Politecnico di Torino

SHELL

SYNTHESIS AUTOMATION OF A BIOMIMETIC BUILDING ENVELOPE PATTERN THROUGH THE LIFE CYCLE PHASES

Politecnico di Torino

Master of Science degree in ARCHITECTURE FOR SUSTAINABILITY
Degree Class LM4-ARCHITECTURE AND ARCHITECTURAL ENGINEERING

A.a. 2022/2023
February 2023

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Politecnico di Torino

MAGISTRALE in ARCHITETTURA PER LA SOSTENIBILITÀ
Classe di laurea LM4-ARCHITETTURA E INGEGNERIA EDILE ARCHITETTURA

A.a. 2022/2023
Febbraio 2023

CONCHIGLIA

Sintesi di automazione di un modello biomimetico dell' involucro edilizio attraverso le fasi del ciclo di vita.

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POLITECNICO DI TORINO *(Polytechnic University of Turin)*
College of Architecture
DAD - DEPARTMENT OF ARCHITECTURE AND DESIGN
Degree Class LM4-ARCHITECTURE AND ARCHITECTURAL ENGINEERING
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Title:

SHELL

Synthesis automation of a biomimetic building envelope pattern through the life cycle phases.

A Master of Science Thesis submitted to Department of Architecture and Design in Partial fulfillment of the requirements of the degree.

Authors: Mahmoud Nagy Elsayed , Maher AAKEL
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Acknowledgment

This work is ***devoted***	to the journey and to beloved ones...
This work is ***dedicated***	to those who helped us* and those we exhausted with good intentions...
This work is ***deserved***	to the patterns of endeavor, perseverance and the results of choice...

**Prof. Francesca Thiebat, Prof. Valerio Maria Lo Verso, Prof. Fabio Favoino, Prof. Mohammed Makki, Ahmed Hazem, Edward Onida, Islam Rihan, Ahmed Osama, Mohamed Ahmed, Yazan Aakel, Menattallah Gama, and Mohamed Abohmdan.*

Abstract (English)

In a remarkable way, Computational Design (CD) methods have enabled architects to enhance their design. Thereafter, one of the main aspects to manage is the Indoor Environment Quality (IEQ).
The overarching GOAL is to develop a new software called (SHELL) that could achieve targeted values to enhance the indoor environment of a blind space. SHELL can automate the design process of a building envelope by creating adaptable units that use a Multi-Objective Optimization Algorithm (MOEA) to achieve a customized envelope to enhance the IEQ of the targeted space.

This research worked to investigate the common areas of the interdisciplinary subjects of building physics, computer science, optimization techniques, and biomimicry through an application in architecture. Through a scientometric methodology, the research aims to automate the process of creating an adaptive envelope able to respond to various
outdoor conditions caused by nature or built environment. while implementing the methodology through a biomimetic- climatic approach and exploring its life-cycle assessment.

This goal was achieved through a holistic workflow of an optimized computational method that achieved the adaptable envelope with its context -in every eventuality-, able to manage different morphological inputs and different climate zones as well, pursuing the comfort key factors to shift from (adjust to respond) to (adapt to comfort) concept.

The workflow aims to establish integrating multidisciplinary criteria by dealing with various controlling factors such as
design geometry characteristics and other parameters that affect the performance of the envelope to produce a holistic automated and customized envelope design pipeline for different users. Which allows the production of an immediate design with minimal human intervention capable mass customization. Through these inputs, the research aspires to contribute to the automation process of the AEC industry's various life cycle phases.

Keywords

Computer-aided architectural design (**CAAD**), Multi Objective Optimization (**MOO**), Indoor environmental quality (**IEQ**), Building Physics (**BP**), Application Programming Interface (**API**), Life-cycle assessment (**LCA**), **Biomimicry**, **Mass Customization**, **Automation.**

For the best experience, read your digital document with facing page mode.

Abstract (Italian)

La tesi mira ad automatizzare il processo di progettazione dell'involucro edilizio per rispondere in modo adattivo a varie condizioni climatiche influenzate sia dall'ambiente naturale sia dall'ambiente costruito.

L'obiettivo generale è migliorare la qualità dell'ambiente interno per gli utenti finali attraverso un approccio biomimetico-climatico che tenga in considerazione l'intero ciclo di vita dell'edificio. Per poter soddisfare tale obiettivo, è stato sviluppato un modello computazionale ottimizzato, denominato SHELL, che ha permesso di gestire diversi input e diverse zone climatiche.

Il lavoro si basa su un approccio interdisciplinare che comprende principi di fisica tecnica ambientale, di rappresentazione e di architettura bioclimatica e biomimetica. In quest'ottica, il design computazionale ha consentito di ottimizzare il processo di progettazione e di considerare diversi criteri di progettazione tra cui la Qualità dell'Ambiente Interno (IEQ).

Un workflow illustra come il modello SHELL, attraverso applicazioni progettuali, permetta di integrare diversi parametri di controllo quali ad esempio le caratteristiche geometriche del progetto, le proprietà dei materiali e le prestazioni fisico-tecniche dell'involucro per ottimizzare la soluzione progettuale ottimizzata per le diverse esigenze degli utenti finali.

SHELL è stato sviluppato e testato su tre diverse scale: il modulo, il prototipo e l'edificio. Tali applicazioni mostrano come il modello possa rispondere a finalità di progetto che vanno verso l'ottimizzazione del sistema tecnologico in ottica di produzione di massa ma anche verso la personalizzazione in base alle esigenze degli utenti.

Parole chiave

CAAD, MOO, IEQ, BP , API, LCA, Biomimetica, personalizzazione di massa, automazione.

01 INTRODUCTION
Points of Departure

SDGs

Climate Change

Production

02 PRECEDENTS
Literature review

Computational Design

Biomimicry — *From imitation to computational*

Evolutionary Architecture — *Genetic Algorithm*

Optimization — *As an AI implementation*

03 DESIGN Proposal
Design the envelope unit

Source of Inspiration

Adaptive Radiation — *From imitation to computational*

Iris — *Genetic Algorithm*

Helix of Cyclone — *As an AI implementation*

SHELL UNIT

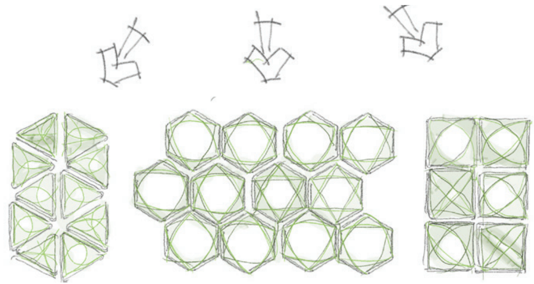
UNIT potential
What can this unit do?

Units Typologies

Trinary unit.

senary unit

Quaternary unit



Triangle *Hexagonal* *Square*

Studied Features

Form — *Structure logic, Technological Design*

Energy — *HDD,CDD*

CFD — *Computational Fluid Dynamics*

Chapter 3

Acoustical

LCA

Chapter 5 (Based on case study)

Separate studies and NOT included in the optimization process (Method)

04 METHODS
Review, Framework, trials

Building Envelope — **Review** — *Indoor Environment Quality*

Optimized Features

Solar	**Visual**	**Thermal**
Equivalent solar area (A sol, east)	*Daylight Factor (DF)*	*Radiation Analysis*

Framework

01 *Constructive algorithm*

02 *Environmental processing*

03 *Optimization prediction.*

Solution (the Envelope)

Optimized Units

Empirical Studies on a Prototype

without Panels (SHELL NOT applied)	SHELL applied *Annual (Static) case*	SHELL applied *Instantons (Kinetic) case*

COMPARISON

Static case — **& Trials** — **Kinetic case**

Static case	Kinetic case
·Trinary case	**·Trinary case** *(Triangle unit)*
Annual fixed (Triangle unit)	*Summer (21 July, 12:00 pm), Winter (21 January 12:00pm)*
·Quaternary case	**·Quaternary case** *(Square unit)*
Annual fixed (Square unit)	*Summer (21 July, 12:00 pm), Winter (21 Jan 12:00pm)*
•Senary case	**•Senary case** *(Hexa-Unit)*
Annual fixed (Hexa-Unit)	*Summer (21 July, 12:00 pm) Winter (21January 12:00pm)*

05 APPLICATIONS
Software - Case study

SHELL
The Software

TWO PHASE process

01 **Prototype -IN** | **Prototype -OUT** — *Initial model (Prototype) simulation*

02 *Choose the recommended unit by the first phase to use in the complex real project in the second phase*

Trinary Envelope | **Quaternary Envelope** | **Senary Envelope** — *Real model simulation*

Case Study

TRIO
Skyscraper - Milan city

Studied Features

(Material) — **Follow CH3** — *Life Cycle Assessment*

06 RESULTS
Optimal solution ,Conclusion.

07 APPENDICES
Analytics, codes, collage.

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**Note: Tables are highlighted in orange in this list of Figures.*

HIGHLIGHTS : #Sustainable Development Goals
#Energy
#Mass-Customization
#Hypothesis

INTRO
CHAPTER I

0 1

MSC THESIS

ARCHITECTURAL
COMPUTATIONAL
SUSTAINABILITY

1. INTRODUCTION

“What we do today, will define tomorrow”

Lailah Gifty Akita 1982 - , (Ghana).

1.1 Premise

According to a lot of theories, scientific and practical evidences, there is the inescapable truth that everything will perish in micro and macro scales and in different relative time spans. This idea has always been baffling, worrying, and stimulating to the human mind. Everything refers to all things, beginning with the entire universe as it was mentioned in the (Ultimate fate of the universe scenario), and in physical cosmology, it is called (Big Crunch) hypothetical scenarios, moving to the planets including earth, living species including mankind!

However, mankind was brought on the instinct of survival and seeking for immortality. As it is a legitimate right, he has many attempts to immortality on the biological, intellectual, and physical levels, he tried as much as possible throughout history to establish civilizations to confront time (Figure 01).

Away from the relativity of facts, theories, and patterns of history, mankind faced great challenges during its known history of survival. According to observers, the current climate change remains one of the most severe challenges we have ever faced which imposes crucial movements in our duty towards survival.

Fig.01: *A 4500 year old human attempt of immortality.*

1.2 Points of departure

this research work targeted to create an envelope unit derived from many general topics and recapitulate under the umbrella of Sustainable Development Goals (SDGs), as well as climate change, energy, and production.

Fig.02: *sustainable development goals as indicated by UN*

1.2.1 Sustainable Development Goals

It is a happy time for humanity to unite and set common goals. The SDGs (Sustainable Development Goals) are a set of 17 interconnected global goals intended to be a (shared blueprint for Peace and Prosperity for people and the planet, now and into the future). The UN General Assembly established the SDGs in 2015, with the goal of achieving them by the year 2030. The 17 goals of the United Nations, which are broken down into the eradication of poverty, failure to secure national development at the price of other national prosperity, achieving justice and equality, and other fair causes, which represent the patterns of sustainability.

As a series of problems are converging in the world today, posing a threat to humanity's basic existence, the SDGs take a comprehensive approach to address each of these crises as well as methods for avoiding and navigating them. The research project targeted some of these goals:

•Goal 3 : Good Health and Well-being

Goal (3) of the SDGs is stating "Ensuring healthy lives and promoting well-being at all ages is essential to sustainable development". Goal 3 has a set of targets including the end of some major diseases and epidemics, but it also includes general insurance of health care actions and faces illnesses from hazardous chemicals and air, water, pollution, and contamination.

Recently and by mid-2022, the COVID-19 pandemic had infected more than 500 million people worldwide, the Pandemic shifted the sustainable goal from its target to mentor the pandemic as it continues to pose challenges to people's health and well-being globally and is impeding, there had been significant progress in many areas of health, but this development had been hampered by enormous regional disparities.

Also, the pandemic has triggered a significant rise in anxiety and depression, particularly among young people. Progress has been made in maternal and child health but glaring regional disparities must be addressed.

This research presents solutions that affect, in one way or another, directly and indirectly, the concept of comfort, health, and wellbeing within the buildings.

•Goal 11 : Sustainable cities and communities

Goal 11 is stating "Make cities and human settlements inclusive, safe, resilient, and sustainable". Today, cities are home to more than half of the world's population. Seven out of ten individuals are predicted to reside in urban areas by the year 2050. Cities are the main contributors to economic growth, accounting for more than 80% of global GDP. However, they also account for more than 70 percent of global greenhouse gas emissions. If well-planned and managed, urban development can be sustainable and can generate inclusively (United Nations 2022, 48).

A lot of recommendations are given by the stakeholders by implementing policies to help more sustainable cities such as energy transactions and decarbonization to achieve the net-zero emissions. The recommendations always highlight the importance of a participatory process, engaging all relevant stakeholders, particularly the more vulnerable populations and sectors within them, like women. All nations should effectively incorporate the SDGs as a guiding framework for their energy transition routes through policy and planning in the near term toward 2025. (Such as sustainable energy policies, Nationally Determined Contributions, etc.). Along with this, inclusive monitoring frameworks with suitable indicators, like those in the Energy for SDG Impact Framework, should be put into place.

A series of adaptation acts coupled through collaborative learning make up adaptation pathways, which may be used to enable transformations in urban and infrastructural systems. Individual adaption actions come with risks and compose planned adaptation pathways that can include a range of unanticipated outcomes. To help the cities, a series of adaptaion pathways such as adaptation through social infrastructure, adaptation through nature based solutions, and adaptation through grey/physical infrastructure are recommended by the IPCC as also offer some cross-cutting Themes such as equity and justice, and also evaluate the enabling environment (political will, governance, knowledge, finance, and social context) that shapes specific adaptation contexts and futures.

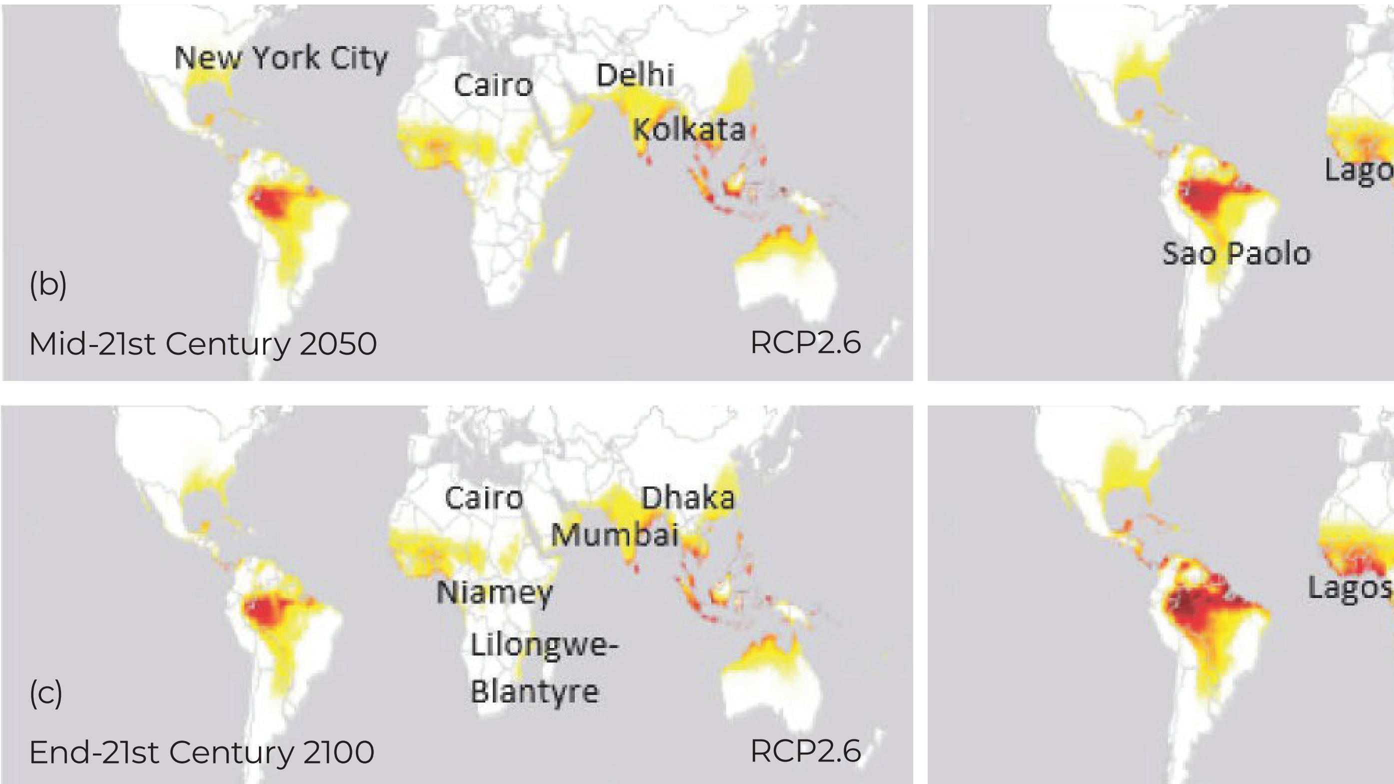
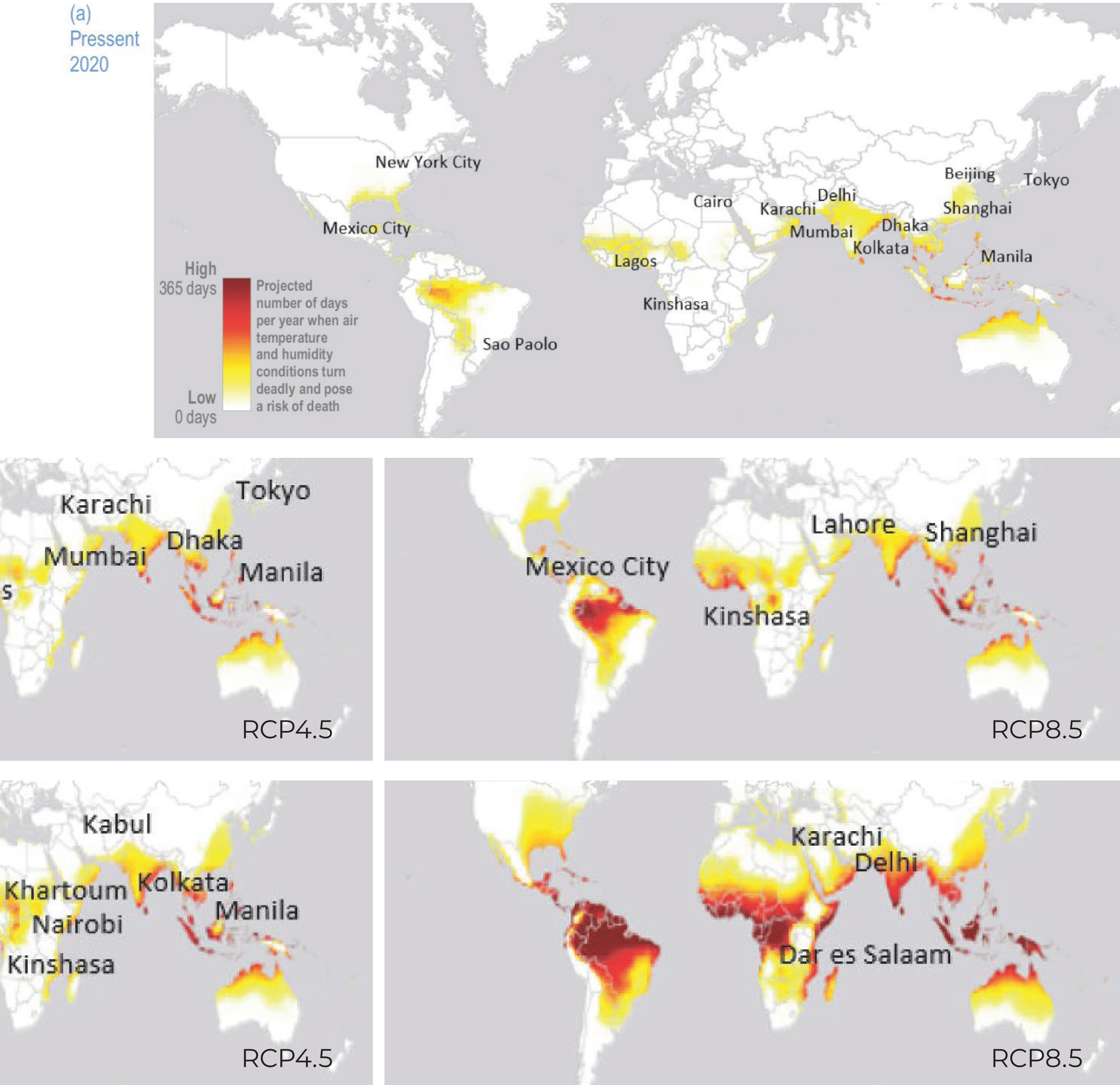


Fig.03: Global distribution of population exposed to hyperthermia from extreme heat and humidity (United Nations 2022, 48).

Description: *Global distribution of population exposed to hyperthermia from extreme heat for (a) the present, and projections from selected Representative Concentration Pathways in (b) the mid-21st century and (c) the end of the 21st century. Shading indicates the projected number of days in a year in which*

Cities, communities, and infrastructure can be significantly insulated from the effects of climate change on a variety of scales thanks to healthy ecosystems (robust evidence, high agreement). Nature-based solutions (NBS) are actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al., 2016), Widely recognized as low-regret measures for disaster risk reduction and climate change adaptation, green and blue infrastructure investments and natural area conservation in cities can provide NBS across scales to reduce temperature shocks and provide natural flood defenses among other adaptation and resilience benefits (Dodman et al. 2022, 984). These policies work in tandem to combat climate change, which leads us to Goal 13, Climate Action.



conditions of air temperature and humidity surpass a common threshold beyond which climate conditions turned deadly and pose a risk of death (Mora et al., 2017). Named cities are the top 15 urban areas by population size during 2020, 2050 and 2100, respectively, as projected by Hoornweg and Pope (2017).

•Goal 13 : Climate Action

Goal 13 is stating "Take urgent action to combat climate change and its impacts". As it appears from the eleventh goal, all goals work in parallel and must support each other. All the window to avert a climate disaster is fast shrinking as the world is on the verge of one. Climate change-related heatwaves, droughts, and floods are already having a significant impact on billions of people. Global ecosystems and maybe bringing about irrevocable changes all around the world. Global greenhouse gas emissions must reach their peak before 2025 in order to meet the Paris Agreement's goal of keeping warming to 1.5 °C above pre-industrial levels. According to the Intergovernmental Panel on Climate Change (IPCC), the United Nations agency in charge of evaluating the science related to climate change, they must then decrease by 43 percent by 2030 and reach net zero by 2050 (United Nations 2022, 54).

With profound urgency, global communities and their organizations are acting and adapting to the earth's changing climate. Different development sectors are frantically searching for more sustainable solutions, whilst the AEC industry offers significant potential to contribute to these solutions!

