BIOMIMETIC FACADES

Evaluating Design Methods for Reducing Energy Consumption

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Adopting biomimetic principles in façade design can offer significant benefits in reducing energy consumption associated with traditional mechanical heating and cooling systems. Traditional mechanical heating systems have proven to be unsustainable solutions for heating buildings and caused long term environmental damage whilst often not addressing the fundamental issue of poor climate consideration. In the last decade, several bio inspired architectural solutions for heating and cooling systems have been explored including Mick Pearce's East gate building and Lift Architect's Air Flow(er). Looking at these examples, behavioural and structural characteristics are understood and translated to the scale of a building component. Although there were positive outcomes from these projects they only focused on a specific climactic condition and if it were to change the system would be detrimentally affected. This research project aims to address passive ventilation strategies, through a facades system which draws on the afore mentioned methodology while exploring the potential of sea sponges [phylum porifera] passive ventilation system. This is intriguing as its asymmetric burrow openings allow for passive ventilation which in turn could control and internal climate. The phylum porifera's adaptive behaviour was explored in order to abstract the fundamental mechanism behind its optimisation process. The mechanism was simulated with in a visual-scripting environment with the purpose of designing a bio inspired dynamic façade capable of actively and adaptively controlling thermal exposure. Reduction in mechanical heating loads were analysed against traditional façade systems and the design optimised. Altering the asymmetric holes on the façade allowed for different levels of thermal exposure which allowed for a wider range of results and lead to a more optimal design. The resulting biomimetic façade reduces the internal use of HVAC systems in cold climates through managing external wind loads and ventilation. The resulting façade can be installed on new or existing building allowing for a broader use of the façade system. Further research could be undertaken to implement bioinspired dynamic facades capable of passive ventilation within specific climates, as a way of addressing global warming and creating a sustainable future.

Keywords: Biomimicry, Façade, Sustainability, Optimisation, Energy consumption

1. Introduction: Research Aims and Motivations

The architectural practice should further explore biomimicry as a solution for the built environment. Biomimicry and its principles can offer the architectural community a valuable source of design and help solve issues including how to reduce mechanical heating and cooling, and also provide better solutions for passive ventilation strategies. The institute of biomimicry defines it as “An approach to innovation that seeks sustainable solutions to humans challenges by emulating natures time tested patterns and strategies” (2017) There are a few key aims which this project looks to achieve including exploring biomimetic strategies and extracting mechanisms. Looking at biomimicry and biomimetic architecture presents a large scope, however there is currently predominately only research on organisms that reduce cooling loads in hot climates. Although this is useful to our ever changing environment in global warming there is still a current situation in which cold environments and especially high rise buildings in these environments are often neglected by designers. One of the aims of this research project is to develop a biomimetic facade which is suited to cold climates. Another aim is to take a specific mechanism from the organism or its structure and look at its pattern in nature and where else it occurs and how other organisms function with it and use it to their advantage. One of the question that must me asked in undertaking a project like this is How do you extract one mechanism out of that and convert it into something useful for architecture? Scale is a major factor for this, as if the mechanism cannot be re produced on a large enough scale to suit the built environment then it becomes redundant and can no longer perform that function effectively. This project also aims to create an optimal facade design through computational programming and use it to give better protection to high rise buildings against external wind loads. The scope of this project will only be one specific pattern in nature or organism and looking at high rise buildings. There are limitations within this project also as a variety of patterns will not be able to be tested and this means that the project could in fact fail and turn out a negative result to say that it didn't reduce the effect of external wind loads on the building. Another limitation is that the project will not be tested in physical form but rather only computationally, so although it may work digitally there could be other environmental factors..

2. Research Observations and Objectives

The overarching aim for this project is to develop a workflow which address the chosen biomimetic mechanism and inputs the design into an evolutionary solver to generate an optimal design outcome. The key focus of this project is the generation of multiple iterations of a facade system which address external wind loads on high-rise buildings and how to reduce them. The overall objective is to produce a facade which can deflect wind and control ventilation around the exterior of the building so that less mechanical heating will be required to be used. It focuses on addressing the gap of the lack of attention paid to certain seasons and high rise building design.

3. Research Question

How can biomimetic principles be implemented using computational methods to generate the design of an environmental facade system in high rise buildings which reduces heat loads?

