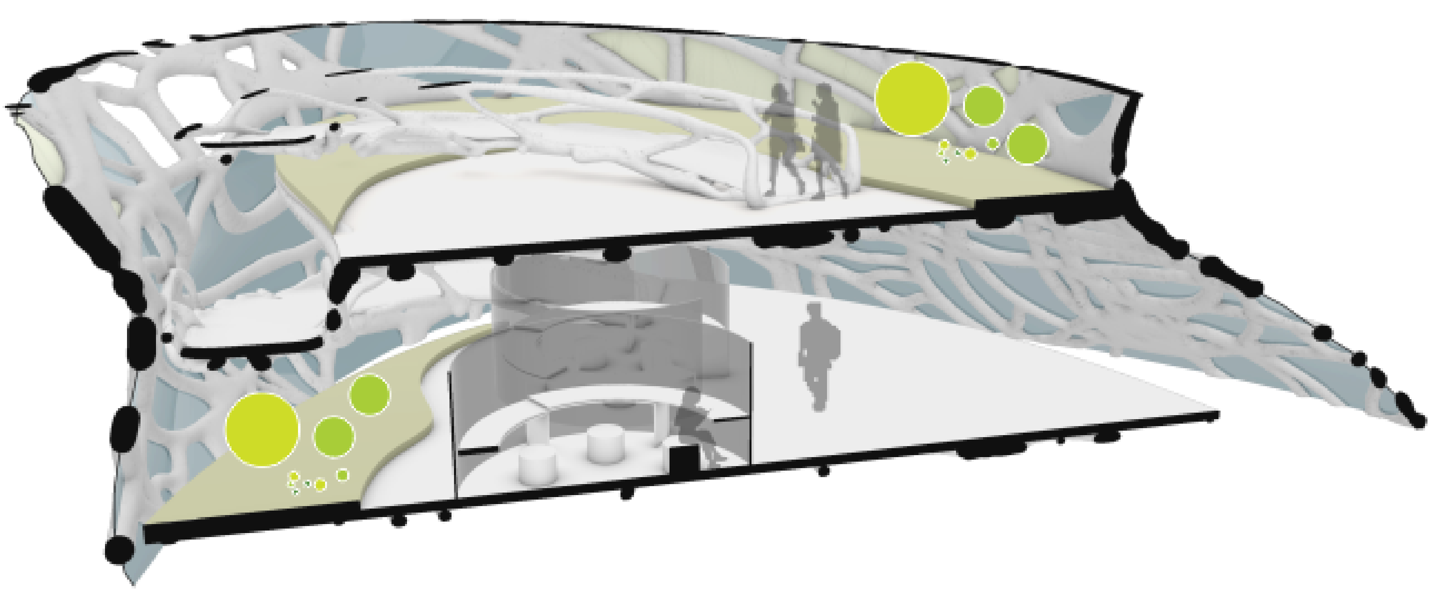
Bio-Cyber Physical Architecture

Integration of Green building strategies for Self - Sufficient Buildings



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Introduction

The world around us is rapidly changing and evolving. In a new report by the World green structure committee, the building and development industry are liable for 38.8% of all CO_2 emissions internationally, with operational outflows (from energy used to warmth, cool and light structures) representing 28%[1]. Our designed structures depend upon many resources during the construction or operational phase. So it is clear that the design decisions we make now for our built environment have a significant impact on the future. As the population increases, the need for freshwater, electricity, and other urban resources grows exponentially. It constantly increases pressure on the urban resources and infrastructure needed to run our cities smoothly. Self-sufficient buildings can be a crucial solution to urban problems like increasing energy demands and poor air quality, which we face today. It is less dependent on active energy systems like mechanical ventilation and electricity from the grid; it is more inclined towards passive energy systems. Self - Sufficient buildings as a concept have existed for quite some time and have made significant impacts, giving us a new vision to move towards a sustainable future. Integrating vegetation into the built environment has proven in many instances that it increases the self-sufficiency of the users' buildings and well-being, according to R.Hassell, 2017[2]. Self-sufficiency index rates the success of a development's energy, food, and water production, the amount of its surfaces allocated to the solar collection and urban farming, and the extent of its systems for recycling and harvesting natural resources [3].

The built environment replaced the former natural environment with the human "normal" environment. In most cases, green is an aesthetic addition in the design project rather than incorporated into the design process. Integrated design solutions are the key to solving many building-related problems[3].

A green building is a high-performance characteristic that considers and reduces its impact on the environment and human health. It uses various strategies to use less energy and water and reduce the life-cycle environmental impacts of the materials used[4]. It encompasses multiple strategies to increase the efficiency of the building; however, the thesis mainly focuses on how vegetation can be integrated into our built environment and understand its implications.

Nature has always provided inspiration and ideas for the field of innovation. It has always inspired newer living and green solutions for the future, environmental, economic, health, and community benefits. The integration of green vegetation into the buildings has various psychological and physiological benefits over the users[5]. More than its aesthetic advantages, it also helps absorb excessive solar radiation on the roofs, which reduces indoor temperatures up to 4 - 6°C[2]. It absorbs excessive stormwater runoff, which is used for various functions in the building. Kampung Admiralty, Singapore, was awarded the title of the building of the year 2018 by W.A.F. It is one of the projects that integrate vegetation not only for its aesthetic purposes but also to improve the self-sufficiency index of the building. The lush green step gardens seamlessly flow into habitable spaces, improving the users' psychological and physiological state[6].

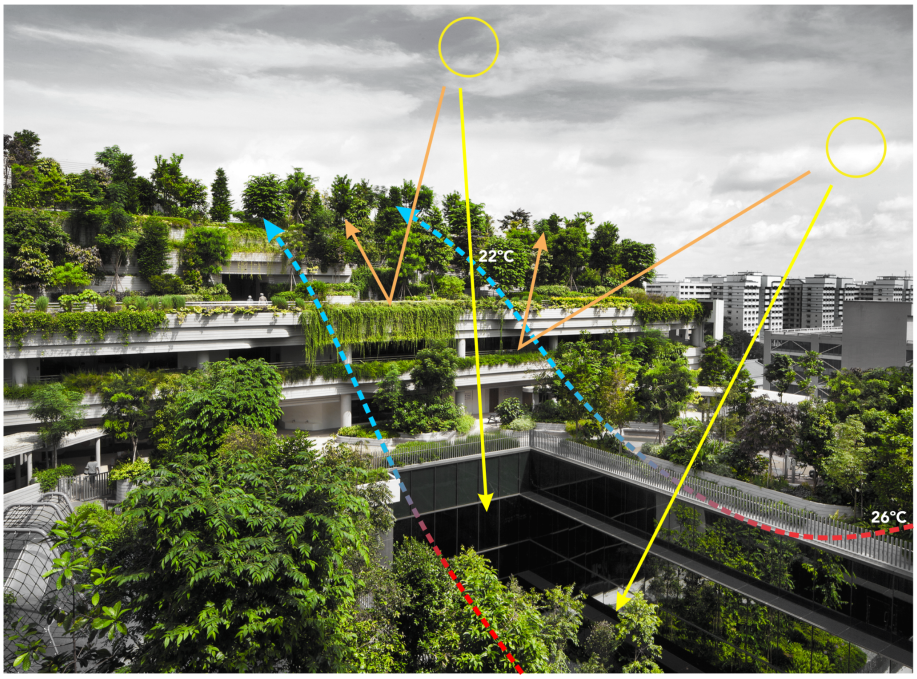

Fig.1: Vegetation integrated at the macro scale to achieve thermal comfort (Kampung Admiralty, Singapore, 2018)

Nevertheless, to understand the impact of the green building strategies(vegetation) in self-sufficient buildings on their future, we need data and statistics from predated green-built projects. Calculating every parameter and testing multiple iterations for a design solution to postulate its impact is quite complex. Computational methods can help solve complex calculations and assess their holistic impact on the built environment.

To summarize, integrating green building strategies can increase the self-sufficiency index in our structures. The research has explored various computational methods used for similar contexts and related them with green building strategies to design a self-sufficient habitat.