As this study program frames a technical study to be a part of the SDGs, likewise this research is working in the scope of Goals 3(Good health and Well-being),11(Sustainable cities and communities), and 13 (Climate Action) while indirectly affect goal 12 (Responsible consumption and production) and goal 15 (Life on land). To face the challenges identified and to be part of the global target to achieve the sustainable development Goals, to provoke new perspectives, new alliances, and concrete action that can form urgently needed transformation of our societies and enable a sustainable equitable, and inclusive future of all, all combined efforts can make a difference as what we do today, will define tomorrow!

1•2•2 Climate Change & COP27

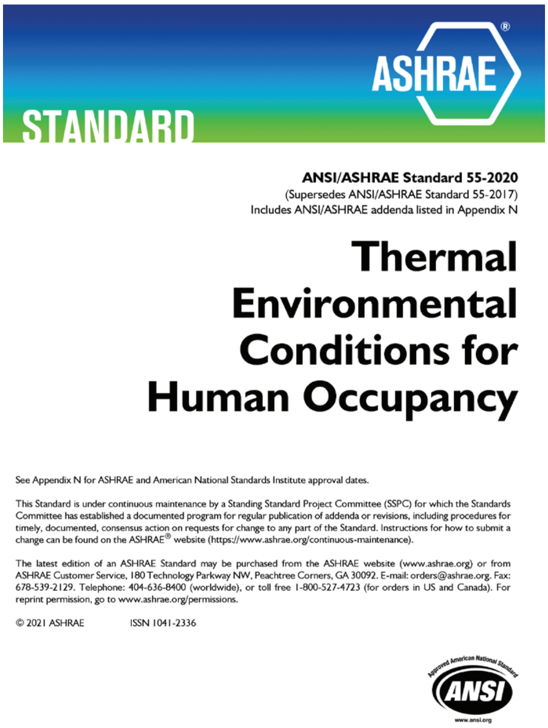
The UNFCCC secretariat (UN Climate Change) is the United Nations entity tasked with supporting the global response to the threat of climate change. UNFCCC stands for United Nations Framework Convention on Climate Change. The Convention has near universal membership (198 Parties) and is the parent treaty of the 2015 Paris Agreement. The main aim of the Paris Agreement is to keep the global average temperature rise this century as close as possible to 1.5 degrees Celsius above pre-industrial levels.

Fig.04: United Nations COP27 opening Speech. Nov 2022

COP27 is the 2022 United Nations Climate Change Conference held in Sharm El-Sheikh, Egypt. The United Nations has set through COP 27 more urgent goals, warning that their failure to achieve them will lead the planet to destruction, the first of which is pressure on industrialized countries to commit to reducing emissions to put an end to global warming, as studies warn of the impossibility of life if the temperature rises by two degrees in several countries.

As they have indicated more resilience solutions by highlighting the power of movement to clean transport for healthy cities and localizing NDCs to unlock more ambitious climate solutions in cities, and investing in Climate – Proof infrastructure as a solution for low-carbon and resilient development ("COP27 Official" 2022)

One of the fundamental aspects is that goals work together, so no goal can be achieved without addressing others. As a part of (Human Rights Day of action), different cross-constituency protest actions happened to call attention to the many silenced voices indicating "No *Climate Justice Without Human Rights*".


STANDARD

ASHRAE®

ANSI/ASHRAE Standard 55-2020
(Supersedes ANSI/ASHRAE Standard 55-2017)
Includes ANSI/ASHRAE addenda listed in Appendix N

Thermal Environmental Conditions for Human Occupancy

See Appendix N for ASHRAE and American National Standards Institute approval dates.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. Instructions for how to submit a change can be found on the ASHRAE® website (https://www.ashrae.org/continuous-maintenance).

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Approved American National Standard
ANSI
www.ansi.org

Fig.05: ASHRAE Standard 55

Standard 55 specifies conditions for acceptable thermal environments and is intended for use in design, operation, and commissioning of buildings and other occupied spaces.

1•2•3 Energy & Environment

Improving energy efficiency is essential for achieving the world's climate goals. According to IPCC, the 2030 target calls for an annual improvement in the energy intensity of 2.6 percent, a doubling of the rate observed between 1990 and 2010. With an average annual improvement rate of 1.9%, the global primary energy intensity, which is measured as the ratio of the world's total energy supply to GDP, increased from 5.6 megajoules per US dollar (2017 purchasing power parity) in 2010 to 4.7 in 2019. Energy intensity improvements until 2030 will need to average 3.2% annually to reach the Goal 7 target and make up for lost time.

The aim is still attainable, but only with a large investment in methodical, cost-effective energy efficiency improvements. Due to variations in economic structure, energy availability, and electrification, regional progress differs. Only Eastern Asia reached the target within an annual average of 2.7 percent in the last decade, driven by strong economic growth.

Buildings (residential and non-residential) consume about 40% of the final energy in the European Union (EU) and are responsible for about 36% of EU CO_2 emissions. Buildings offer a large energy-saving potential. This has resulted in strong attention to the building sector in the EU energy and climate policies. Energy is primarily used in buildings for lighting, hot water production, heating, cooling, and ventilation (indoor air conditioning).

However, investments in energy efficiency are lower than expected from an economic perspective and with perfectly informed and rational end-user which is known as the "energy efficiency gap" in literature.

Additionally, there is potential for energy efficiency, some of which may be beneficial to society in terms of cost by reducing externalities like pollution and CO2 emissions as well as other non-energy benefits (e.g., health, productivity gains, etc.). To overcome these obstacles, researchers have identified a number of hurdles to energy efficiency investments and suggested adopting energy efficiency programs, policies, and packages of policies (Hirst and Brown 1990).

Since the 1970s, The concern about energy and environmental issues has been significantly growing worldwide. Scholars' and decision-makers' attention to related issues including global warming, climate change, and related environmental concerns resulted in recent policies either mandating high energy performance of the building through advanced technologies or reducing energy costs. Similar policies also target different regulations of building envelopes (transparent and opaque levels, building orientation, etc.) high energy performances, and cooling consumption in summer as well to realize the indoor air quality (IEQ) requirements (Asdrubali and Desideri 2019, 1). One of these prevalent standards is ANSI/ASHRAE 55 is concerned to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space (ASHRAE 2017).

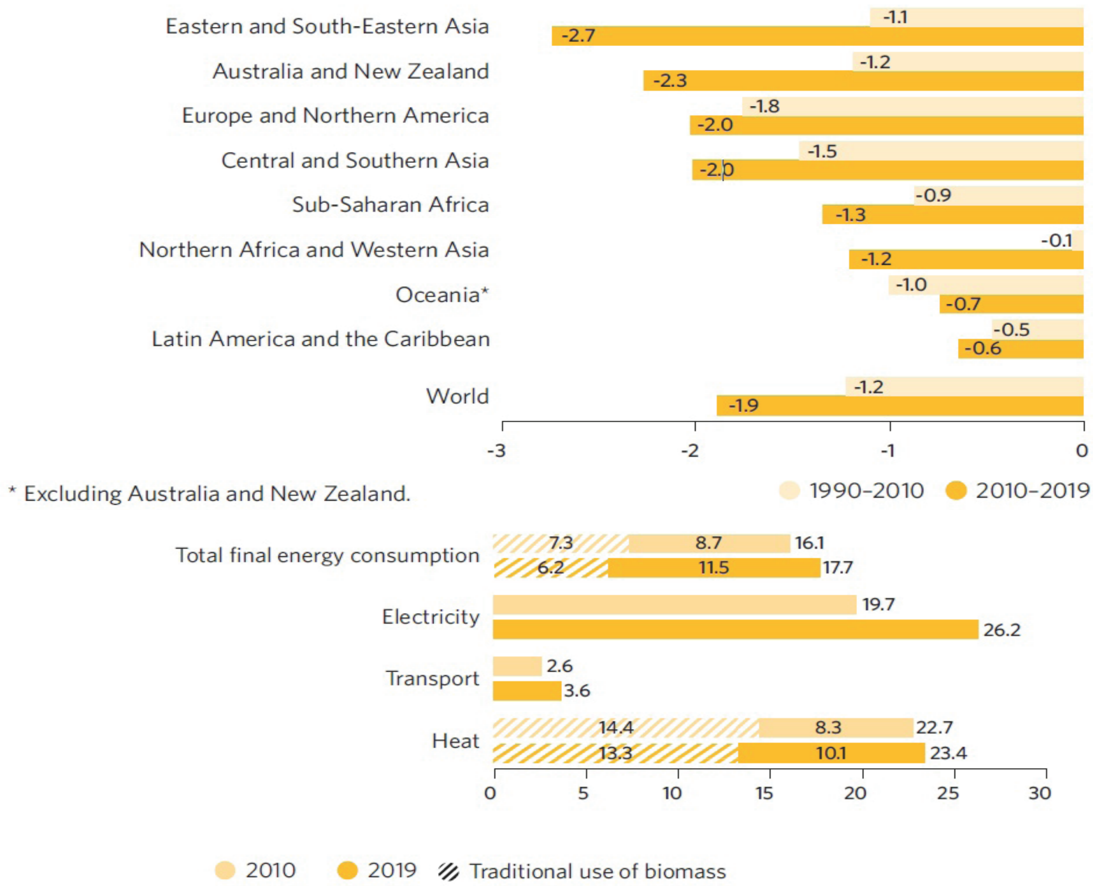


Fig.06: Average annual growth rate and Share of renewable energy

Average annual growth rate of primary energy intensity, 1990–2010 and 2010–2019 (percentage) (Upper), Share of renewable energy in total final energy consumption and by end-use, 2010 and 2019 (percentage) (Down).

1•2•4 Production

•Manufacturing

Globalization is the interdependence and integration of global markets and resources while creating goods and services for consumers. For the manufacturing sector, globalization has produced a new, unprecedented environment marked by intense competition, limited window of opportunity, frequent product debuts, and quick shifts in consumer demand. Globalization is difficult, but it also offers opportunities and risks. Industry must provide products that are cutting edge and can be marketed to consumers from many cultural backgrounds in order to take advantage of the opportunities. One of the most important combinations of globalization is the mechanisms of industrialization.

As it has always been, manufacturing is a key component of the economy and it got more complication and requirements in recent decades, thus the shifting from mass production to mass customization is a key point in the current era.

As it will be detailed later in the hypothesis part, the main target of this research project is to create a (Product) of an adaptable envelope unit that could be installed in different types of facades which will help for human comfort in various environments and conditions, it depends on the adoption of core manufacturing pattern concepts to have such a (Product) that will require to be useful in different zones in the world and need to be manufactured in large quantities.

•Mass Production to Mass Customization

Mass production

A manufacturing system capable of mass production must be designed for vast numbers of products. The ten years between 1991 and 2001 saw a number of significant events that helped to create the globalization revolution. The final decade of the twentieth century saw the beginning of the global manufacturing revolution.

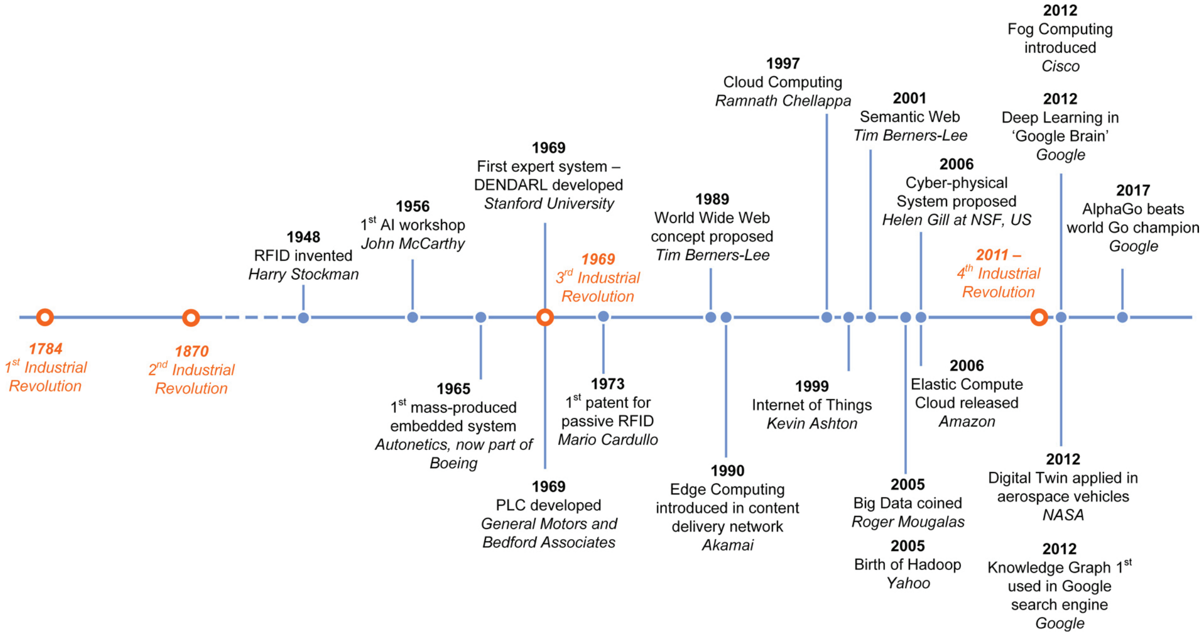


Fig.07: *Algorithm, connectivity and computation technology explosion over recent history ((Lu, Xu, and Wang 2020).*

A new manufacturing paradigm is created by the integration of the new manufacturing system with the new business model and the product architecture. Currently, there are four main paradigms for producing consumer goods: (1) craft production, (2) mass production, (3) mass customization, and, most recently, (4) global manufacturing, which simultaneously emphasizes regionalized and individualized production. Every manufacturing paradigm has its own unique set of requirements, either driven by societal needs or by Market forces (Koren 2010, chap. 1).

Mass Customization

While smart manufacturing is arriving. It promises a future of mass-producing highly personalized products via responsive autonomous manufacturing operations at a competitive cost (Lu, Xu, and Wang 2020). With the onset of the new millennium, manufacturing replaced mass-production with mass-personalization.

When businesses started looking for alternatives to mass production in the late 1980s as a result of growing market competition, mass customization was born. Mass-customized products can be produced at a low cost if the product design is done with a set of options and product variations in early phases. Mass customization eventually gave way to some kinds of personalization. With personalized production, Products are efficiently created or put together to meet each customer’s unique requirements. Product modularity is an enabler of customizable products that is the core of mass customization and personalized production. The modular architecture is created using guidelines that support inexpensive product manufacturing. Products that are reconfigurable can change their design over time to accommodate new uses, more unmet demands, and shifting consumer preferences. (Koren 2010, chap. 3)

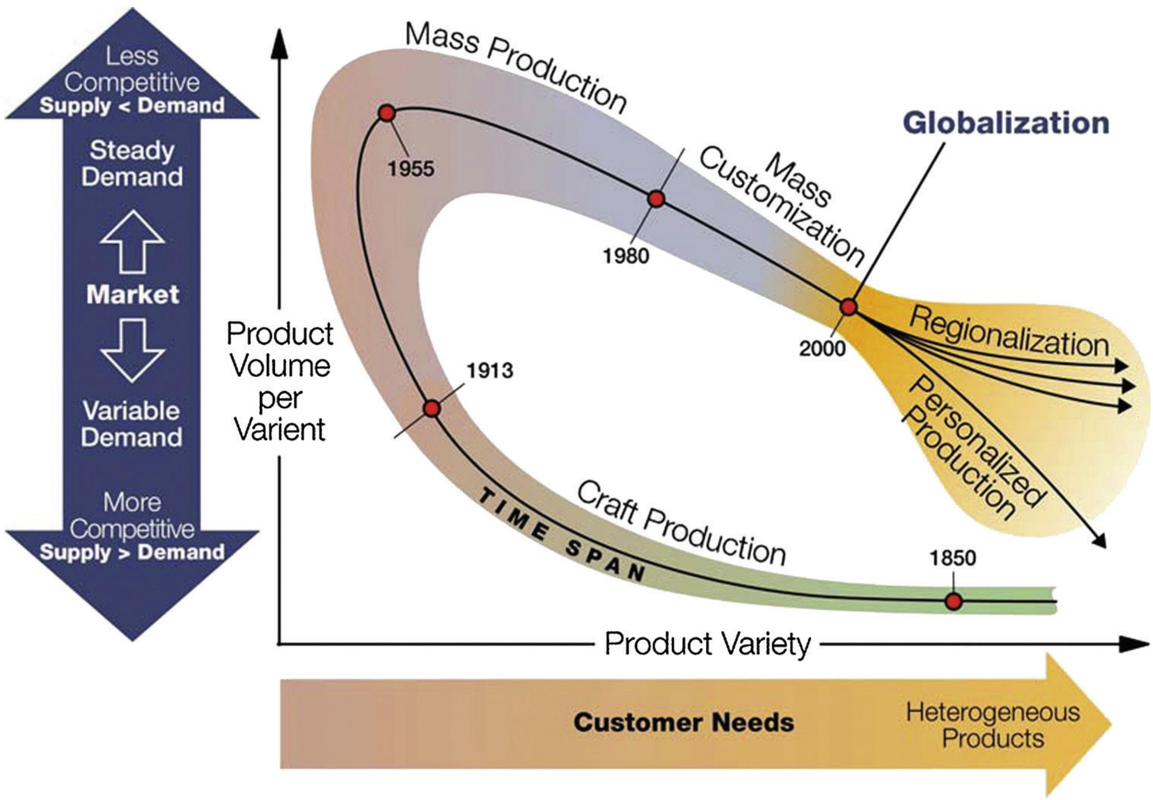


Fig.08: The drivers and shifts to new manufacturing paradigms are market and society needs.

The characteristics of four manufacturing paradigms (Craft Production, Mass Production, Mass customization, and global Manufacturing) are society's needs, market demand paradigm goal, technology enabler manufacturing system, and product architecture business model principles.

Mass customization is more suitable for society's needs as it gives a large product variety with a high-quality fit. as it is unstable with a wider variety regarding market demand paradigm goal, but the continuous development in computers will allow more suitable manufacturing systems and technology.

The benefits we can get are a high level of precision, lower costs from automation (Affordable), fewer workers, higher levels of efficiency, and prompt distribution and marketing of the product. In addition to the last benefits, we need to add the user-specific needs to move from mass production to customized mass production.

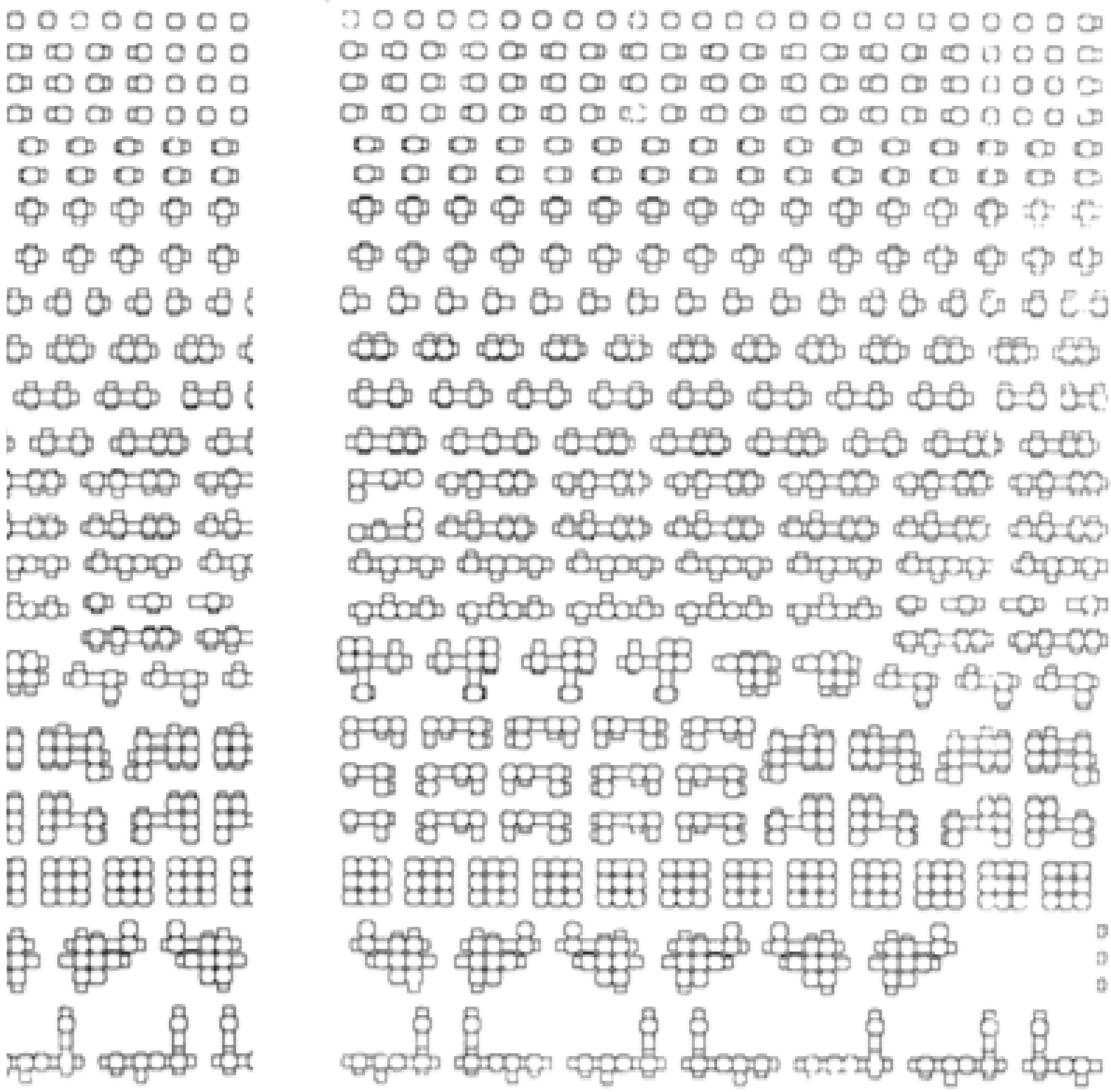


Fig.09: *Example of mass customized system*

Example of a mass customized system according to modular rules. Kiosk K67, expansion options, and combinations. Image Courtesy of Museum of Architecture & Design, Ljubljana.

1•3 Thesis Hypothesis and Structure

We can develop adaptable solutions (by Creating Software Addin) that targeted specific values to improve the Indoor environment quality of a blind space depending on users' inputs. By automating the design process for a building envelope that puts computation potential in confronting the continuous change of Climate, enabling precise Mass-customization.

1•3•1 Research Problem

. The traditional design had many obstacles when adapting to a specific design in certain conditions, the process of producing shop drawings takes a lot of time and effort. This research explores, by working on the design of a skyscraper envelop derived from biomimicry architecture, the possibility of automating the above-mentioned processes through the computational tools.

•Research Questions

***1- How** far can we enhance Indoor Environmental Quality(IEQ) by developing an envelope based on biomimetic architecture, and how automation could boost the economic aspects?*

***2- How** can we improve and customize the design of a building envelope by automating the process and to be capable of adapting to its context ?*

***3- How** can we improve the design of an envelope unit by improving its morphological shape and characteristics to enhance environmental performance based on mass customization manufacturing principles?*

***4- How** can these improvements affect the Life cycle analysis of the mentioned envelopes?*

***5- Is** it possible to improve the quality of algorithmic design tools by controlling the backend script design through the programming features?*

1•3•2 Mission

The research project aims to apply computational architecture means to serve the architectural practice of designing envelopes, by controlling the (Building Physics) factors that affect some objectives of the Indoor environmental quality (IEQ). The research project aims to automate this design process of an envelope that can control these factors through kinetic units (that form the whole envelope) and adjust themselves till it catches the targeted values of the objectives which successively will enhance the indoor environmental quality.