4. Methodology

4.1 ACTION RESEARCH METHOD

Action research (AR) is a research methodology which can be described as an informal qualitative, formative, subjective and interpretative experiential model. It has the intent of providing a framework for qualitative investigations using a collaborative model. This research project falls into the action research paradigm as it identifies and explores a problem using a created workflow situated with in the computational design realm, specifically using the tool of grasshopper. The project will actively explore an iterative design process which includes stages of design, evaluation and optimisation. The project is situated with in a collaborative environment, in this project it is the industry partner Bates smart.

Within the action research paradigm there are a number of methods which are used to achieve the overall project. These methods also align with the project being conducted in this paper. Methods that will be used include the digital design of a biomimetic facade, the testing and analysing of this facade design and consequently the evaluation and further optimisation of the facades. Digitally designing a façade which utilises a biomimetic feature is the first process to take place using grasshopper as a tool. Subsequently, testing is the next method step which will completed. Testing carried out on the facade will be completed using plugin software such as DIVA and lady bug. Testing is a key part of the method as it allows for results to be acquired and also push the project forward into another iteration. Without iteration in the project the action research methodology is not as strong. For action research to take place they need to be practical outcomes of the project. Testing allows for these practical outcomes to occur within the project. After these initial outcomes has been achieved the analysation of the results and evaluation of the facade can take occur which can give birth to a new iteration of the design, resulting in a more optimal facade. Within the action research paradigm there's a large amount of participation by individuals as well as industry which allows it to invoke social change or change within the built environment. Reflection is another key aspect of action research as it is a highly rigorous process but also highly effective in being able to produce iterations which continually seek to produce better outcome for the project. Reflecting and analysing the data to then create a more optimal façade is a key method in this project as it gives validation to the notion of biomimicry and more specifically the biomimetic organism chosen.

Through using these methods of design, testing, analysing, evaluating and optimising in a collaborative environment the research question can be addressed in a way that has validity and results which prove that the last iteration will be the most optimal design in producing the largest reduction in heating loads in buildings. Using all of the key processes mentioned above a method can has been composed which directly correlates to the action research paradigm.

5. Background Research

6.1 LITERATURE REVIEW

Biomimetic architecture is an area which has been explored for centuries, mainly in the past as a way of humans adapting to their environment and being able to survive in hostile environments. In todays society biomimicry is being utilised as a source to create more sustainable buildings which look to provide to the future of cities. Biomimetic architecture can be seen as an approach to innovation which utilises sustainable solutions to help solve human challenges by emulating natures time-tested patterns and strategies. In 2007 the Biomimicry Guild defined three levels of biomimicry, which are the form, process and ecosystem (El Ahmar 3013 pg540) Biomimetic architecture is often started with good intent and there are many examples of project which have been completed successfully. Whether structures utilise the organism, a mechanism with in it or its habitat, each form provides its own outcome within the biomimetic realm.

Salma El Ahmar’s paper Biomimetic - Computational Design for Double facades in Hot climates published in 2015 addresses and designs a solution to reduce cooling loads using biomimicry. Taking inspiration from termites and their mounds she is able to pinpoint a mechanism and use this in order to parametrically create a double facade. Her success comes from her ability to realise that; "features are simplifies and abstracted to be able to apply them in an architectural context" (El Ahmar 2015) She then goes on to produce her design iterations stating that there are key performance criteria which cannot be ignored when conducting experiments in this area of research; "They include cavity operative temperature, cavity air flow measured in air changes per hour, and Daylight factor in the office space. They represent the fitness in revolutionaries are the remix all the octopus which attempts to optimise design variables to reach the solution and achieve the best balance or trade-off between these criteria." (El Ahmar, 2015 pg 691) As her design iterations flow on she utilises grasshopper and octopus for testing and design. El Ahmar, then optimises her facade so that it caters and optimises the temperature and ventilation within the building, also a key focus of this project. At the end of this optimisation period she explains that; The difference between cavity and ambient temperatures is within the range of 1.7°C which implies that overheating is prevented at least in the specified typical day in which simulations calculated. This shows the importance of increasing heat loss by convection in better regulation of the double facade. (El Ahmar, 2015 pg 693 - 694) El Ahmar’s work illustrates why it is necessary for a double facades and also that utilising biomimicry in facade design is a sustainable and efficient way of controlling internal temperature and ventilation within a building.