The research question mainly revolves around developing a design process that explores computational methods in green buildings and landscapes. After careful deliberation, all investigations are moving towards understanding different aspects and finding the overlaps between these two emerging fields because innovation and new ideas can be explored in that overlap. To summarize, the research question is "How to integrate green building strategies using computational methods to design self-sufficient buildings."

Concept & Theoretical Framework

The research framework is called as Bio-Cyber Physical Architecture. It comprises strategies that drive a project from its design stage to its construction stage. It is an amalgamation of 3 different aspects, such as Bionics(Green building strategies/vegetation), Cyber(Computational methods), and Physical (prototyping). Each plays an important role where it aims to achieve a symbiotic relationship between these different aspects. Each sub-section caters to the diverse needs of the user. The research has explored various parts of the framework in order to achieve a holistic design.

1. The research investigated Self-sufficient buildings proposed by the International Living Future Institute consisting of seven petals of self-sufficient design. The design takes inspiration by decoding its elements into a new framework for integrative design and building processes. Based on this thesis's research and ideas, Fig 2 proposes a framework for integrating it into the current design process.

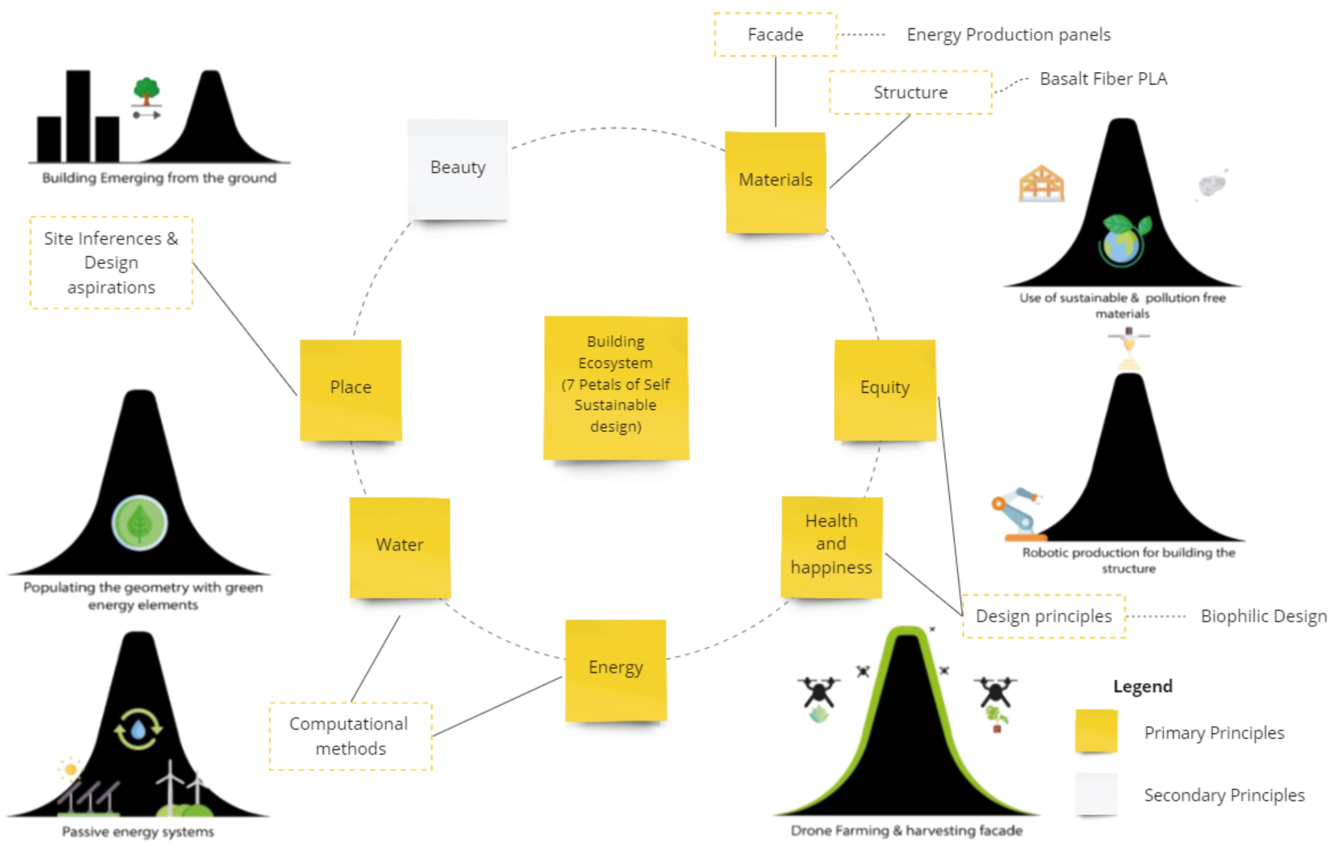

Fig.2: 7 Petals of Self Sufficient Design by International Living Future Institute

It provides various strategies that help in tackling different aspects of a design to move it towards self-sufficiency. The design should cater to the local climatic conditions and source local materials to build it. Integration of vegetation into the built environment helps in boosting the health and happiness index while also creating an environment that invites not only humans but also local flora and fauna into the site. The computational methods help integrate passive energy systems and populate energy-generating elements that decrease their dependency on the local electricity grids.

2. The research investigated "What is green building strategies?" How can it improve the design's self-sufficiency index? Biophilic design is one of the strategies which is incorporated in the design principles. The concept of using direct nature, indirect nature, space, and location conditions enhances resident connectivity to the natural environment. The term "biophilia" was first coined by social psychologist Eric Fromm (1964) and later popularized by biologist Edward Wilson (1984)[7]. The strategy was to study existing precedents where biophilic design has made a significant impact on its environment. Furthermore, Green Dip is a research project under the think tank of The Why Factory, T.U. Delft. This project proposes a new lifestyle in a city that looks and feels different from the concrete jungle we live in today. Users can test implementation strategies for all projects, measure positive benefits in real-time, and dynamic solutions can mitigate urban emergencies through new possibilities and new visions. Nevertheless, it could not optimize the strategies to find the optimal solution for a specific area in the entire design. It can be used to speculate solutions for schematic design, but it needs more research to integrate to encompass a nourished design. The research analyses the project and finds the missing links and data required to realize this thesis's goals. After analyzing various precedents which use green building strategies, it was clear that it can be implemented on different scales in the building design ranging from macro-scale to micro-scale. Each has distinct tangible and intangible benefits of integrating them into building design. Precedents from the book "The Garden City Mega City" give us more insight into the project built and explain its contribution to its users and neighborhood[3].

Existing theoretical frameworks such as D2RP&O (Design to Robotic Production & Operation) are material and energy-efficient to achieve customizable, adaptable, and reconfigurable robot building components and buildings for sustainable use. It is a design process aimed at optimization. Traditional construction can be a slow and inefficient process. However, robotics has the potential to revolutionize the way we build. Before building a design, some simulations can help the user understand real-time effects in our built environment. Once the design is in operation, sensor actuators can provide continuous feedback to complete the process and create a closed-loop system[8]. This framework can enable to prototype the proposed design to understand its real-world implications.

Each fragment in the framework is a broad-spectrum topic that requires more in-depth analysis using various case studies. The next chapter explains the methodology adopted to develop a symbiotic approach to integrative solutions towards designing self-sufficient buildings.

Methodological Reflection

The overall formulated design process consists of three parts- Bio, Cyber, and Physical. These elements are broad-spectrum topics; hence we need to understand their various aspects. The research started with testing different possibilities together and then taking a deeper dive into the selected topics.