Automating parts of this process will affect the pre-design and design development process, and then the operation process as well, which will effectively enhance its life cycle assessment by automation.

The research core followed consists of three main steps, first the Design Proposal to create and improve an adjustable (envelope) unit with different polygonal options and different geometry possibilities and a lot of poteintals to serve different analyses. Secondly set targeted values of IEQ and building physics objectives, then adjust the computational tools and scripts to adapt the envelope units for different morphological outputs through an optimization process. Finally, introduce the envelope solutions (adapted Units) that are tailored to the selected scenario and optimized for its context.

The mission is to have an Addin (computer software) which can help users to get an optimized solution for their preferred envelope which has the potentiality to be adapted in both fixed and kinetic solutions by manipulating the integrated façade screen at its different spots (through the kinetic units) to have a significant impact on building performance, either by making it more efficient or by expanding its controlling boundaries.

A case study was conducted in the climate zone of northern Italy, where the optimization method was used and interpreted in the context of Milan city in a prototype and then on an architecture project. the case study was conducted by fixing the thermal transmittance factors (H'T) in the dedicated face and applying an adiabatic in the other parts, then to achieve the following targeted comfort values of IEQ, the (1. *Equivalent solar area* ($A_{sol, est}$)*), (2. radiation levels) and (3. Daylight factor (DF)*) with their internal parameters optimized by adapting the envelope units through the evolutionary multi-optimization process.

The project follows the environment and the practice of Visual Programming Language (VPL) approaches in the architectural design field that start with the environmental analysis which includes solar radiation, heat transfer coefficient, solar equivalent area, daylight factor, and wind analysis derived from rhino program and grasshopper plugins especially ladybug and honeybee to have a comprehensive approach to the internal and external building environment. then distribute the preferred panels as required and in dimensions that do not conflict with the structural elements while checking the results of the optimization process.

This practice is followed by the production principles applied to the unit design will be led to mass customization by addressing users' preferences (*the users are the designers who will use the automated Addin software to create there preferred envelopes*) and transferring the digital building envelope elements into a production line in both fixed and kinetic scenarios. by automating the full process, this technology will have a significant investment in terms of time and money, high level of precision, and higher levels of efficiency prompt distribution and marketing of this customized product.

1•3•3 Thesis Workflow

The whole structure of the thesis is shown in the accompanying diagram (Figure 10), which begins with the approaches used to address the issues raised in the introduction chapter on climate change, SDGs, energy and environmental concerns. moving on to the following chapter to highlight the literature review and its findings to be set as an objective of having an ecological solution under the concept of biomimicry architecture and automate the creation of a building envelope or a building facade which will be more detailed in the application chapter.

The design proposal for the envelope unit and how it was influenced by the literature review and the created unit's researched attributes were presented in chapter three. The fourth chapter describes the research's techniques, including how to control indoor environmental quality, the targeted goals, and a framework for incorporating an optimization process that will aid in achieving these goals.

The research presented its application process in the fifth chapter by using the previous methods to create a Software Addin (Plugin) Called SHELL. The shell allows users to create their own customized envelope that suits their preferences through a two-phase method. The first phase is applied to a prototype and gives you a suggested unit typology in a limited time process, The second phase is to apply the process with the chosen unit typology and present the results to have the real architecture solution.

This process was followed on the climate zone that was selected to be in Milan city (Northern Italy) on a prototype then apply it in a newly designed skyscraper influenced by its context to test the methods as well. The architecture project was called TRIO, and it was chosen to be a component of city life in the Milan district because of its high-rise architectural characteristics and because it could effectively depict the findings of the investigation. Finally, the results and the optimal solution were then interpreted, and appendices describing the employed algorithms and complete optimization results were added.

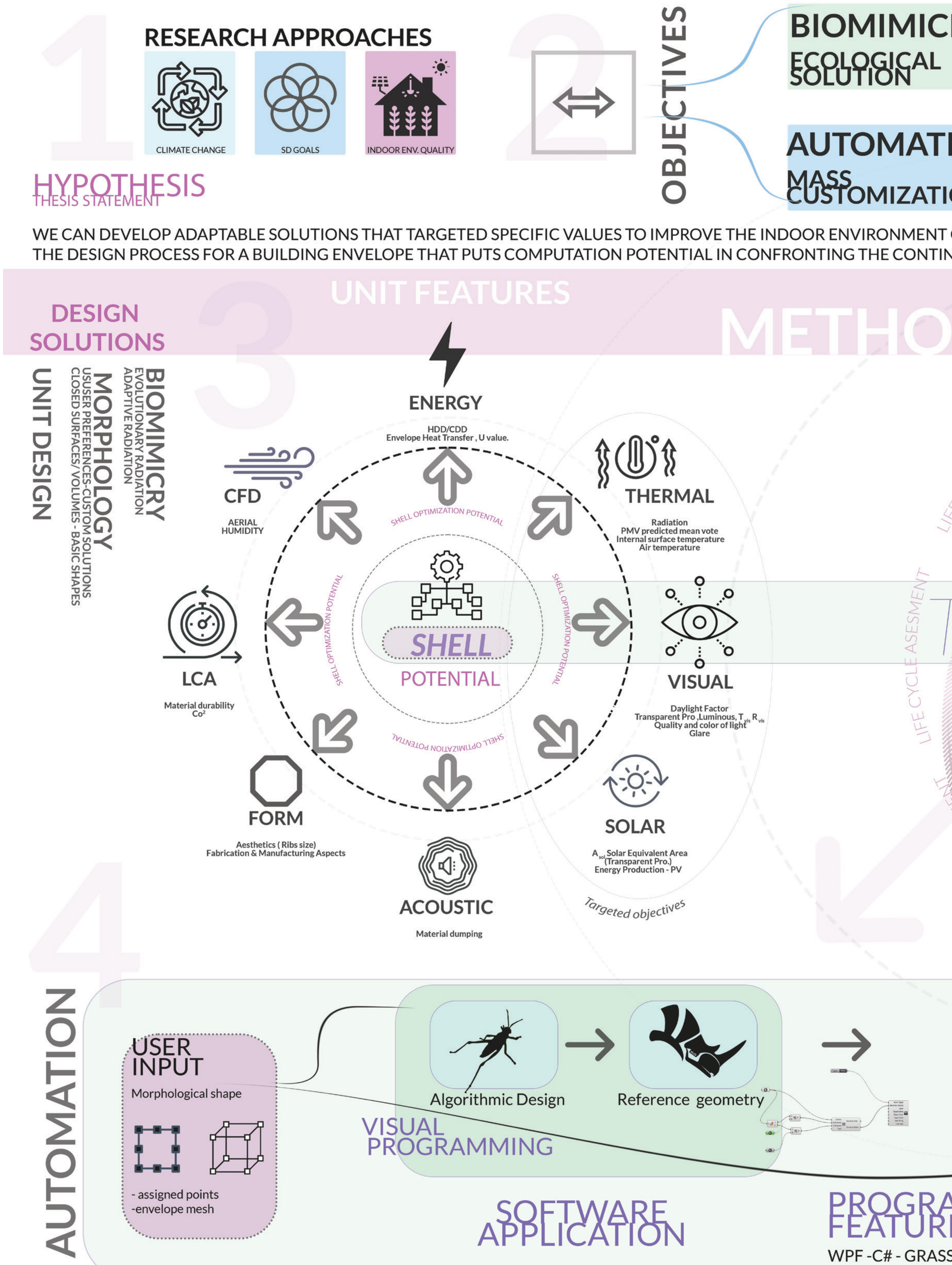
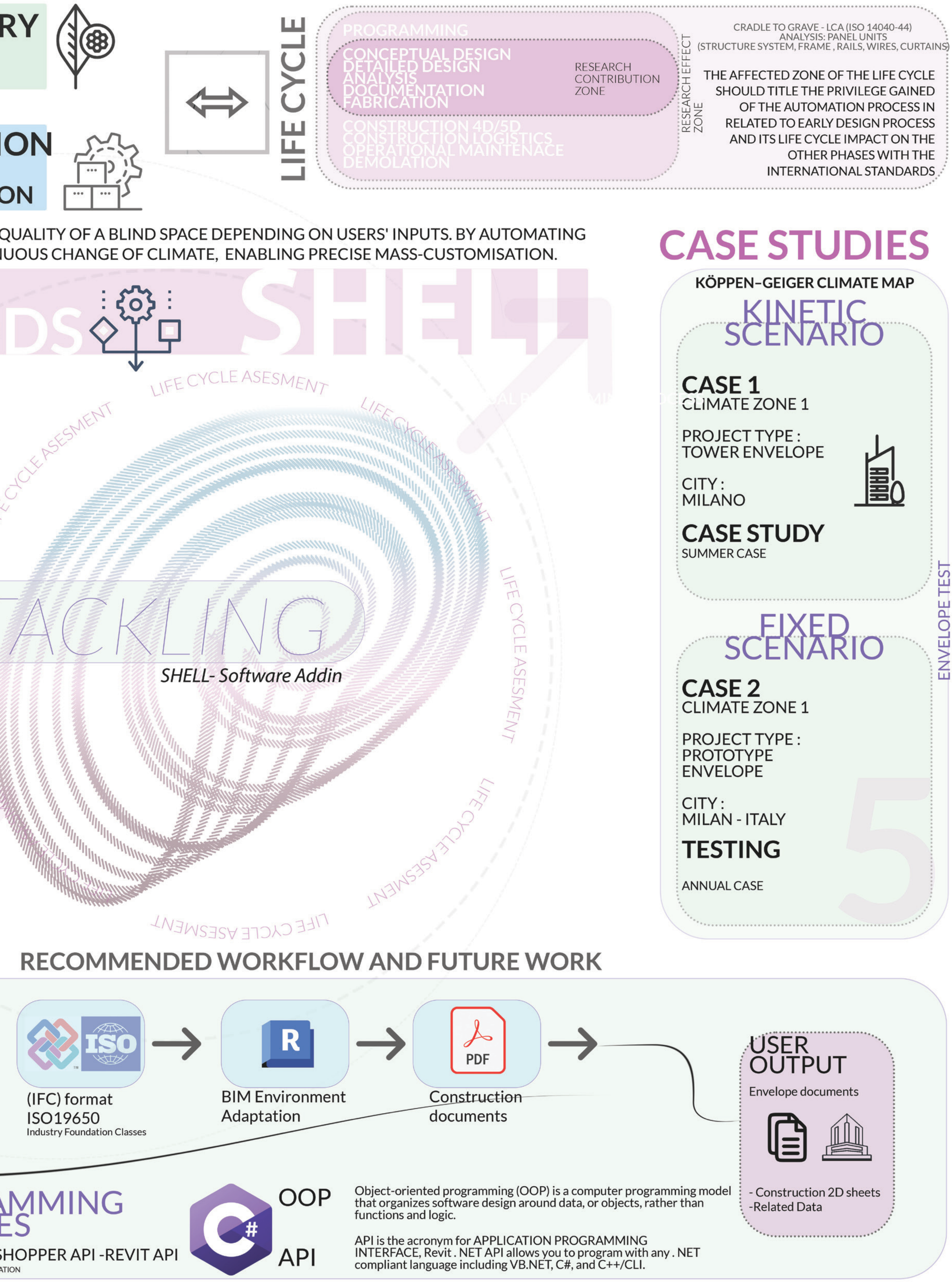


Fig.10: Research project workflow (Authors).


RY
ION
ON
LIFE CYCLE
PROGRAMMING
CONCEPTUAL DESIGN
DETAILED DESIGN
ANALYSIS
DOCUMENTATION
FABRICATION
RESEARCH CONTRIBUTION ZONE
CONSTRUCTION 4D/5D
CONSTRUCTION LOGISTICS
OPERATIONAL MAINTENACE
DEMOLATION
RESEARCH EFFECT ZONE
CRADLE TO GRAVE - LCA (ISO 14040-44)
ANALYSIS: PANEL UNITS
(STRUCTURE SYSTEM, FRAME , RAILS, WIRES, CURTAINS)
THE AFFECTED ZONE OF THE LIFE CYCLE SHOULD TITLE THE PRIVILEGE GAINED OF THE AUTOMATION PROCESS IN RELATED TO EARLY DESIGN PROCESS AND ITS LIFE CYCLE IMPACT ON THE OTHER PHASES WITH THE INTERNATIONAL STANDARDS
QUALITY OF A BLIND SPACE DEPENDING ON USERS' INPUTS. BY AUTOMATING
IUOUS CHANGE OF CLIMATE, ENABLING PRECISE MASS-CUSTOMISATION.
DS
SHELL
LIFE CYCLE ASESMENT
TACKLING
SHELL- Software Addin
CASE STUDIES
KÖPPEN–GEIGER CLIMATE MAP
KINETIC SCENARIO
CASE 1
CLIMATE ZONE 1
PROJECT TYPE :
TOWER ENVELOPE
CITY :
MILANO
CASE STUDY
SUMMER CASE
ENVELOPE TEST
FIXED SCENARIO
CASE 2
CLIMATE ZONE 1
PROJECT TYPE :
PROTOTYPE ENVELOPE
CITY :
MILAN - ITALY
TESTING
ANNUAL CASE
5
RECOMMENDED WORKFLOW AND FUTURE WORK
ISO
(IFC) format
ISO19650
Industry Foundation Classes
R
BIM Environment Adaptation
PDF
Construction documents
USER OUTPUT
Envelope documents
- Construction 2D sheets
-Related Data
AMMING
ES
SHOPPER API -REVIT API
OOP
API
Object-oriented programming (OOP) is a computer programming model that organizes software design around data, or objects, rather than functions and logic.
API is the acronym for APPLICATION PROGRAMMING INTERFACE, Revit . NET API allows you to program with any . NET compliant language including VB.NET, C#, and C++/CLI.

HIGHLIGHTS : #Computational Design
#Biomimicry
#Evolutionary Architecture

P O L I T E C N I C O

PRECEDENTS
CHAPTER II

0 2

2. PRECEDENTS

“Imitation is the sincerest form of flattery, that mediocrity can pay to greatness.”

Oscar Wilde 1854 – 1900, (Ireland - France).

The way we live has altered as a result of computers! today our mobile phones rarely leave our hands, The majority of laptops can run very demanding programs, and in scientific contexts, computers are able to perform computations that we could never hope to attempt on our own.

Computers have a long history dating back to the development of mathematical sciences till silicon technologies. Algorithms is the base of the mathematical systems of computers, it dates back around 900 years. (Algorithm) as a word derived from the name of Muhammad (Al-Khwarizmi) a mathematician (the father of algebra). In medieval Latin, algorithms meant the decimal number system till the late 19^{th} came to mean a set of rules to solve a problem. By the 20^{th} century, Alan Turing (the father of computer science), translated the algorithmic instructions to be done by machines (Ben-Menahem 2009).

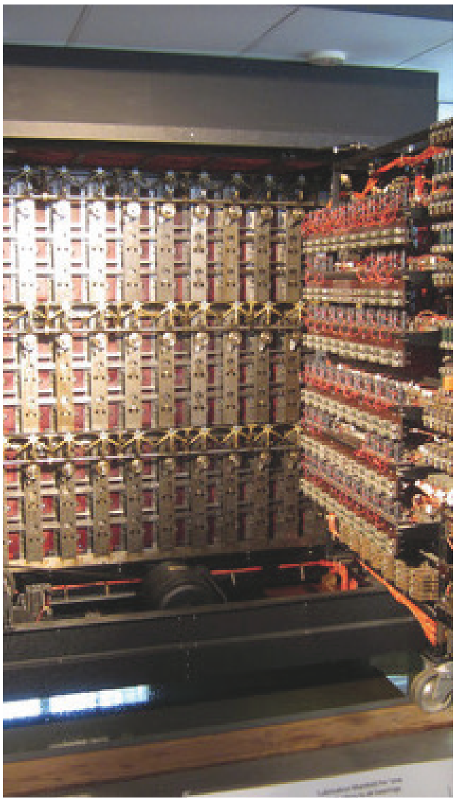


Fig.11: *Alan turing (Left), Turing Machine at Bletchley Park was a giant piece of technology, but very basic by today’s standards. Douglas Hoyt/Flickr (Right) (CC BY-NC-ND 2.0)*

Fig.12: *Monument to Muhammad al-Khwarizmi at Universitaria of Madrid*

2•1 Computational Design

The growing computational capability of tools and the variety of available Computational Design (CD) methods have enabled designers and architects to increase their design processes' efficiency and broaden their conceptual horizons.

These methods enable architects to investigate and assess additional difficult solutions, develop and apply cutting-edge production techniques, and impressively manage the design process at various phases.

Successively, building design underwent a "computational turn" as a result of the development and diffusion of computational design (CD), which completely altered traditional design methodologies (Rocker 2006).

The Architectural design process is almost always iterative. The solutions that designers come up with then prompt additional inquiries that are looked into to produce improved or maybe brand-new solutions. Designers frequently create models and aid in their idea visualization using computer-aided technologies (Jabi 2013, 11:10). CD challenges the traditional way based on manual drafting tasks and renovating previous architectural design conventions and praxis.

Early examples of CD are CRAFT, an algorithm-based system that makes use of a heuristic to optimize the spatial position patterns for physical facilities like manufacturing plants. CRAFT was among the first systems to automate design procedures using optimization techniques. It did not address geometric descriptions or provide a graphical user interface (GUI) that designers could use; instead, it was restricted to the design of the topological relationships between various programmatic components of an industrial facility.

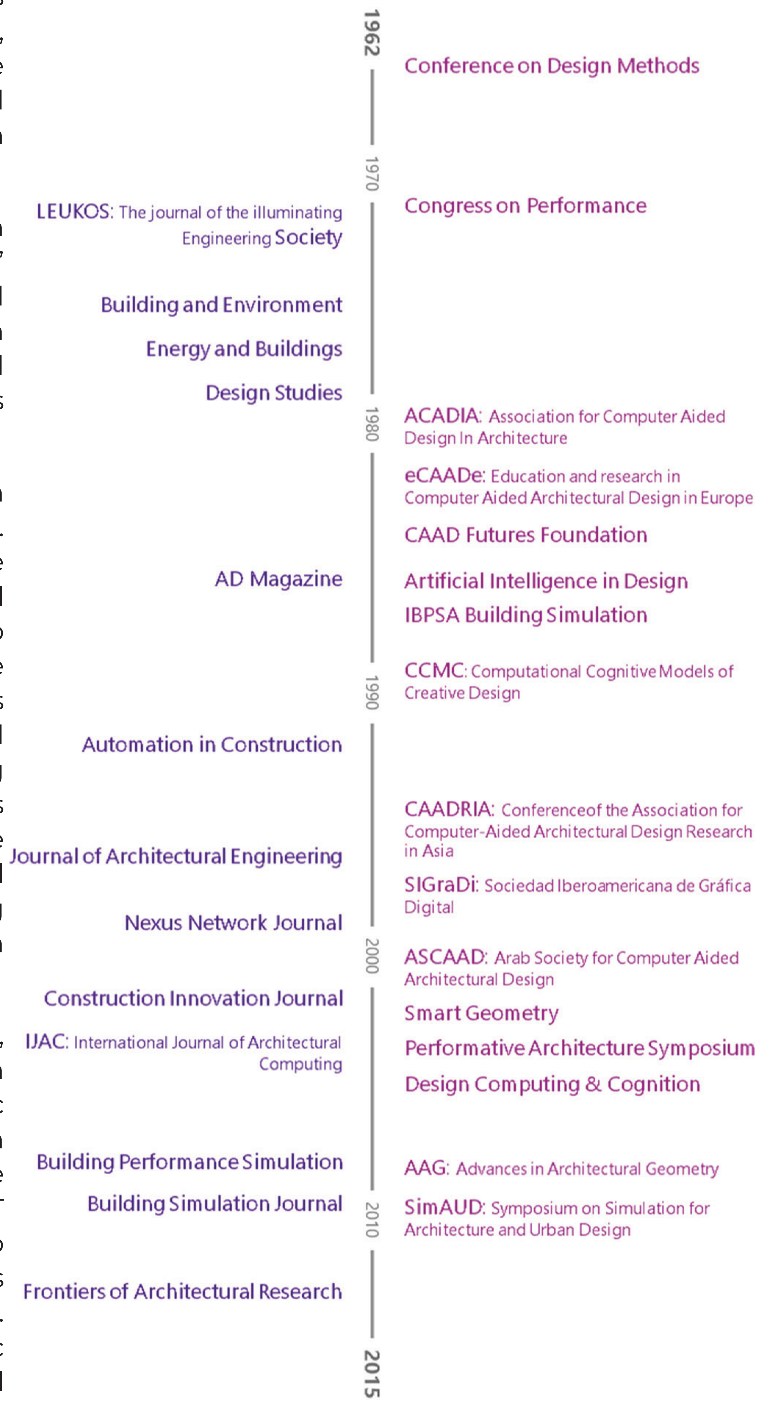


Fig.13: Timeline of scientific conferences focused on CD (top) approaches and journals that included CD research in their scope ,(left). aetano, Santos, and Leitão 2020)

Meanwhile, Ivan Sutherland introduced the Sketchpad computer program the ancestor of computer-aided design (CAD), which enabled not only the automation of drafting tasks but also the setting of parametric relationships among geometric entities using a GUI. In the same decade, General Motors developed the CAD-like system DAC-1 (1964), and some authors addressed the automated optimization of programmatic layouts of industrial buildings (Caetano, Santos, and Leitão 2020)

The first commercially viable CAD and Building Information Modelling (BIM) tools didn't appear until the early 1980s. Tools for simulating the performance of buildings have also developed, enabling designers to evaluate their designs in terms of many performance parameters.

For the acceptance of computation-based approaches in architecture, various scientific events on CD that occurred concurrently with the creation of CD technologies were crucial. The Design Methods conference in 1962 was a trailblazing occasion that charted the early advancements of CD in architecture. The issue of using computing to model building performance was first brought up during the First International Congress on Performance in 1972. In the decades that followed, there were constantly organized more international conferences on CDs. Similarly, several scientific journals, such as Automation in Construction (1992), International Journal of Architectural Computing (2003), and Journal of Building Performance Simulation (2008), exclusively focused on CD research. (Figure 16) shows a timeline of CD-related conferences and journals.

Primarily due to their overlapping scopes, The use of CD in architecture led to the emergence of numerous terminology for various methodologies. However, the definitions of numerous CD-related words in the existing literature are inconsistent (Caetano, Santos, and Leitão 2020).

2•1•1 Definitions

•Parametric Design (PD)

The Oxford Dictionary defines a parameter as "*a numerical or other measurable factors forming one of a set that defines a system or sets the conditions of its operation," or as "a limit [...] which defines the scope of a particular process or activity," and the word parametric as "relating to or expressed in terms of a parameter or parameters*."

