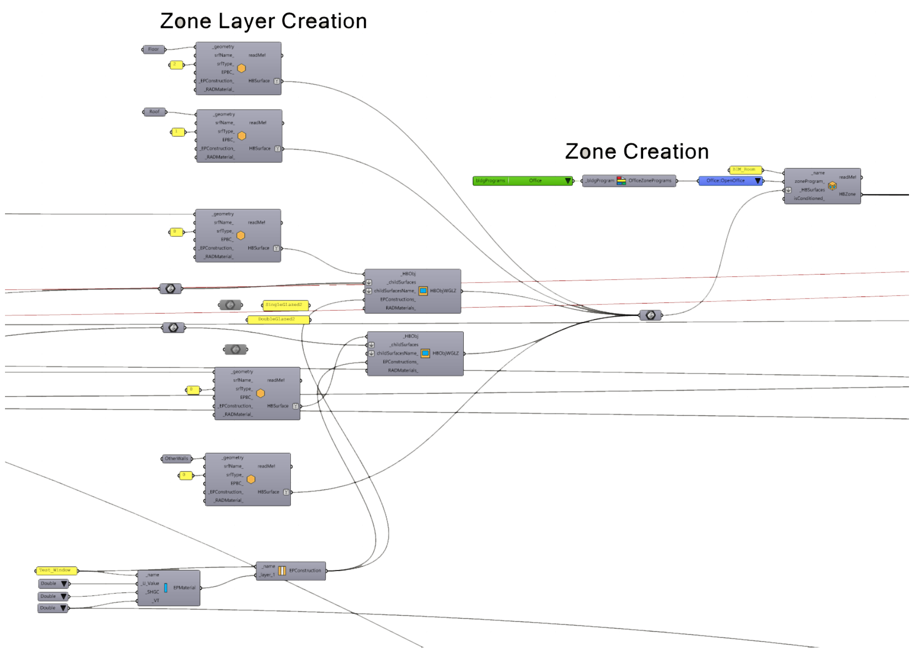

Figure 5: Zone Allocation

This information was then all combined, but this time the box was broken down into “HBzones”, this allowed construction material types to be assigned using the EnergyPlus database (Figure 6).

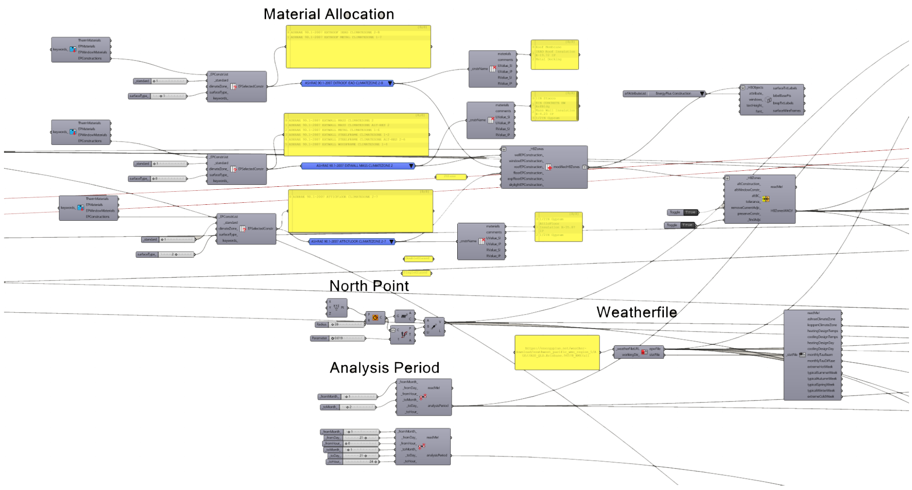

Figure 6: Material Allocation

Windows were at this point still being referenced as physical Rhino geometry but were assigned to window walls and then applied to the whole model as a “HBglazing” (Figure 7). Glazing was constructed using an “EPWindowMaterial” component, this component consisted of 3 parameters U-value, Solar Co-Efficient and Visual Transmittance, these 3 values were only required as this component included the framing within the energy simulation. As the testing progressed through revisions to the geometry/model set-up produced more accurate and substantial results in comparison to other forms of creating glass types.