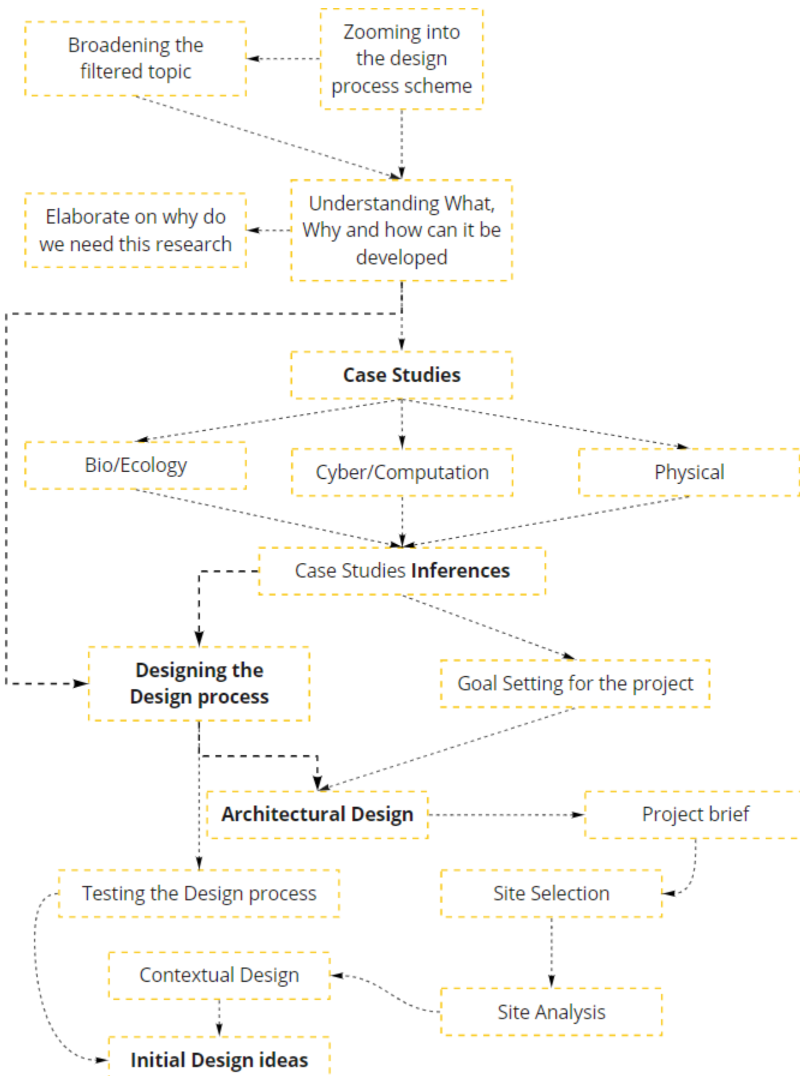

Fig.3: Methodology

In this research project, the methodology was always to look at relevant case studies, and its analysis would help formulate the different aspects of the project (Fig 3). Streamlining the thoughts into a flexible research framework creates a non-rigid process that keeps room for more improvement at every stage. Having a flexible research framework keeps room for innovation and, at the same time, does not let the researcher move too far away from the topic.

Several topics ranging from built architectural projects to innovative research projects were explored to help formulate the design process and architectural design intervention. Figure 4 explains how the inferences from each project helped in developing various sections for Architectural design intervention.