PD is a phrase that is frequently used in conjunction with other terms, such as parametric

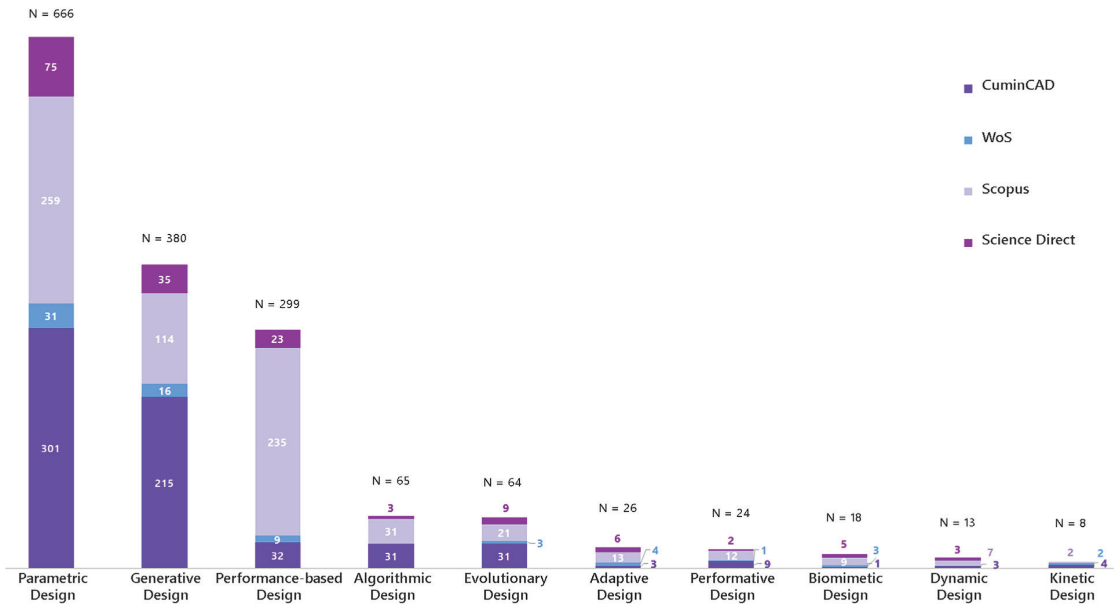


Fig.14: *Number of times each CD term appeared in the literature between 1978 and 2018 (Leitão 2020).*

model, modeling, and parametric systems. As a result, PD is an approach that uses parameters to symbolically describe a design.

As an illustration, symbolic parameters with defined domains are used to design walls rather than utilizing precise placements, lengths, heights, and thicknesses. As a result, a set of walls is figuratively represented. This method is frequently applied in BIM tools, and it is expressed by the idea of a family or object that classifies groups of architectural components. Each set of parameter values, for instance, corresponds to a distinct wall in a family of walls. In this example, the parameters and the resulting design are directly related, but in other instances, this relationship might not be obvious because the parameters might be employed in sophisticated ways to create complex designs.

•Generative Design (GD)

The Cambridge Dictionary defines generative as the "capacity to produce or create something."

GD, which frequently coexists with PD. Limiting GD to evolutionary processes is restrictive since it leaves out alternative techniques that can produce design. Additionally, GD needs to be distinguished from other terms like PD. As a result, we characterize GD as a design paradigm that makes use of algorithmic descriptions that are more independent than PD. Generally the generative design introduces a new method of design that enables to discover of unexpected novel designs and navigate trade-offs between high-performing designs, sketch constraints, and goals rather than form and co-design between human and computers.

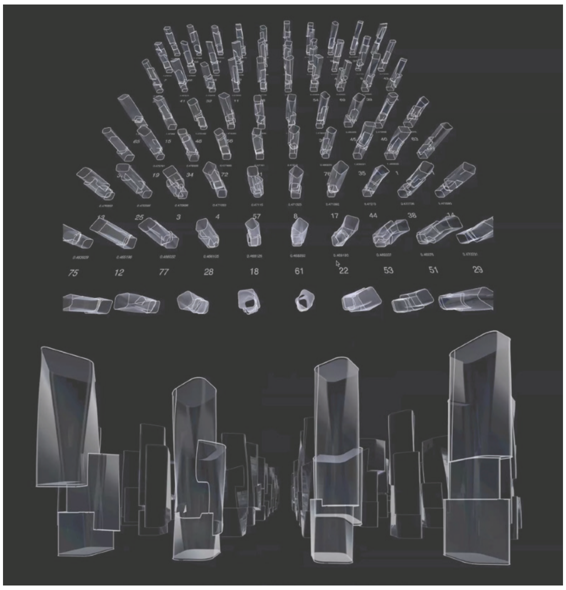


Fig.15: Generative Design samples represents evolving permutations. Zayad Motlib 2021).

•Algorithmic Design (AD)

According to the Cambridge Dictionary, an algorithm is a "set of mathematical instructions or rules that [.] will help calculate an answer to a problem."

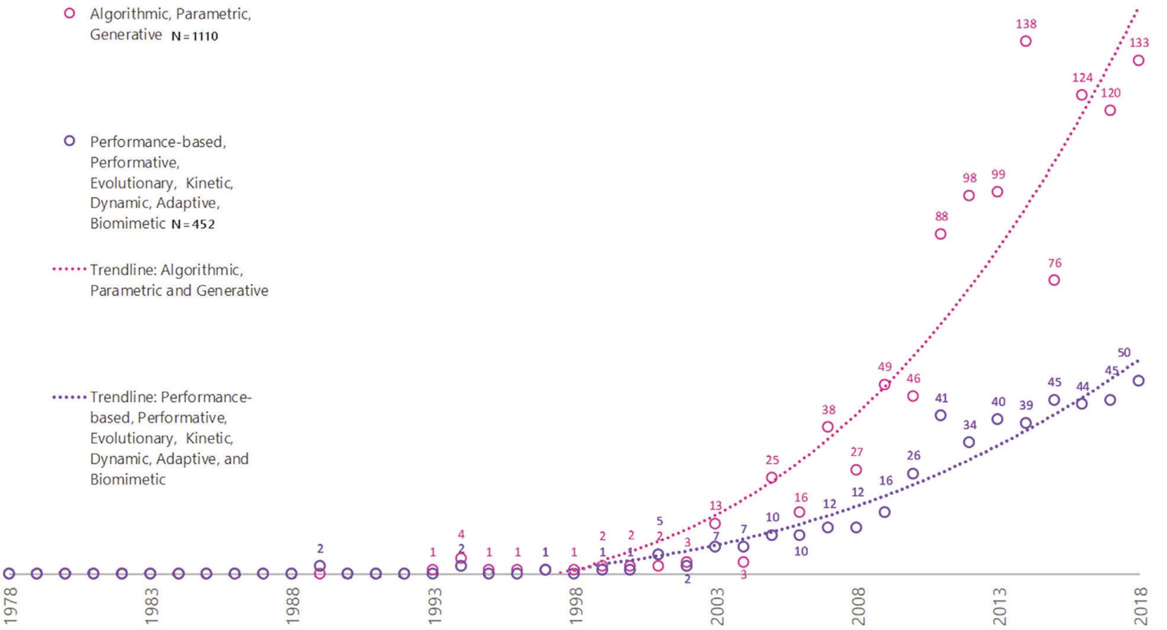


Fig.16: Frequency of use of selected and non-selected CD-related key words between 1978 and 2017. For each group, also present a third-order polynomial trend line. (Leitão 2020).

Fig.17: MaRS generative project, It involves the integration of a rule-based geometric system, a series of measurable goals, and a system for automatically generating, evaluating, and evolving large number of design options. (Autodesk).

There are some ambiguities in the definition of AD due to the term's scope in the literature colliding with those of PD and GD. For instance, some authors claim that AD incorporates GD, while others claim that AD and GD are two different approaches, and yet others think of AD as a method dependent on PD tools.

AD is a design paradigm that uses algorithms to generate models and, therefore, it considered generative. Nevertheless, in AD, a correlation between the algorithm and the generated model exists, thus providing traceability and allowing the user to identify the parts of the algorithm that generated a given part of the model (Caetano, Santos, and Leitão 2020, 8).

According to the definitions for AD, GD, and PD clarify the confusion between the terms. The mentioned definitions consider that GD requires the explicit use of an algorithm that generates a design. Also, The algorithm is also deemed AD if it satisfies the traceability property, which requires a discernible connection between the algorithm and the created design. Finally, if the design is dependent on a set of parameters, then it is PD.

Many authors associated GD with the use of evolutionary-based processes (Fischer 2001). However, GD includes these processes and other algorithmic approaches as mentioned by different authors. Given the broad scope of the definition, one should always use the more exact term AD if a GD process satisfies the traceability criterion.

As a result, there is a considerable scope overlap between different discussed terms, which is the cause of the design community's unclear use of various CD-related terminologies. Defines such definitions' precise scopes and illustrates potential interactions in order to give them some foundation which has a theoretical framework for a CD-related taxonomy, as it could be improved to reach a developed stage of widespread agreement. The figure 18 proposed taxonomy introduces the following fundamental definitions in total:

- **GD** is a design approach that uses algorithms to generate designs.
- **AD** is a GD approach characterized by an identifiable correlation between the algorithm and its outcome.
- **PD** is a design approach based on the use of parameters to describe sets of designs.

It is crucial to distinguish between such terminologies as they are important to differentiate between methods utilized in this research regarding constructive algorithms and others in analysis, simulations, and evolutionary process.

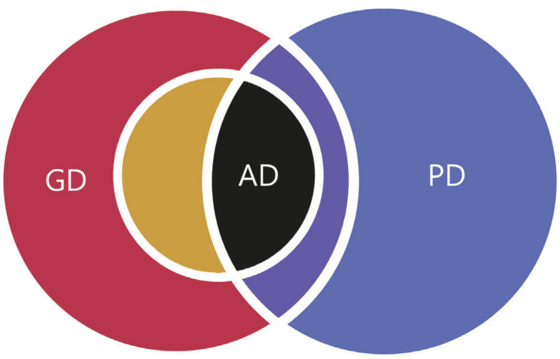


Fig.18: Conceptual representation of the terms' extension regarding the CD paradigm (Leitão 2020).

2•1•2 Aided Design

Algorithmic design is more than just using computers to create structures and other things. Designers can transcend the constraints of standard CAD software and 3D modelers by using algorithms to achieve levels of intricacy and control that are beyond the manual capacity of humans (Tedeschi and Fiell 2014).

We can see from the current (and still developing) stage of digitalization applied to architecture that digital tools are helpful to investigate a potentially infinite number of design options in order to discover the best answer to a particular challenge.

It is challenging to identify the connections between architectural history when examining the computationally generated designs by some of the largest architectural firms in the world, but the simple notion of a parameter has shown a connection to tradition. Although Frei Otto and Antoni Gaudi are among the significant personalities most frequently mentioned, they are by no means the only ones. In a fascinating article, John Frazer also discussed the life of Italian architect Luigi Moretti, who is thought to have developed the idea of parametric architecture for the first time in 1940. In an article that was published in Moebius two years before he passed away, Moretti (1971) reaffirms the need for a new architecture that is rigorous in the definition of form with the aid of mathematical logic, computer techniques, and operational research methods, in order to overcome the empirical state of current architecture. This article contains a substantial development of the concept of parametric architecture. Moretti then lists the following eight characteristics of his parametric architecture:

Fig.19: Antoni Gaudi 1852-1926 (Up-Right), Frei Otto 1925-2015-(Down Right), and Luigi Moretti 1906-1973 (Down-Left).

1 - Rejection of empirical decisions.

2 - Assessment of traditional phenomena as objective facts based on the interdependence of expressive, social and technical values.

3 - Exact and complete definition of architectural themes.

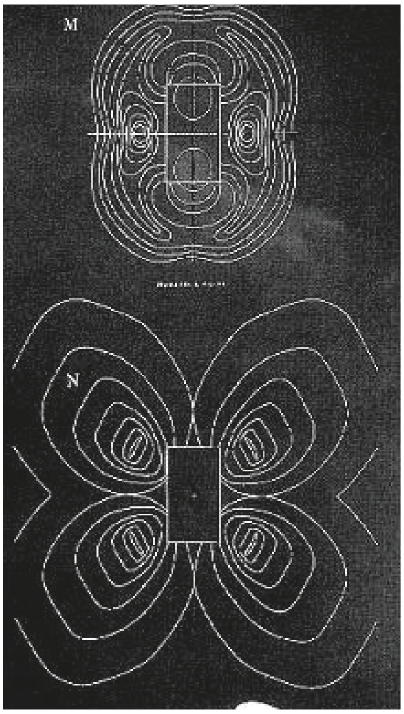
4 - Objective observation of all the conditioning elements (parameters) related to the architectural theme and identification of their quantitative values.

5 - Definition of the relationships between the values of the parameters.

6 - Indispensability of different skills and scientific methodologies according to the criteria of operational research to define conditioning elements and their quantities.

7 - Affirmation of the Architect's freedom in decision and expression, only if it does not affect the characteristics determined by the analytical investigations.

8 - Research of architectural forms towards a maximum, therefore definitive, exactness of relationships in their general "structure".



In these statements, it is clear that Moretti, in his advanced age, is still advocating for a methodology that ensures the best solution to address architectural needs, rejecting any empirical decision in favor of the scientific method for the functional solution of the form while also announcing the freedom of expression of the architect and viewing the latter as an artist who is capable of overseeing the entire architectural process. (Gallo and Pellitteri 2018).

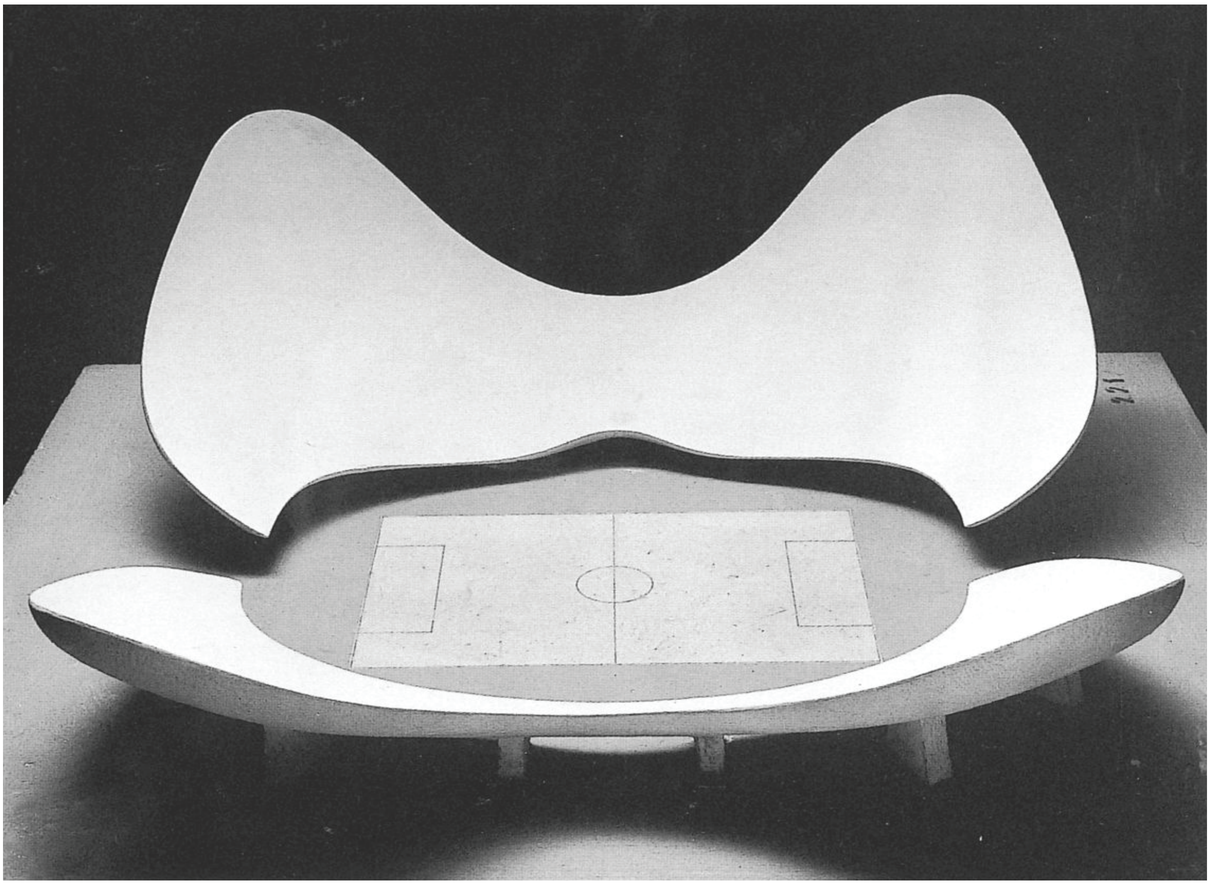


Fig.20: *Architettura Parametrica" research. Milan Triennale exhibition, 1960. Solution for a soccer stadium (Down) and diagrams (Up-Right) (Tedeschi and Fiell 2014, 20).*

2•2 Biomimicry, from imitation to computational

BI-O-MIM-IC-RY [From the Greek bios, life, and mimesis, imitation]

We frequently discover that nature was there first when looking for genuinely sustainable building design and technology designs that go above and beyond conventional sustainability to be truly restorative. Natural history, which spans more than 3.5 billion years, has produced countless examples of forms, systems, and processes that can be used in contemporary green design (Pawlyn 2019).

Nature guided mankind and has been an inspiration for all the wonderful things it accomplished throughout history. Learning from the natural environment comes as sustainable model since natural systems tend to recycle their waste based on a circular approach. Accordingly, the three pillars of biomimicry are:

First: Nature as model.

Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g., a solar cell inspired by a leaf.

Secondly: Nature as measure.

Biomimicry uses an ecological standard to judge the "rightness" of our innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts.

Third: Nature as mentor.

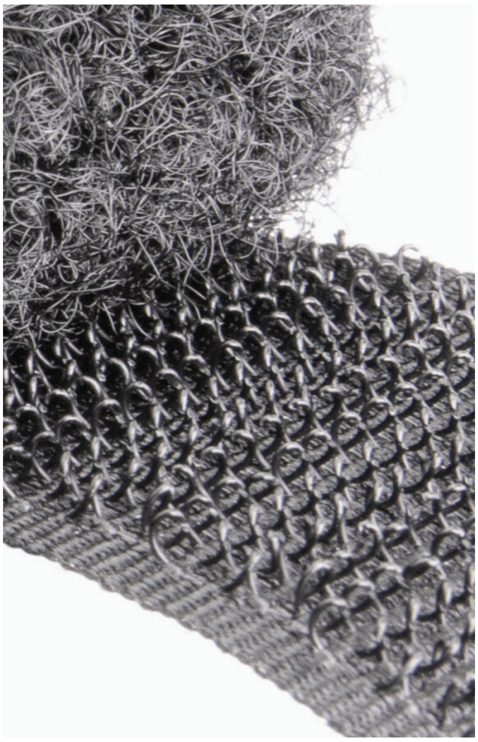
Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it (Benyus 2009).

2•2•1 Imitation

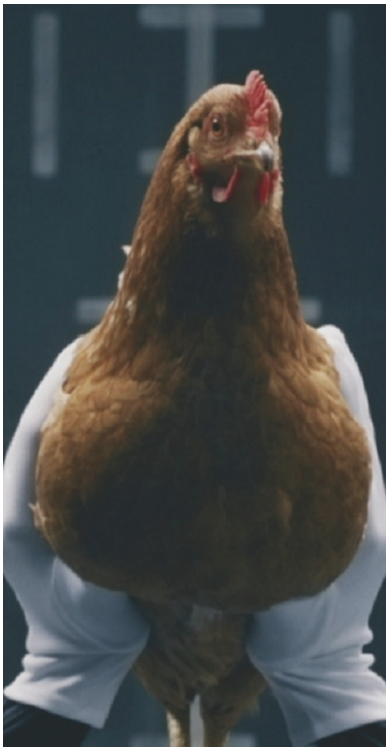
The fundamental tenet of the biomimetic philosophy is that nature's occupants, such as animals, plants, and microbes, have the greatest experience dealing with issues and have already figured out how to survive on Earth. Similarly to this, the evolutionary process has ensured that natural structures have the ability to safely fulfill their particular functions and survive in their specific environment through well-adapted mechanical (material) and geometrical (form) properties. Though Sustainability is the primary goal of biomimicry. During evolution, living things have adapted to a continually changing environment through mutation, recombination, and selection.

There are a lot of innovations that are inspired by nature as those that observe nature and then copy or draw ideas from its designs and methods to address human problems in different disciplines.

Humpback whales are one of the largest animals on Earth, and yet they move with speed thanks to the momentum of their well-designed flippers. Humpback fins have been studied and modeled for wind turbines.



Velcro was invented by George de Mestral in 1941 and was inspired by the burrs he found on himself and on his dog. Velcro has become integrated into daily life and has revolutionized the fastener industry.



Chicken: Mercedes-Benz; Mercedes-Benz uses a genetic quirk of chickens as inspiration for its new Suspension Technology "equipped" with the vestibulo-ocular reflex (VOR).

Albatross: Drones. The albatross is a majestic, ocean-faring bird that truly soars, meaning it rarely flaps its wings to fly. Instead, it uses the wind to fly more than 600 miles a day. Researchers at MIT are using this flight design to develop drones. They're hoping to create a fixed-wing, wind-propelled drone that would be able to fly overseas without stopping. (EMILY SHIFFER, 2019, Mo'men Nabil 2022).

Fig.21: *Imitation between nature and industry (Whales,Turbines),(burrs,Velcro),(hens,Suspension systems),(Albatross,Drones). (EMILY SHIFFER, 2019, Mo'men Nabil 2022).*

2•2•2 Biomimicry Architecture.

Biomimetic architecture is a branch of the new science of biomimicry that tries to replicate natural forms while also studying the principles that control them in order to find solutions for building sustainability that are already existent in nature.

From an architectural standpoint, there is a crucial difference between "biomorphism" and "biomimicry". The architecture of the 20th century frequently drew inspiration from nature for its unusual forms and symbolic associations. Bio-morphism has produced majestic works of architectural forms, such as Eero Saarinen's TWA terminal (Figure 22), and was used to great symbolic effect by Le Corbusier (figure 22).

While the parametric design is currently based on computer-aided technologies, Pier Luigi Nervi, an architect and engineer, was a master of this craft and experimented with biomimetic architecture already in his period, building wonderful, functional structures. This is an important example of how biomimicry was introduced to architecture and how it greatly influenced the 20th century. For instance, the huge quadrangular pavilion at the Palazzo del Lavoro in Torino in 1961, which was composed of 16 modular pieces and had a square-based roof, measured 22,500 m2 and 156 meters on each side, Each of the sixteen modules, which are 40 meters on each side, are supported by a central pillar that tapers in height from 25 to 25 metres and ends in a distinctive radial pattern made of the 38-meter diameter reinforced concrete beams that provide natural sunlight through skylights, as currently, it Is under renovation process to be an innovation and technology hub serving the city of Turin. Another illustration by Nervi is his futuristic design for the dome architecture in the Palazzetto Dello Sport (sports palace) in Rome (Figure 23), which straddles the line between a strict formal taste and an encompassing aesthetic.