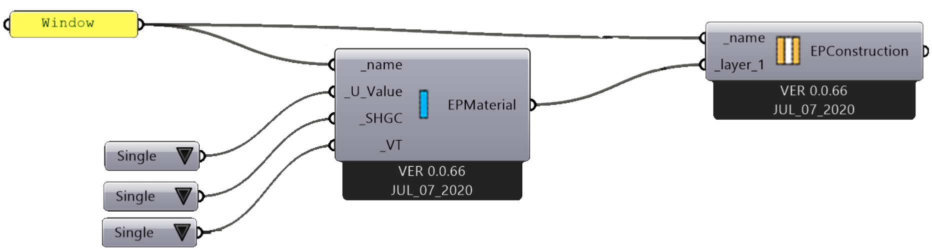

Figure 7: Glazing Construction

6.2.1 Grasshopper – Window and Shader Generation

The next formation in this script was window and shader generation, an important component as the windows had to be adaptive and parametric to allow for easy user input and effective optimization runs. The windows and shaders had to be setup in a way that allowed for easy manipulation of WWR, with the shaders appropriately adapting themselves to them. The process of window generation was predominantly seamless, the goal was to produce a small recipe that would use the "window walls" to generate rectangular windows that shared the same sizing parameters to control Window to Wall Ratio (WWR). This generation system in its current state requires a window wall to be setup, it does not project windows, it generates them, as projecting them resulted in recognition failure from HB. The shader generation system was a system that would need to be robust, a challenge here was the research recipe would only order a list according to a certain condition, in response a system was created to sort the list based on conditions to system that used vector points to cull the unnecessary lines to always select the correct one (Figure 8).

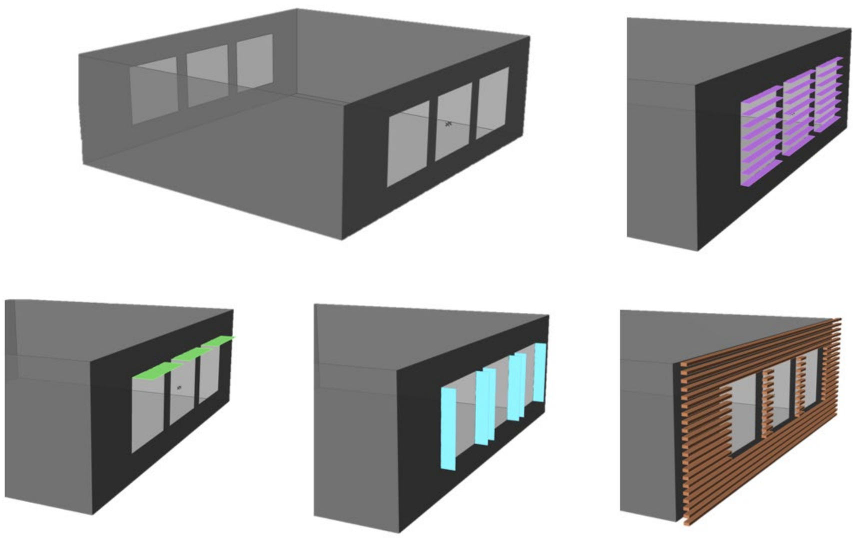

Figure 8: WWR and Shaders

6.3 Results – Thermal Performance

The next stage of the research involved connecting and running the environmental simulation and analysis plugin Honeybee on the established 3D geometry, this process using the rooms floor surface that is tested for the projection of the visual energy mapping. Given the limitations of the research project time, against the time required to undertake multiple simulations, the scope of testing was limited to the summer season. Equally, given the case example context of the Sunshine Coast, Queensland the summer season was deemed more significant as conditions are more extreme in comparison to the Winter season. Thermal performance testing was measured using a comfort matrix component, where the values of operative thermal adaptive comfort and temperature were derived and used to evaluate the performance of the glazing. When comparing thermal adaptive comfort which is percentage of space that occupants would find comfortable, the ideal percentage to aim for is 85%, therefore at least 85% of people in that space are comfortable. For a test area of three, 2mx2m windows, the outcomes indicated a performance difference between single and double glazing of 4% and then only a 0.5ºC reduction in temperatures (Figure 9).