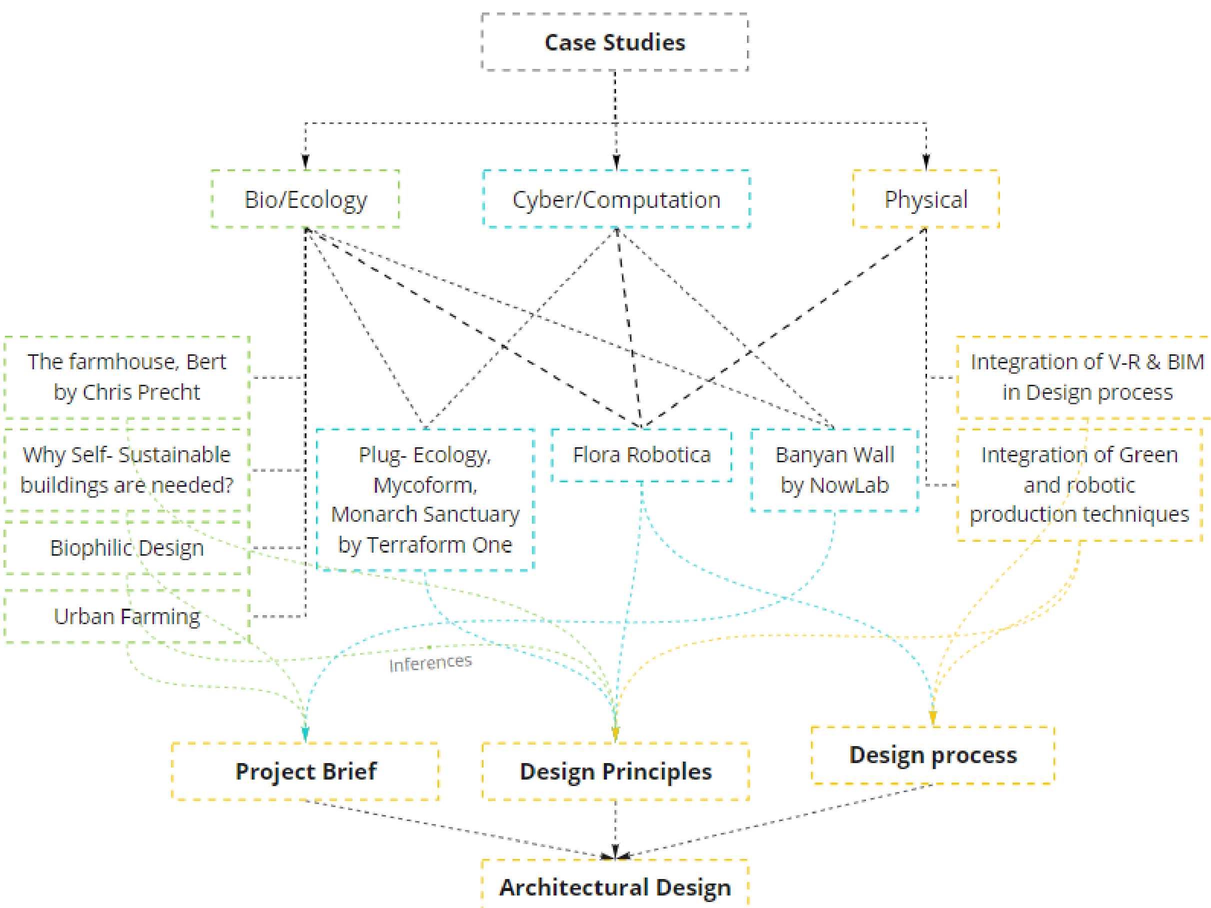

Fig.4: List of Case studies for the research design

Precedents

1. C.R.O.P - Cultivation Robust Operating Panel

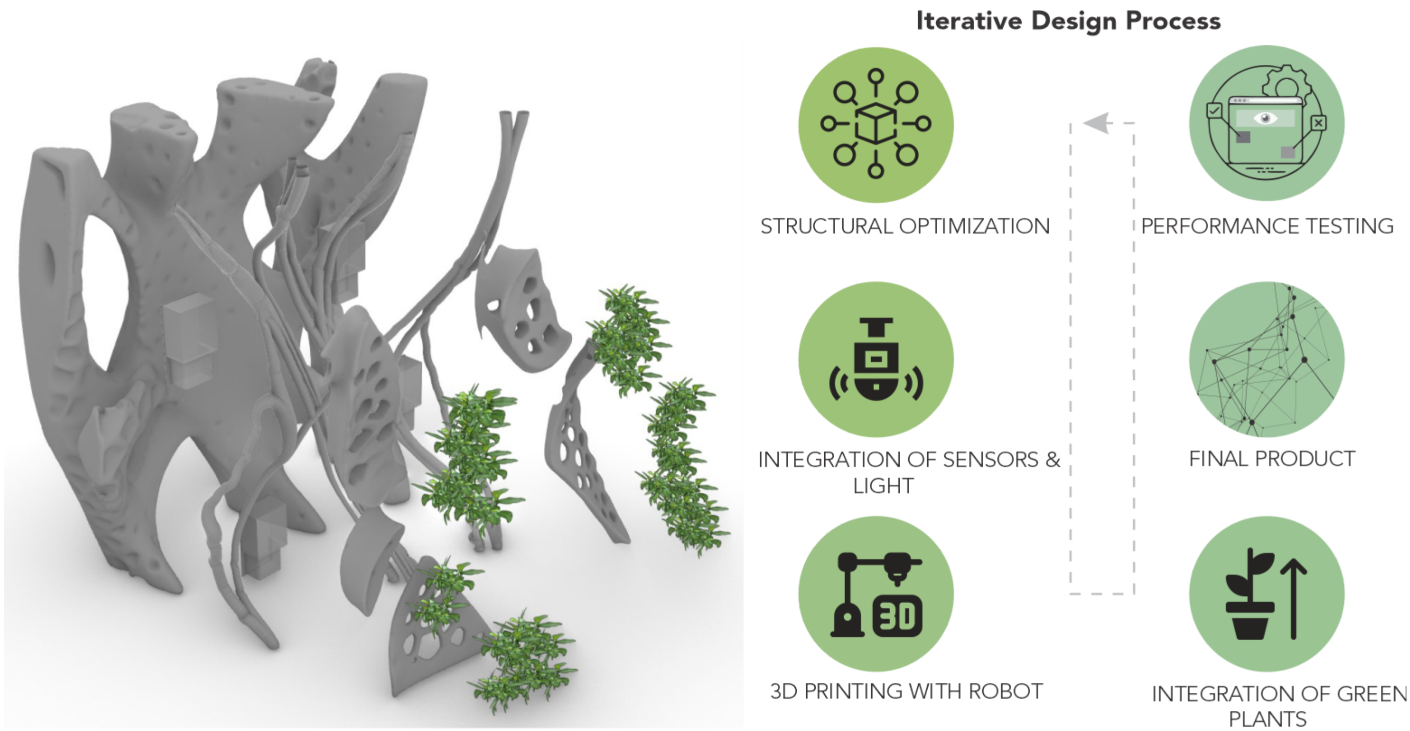

Fig.5: C.R.O.P- D2RP&O workshop, RB Lab, TUD 2020

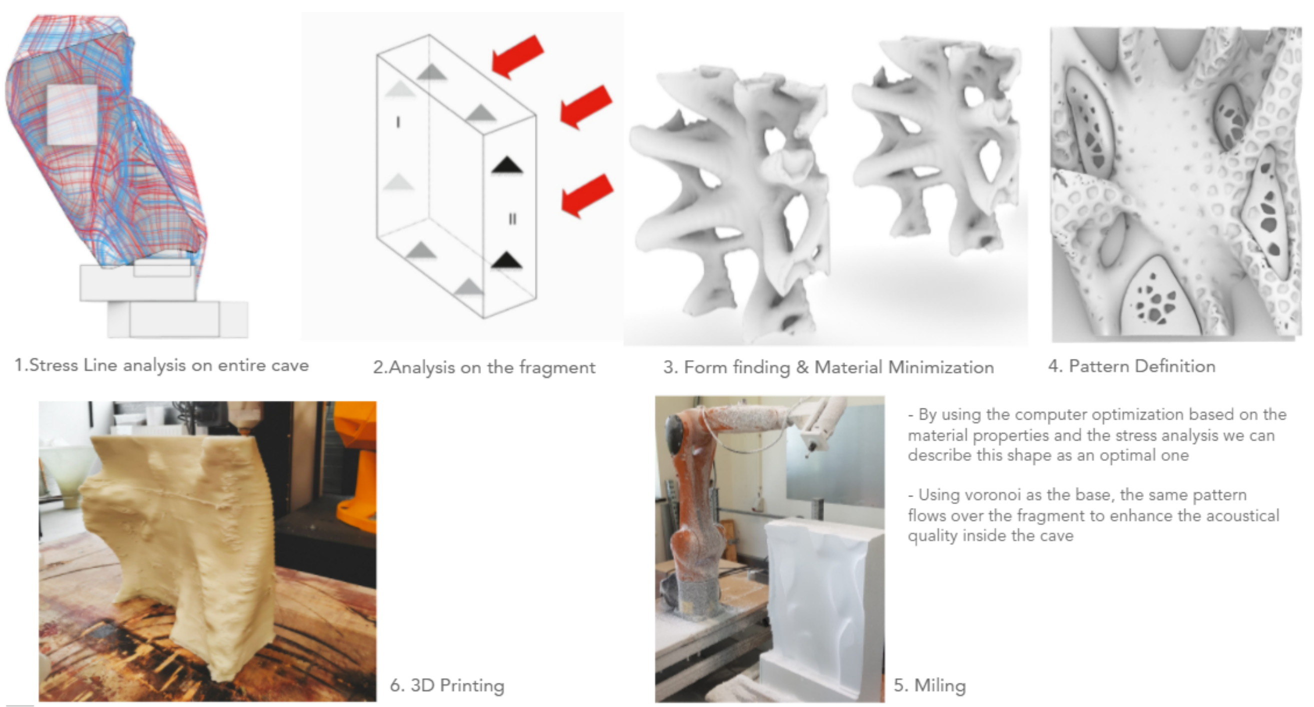

Fig.6: C.R.O.P- Design Process, D2RP&O workshop, RB Lab, TUD 2020

The C.R.O.P project was a workshop on hybrid componentiality 2.2: D2RP&O by the Robotic Building lab at TU Delft. It was a design proposal for Underground Habitats on Mars. It stands for cultivation robust operating panel where the design process integrates computational methods to analyze and structurally optimize the shell to withstand the harsh environment on Mars and investigates the integration of plants to sustain life on off-earth habitats[9]. Fig. 5 and Fig 6 explain the design approach where Karamba 3D was used to perform stress line analysis on the initial shell of the habitat. This method helped form-finding and material minimization of the internal structure, which is a crucial aspect of the project when designing on mars as the materials available to build in space are limited. Furthermore, it materialized the sensors and actuators needed to grow plants on the panel; this speculates the possibility of automation in monitoring the growth of the plants developing the life support system[10].

The computational approach from this project is further explored to develop the design process for this project.

Computational Approach

The computational strategy is implemented at various scales ranging from meso to micro for form-finding to integrating green building strategies within the project. The idea is to develop a framework that meets the different requirements of the project to increase its self-sufficiency index and cater to the seven petals of self-sufficient design. In the future, the framework can be used as a guide to developing the integration of vegetation in self-sufficient buildings. The goal of the computational methods is to maximize material efficiency and green plot ratio in the building. The approach is mainly developed based on the inferences from the case studies. To increase the material efficiency, the design process of C.R.O.P is adopted and enhanced to suit the project needs. To increase the green plot ratio, the inferences from the green dip projects are adapted, mainly the way environmental analysis is used to define the green scapes that can host the vegetation. Each step is further elaborated in the sub-chapters below.

A. Form Finding:

The site is populated with initial geometry based on the functional requirements and the design principles. Passive design strategies are critical factors in reducing the building's operational cost as it relies on renewable energy sources, and the initial form can play an essential role in reducing its environmental impact in the future. The initial form is evaluated based on several design parameters and environmental analysis such as solar radiation and wind CFD analysis in rhino. The solar radiation analysis is used as a base to overlay the functional spaces of the building (Fig 7). The spaces that can take advantage of natural daylight, such as working spaces and study spaces, are oriented towards the north side to need less artificial lighting reducing the energy cost.