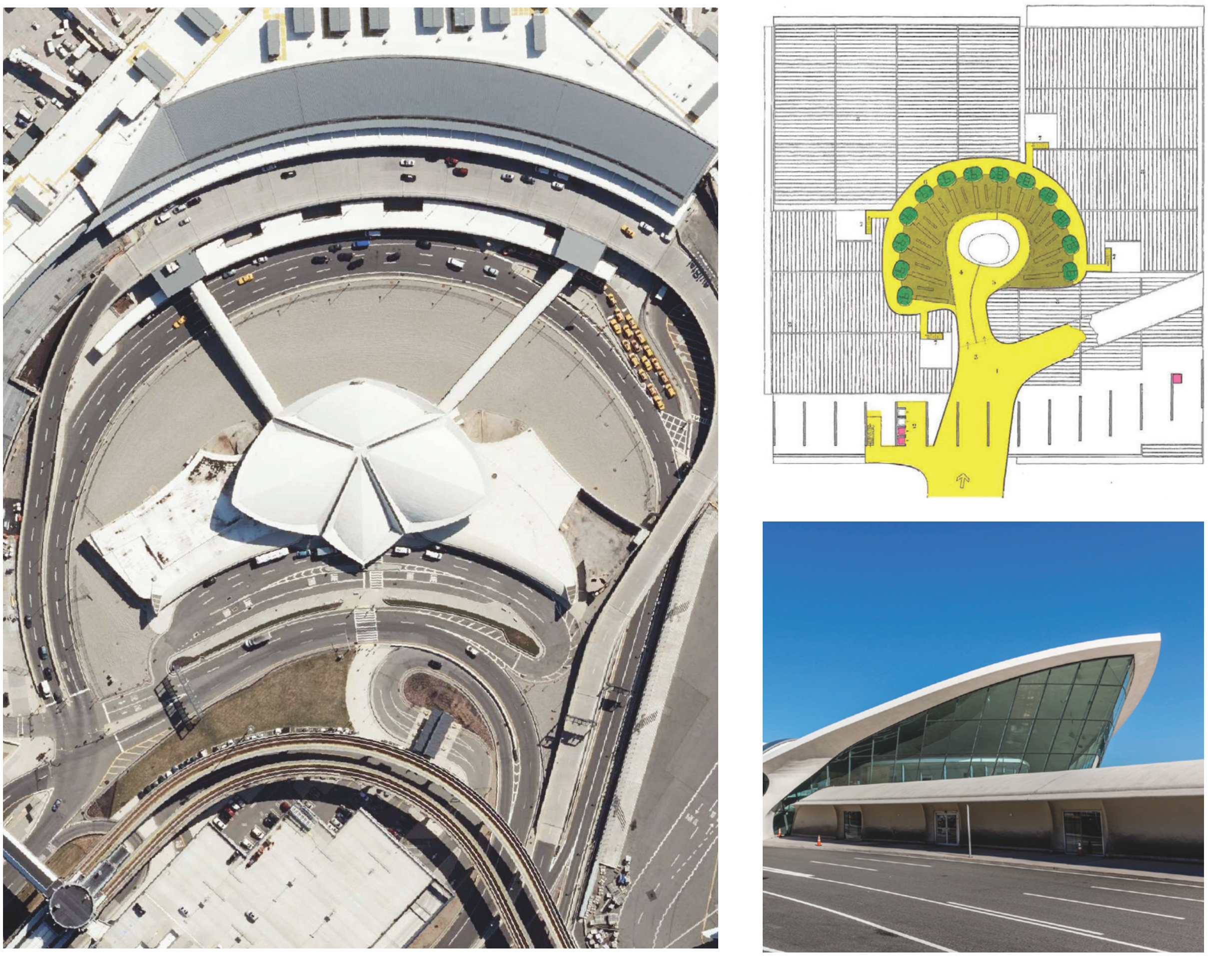


Fig.22: Eero Saarinen's TWA terminal ,USA (Left). Le Corbusier, symbolist architecture make deliberate reference to the cleansing function of kidneys in washrooms, Unbuilt Olivetti Headquarters, Italy (Right).

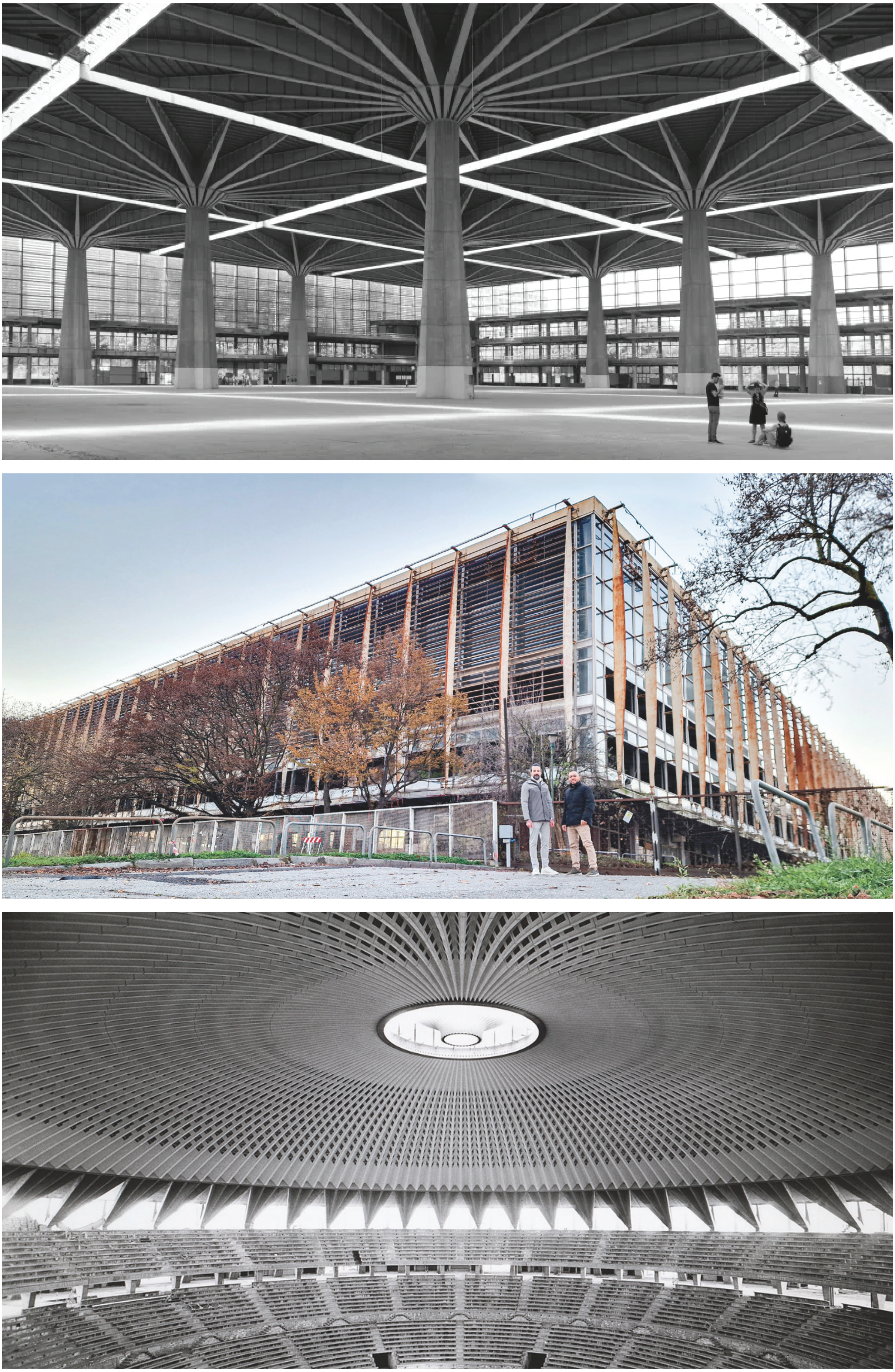


Fig.23: *Biomimcry architecture samples by Pier Luigi Nervi :PALAZZO DEL LAVORO (palace of work), the authors in front of the building facades, Torino/Italy (Up) and PALAZZETTO DELLO SPORT (Sports hall) Rome /Italy (Down).*

Democratization of design) is a key idea described by Branko Kolarevic which a concept that might be combined with biomimicry in architecture to create cogent architecture by shifting from mass production to mass customization and moreover design (Democratisation).

The implied 'democratization' of design – through mass customization – raises additional questions, such as the authorship of design and the functional and aesthetic quality of products (shoes, tableware, furniture, houses) created by non-designers. Additionally, it poses intriguing conceptual difficulties for the creation of software that supports modification. For instance, the parametric design "engine" should guarantee the effectiveness of each dimensionally modified product (structurally and environmentally in the case of houses). Additionally, the designs must be aesthetically pleasing, necessitating the measurement and quantitative evaluation of only qualitative components of design within the software.

Fabio Gramazio and Matthias Kohler went a step further in 2002 with their mTable, a parametrically variable table design (with holes) that customers could (co-design). They created an interactive application for mobile phones so that customers could easily specify the size, dimensions, material, and colour of the table. then by placing (deformation points) on the underside of the table and (pressing) them, the customer could create holes with very thin edges. after the design process the final step was the placement of the production order, with the table fabricated by a CNC milling machine (Kolarevic 2015).

Fig.24: *Various mTable designs created by customers using a mobile phone app. Gramazio and Kohler mTable, 2002*

But, in contrast, biomimicry is concerned with the way in which functions are delivered in biology. The distinction is important because we require a functional revolution of sorts, in seek of biomimicry rather than biomorphism that will deliver the transformations described above (Pawlyn 2019).

Due to inefficient building designs and overuse of energy during a building's operating the phase of its life cycle, energy waste has become a common occurrence in the 21st century. In parallel, recent advancements in fabrication techniques, computational imaging, and simulation tools have opened up new possibilities to mimic nature across different architectural scales. As a result, the development of creative design methods and solutions to address energy issues has grown quickly. Biomimetic architecture is one of these multi-disciplinary approaches to sustainable design which seeks to use nature to solve problems with the building's functionality and energy efficiency rather than just drawing inspiration from it for its aesthetic elements. It adheres to a set of principles rather than strict stylistic rules.

•Context Matters

LabStudio in a collaboration with architect Jenny Sabin and Molecular and cell biologist Peter Lloyd Jones has conducted research and teaching focused on the multiscale, interconnective architectures of nonlinear biological systems began in 2006 at the University of Pennsylvania. with the collaboration of some cross-disciplinary explorations such as nanoscale material, transformations of topological structures, molecular biology, biophysics, mathematics, and pharmacology. The collaboration aimed to merge their approaches -the intuitive, computational, and spatial skills of Sabin with the theoretical and technical biomedical laboratory expertise of Jones - to devise new ways of seeing, thinking, and modeling cell and tissue morphogenesis under different conditions and structures (Cogdell 2019, 153). Similar to the architecture of buildings, cells exist within contexts where physical forces matter significantly; structural collapse or major architectural changes can signal disease. The most valuable contribution was introducing the concepts, terminologies, and methods from different academic disciplines. Together, these different disciplinary viewpoints offer the potential of unique insights into structural design processes, whether biological or inorganic, whether nano-or macroscale.

Fig.25: PolyThread Knitted Textile Pavilion, Design Museum for Beauty, Cooper Hewitt Triennial, 2016.

Compare with Sabin and Jones's images of cells in their matrix environment in vitro images. Here, the hooplike border visually references the extracellular matrix, while the cellular archi-textile made of thread that glows in response to light within its borders shows tissue morphology. Jenny Sabin, Matt Flynn, and William Staffeld.

•Scaling Up: From the Nano to the Macro

The creation of human-scale models of nano- or microscale material formations from laboratory research has been a significant aspect of the LabStudio collaboration. These models demonstrate various applications of Appling biomimicry in architecture from numerous perspectives.

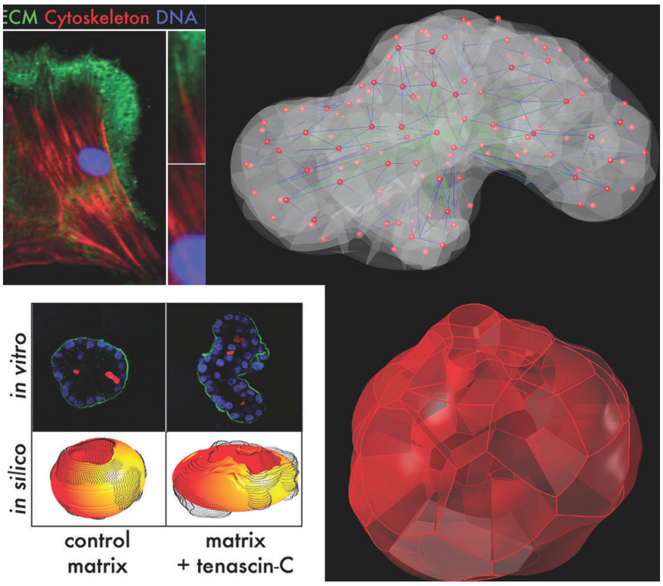


Fig.26: *Nonlinear Systems Biology and its Design, University Of Pennsylvania, ARCH 745 (Jones, Sabin's 2008).*

Demonstrate their process of computational modeling of pathological and normal tissue morphologies in breast cancer. "Quantitative Analysis of Three-Dimensional Human Mammary Epithelial Tissue Architecture Reveals a Role for Tenascin-C in Regulating c-Met unction," American Journal of Pathology 176, no. 2 (February 2010): 827–38; "Lulu Press, 2008), 54–65.

For instance, Sabin was inspired by cellular networking to create the room-sized PolyThread Knitted Textile Pavilion for the 2016 exhibition Beauty: The Cooper Hewitt Design Triennial (Figure 26). In a manner comparable to Philip Beesley's Hylozoic sculptures, which move and rustle in reaction to human motion and heat, this piece was given life, so to speak, by light and shadow.

However, whereas Beesley's installations incorporate small sensors, Sabin's thread merely reacts to light as a result of its makeup as a material. The pavilion transmitted colored light throughout the threaded network, which would react to shadows cast by the presence of visitors and absorbed colored light from the space in addition to sunlight. The digitally knitted fabric was tensioned through its connection to a freestanding fiberglass tubing edge,

which represents the extracellular matrix around a tissue's edge metaphorically.

Comparing the pathological breast cancer tissue morphology's green-fluorescing matrix edge at the top and second from the right (Figure 26). Thus, even though the tube in this pavilion appears more like a hoop used for knitting, Sabin was undoubtedly alluding to cell and matrix networks as tensegrity structures.

Sabin's method demonstrates her strong theoretical commitment to nonlinear complex adaptive systems as the biological basis for her work rather than a gene-centric linear focus. Compare it to the Foreign Office Architects (FOA) practice diagram from Breeding Architecture as well (Figure 31, 32). It is possible to follow numerous pathways in Sabin's, with the implication that each one dynamically influences and transforms the others.

FOA is purely linear, where all phenotypic traits are defined by their firm's "design DNA" despite various expressions fitting the programmatic and location-specific requirements of various projects. Another research on nanomaterials in architecture and biology has been carried out.

These and other instances highlight numerous intertwining theories of the connection and inspiration between architecture and biological systems, from the superficial level to the depth of formation, which may be applied in a variety of research and Architecture and construction-related sectors.

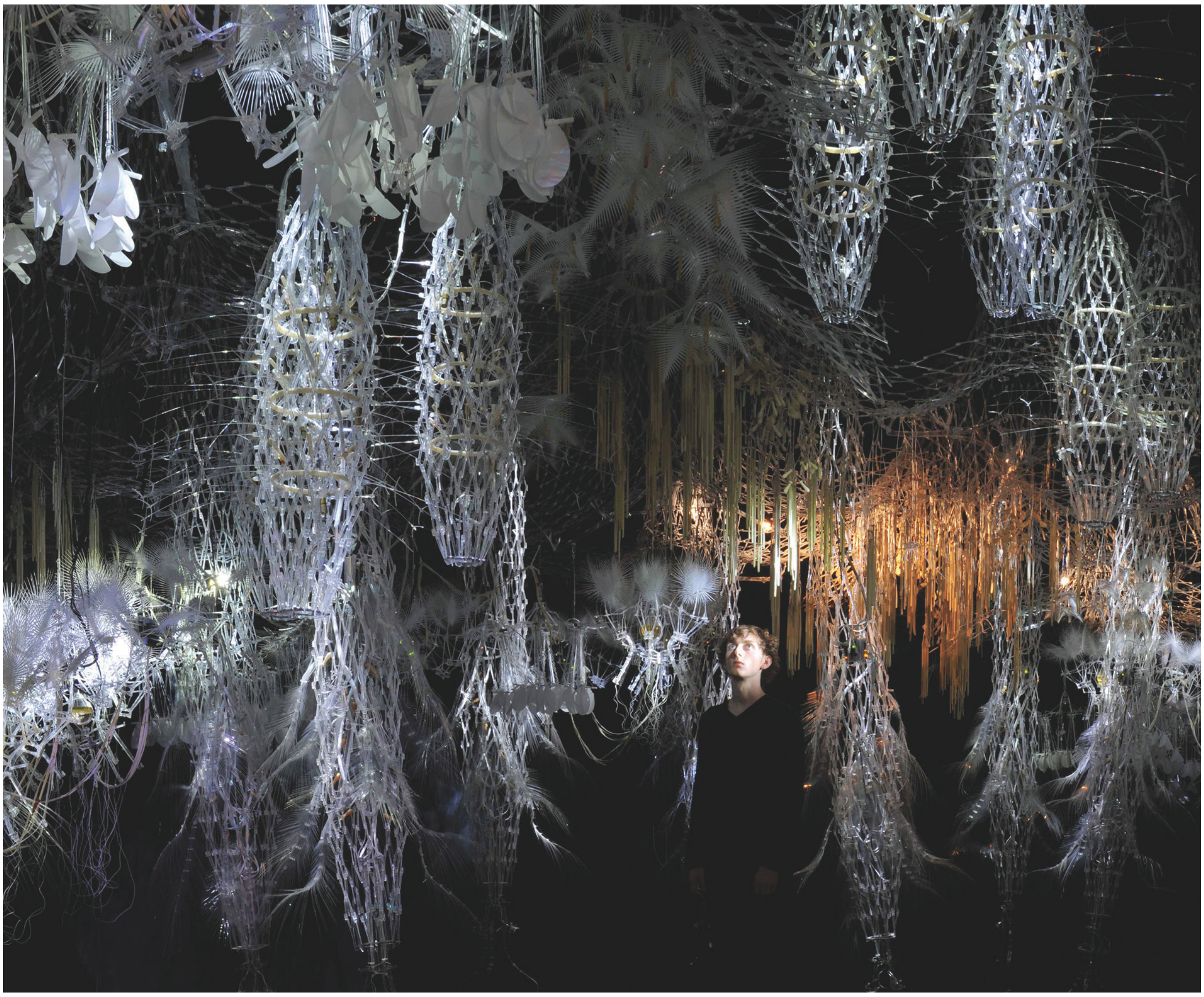


Fig.27: (Up)SynBioDesign , Hylozoic Ground, by Philip Beesley, at the Venice Biennale, 2010. Image by Philip Beesley,(Toronto: Riverside Architectural Press, 2014).

The person in the center-right provides a sense of scale to this interactive sculpture that moves in response to the motion in the room. The programming of acrylic fronds in Philip Beesley's sculptures to mimic human hand gestures are intended to evoke greater affect, empathy, and responsiveness in viewers of the works. Using effect to increase empathy in near-living architecture, by Ali-Akbar Samadani, Dana Kulic, and Rob Gorbet. From Near-Living Architecture.

Fig.28: (Right) Hylozoic Ground, by Philip Beesley, at the Venice Biennale, 2010. associated with graph leather.

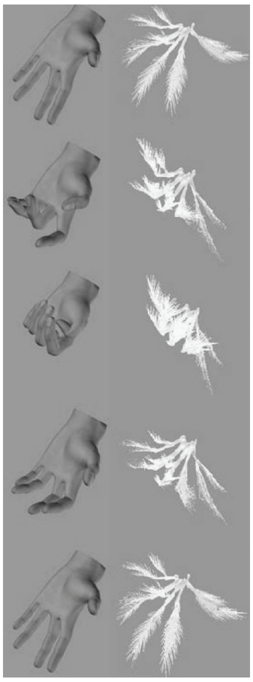
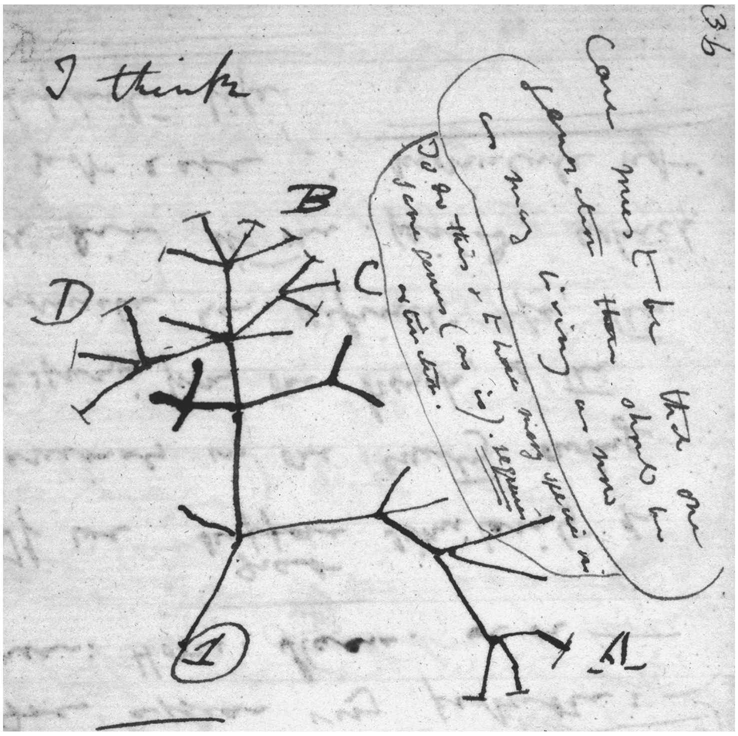


Image by Philip Beesley. Olive oil and water in this glass vessel, along with other trace chemicals and small infusions of Venice seawater and carbon dioxide exhaled by visitors to the installation, form pre-protocells.