Filip Tejchmans paper The Cave is the Camp Fire: Thermal Forms in Architecture published in 2015 explores the notion of how architectural geometries that control or transform ambient thermodynamic flows in order to reduce or simplify environmental control systems are being used to temper buildings. His research delves into ventilation and how these thermodynamic forms can be used to create a more sustainable environment, and that it shouldn't be viewed as mechanical systems but rather as part of the envelope or structure. Even though Tejchman explores thermo1 z5120584 dynamic forms he still utilises biomimicry in order to have an effect on the built environment focusing on ventilation and passive architecture, which is in direct relation to the research being undertaken in this paper. During his final comments of the paper Tejchman states; “By changing our disciplinary definition of passive architecture, through the formal and experiential criteria of work instead of energy, we open the simul-taneous possibility of reinvesting the profession with a more comprehensive design scope.” (Tejchman 2013 pg 401)

Although there has been many examples of biomimetic architecture completed in the past not all have been successful. The simple copy and paste method is not what allows biomimicry to be such a successful way of designing. Rather it is the ability to take from an organism and manipulate that mechanism so that it functions for the built environment of a large scale. Simply taking inspiration from nature and copying it can be seen in Asterios Agkathidis' paper "Implementing Biomorphic design" published in 2016 explores the notion of implementing biomorphic design into studio. However, his paper includes biomimicry inspired projects but none of them fully take the mechanism and adept it, merely they take the feature and copy. This is also what can happen within the biomimetic realm as mechanisms aren't broken down enough and then scaled up in an abstract way. Leaving the function lacking and the form more nature inspired rather than developing an architectural biomimetic structure. This relates to this research as its aim is not to simply be inspired by nature however, create something that serves a function and not just for decorative purposes.

Asymmetric burrows are a shape of cell which the sea sponge has. Its cell structure is shaped like this which a unique feature to it. Although the sea sponge lives under water it can be valuable for uses on land. Cassuci and Eroli give mention to the seas sponge in their paper Behavioural Surfaces: Project for the Architecture Faculty library in Florence (2012). Their paper focuses on "Exploiting material self-organization in sea sponges as surfaces that deploy function and performance through curvature modulation and space definition" (Cassuci, 2012) Through this it can be seen that sea sponges present themselves as a useful organism and especially when it involves surfaces. The sea sponge has a porous structure and is able to expand and contract passively as water pushes through it.

Overall, biomimetic structures can be adapted into the built environment and serve functions including reducing cooling loads, controlling ventilation and optimises the thermal properties of a building. Also, when implementing biomimicry it is important that the abstraction of the mechanism occurs so that it can be successful on a larger scale.

6. Case Study (BIOMIMETIC FAÇADE)

When developing a façade system there are a few key factors which need to be taken into account; including the type of buildings it will be situated on, will it be implemented on to existing or new buildings and will the façade be a whole front or panelised system.

6.1 EXTRACTING AND ABSTRACTING THE MECHANISM

When undertaking the process of biomimicry it is important to divide the process into each of its components. First, however it is important to understand what is the issue being addressed; in this project it has been passive ventilation and how external winds hit high rise buildings directly and penetrate the exteriors forcing more mechanical heating to be used. Researching into asymmetric burrows it was found that their shape was able to redirect wind and control ventilation. Further delving into the mechanism fauna and flora were researched which had this mechanism and the sea sponge was an organism that had them in its structure. A correlation between the sea sponge and asymmetric burrows was found and the movement was looked into. Although the sea sponge is an aquatic animal its movement can be abstracted for on land purposes. This is due to the waters current having similar properties to wind currents. As more water pushes through the sponge the cells expand and as lest water pushes through the sponge its cells contract. Based off this movement of the mechanism and its flexibility as an organism the mechanism was extracted.

6.2 USING AN EVOLUTIONARY SOLVER

Octopus is an evolutionary solver which plugs in to grasshopper. It uses criteria which the user inputs to give optimal design solutions for a particular design. It is one grasshopper component which has three main inputs; the mesh designed or design you want to be optimised, the genotype (usually a set of randomised values) and the phenotype (a set of fitness criteria which will become the axises of the graph) Using octopus allowed for many design solutions to be accounted for fast and effectively. It is able to present these options visually in a graph systems where the user can visualise the different design outcomes over generations. This is highly beneficial especially when undertaking designs based off biomimetic principles or those which are bio inspired. Octopus aims to produce design solution which target towards zero on its graph. Fitness criteria can be set up, and these become the axes on the graph. The axes which were set up in this project were the surface area of the entire panel, the surface area of just the inflated spheres and the how much the spheres were inflating. When setting up fitness criteria it was important to recognise that these had to be fighting against each other or the solver does not work effectively.