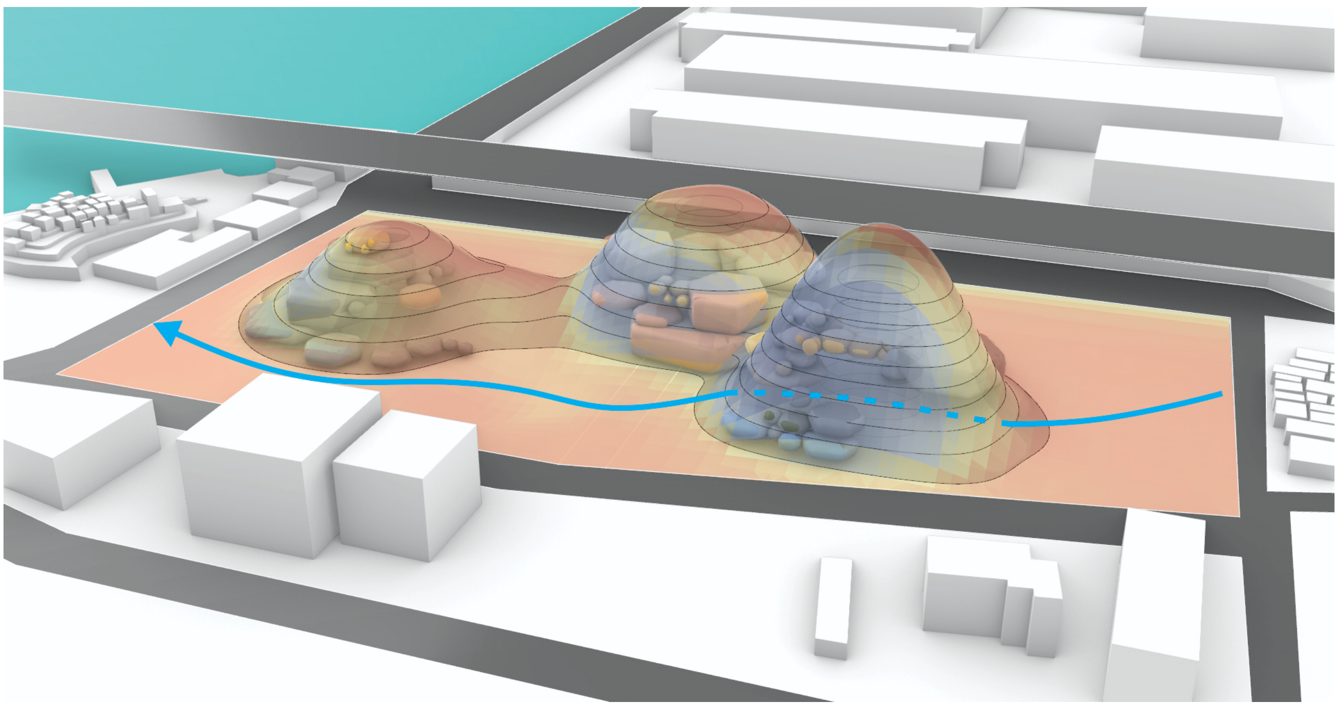

Fig.7: Environmental Analysis on the initial shell and functional schematic distribution

B. Structural System:

Material efficiency is essential in self-sufficient buildings where they are deliberately curated to reduce their impact on the environment as a whole. The functional distribution is further explored to derive the final form of the fragment. Structural analysis is used to inform the materialization of the shell, and the structural system is derived from its results. The stress lines are then bundled together, where the maximum forces are accumulated on the utilization mesh derived from the structural analysis through karamba 3D(Fig. 8). The designer feeds the sizes of the structural members in the script, and later dendro is used to populate the force lines with the set domain to form the final mesh. The same methods are scaled-down and used to derive the beam networks for the floors, spaces and ramps.

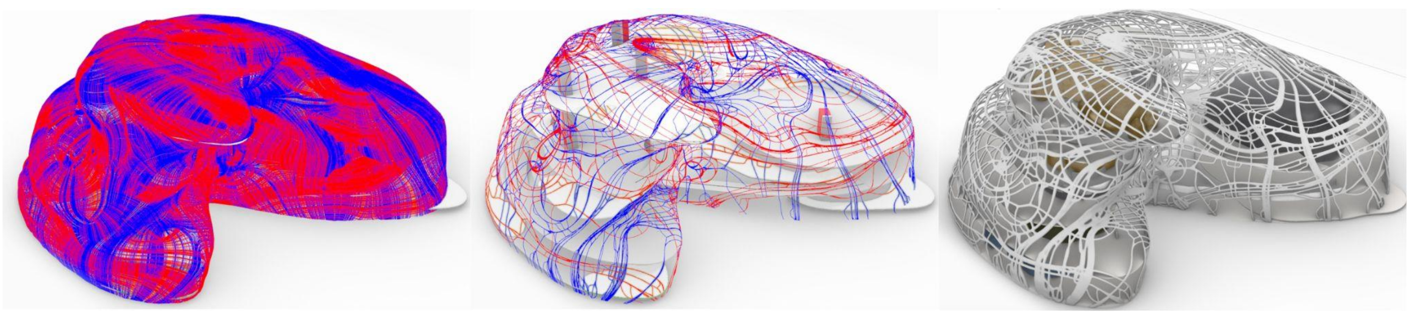

Fig.8: Computational process for the materialization of structural members

C. Facade:

The heat gain from the facade is one of the factors in the design to lower down the cooling loads and achieve thermal comfort within the building. The solar radiation analysis is performed thrice on the facade considering the three major climatic seasons of Mumbai, and a weighted average of the results is further evaluated. The stress points are analyzed to understand the impact of solar radiation, which can penetrate into the spaces. The resultant mesh is fragmented into three parts: high, medium, and low radiation zones(Fig. 9). Each zone is either green, blue or transparent panels based on its proximity to the spaces below and its functional requirement for views and vista. The green is an integrated composite panel, the blue is building-integrated photovoltaics, and the transparent is either glass or hollow panels based on the spatial requirement.