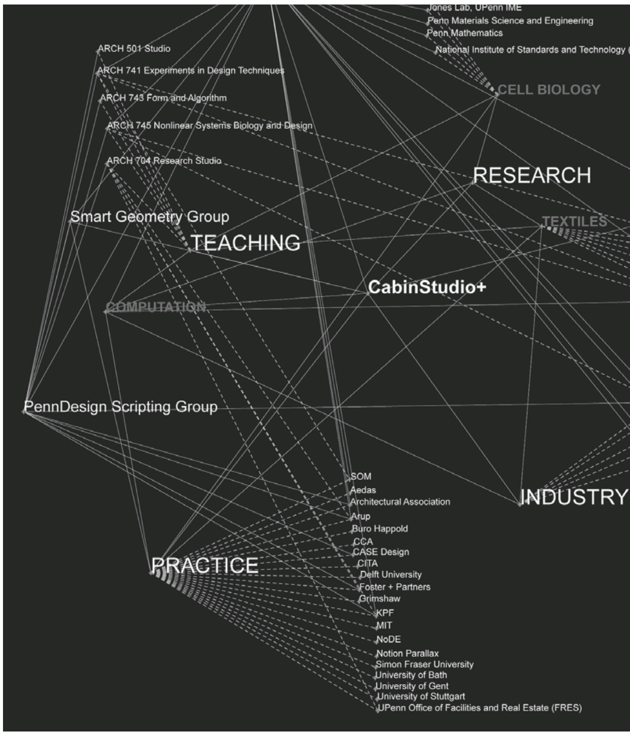


Fig.29: *Sketch, the tree of life, by Charles Darwin, 1837.*

The structure of the tree is based solely on vertical generational hereditary transmission, and it has a single trunk that successively branches outward, (DAR.121, p. 36).

Fig.31: *Jenny Sabin practice diagram, digita in Generative Components, 2008.*

Courtesy Jenny Sabin. In lieu of the normal linear CV reveals the multiple connections and crossovers l architectural practice, teaching, research, and work is of a web. (For comparison, see (Right); for contrast

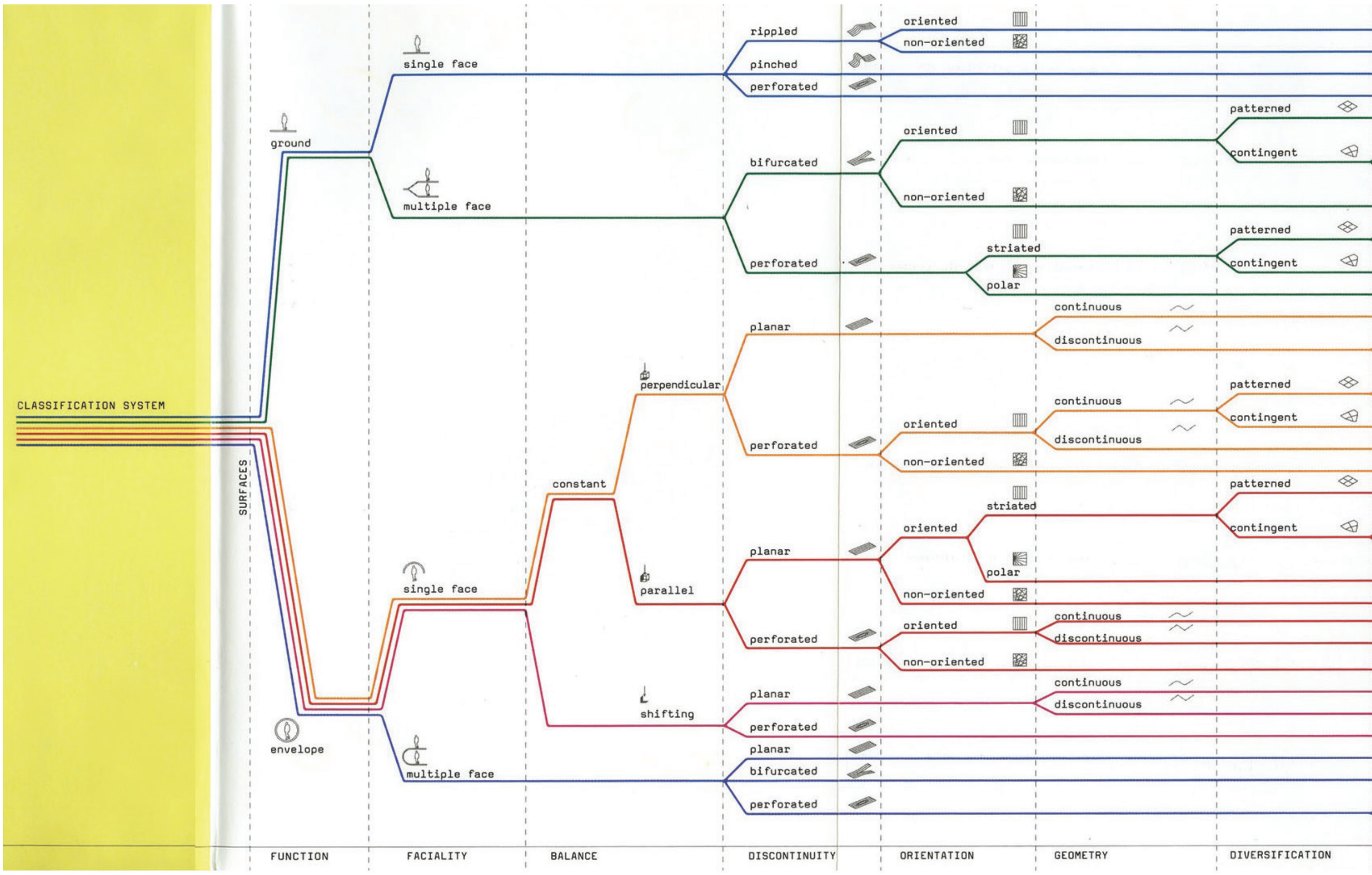
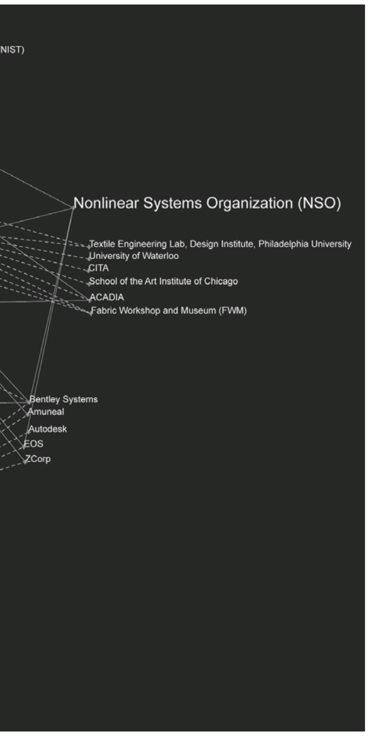
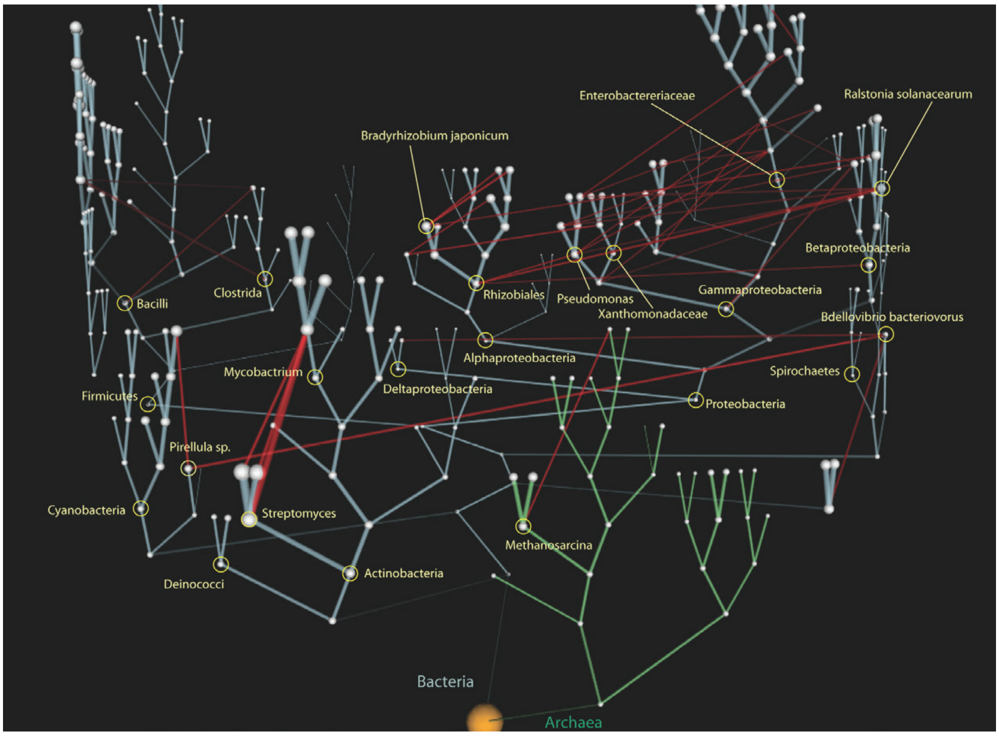


Fig.30: *FOA's phylogenetic tree diagram, (Barcelona: Actar, 2003).*

Inserted at the back of Michael Kubo and Albert Ferre in collaboration with Moussavi and Zaera-Polo, eds., Ph conceptual and linear branching structure as Darwin's tree of life (left).



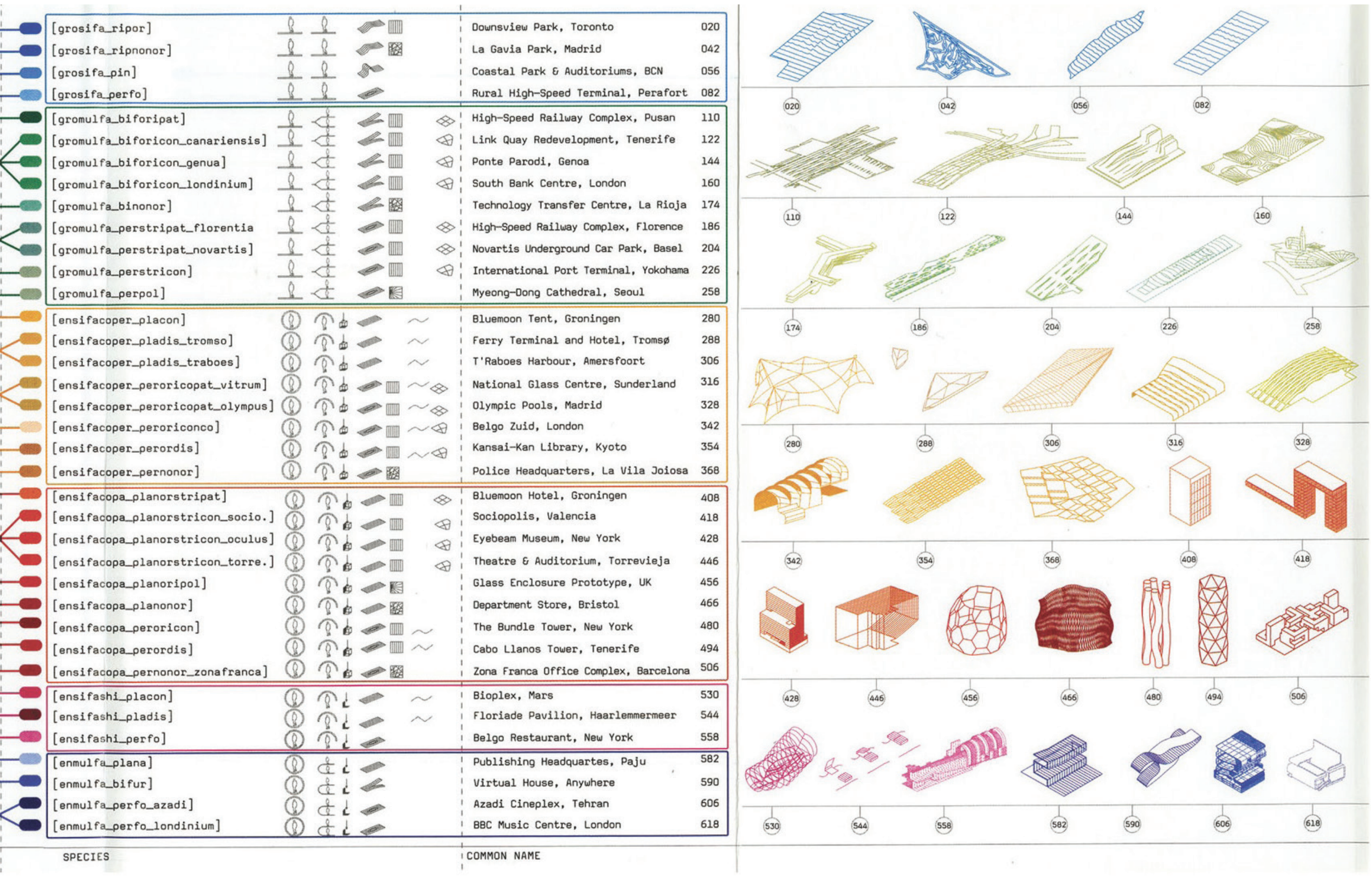


l curriculum vitae created

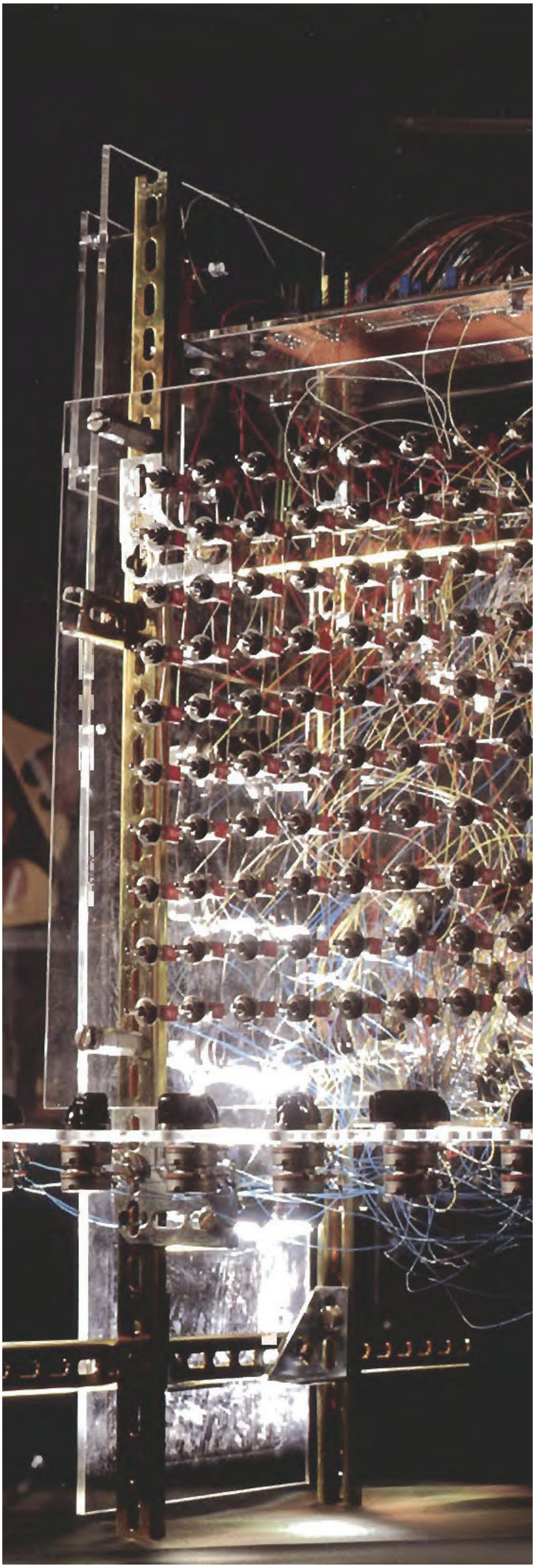
Fig.32: Horizontal gene transfer reconfigures microbial tree of life into a net of life by Victor Kunin, Leon Goldovsky, Nikos Darzentas, and Christos Ouzounis.

text to be read on paper, this between different facets of her for industry. The overall effect t, see Down)

The Netof Life: Reconstructing the Microbial Phylogenetic Network," Genome Research 15 (2005): 954–59, available at http://genome.cshlp.org/content/15/7/954. full. Color key: bacteria = cyan, archaea = green, horizontal gene transfer (HGT) = red.



ylogenesis: FOA's Ark (Barcelona: Actar, 2003). This diagram of FOA's architectural practice is based on the same



2•3 Evolutionary Architecture

According to Louis H. Sullivan in (the System of Architectural ornament), the germ is the seat of identity. Eventually, within its delicate mechanism lies the power and the function of which is to seek eventually to find its full expression in the form. Evolutionary Architecture investigates fundamental form-generating processes in architecture, paralleling a wider scientific search for the theory of morphogenesis in the natural world, It proposes the model of nature as the generating force for architectural form (Frazer 1995). The aim of an evolutionary architecture is to achieve in the built environment symbiotic behavior and metabolic balance that is characteristic of the natural environment (Holland n.d.).

2•3•1 Problems of Complexity

The 'sheer imponderable complexity of organisms' overwhelm us now as surely as they did Darwin in his time (Frazer 1995, 19). Complexity is a byproduct of nature's developmental processes, but they work with simple building pieces to introduce complexity in a hierarchical way, the coding of all natural forms in DNA is achieved with just four nucleotides. Owing to the precociousness of Alan Turing, In 1935 was concerned with a probability-related issue. He came up with the concept of a universal computing machine that is capable of performing any computable process by adhering to a set of logical instructions. likewise, a life surrounded introduces a very complex system that leads to the edge of chaos, and this is where our new architectural model begins (Cogdell 2019, 116).

Fig.33: *opposite: Experimental neural network, Computer: Miles Dobson, 1991.*

Neural network computers are intended to be more closely analogous to the human brain than conventional serial computers. The function of neurons is simulated by components that are arranged in a network, Several inputs represent synaptic connections that cause the neuron to learn to fire when a particular threshold signal level is reached. This model was constructed so that the logical structure, the switching the network, and the adjustment of the threshold levels could all be seen and understood.

The modeling of these complex natural processes requires computers and and continuous development of computing systems. A problem arose in the sixties when architecture start toying with new design processes, especially with a generic approach. Christopher Alexander dismissed the use of computers as a design aid, the same as a huge army of clerks, equipped with rule books, pencils, and papers.

As William Lethaby mentioned in his book (An introduction to the History and Theory of the Art of Building,1911) that "Modern builders need a classification of architectural factors irrespective of time and country, a classification by essential variation. Some day we shall get a morphology of the art by some architectural Linnaeus or Darwin, who will start from the simple cell and relate to it the most complex structures" (Lethaby 1911), we are now in the midst of a boom in evolutionary systems.

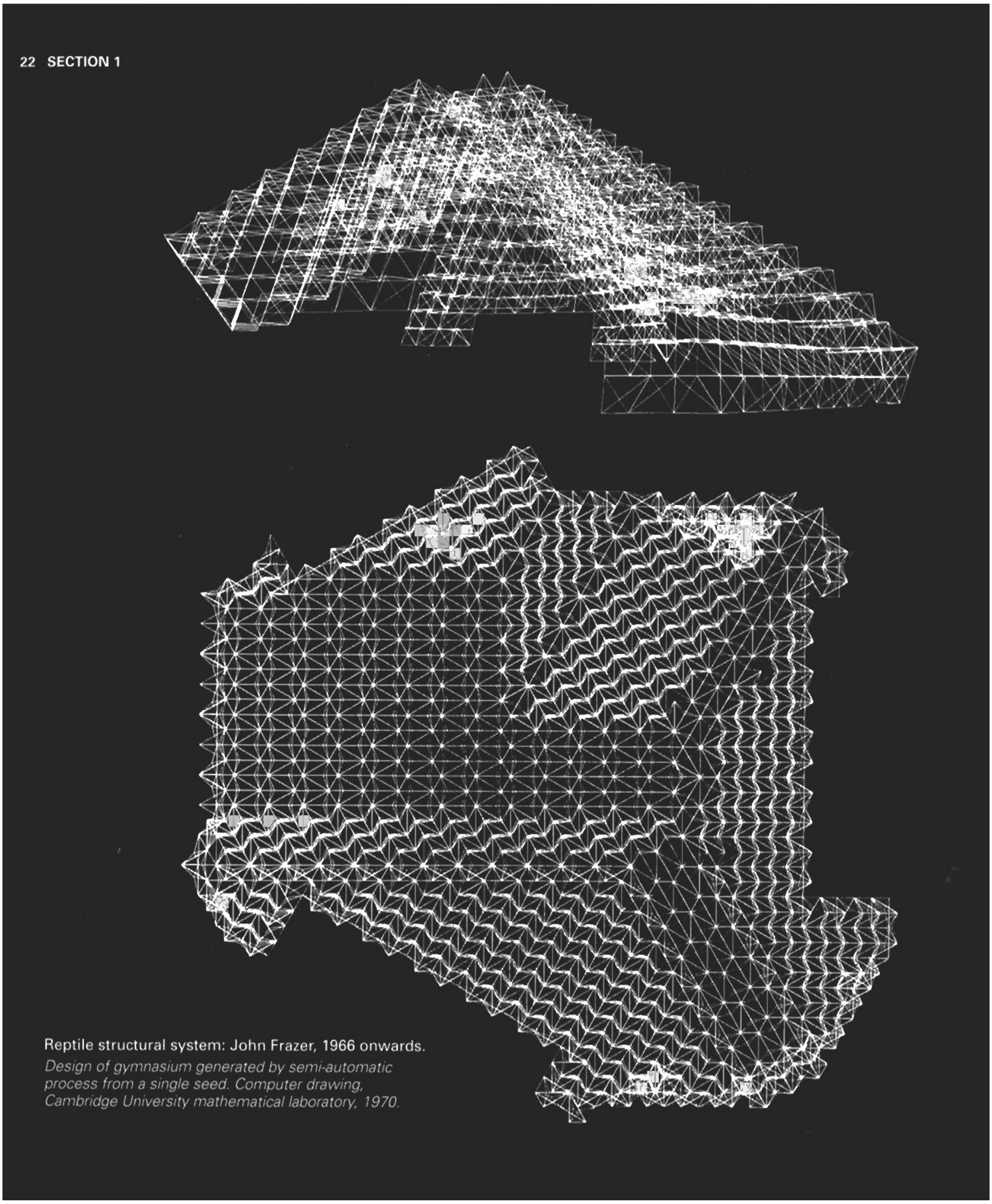
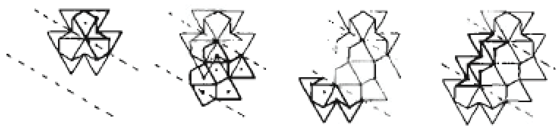


Fig.34: Reptile structural system: John Frazer , 1966 onwards.

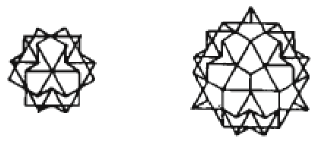
2•3•2 Evolutionary Techniques.

The simplest method to solve problems with computers is to measure a given performance and select the improved provided solutions while rejecting the remaining solutions. This is typical for optimizing already satisfactory solutions, in cases, the optimum solution does not exist, or a possible improvement may be radically different, more sophisticated techniques have to be developed, John Holland has developed a theoretical framework for an adaptive model which first requires a restatement of the biological position (Frazer 1995, 57). He defines salient characteristics of an adaptation as the gradual change of a given structure by the repeated action of certain operators thus chromosomes as the structure for genetics, mutation, and recombination as the operators. This forms the foundation of a mathematical formalism which defines a set of structures applicable to the field of interest using all possible combinations of these (chromosomes).