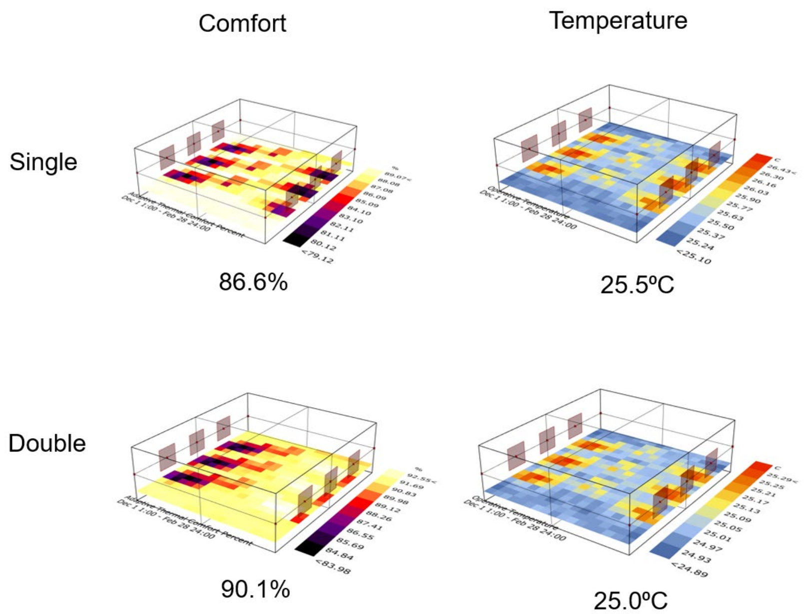

Figure 9: 2mx2m Analysis

When increasing window size, it decreases the extent of framing required which reduces the opportunity for thermal loss through framing, which has a greater impact on winter performance. When the window size increased the difference between the 2 glazing types became more significant. Ultimately through consecutively increasing window size it became apparent that as windows increase in size the potential of single glazing decreases and the necessity for double glazing increases, this was demonstrated through the results. Analyzing three windows at a sizing of 3.5 x 4.2m resulted in a 20% increase in thermal performance (figure 10).

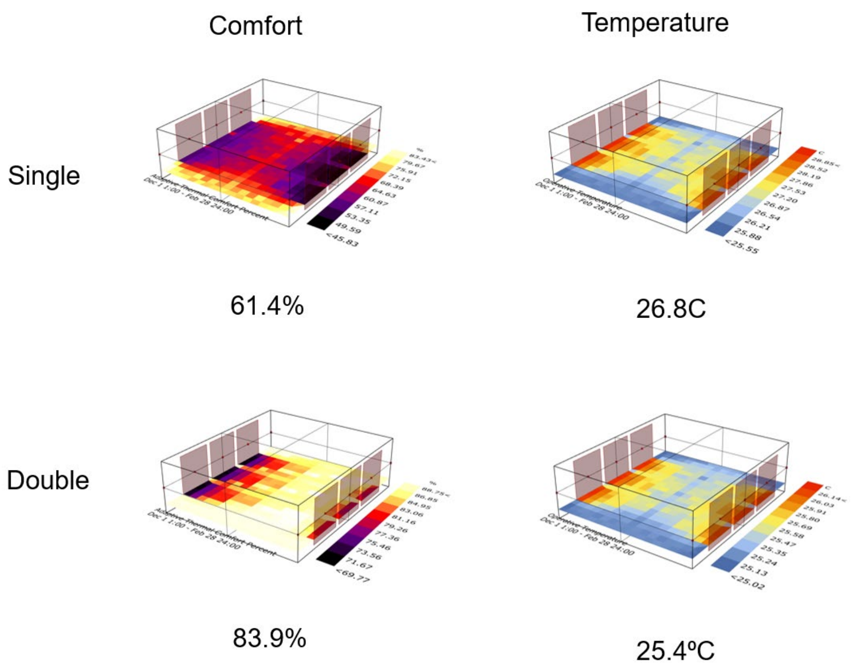

Figure 10: 3.5mx4.2m Analysis

When expanding the window size even further to cover the entire span of the wall to emulate a a curtain wall glazing, the results really lean in favor of double glazing with roughly a 30% increase, with single glazing remaining far below the required comfort rating at 48%, whilst double glazing still maintaining 78%. (figure 11). A few tests were run in Winter for comparisons sake, where it was discovered that there was an 8% increase in thermal performance, and a 20% increase in thermal performance when using double glazing. The shaders provided marginal differences in performance with top and side shaders increasing annual performance by 2%, whereas louvre shaders provided an 8% increase in thermal performance.