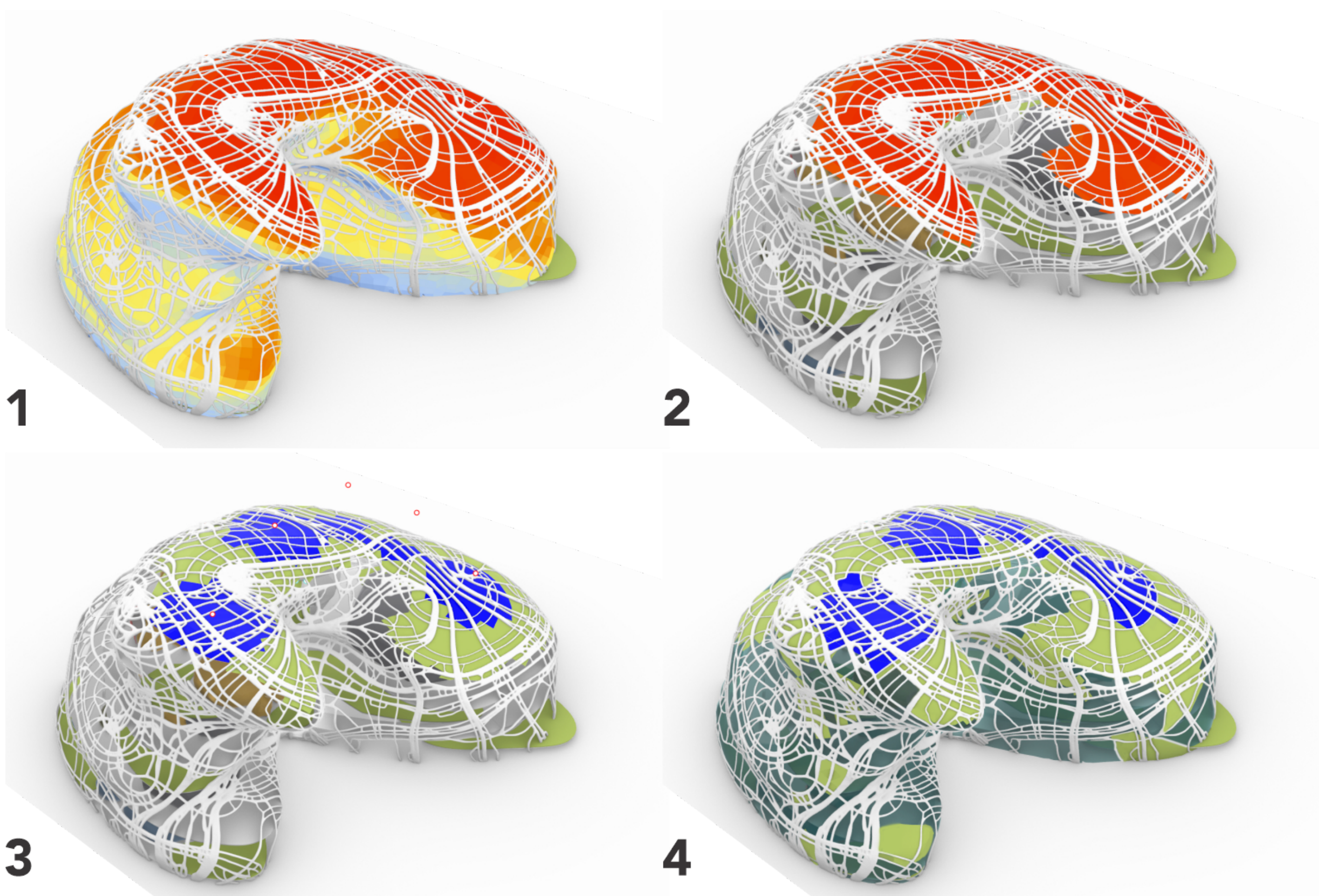

Fig.9: Computational process for the materialization of Facade

D. Floors

Integrating green vegetation elements into the building at various scales has been one of the goals for the project. Scaling down the strategy used to distribute the panels in the facade has been adapted for the floor systems. Based on the spatial requirement, the circulation flow is modified to achieve the shortest distance possible to the ramps and lift within the building. Cutouts in the leftover are created to enhance the atrium and allow more daylight into the workspaces. Solar radiation and sun hour analysis defines the green breakout spaces adjacent to the circulation corridors and workspaces. They shield the workspaces from excess solar heat and seamlessly flow into them, adapting the green building strategies to heighten the spatial experience within the building and circulation corridors (Fig 10).

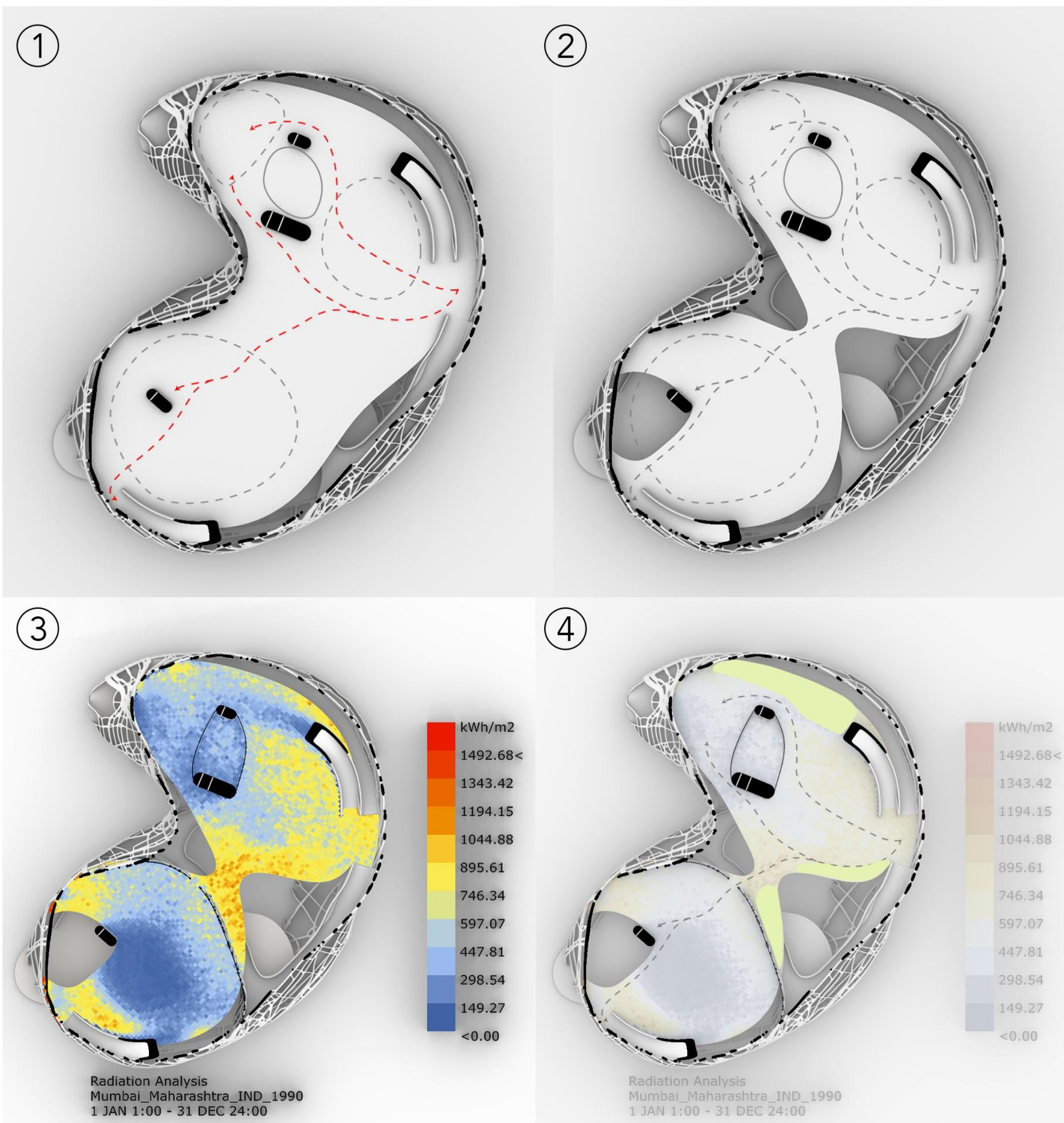

Fig.10: Computational process for the materialization of Floor systems

E. Ramps

The user can experience different spaces within the building through ramps and corridors. They allow them to connect with different levels and guide them towards various experience zones. The ramps are developed from similar strategies used to define the structural system for the building. All the ramps are defined close to the structural facade, sharing the loads with the existing beams. It reduces the beam sizes resulting in better material efficiency. Fig 12 illustrates the various cross-sections of the ramp in order to integrate functions like seatings and tables.