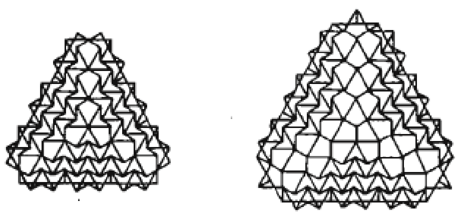
Structure of the program.



Automatic cutting and stretching.



The two seeds.



The two seeds starting their growth.

Fig.35: Reptile structural system, interactive computer developments: John Frazer, Richard Parkins. 1969

In the mathematical lab at Cambridge University, research on seeding methods was conducted. A set of developmental instructions were then given, allowing the seed of the structure system to be automatically developed and controlled in the computer to produce more sophisticated structural forms. The seed of the structure system was specified in a genetic computer code.

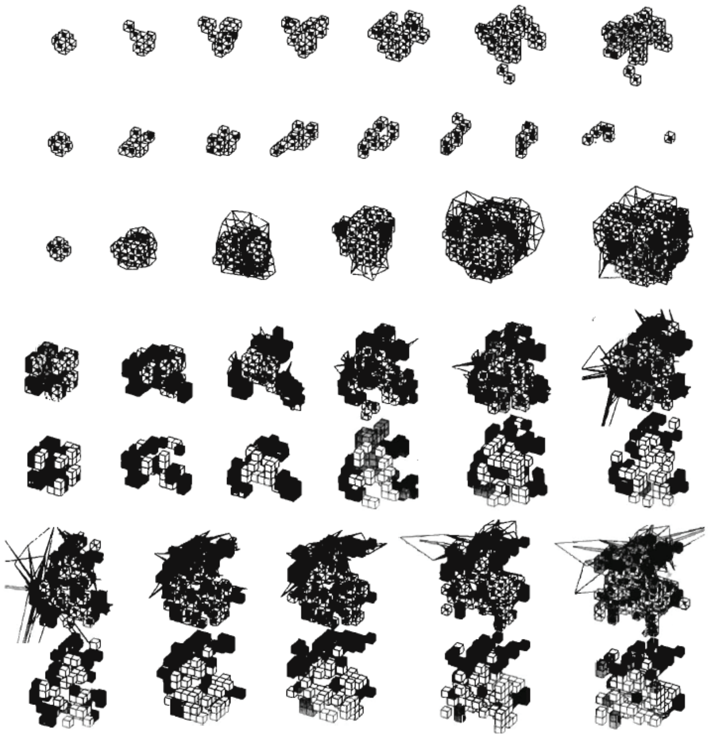
•Genetic Algorithms.

They are a class of highly parallel, adaptive, evolutionary search methods that are distinguished by a string-like structure equivalent to the chromosomes. The genetic algorithm technique was created primarily for problem-solving and optimization in situations where it was possible to state clearly both the problems and the criteria to be fulfilled for the successful solution. This method can be used to tackle issues whose intricate structures were not understood as well as to optimize and provide solutions that were not “imagined” yet.

Genetic Algorithms are a class of highly parallel, evolutionary, adaptive search procedures that were initially developed for scientific problems requiring search and optimization techniques with precise technical applications. They are characterized by a string-like structure equivalent to the chromosomes of nature. These serve as a coded representation of the criteria that govern the issue under investigation. They search employing populations of potential solutions as opposed to searching randomly or modifying a single potential answer, which makes them highly parallel searches. They are adaptive as well since optimum solutions are obtained by gradual changes over generations. then the selection comes according to a measure of fitness criteria.

Using classifier systems, the emphasis moves away from the search for one optimum solution to the production of a population that has learned to respond in an appropriate way to particular inputs. They are more appropriate to classes of learning problems than to optimization.

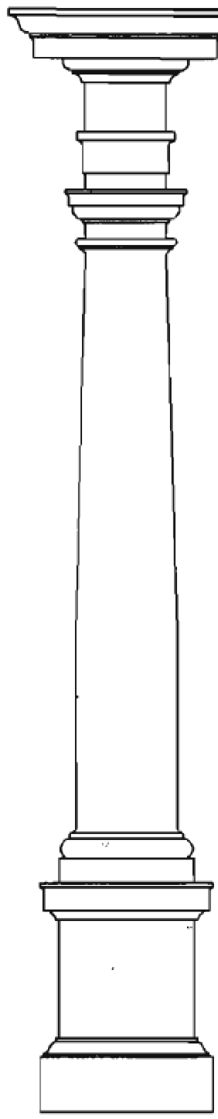
Fig.36: Three-dimensional self-organizing constructor : Ichiro Nagasaka. 1991.(Right)

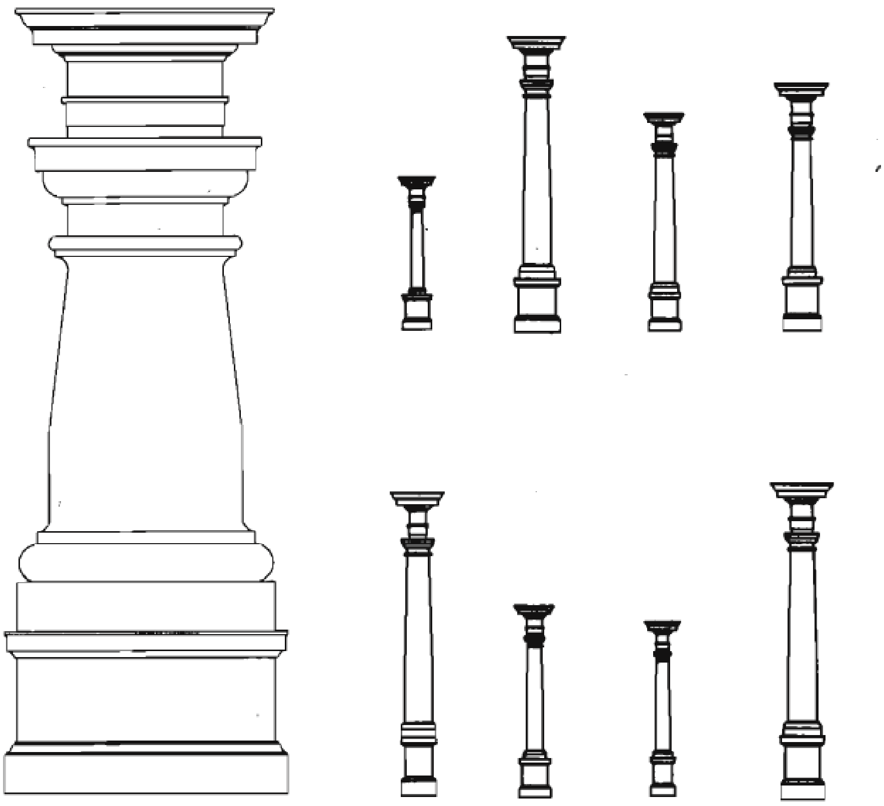


Similar to three-dimensional cellular automation, this self-organization experiment uses positive and negative feedback to change how adjacent cells interact. Instead, the interaction between cells depends on their comparison of the characteristics of their internal growth and their attempt to imitate successfully behavior.

Fig.37: Evolution of Tuscan columns by genetic algorithms: john frazer with peter Graham,1993 (Down).

Research at Ulster university used genetic algorithms to evolve proportional information. James Gibbs' rules for drawing Tuscan columns specify the ratios between all the parts of the column. The structure and the logic are programmed into the computer but a gene is substituted for each of the carefully specified proportions and a population of random mutants is generated. Selection could be by Nature or Artificial Selection. in the Nature (computer selects) for breeding the two columns closest to Gibbs' ratio





2•4 Optimization as an AI implementation

All prior developments are viewed as a continuation of what started out as computing applications in architecture in the 20th century. One of the earliest computer applications in the twenty-first century is ***Artificial Intelligence (AI)*** which will have a huge potential to introduce as Alan Turing wrote for his experiments that “This is only a foretaste of what is to come, and only a shadow of what is going to be”.

Even though we may not be aware of it, AI is now a significant part of our life. AI recognizes our social media activities and using information from our online history, it feeds us news and adverts. as It provides us with preferred movies and music. moreover all the assistants on our smart devices are depending on AI. Also, it could control our homes as it monitors our heating checks, and the quality of the water controls different devices, and organize our lives.

Therefore, AI is already having a major impact on Architecture. As it still in the academic circles, where AI has burst onto the scene in design studios in certain progressive schools of architecture. Inspirational images of buildings and urban design proposals are now being generated automatically. Additionally, it is beginning to affect innovative architectural practice. A growing number of well-known architects are beginning to apply innovatively AI-based methods to their design processes. Thom Mayne, the recipient of the Pritzker Prize and founder of Morpho-sis, has started to investigate how AI might expand the variety of design alternatives. It has been utilized by Wolf Prix of Coop Himmelb(l)au to enhance the design process. In the meantime, Patrik Schumacher of Zaha Hadid Architects (ZHA) has employed it to mimic how people would behave in one of his buildings (leach 2022, 15) .

Fig.38: Daniel Bolojan, Machine Perceptions: Gaudí + Neural Networks (2020)

To transfer one domain’s style to another, but rather to transfer one domain’s underlying compositional characteristics to another domain. The neural network learns to discriminate towards less relevant compositional features while enhancing the relevant ones, in a similar way to how humans learn, by sorting and filtering irrelevant information (leach 2022, 16) .

Human-level Intelligence is limited as it does not constitute the absolute pinnacle of intelligence. After all, there are already domains in that AI outperforms human intelligence as it has a great potential to exceed humans. Alternatively, AI research could define as an attempt to understand intelligence itself.

AI typically uses learning and problem-solving to complete tasks. However, not all of these tasks need intelligence, thus it's important to distinguish between AI and human intelligence. AI does not currently have consciousness, at least not yet. Realizing this is crucial. For instance, artificial intelligence (AI) could be able to defeat humans in a game of chess, but this does not necessarily entail that AI is aware that it is playing chess.

The attempt to imitate or simulate human intelligence is a typical definition of artificial intelligence (AI). "AI attempts to make computers do the kinds of things that minds can do," as Margaret Boden puts it. In the longer term, AI is likely to exceed the intelligence of the human mind. The following classification includes the main branches of AI applications linked to the Optimization process as part of Genetic Algorithms, which in turn are part of Unsupervised Learning / Machine Learning.

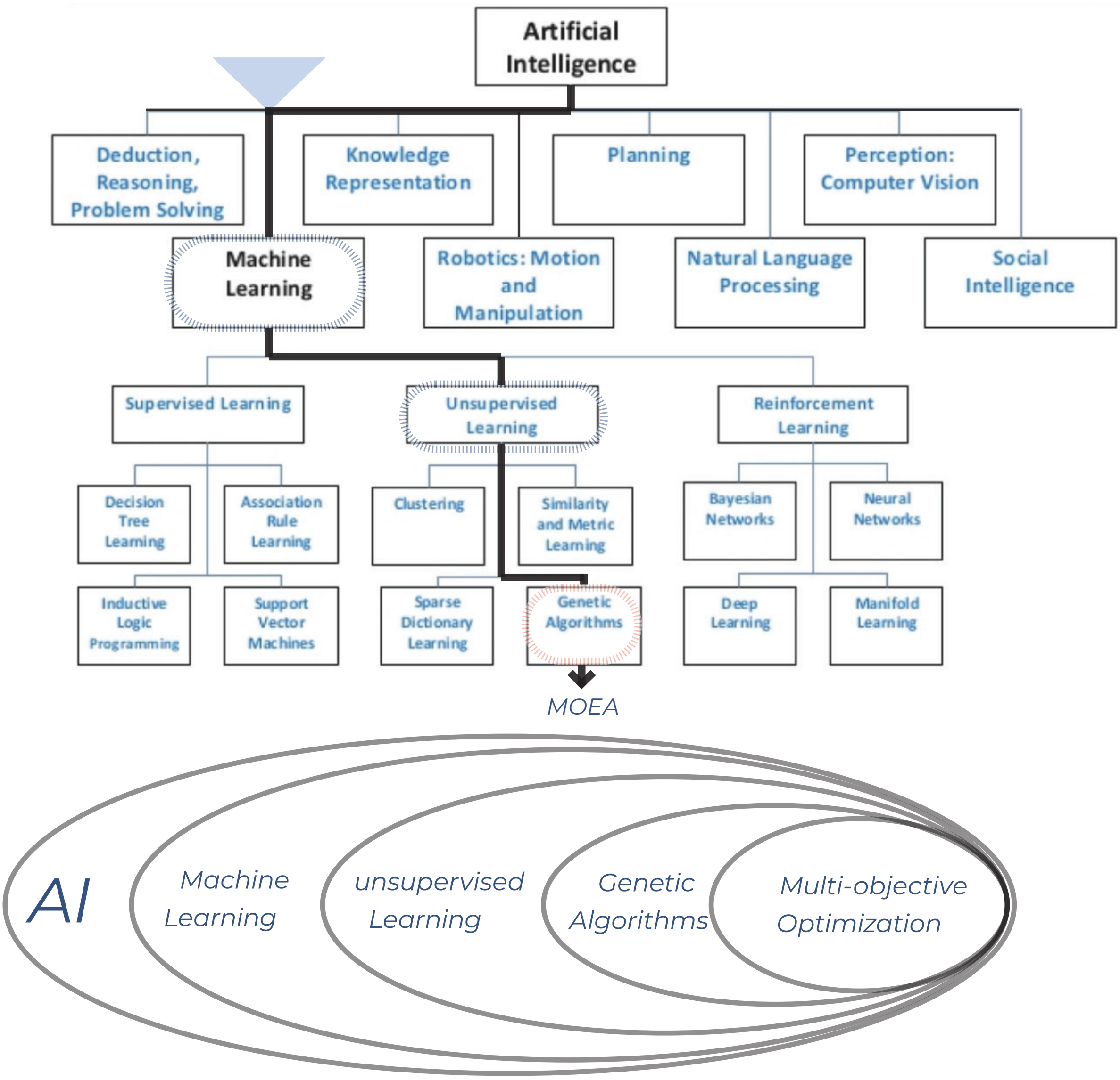


Fig.39: Artificial Intelligence (AI) classifications and the relationship between evolutionary optimization / Genetic Algorithms. (Nazre and Garg 2015, 3)

•OPTIMIZATION

Compared with the conventional architecture design methodology, the performance-driven architectural design emphasizes integrated and comprehensive optimization to maximize its impact (Shi and Yang 2013), this methodology should be used from the early design phase. However, optimization can introduce high-performance techniques as it is becoming a popular exploratory tool as well with the advantages of its original purpose as a precise problem-solving tool.

The idea of optimization is to get the primary objective to fulfill one or more given criteria by finding the best solution or the most advantageous set of alternatives. many related odds objectives must be maximized or decreased to address most problems in the actual world, which makes it contradictory. in such a setting, it is more difficult to define all of these at-odds objectives in terms of a single objective using the single-objective optimization (SOO) approach. One approach to getting around this limitation is multi-objective optimization (MOO). It can be quite challenging to solve optimization problems with many (often conflicting) objectives.

2•4•1 Multi Objective optimization.

Evolutionary Algorithms (EAs) were initially developed in the mid-eighties to stochastically address issues belonging to this generic class. A variety of multi-objective optimization (MOO) problems and certain related concepts, present and evaluate MOEA classification schemes (Figure 40). Currently, the MOEA evaluated specific topics including fitness functions, Pareto ranking, niching, fitness sharing, mating restrictions, and secondary population (Veldhuizen and Lamont 2000).

A lot of scientific disciplines including engineering, economics, and logistics have embraced multi-objective optimization to help them make optimal decisions when there are trade-offs between two or more conflicting goals (Abraham, Lakhmi, and Goldberg 2005).

The first step in performing a MOO is to formulate the problem appropriately. A MOO problem is defined by four parts: a set of decision variables, objective functions, bounds on the decision variables, and constraints. Since objectives can be either minimized or maximized to find a set of optimal solutions that satisfy involved constraints (Nagy, Mansour, and Abdelmohsen 2020).

•MOO Problem Representation

Since changes in objective values with changes in design variable values are expected to be different for various purposes in MOO, each objective has its own fitness landscape. Objectives often conflict with one another, making it possible for solutions to one problem to exacerbate values in another. Because the solution that produces the biggest peak in the fitness landscape for one aim may also produce the lowest peak for the other objective, and vice versa, it is less evident which

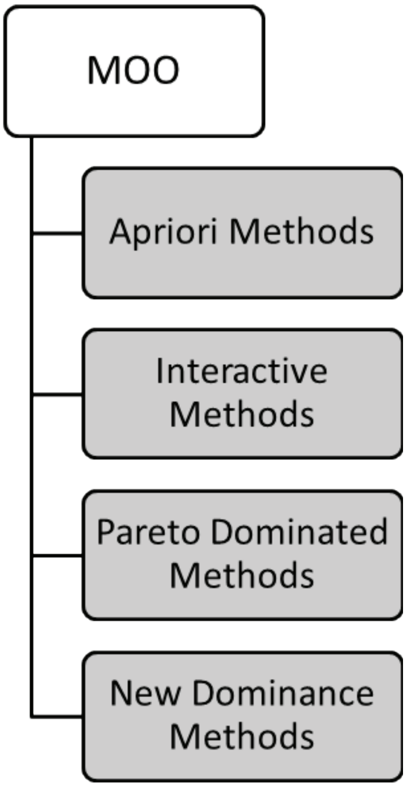


Fig.40: *Multi-objective optimization methods*

solutions are superior to others. In these circumstances, the concept of dominance is used to establish whether a solution is best. Unlike SOO problems, where the superiority (optimality) of a solution over other solutions is easily determined.

•MOO Problem Solution

Finding a single solution to a Moo issue that simultaneously maximizes all of its objective functions is unusual and ideal. As a result, the term “optimality” in this context has a different meaning. Instead of finding a single solution, a MOO issue solution seeks to identify good compromises or “trade-offs” of competing objective functions in an optimal way.

The notion of optimality for MOO problems that are most frequently used in mathematics was first put forth by Francis Ysidro Edgeworth and later generalized by Vilfredo Pareto under the name Pareto optimality.

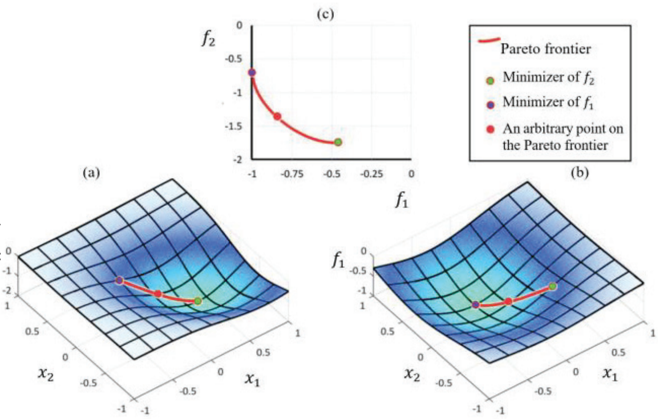


Fig.41: *Illustration of the relationship between (a) the fitness landscape of objective 1, (b) the fitness landscape for objective 2 and (c) the Pareto frontier (Nagy,2020).*

For a given set of solutions in the design space, where the set of all possible combinations of design variables exists, the non-dominated solution set is a set of all solutions that are not dominated by any other member of the solution set. The non-dominated set of the entire feasible design space is called the Pareto-optimal set which represents a complete set of Pareto-optimal Solutions. They are trade-off solutions for which any improvement in one objective results in the worsening of at least one other objective. The boundary defined by the set of all points (Pareto-optimal points) mapped from the Pareto-optimal set to the feasible objective space is called the Pareto-optimal front or Pareto frontier (Nagy, Mansour, and Abdelmohsen 2020) .

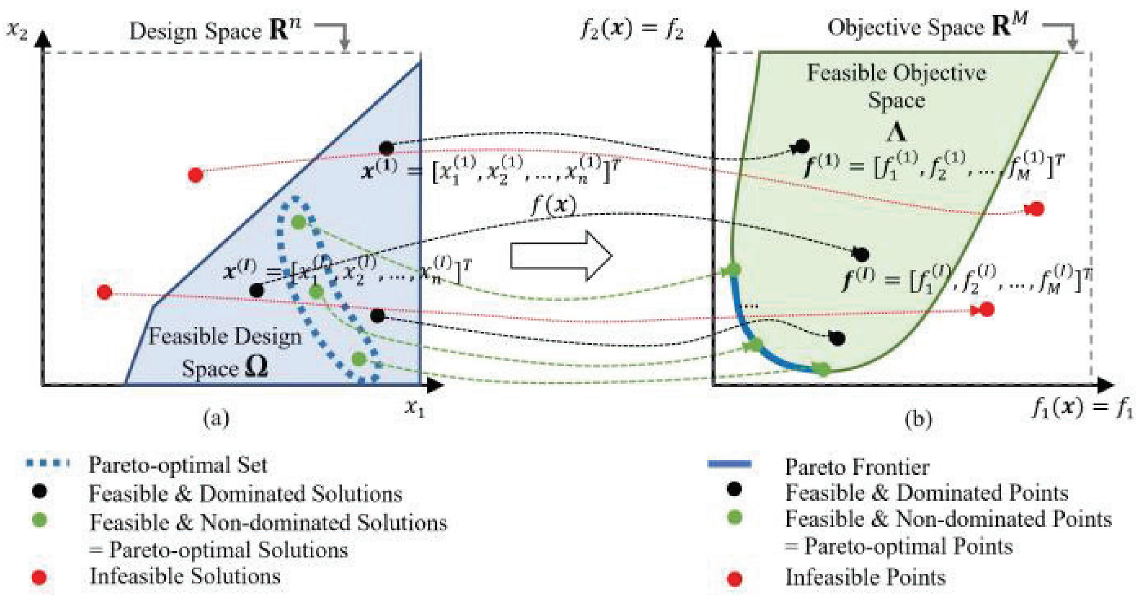


Fig.42: *Graphical depiction (mapping) of (a) a decision space onto (b) an objective space, where both objectives are to minimize (Nagy,2020).*

POLITECNICO

HIGHLIGHTS : #Inspiration
#Design
#Units

DESIGN PROPOSA

CHAPTER III

0 3

MSC THESIS

AL

ARCHITECTURAL
COMPUTATIONAL
SUSTAINABILITY

3. DESIGN PROPOSAL

“Those who can imagine anything, can create the impossible”

Alan Turing 1912 - 1954, (UK).

This chapter aims to design the (UNIT) that form the basis of the envelope. The Unit is the envelope or the facade panels which has different technological aspects allows it to manage and treate different scenarios, the unit charactersitics should adapt the means of mass customization product of a low-cost manufacturing, the design needs to be fully automated with interchangeable parts, a moving assembly line and machinery systems (Koren 2010, chap. 4). To apply such principles this chapter propose a design developed along two main avenues: (1) Unit structure and (2) Studied feature with a prior overview of the source of inspiration.