6.3 PANEL DEISGN AND ITERATION ONE

Creating a workflow which utilised the above criteria was completed to ensure that and optimal design outcome would be achieved. A panel was created which utilised a three by three grid system for the inflating spheres.

In theory panel would be made out of the flexible material which could expand based on how much ventilation was entering the spheres. In total panel have nine spheres that could inflate separately and Independently of each other. The panel then assessed on three separate criteria; volume how much the spheres would inflate, surface area of the whole panel and the surface area of just the spheres. The panel was then optimised in octopus which gave a variety of results. However, after ten generations there was no optimal design results as all solutions remained far from zero on the axes as seen in figure 1

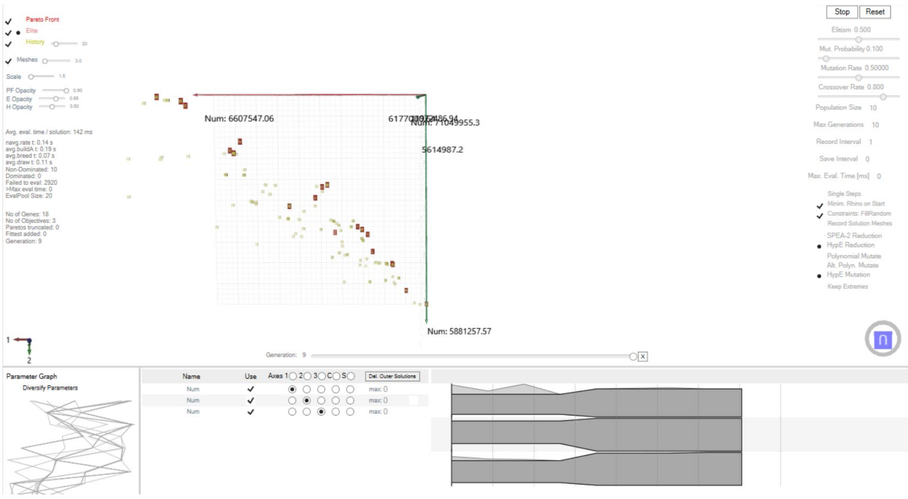

Figure 1: top down view of octopus evolutions

This panel design was also not a good fit as it produced a stiff panel where no external ventilation could be let into the building. Applying wind vectors to the panel further proved this as the wind could not penetrate through the panel meaning the building would be receiving no passive ventilation at all. As seen in figure 2 the arrows are representative of the wind pushing into the panel. The wind is completely stopped by the panel and has no way of entering the building; and even though this would completely solve the problem it is not an optimal solution. Another issue with this panel design and method of design is that although it is a flexible material it does not have perforations and therefore if too much wind was to inflate into the spheres in theory it would tear.

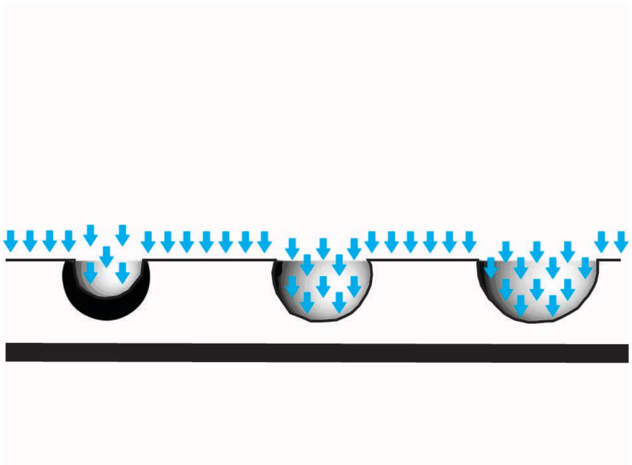

Figure 2: Wind vectors on the first panel

6.4 ITERATION TWO: DESIGN CHANGES AND ASSESSING MAXIMUM AND MINIMUM CRITERIA

Looking at iteration one there were a few design issues which needed to be addressed, including the lack of ventilation coming into the building. A new panel was design with the same basic structure however four of the nine original spheres were made into ventilation holes. This 4:5 ratio allowed for ventilation to reach the building whilst still hoping to achieve the original aim. The ventilation holes were set up in a diamond shape so that when the spheres inflated they would be able to deflect the wind appropriately. The aim of this panel design was to have the spheres inflating enough to a point where they would cover or partially cover the holes so that the external wind which was coming through into the building would be deflected and enter at a slower rate and not hit the building directly at full speed.