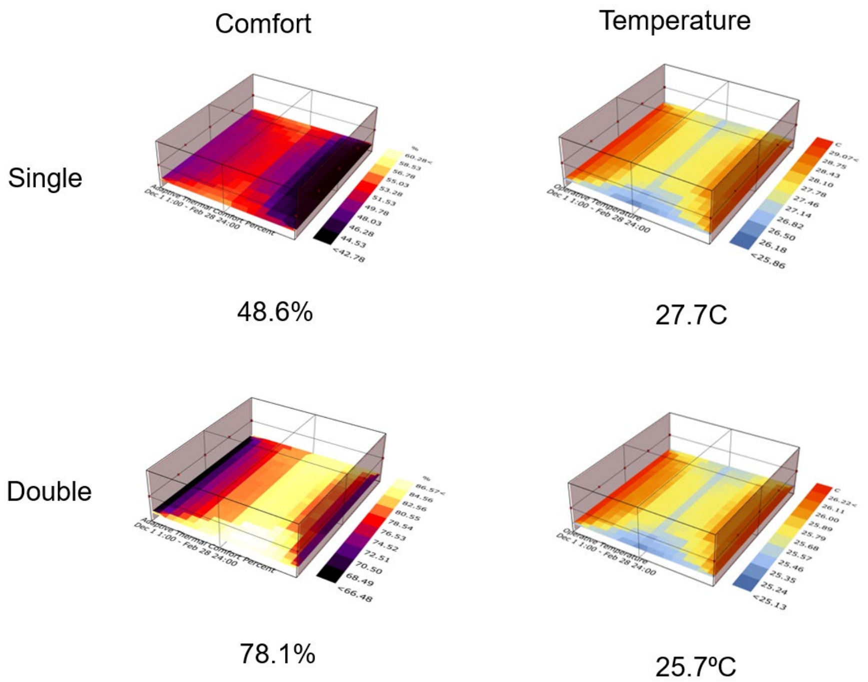

Figure 11: Curtain Wall (Entire Wall)

6.3.1 Results – Lighting Performance

Lighting performance delivered expected results with a low difference in performance between each glazing type, the only factor controlling its performance was visual transmittance, and after consistent testing of summer, winter and annual periods the only substantial change in lighting conditions were due to change in WWR.

6.4 – Multi Objective Optimization

Finally, optimization being arguably the most important factor to this research paper delivered results that ultimately benefitted the final evaluation. As previously described MOO is a process of mass iteration that is refined through an algorithm to deliver the most optimal result. This process began with using Galapagos, a vanilla Grasshopper component that was only single objective, and was also not capable of running the intense energy data. Therefore Wallacei, a MOO evolutionary solver plugin was used as replacement, delivering more controlled and faster optimization with better visualization platforms. Parameters represent the "genes" which equate sliders related to window sizing being changed. The energy results are the fitness objective, which wallacei is able to use as standards for control, where each gene adjustment is made in effort of achieving those fitness objectives (figure 12).

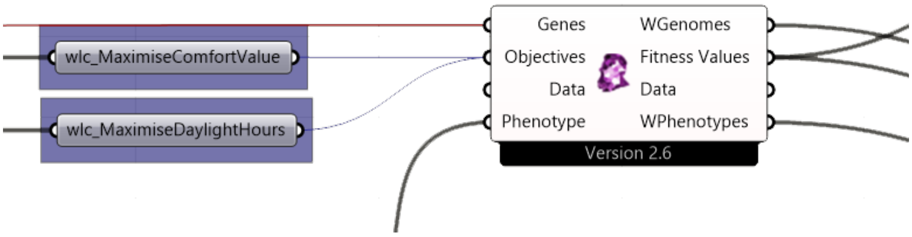

Figure 12: Wallacei Plugin

Optimization is a time-consuming process in collaboration with this energy simulation as Honeybee is slow to process. Therefore, every time a parameter was changed, Honeybee had to reboot itself resulting in a smaller array, resulting in 5-10 min intervals between the next parameter alteration. Furthermore, this equated to roughly 1-hour optimization times on a Summer period run period to achieve feasible results to make a judgement. One run period for an hour would produce roughly 10 generations with 10 iterations within each generation (Figure 13), where the more generations produce a higher likelihood of achieving desired results.