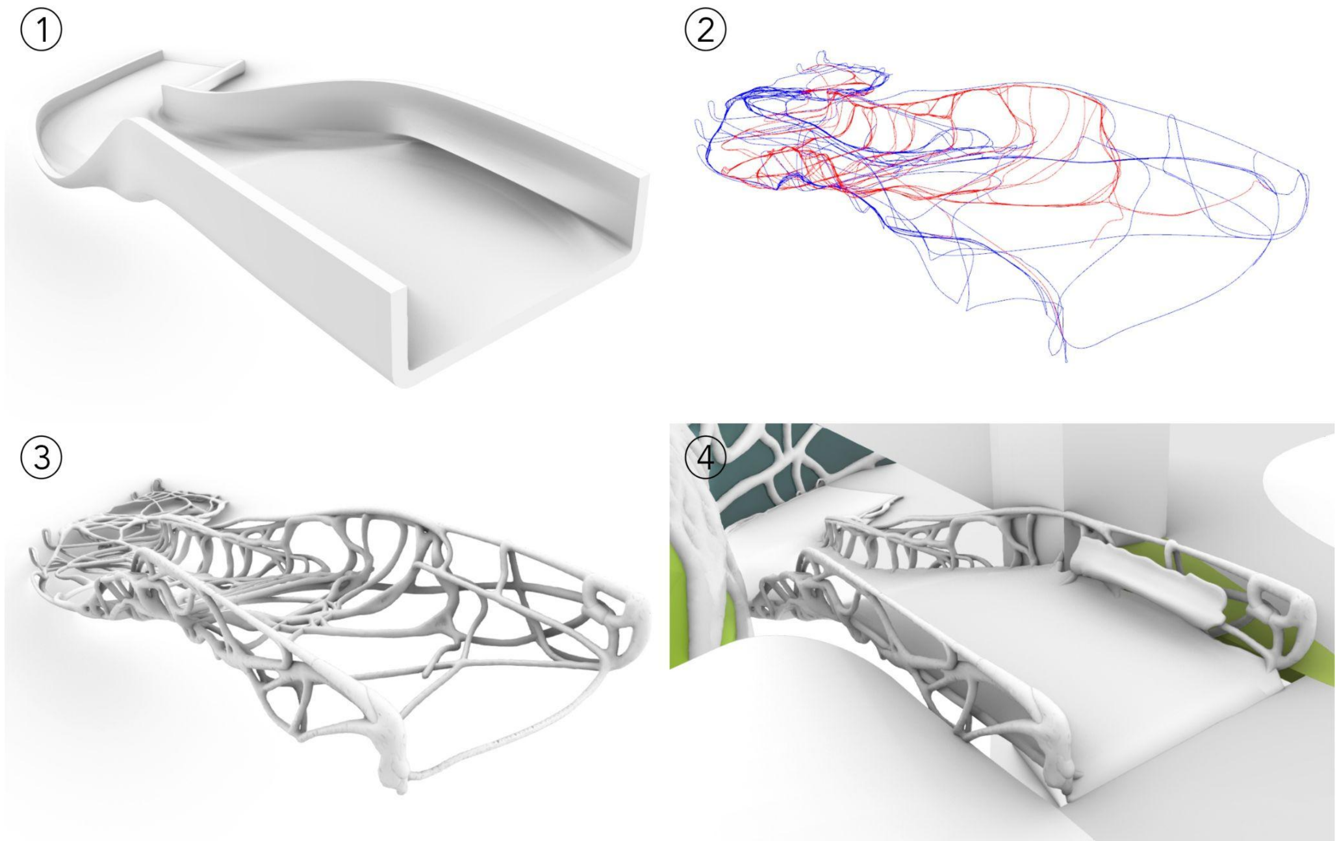

Fig.11: Computational process for the materialization of structural members.

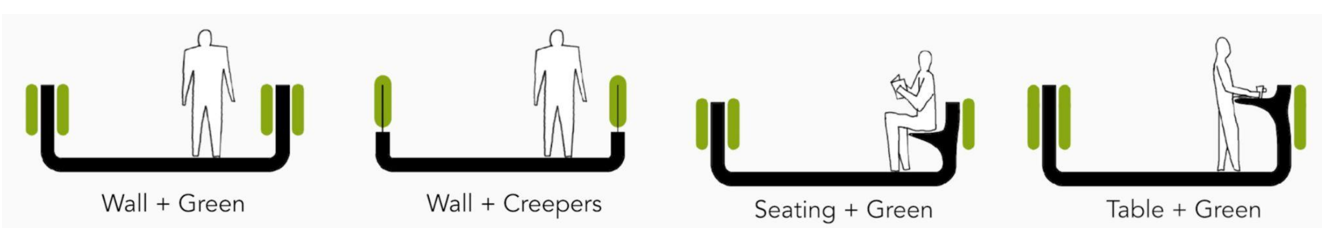

Fig.12: Different cross-sections to integrate various functions in the ramp

F. Materialization through 3D printing.

The building form after the entire process is quite complex to be built with traditional methods. 3D printing is one of the solutions in order to materialize the design into reality. Fig 13 explains the various iterations explored in order to 3D print the facade fragment. The material chosen to print the fragment is Basalt Fiber PLA because it can take 3 times the load of regular concrete used for 3D printing[11]. Each iteration explores various angles and orientations to have minimal supports during the printing process. Constraints like the maximum overhang angle are 45 degrees which need to be incorporated within the form. The fourth image explains the supports indicated in blue needed to print without optimizing the geometry. It was concluded that the geometry needs to be more rationalized to have supportless printing.

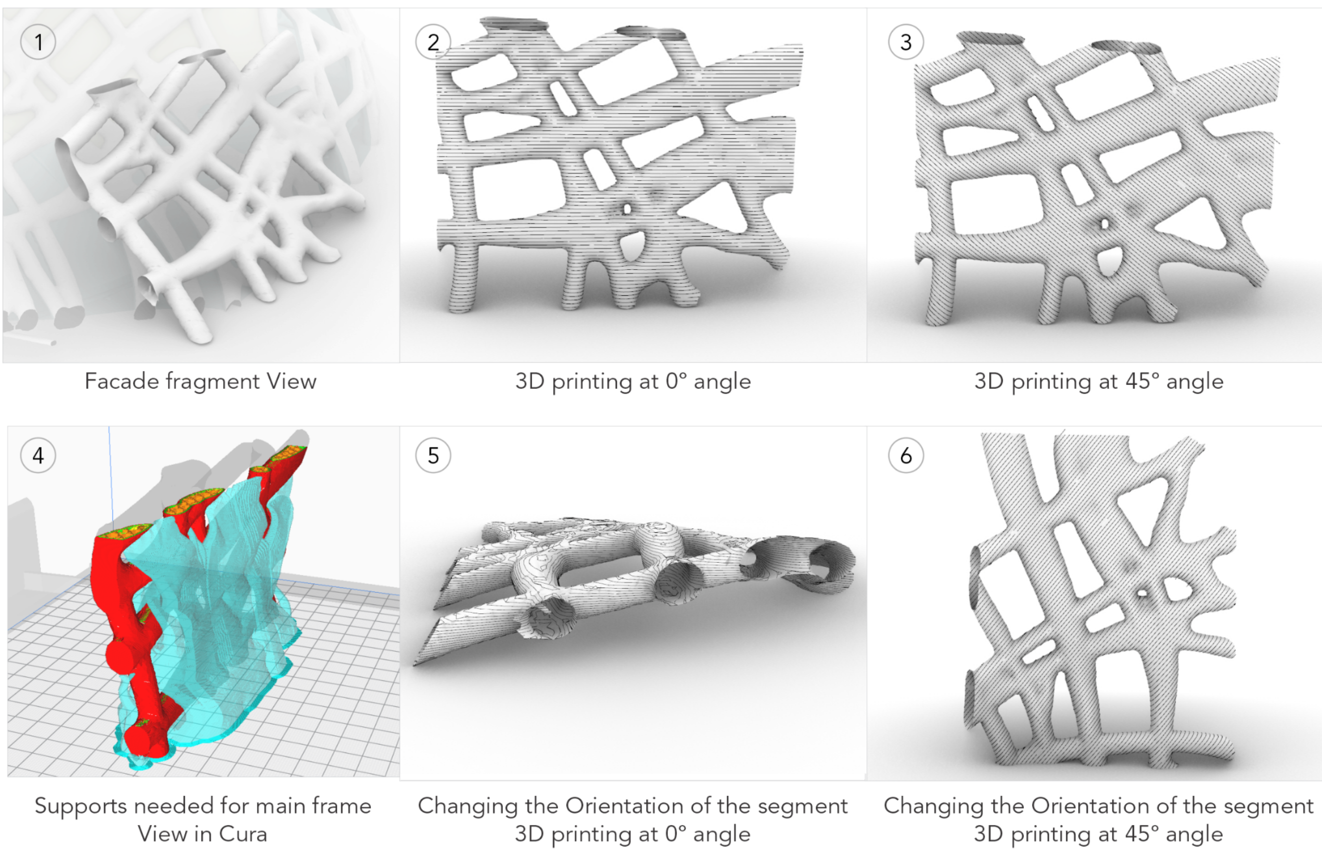

Fig.13: Iterations for 3D printing the facade fragment

Research reflection and future recommendations

Developing a complete Bio cyber-physical architecture (B.C.P.A) system is a lifelong project. The ideas are streamlined into testing a specific part of the design process, considering the Graduation timeline. The project brief is developed to design an innovation hub for emerging Eco-Tech. Using Biophilic design as design principles, the attempt is to integrate vegetation seamlessly in all scales within a building. The architectural design aims to create a hub that will inspire its context to promote green living and newer technologies for a sustainable future. Hence Mumbai, India, is chosen as the city for its context as it has a cultural and economic impact all over India. As Mumbai is a densely populated city, there are very few opportunities where a vast site is available; hence, the attempt has focused on developing strategies that can design newer interventions and be populated all over the city. B.P.C.A systems do not stop designing at this project; however, it works as a proof of concept that after analyzing the impact of this design, does it hold future possibilities to be adapted into new constructions within the city to have a more significant environmental impact. In the future, we can also create green modules as design elements that can be retrofitted into new constructions and give a second life to old buildings. Some secondary goals for the project were to test the design ideas on a prototype scale using robotic production techniques and evaluate the project's overall impact on the built environment; however, the idea could not be realized due to limited funding options. A schematic workflow was created to speculate its future possibilities of adapting this method into new design problems during the research phase (Fig. 14).