Creating a work flow which worked at achieving this was set up and new fitness criteria were established to create an optimal design. The new fitness criteria which were set up included the surface area of the entire panel, the surface area of just the inflated spheres and the how much the spheres were inflating which included the setup of a wind vector using the plug-in kangaroo. After this work flow was set up the spheres were blown up to their largest point of inflation where they were large enough to be touching but not overlapping. Using this precedent, the genomes were all set to 1.0 so that the spheres would stay at their largest inflation point. Octopus was used to text this design method and produced designs which illustrated a smaller set of results. The spheres were usually deflated over half way and included one or two fully inflated ones.

A wind vector diagram was then constructed to illustrate how the wind would be deflected if all of the spheres were at their maximum points of inflation. This can be seen in figure 3 where a section view has been cut from the panel. The blue arrows represent the wind coming into the panel whilst the yellow arrows represent the wind which is penetrating through the open ventilation holes and reaching the building. As seen in figure 3 the wind is being deflected extremely well by the inflated spheres and little to no wind is directly hitting the exterior of the building.

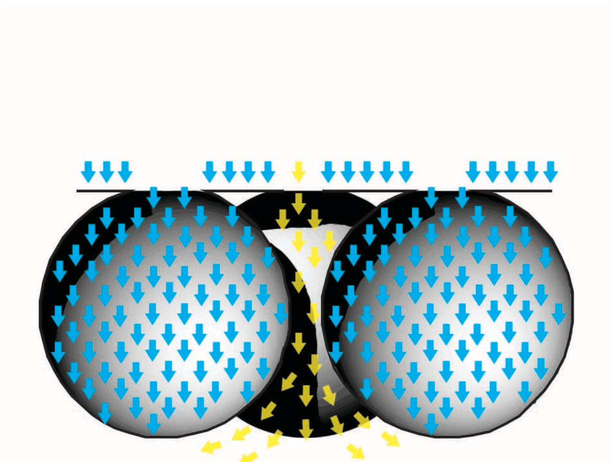

Figure 3: Maximum inflation wind vector diagram

After this experiment was conducted the genomes were all set to zero and the same test was completed using the minimum criteria values. This time octopus produced a better set of results as they were all close to zero with only a few outliers. The results showed more optimal design solutions as the inflation of the spheres was more even throughout the panels. However, a limitation of this is that only one generation can be produced which counteracts what octopus as an evolutionary solver is trying to achieve. another wind vector diagram was then constructed to illustrate how the wind would be deflected if all of the spheres were at their minimum points of inflation. As seen in figure 4 where a section view of this panel has been cut. The blue arrows can be seen filling the spheres and the yellow arrows can be seen entering the openings in the panel. However, as the image shows the wind is not being deflected at all when the spheres are at their minimum point of inflation. This result proves that this would not be an optimal design method as at its base no wind is being deflected and therefore ventilation is not being controlled.

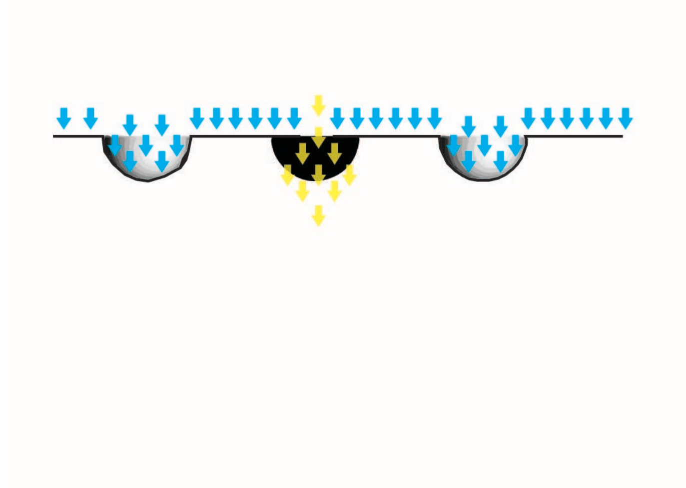

Figure 4: Minimum wind inflation wind vector diagram

6.4 ITERATION 3: RANDOMISING THE GENE POOL

Through gaining the results of iteration two, it was noticed that neither provided an optimal design solution when put into octopus. Although octopus provided a range of panels it was not with in the correct realm of what needed to be achieved. Changing the gene pools values so that they aligned more to octopus' nature and that of an evolutionary solver was then done. Randomising the gene pool allowed for a wider variety of results which could be better used when gaining an optimal design. With this method the fitness criteria remained constant to what they were in the previous iteration. When the gene pool was randomised and octopus was run with the new set of values a larger range of results were produced. This included ten generations of results, each generation including ten panels.