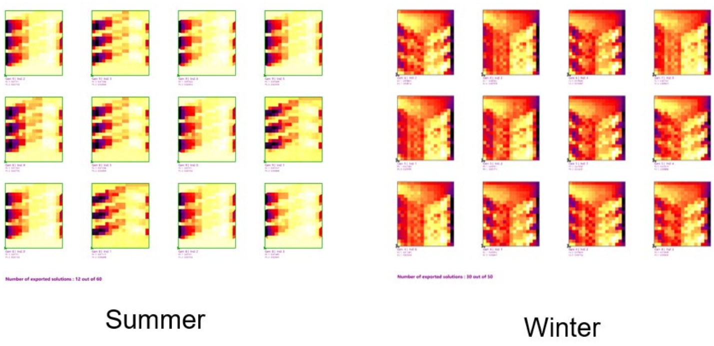

Figure 13: Example of some optimized results

Through the simulations conducted, three single glazed windows produced 3.5m x 2.8m as the most optimal sizing for that arrangement, whilst double glazing of the same arrangement delivered 3.1 x 3.8 as the most optimal sizing arrangement. This arrangement of windows follow the original window arrangement on the test building, when re-adjusting that one window per window wall, a greater result can be achieved with the optimization. Therefore, after testing one window on each of the 2 walls being used, the WWR was able to jump form 20% on single glazed to 60% on double glazing , a 40% increase through using double glazing when testing for thermal comfort (Figure 14).

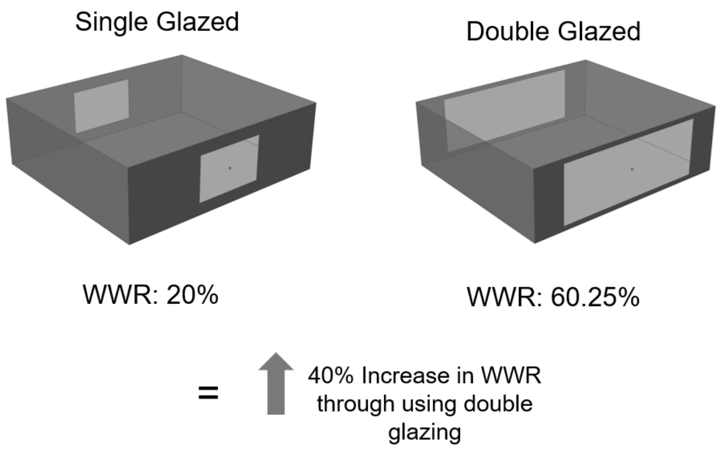

Figure 14: Window to Wall

Through continuous analysis it was identified that single glazing will have a much lower tolerance threshold as opposed to double glazing. This was apparent through comparing results as it was clear that as the windows grow in size the performance difference between both glazing's becomes distant (Figure 15) as single glazing fails to meet standards where as double glazing is able to maintain performance consistently.