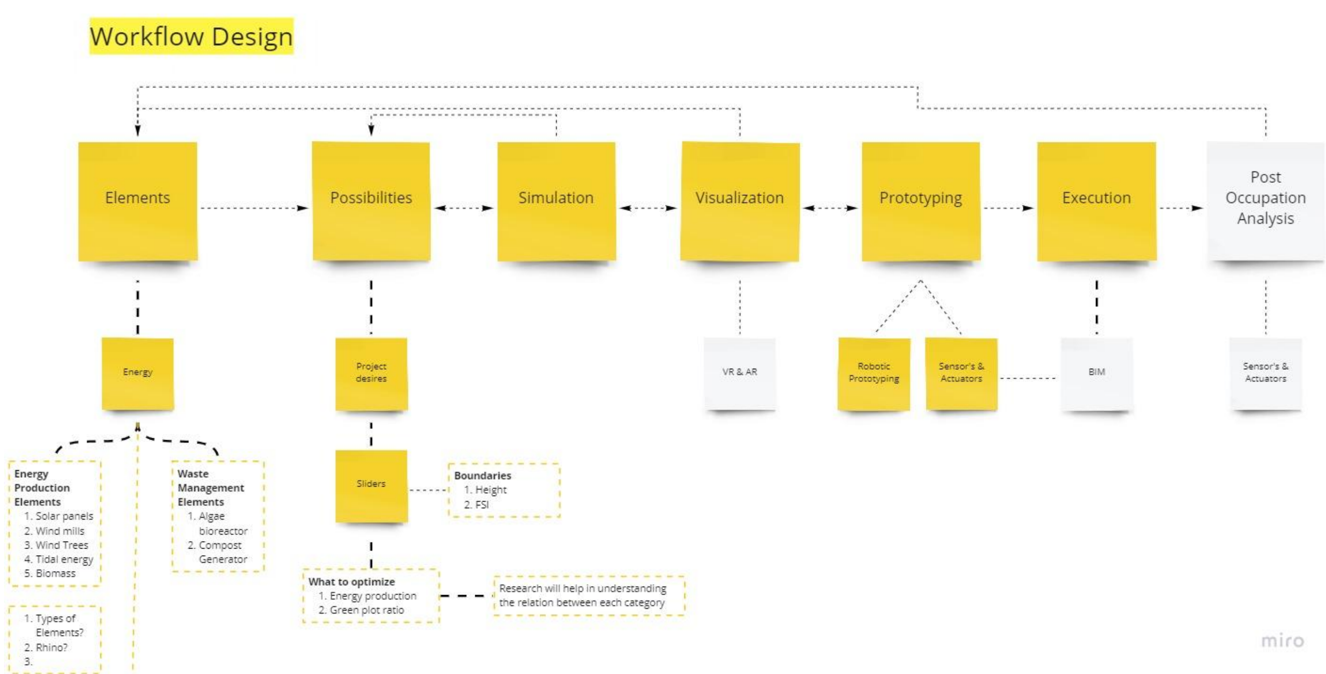

Fig.14: Schematic Design process- B.C.P.A Systems

Future Computational approaches:

Few possible computational workflows to integrate were not detailed further, considering the project's complexity and the graduation timeline. However, they are discussed in this section to provoke future discussions and possibilities to research more in-depth to integrate green vegetation and computational methods in a design process.

A. Implementation of Green design strategies at the spatial scale

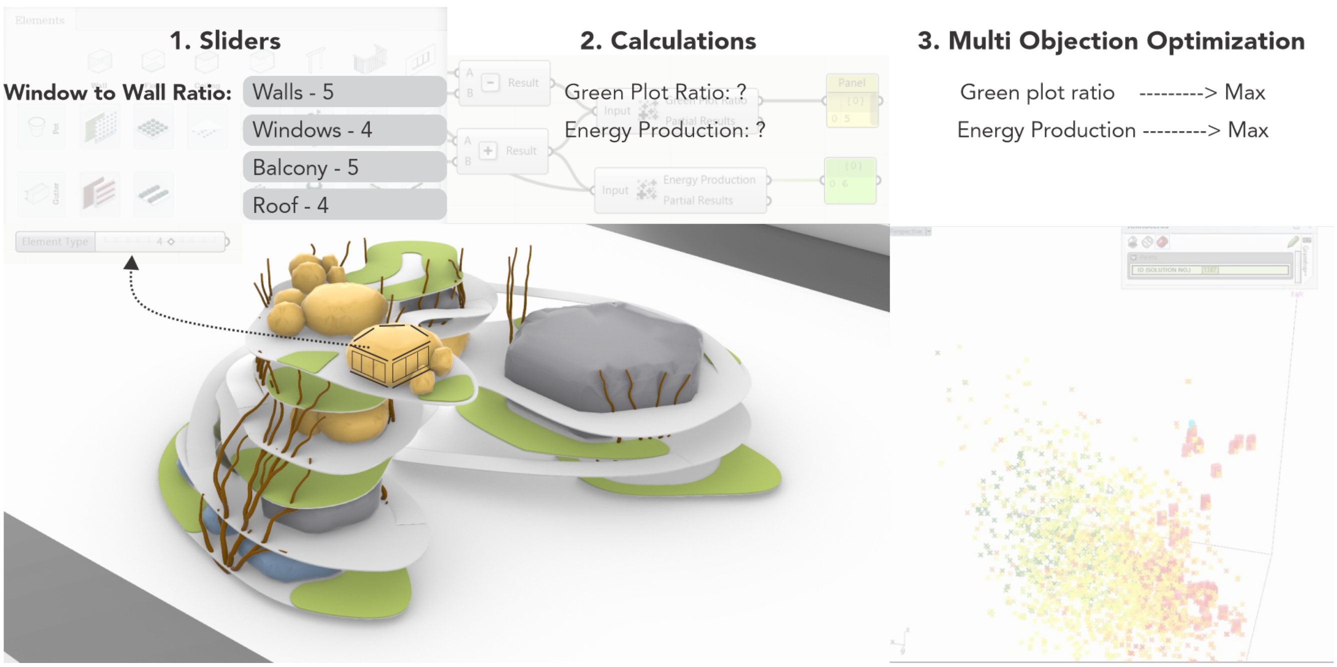

Fig.15: Optimization workflow for Spatial formulation

Taking inspiration from The Green Dip project by The Why Factory at TU Delft, we could populate cities with green modules and understand their impact; however, it could not optimize and propose the possible solutions considering location-specific conditions. After analyzing and learning from the limitations, the green modules can be adapted into a new computational workflow. This strategy can be used to develop the skin of the interior spaces of a building. The initial form can be subdivided into various building components, and the designed elements can be replaced using grasshopper components. All the possible elements can be inserted as sliders in GH, allowing any optimization plugin like Galapagos or Octopus to test multiple iterations and compare all the possibilities. Based on the research, Octopus or wallecei are recommended plugins for multi-objective optimization for this approach. A script needs to be developed for calculating the green benefits like O_2 Production or biomass for each iteration. The designer can then decide on which objectives to be optimized and set the goals accordingly. Understanding the symbiotic relationship between various design elements can be inspired by a virtual game called Blockhood developed by the Plethora project[12]. It emphasizes ecology, interdependence, and decay, which is essential to evaluate the impact of the design in the future.

Conclusion

To conclude, after doing many case studies that helped understand various aspects of B.C.P.A, the project envisions speculating and designing an Innovation Hub for emerging Eco-tech, allowing innovators to come from all over the globe and work together in the field of Ecology and Computation. This research helped in developing a design process, which acted as the primary driver for architectural design. Biophilic design[13] and seven petals of self-sustainable design[14] are the project's primary design principles. After understanding the project's need and the developed design process framework, the computational approach using environmental analysis and data has driven the design decisions to minimize the negative impact of the design intervention in the future built environment. The following steps are to speculate on how the building will perform in the future and make better-informed design decisions for the project.

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