Octopus was able to produce iterative designs which focused on gaining an optimal solution. Through this octopus showed that generation five was the most optimal generation as all ten panels were closest to an axis and to zero. The closest panel to zero or the optimal design was then taken from this generation and a section was cut and a wind vector diagram was produced. As seen in figure 5 the wind is entering the spheres and going through to the building. Although the deflection is small and slower than that in iteration two where the maximum criteria was established it provides a more optimal and realistic result. The wind will eventually be deflected with a proportion of wind still hitting the building straight on.

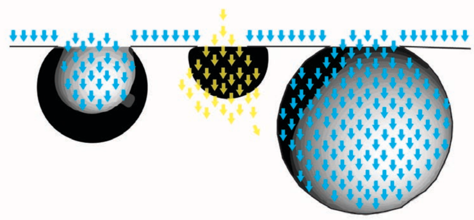

Figure 5: Randomised gene pool wind vector diagram

7. Significance of Research.

This paper argues that passive ventilation is something that can be controlled through looking at solutions which have already been tested in nature. Through investigating academic papers which address biomimicry, ventilation and other precedents a successful work flow has ben developed which addresses how using biomimetic principles can be useful in architecture. This panellised facade system allows for the architecture practice to understand that biomimicry can be used and there is a real need for buildings to have the issue of external wind loads addressed, especially in high rise buildings. It offers designers an option into facade systems which might have not previously been thought of, and also offers new ways of constructing buildings by taking something that nature has previously done well for so long and adapting it into the built environment. Through using software's and materials which are already available this project can be used to merge what is already available and what can still be discovered. Octopus also offers architecture a lot of benefits including being able to produce a large amount of design outcomes in a small amount of time. This can further be used in industry when looking at designing innovative building envelopes, or when space is restricted. Also allowing for more options to be developed in pavilion and facade design.

8. Evaluation of research project

This project focused heavily on using an evolutionary solver to develop an optimal facade design which addressed biomimetic principles. It focused on using a mechanism of opening and closing based off asymmetric burrows and the sea sponge to develop a flexible facade system which could deflect ventilation around high rise buildings. Although the case study produced a panel which does not fully deflect the wind in the ways it should it does illustrate that there is potential in this area and that with further development something similar or an extension of the case study would be beneficial to industry. When comparing iteration two and three of the case study above it can be noted that although randomising the gene pool produced a more optimal design, the only design option which would deflect the external wind entering through the openings at a fast enough rate would be the maximum inflation panel. However, if further experiments were ran using different variable there may be a result which is able to deflect the wind appropriately with an optimal design solution. This project has also developed a design method which allows for multiple design options to be produced, with taking wind vectors into account. However, one limitation of this is that the wind in the created workflow is constantly moving in the same direction, unlike in the real-world where wind is an unpredictable and uncontrollable variable. The case study focused on wind entering the panel from only one direction, which means there is a limit on how accurate the inflation of the spheres would be. Another limitation of this project is that no physical prototype was ever created so the materiality and how the material would function cannot be fully known. Looking further into an enclosed system would provide a more beneficial outcome rather than an open panel and may help assist in better controlling the overall wind loads. Given that the objective of this project was to create a facade system which utilised a biomimetic principle which reduced heat loads, it was mostly achieved. An optimal design was produced using octopus an evolutionary solver and the facade system was bio-inspired. However, this panellised facade does not actively reduce mechanical heating in buildings and only deflects wind loads to a certain percentage. Scholars within the field of architecture have become increasingly aware of the importance of sustainability and the effect the built environment can have on it. It has become a more common practice to conduct solar and wind tests on new structures being designed and built. Also more and more innovation and the use of biomimicry is being seen within the field of architecture as they look towards solutions which are time tested and work well. It is within this realm that my project is situated and it is an important study as options and different organisms should be further explored in order to create better architecture and a more sustainable built environment.

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