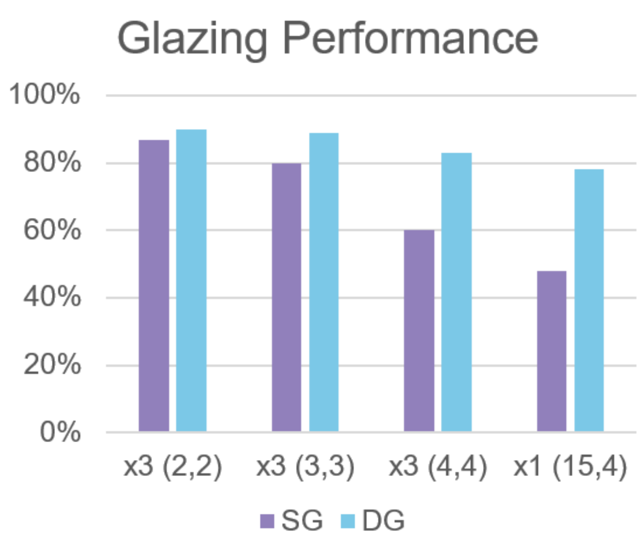

Figure 15: Comfort Performance Comparison

7. Discussion (evaluation and significance)

This research has successfully demonstrated the potential integration of computational tools into a standard project design decision, through the construction of an energy simulation tool that is able to be implemented into a computational designer's workflow. As previously stated, the overarching aim of this research project was to construct a tool for façade glazing decision making that is able demonstrate the thermal performance of an internal space. This tool was developed, and a viable outcome was achieved, this outcome used environmental simulation to visualise the impact of glazing choice. The result from this simulation was extracted and evaluated through a multi-objective optimization engine to perform mass iteration of the room geometry to quickly find the most optimal solution. This form of testing produced a comparative analysis between glass types in different climate conditions in a way that ultimately developed the users understanding of the impacts the glazing type and size had on the internal performance. The environmental simulation section of the project produced results that accurately represented the changes being made when analysing both glazing types. It was demonstrated that as the windows increased in size, naturally the heat within the space increased, the requirement for double glazing became apparent as window sizing increased more than 3m x3m each window. The difference between single and double glazing on the original three 2m x 2m configuration was negligible therefore in terms of cost saving a single glazed variant would still be suitable. This form of evaluation becomes particularly useful in scenarios like this where a budget may allow for double glazing to be used on an arrangement of this size but may not be entirely necessary for performance. MOO produced an array of iterations that were altered in effort to achieve desired fitness objectives to deliver a set of configurations that were considered most optimal. When comparing the original 3 window arrangement it was discovered that there was not a big difference in performance. Alternatively, when a single window per wall configuration was tested, there was roughly a 40% increase in Window to Wall Ratio when testing for thermal occupancy comfort. Double glazing's potential proved to be a lot higher than single glazing's through that test, it demonstrated the limits it was able to be pushed to. There are limitations to this research, firstly is the complexity of the script, as currently the script can be understood by an experienced GH user, but a novice GH user would struggle to make sense of the operation. Therefore, implementation of an interface that allows for standard operation and manipulation of the input geometry, and then the visualisation would allow a more feasible integration of this tool into modern workflows. Secondly is the speed of the energy simulation, itself, this is mostly due to Ladybug and Honeybee as they have always been slow systems. As of the making of this research paper, the new “ladybug tools” has been released which supposedly amends the speed issues, but the microclimate tools are still required for this project which are coming to a future update. Regardless the aims of this project were met, and a tool was developed that delivers the specified project outcomes, a tool that has potential to be implemented into modern workflows. This research can be expanded into a system that is more robust and expansive in application, it represents itself as an example of how computational design can be implemented into AEC workflows sufficiently.

8. Conclusion

This research integrates computationally assisted workflows into traditional architectural decision making to achieve a more advanced outcome. It highlights the impact of glazing choice impeding on an internal space through returning visual feedback to the user in the form of data, and then optimizing that data to deliver a further refined solution. Due to the current state of the world’s climate conditions, this form of energy simulation is of growing importance for designers in order to begin implementing sustainable decision making into current workflows. This paper delivers that ethos through creating an adaptive tool that can simulate the impact of glazing choice, and then use a Multi Objective Optimization (MOO) system to mass iterate the input geometry and find the most optimal solution. The environmental simulation system can deliver results that visualise thermal occupancy comfort, operative temperature, air temperature and lighting conditions according to the glazing choice. The results from this simulation are optimized through a MOO engine to deliver a set of optimized results. These results bring benefit to the project through delivering a set of results that have been iterated in accordance with a set of objectives therefore representing a selection of alterations that are considered most optimal. Although this project still requires simplification to approve its viability within standard design workflows, it contributes to the implementation of computational design into everyday design practise.

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