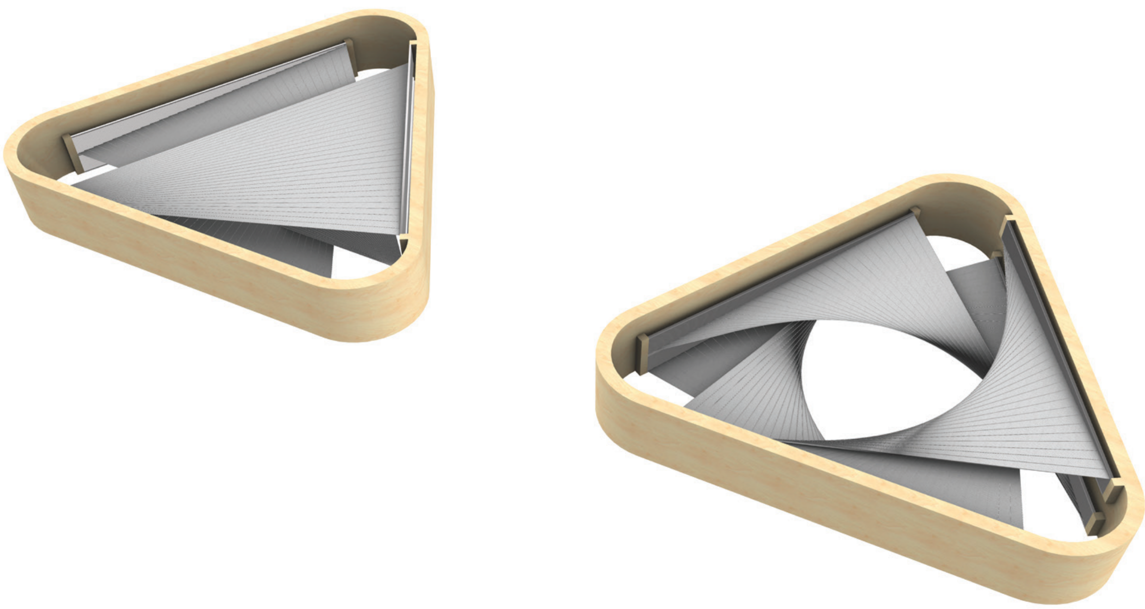


Fig.43: *The Adaptive innovative trainary unit (Fully opened and fully closed) (Authors).*

3•1 Sources of Inspiration

As explained previously, there are many biomimetic patterns and ways of inspiration from nature. The following samples were adopted on its principles and inspired by them during the study of the research project, all of them we can conclude in one term of (Systematic Context-Sensitive)

•Adaptive radiation

Evolutionary radiation is a theory indicating an increase in taxonomic diversity that is caused by high rates of speciation, which may or may not be accompanied by an increase in morphological difference. Radiations may affect one clade or many, and be rapid or gradual, where they are rapid, and driven by a single lineage's adaptation to their environment, they are termed adaptive radiations (Figure 44).

Perhaps the most familiar example of an evolutionary radiation happened about 66 million years ago, is that of placental mammals were mostly small, insect-eating animals similar in size and shape to modern shrews, then they had evolved into such diverse forms as bats, whales, and horses.

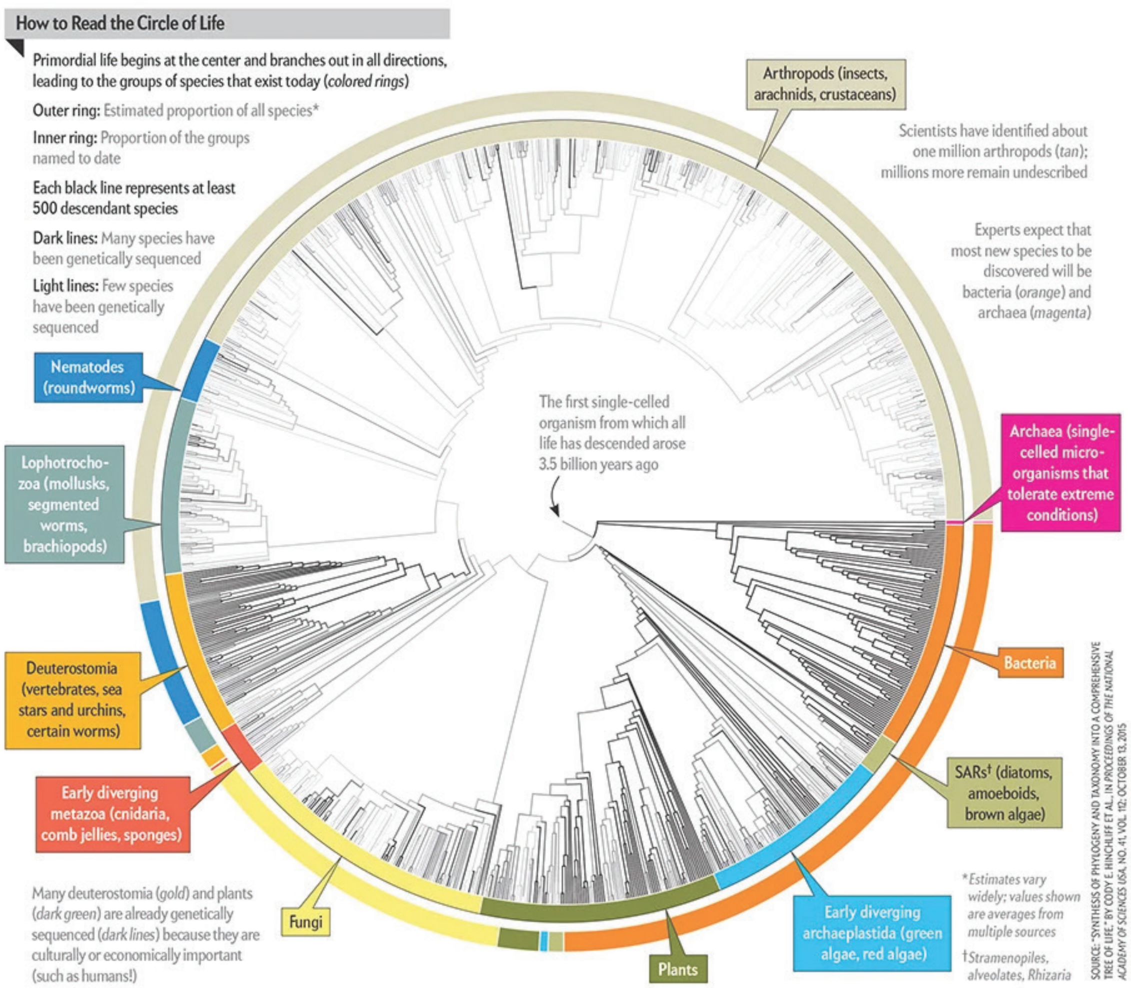


Fig.44: *"The Circle of Life" in Scientific American 314, 3, 76 (March 2016)*

Adaptive radiation

Adaptive radiation is a rapid increase in the number of species with a common ancestor, characterized by great ecological and morphological diversity. The driving force behind it is the adaptation of organisms to new ecological contexts.

Biologists added branches to countless trees that represent various areas of the animal, plant, and microbial kingdoms to illustrate how new organisms evolve from older ones since Charles Darwin's time. Recently, a three-year project by researchers from a dozen institutions to merge tens of thousands of trees into one diagram, best readable as a circle, was finished (Figure 45).

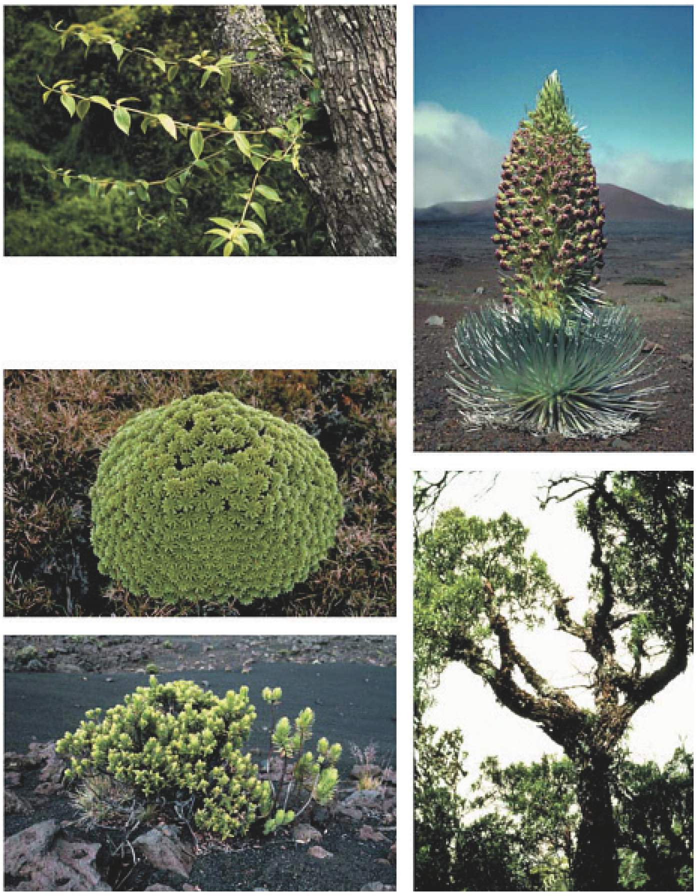


Fig.45: *Descendants of a single ancestral plant species evolved into many different forms in Hawaii.*

Collectively called the silversword alliance. Counterclockwise from above, a vine, mat, shrub, tree, and the silversword plant.(National Academies of Sciences, Engineering, and Medicine. 2004).

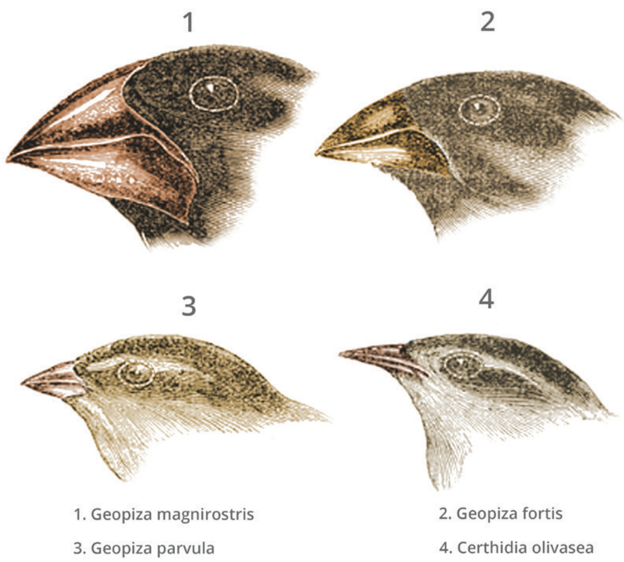


Fig.46: *Species of Hawaiian honeycreepers descended from a common ancestor, have evolved many different bill shapes and food sources.(National Academies of Sciences, Engineering, and Medicine. 2004).*

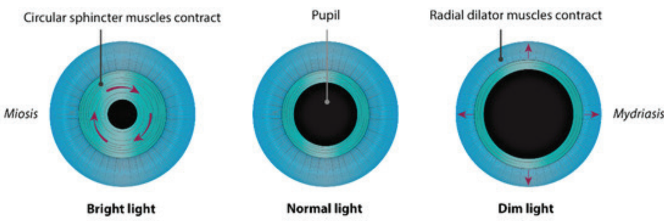


Fig.47: Iris muscles and adaptation of pupil aperture to light intensity (Angée et al. 2021).

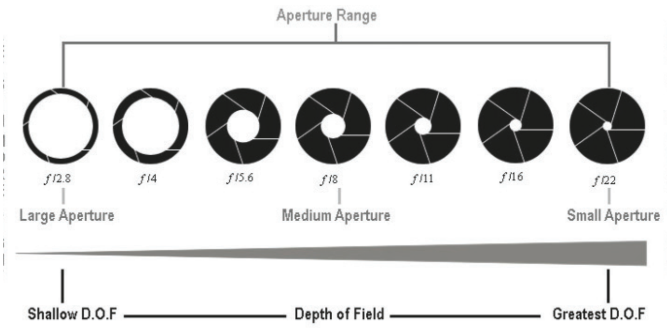


Fig.48: Camera Aperture (Shutter): Inspired from iris.

F it is the opening in the camera lens that regulates the amount of light reaching the film. The aperture may be fixed in size or adjusted by a diaphragm. ReddevilPhotography.

• Iris

The iris in humans is the coloured (typically brown, blue, or green) area, with the pupil (the circular black spot) in its centre and surrounded by the white sclera It's a small, annular structure in the eye that regulates the pupil's size and diameter, hence determining how much light reaches the retina. The iris's colour determines the colour of the eye. In terms of optics, the iris is the diaphragm, and the pupil is the eye's aperture.

According to medical definition, iris is a flat ring-shaped ocular membrane located between the cornea and the lens. Its root is attached to the corneoscleral junction on the anterior side and the ciliary body on the posterior side, next to the lens, and its center is perforated to form the pupil. The iris is composed of a stroma, bilayer epithelium, and two smooth muscles that work in opposition to adapt the pupil aperture to light intensity. The circular sphincter muscle lies within the stroma, near the pupil margin, and can constrict the pupil in miosis. The dilator muscle extends longitudinally within the stroma, from the iris root to below the midpoint of the sphincter , and can

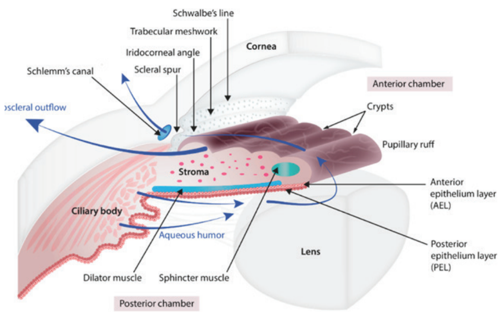


Fig.49: Anatomy of the iris, ciliary body, and aqueous humor pathway.

The iris is organized into four layers (from the visible surface layer to the posterior region next to the lens): anterior border layer, stroma, and sphincter muscle, the lightly pigmented anterior epithelium layer (AEL) and dilator muscle, and the heavily pigmented posterior epithelium layer (PEL) (Angée et al. 2021).

contract to expand the pupillary aperture in mydriasis (Angée et al. 2021)

As (Figures 47, 49) show, iris muscles and adaptation of pupil aperture to light intensity. The circular sphincter muscle (pupillary constrictor), near the pupil margin is composed of smooth muscle cells, which can constrict the pupil (miosis) when exposed to bright light. It functions in opposition to the muscle fibers of the radial dilator, whose contraction widens the pupillary aperture (mydriasis) under low light.

•Helix of Cyclone

A tornado is a violently rotating column of air, that is in contact with both the surface of the Earth and a cumulonimbus cloud or, in rare cases, the base of a cumulus cloud. It is often referred it to twister or a hurricane. A cyclone is a severe type of tropical storm. the recalling part here is the form of them which accelerate the wind through the spiral flow in both cyclones or tornados. The idea of wind turbines depends on the same shape to accelerate the air and move the blades to enhance the turbine design. Engineers adapt new axis wind turbines that optimize wind energy capture capabilities and decrease noise. As the (Figure 51) shows, a helical twist of the vertical blades to optimize wind capture with some structural advances.

The Darrieus turbine (Figure 51), which UGE chose, features two or more parabolically shaped airfoils oriented in the same direction as the turbine axis “We wanted to make a turbine that is efficient, quiet, durable, has little vibration and looks good,” Blitterswyk (The designer) recalls.

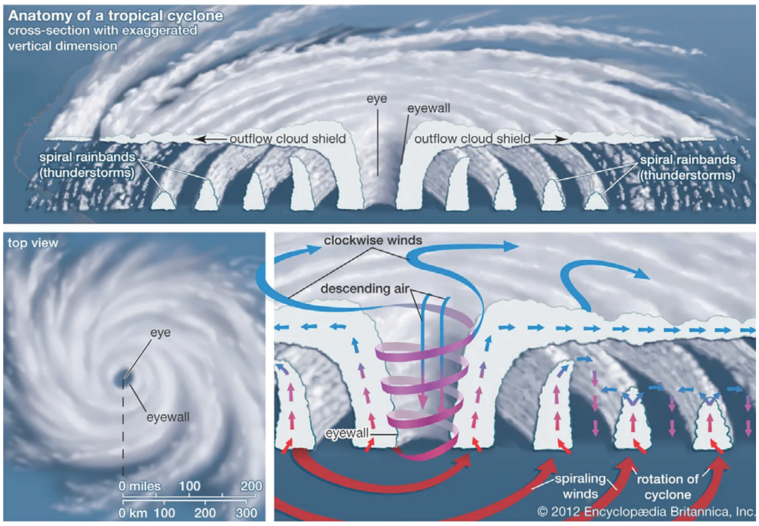


Fig.50: *Infographic showing the anatomy of a tropical cyclone. (Encyclopædia Britannica, Inc).*

Fig.51: *UGE’s innovation is the helical blade design, which adds aesthetic appeal.*

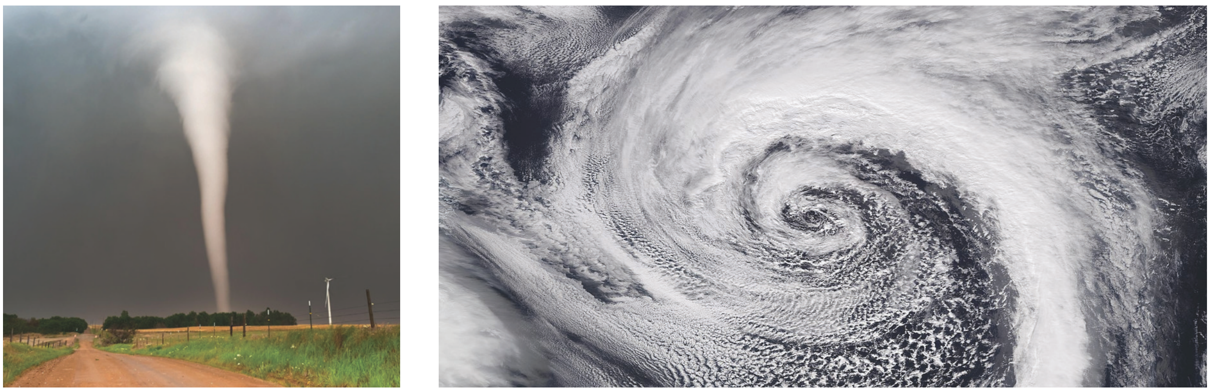


Fig.52: *Tornado (Left), Tropical cyclone (Right), MedlinePlus.*

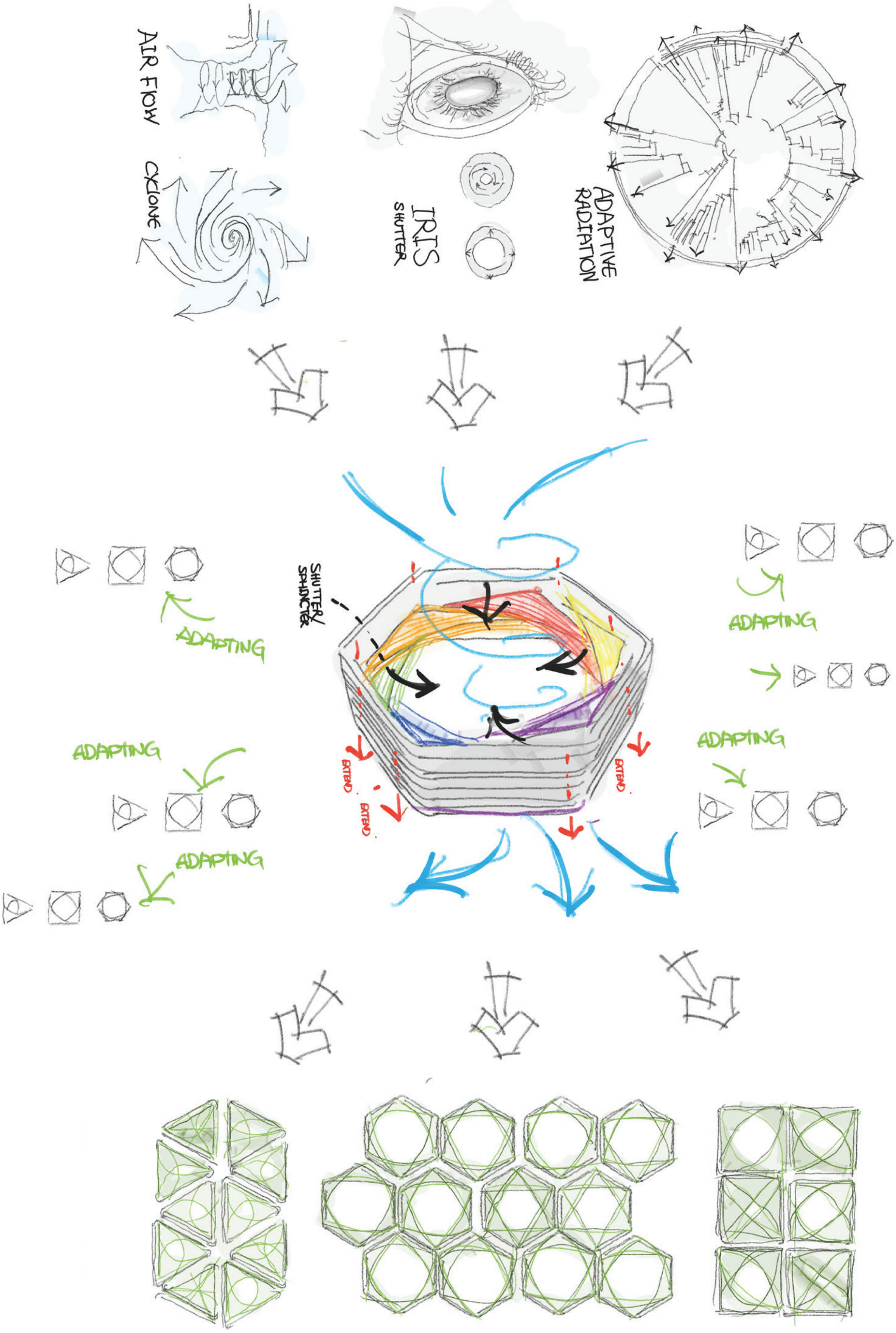


Fig.53: *INSPIRATION to A PRODUCT, schematic diagram of the concept, to translate the biomimetic imitation to a unity product. (Authors)*

3•2 The Unit (Envelope Unit)

Moving from the inspiration part to the design process, the research targeted to design an innovative envelope unit to be the base of a contextually adaptable building's envelope. This unit should be designed to manage the various user-targeted scenarios and different envelope formulations in order to improve the practical envelope design model.

3•2•1 Unit Potential

The design of the unit itself needs to gather a lot of features that could affect the performance of the building, especially the indoor environment. Also, the design should be subject to the frameworks of industrial production and mass customization, which means that it should be able to fit any shape of facade or envelope.

For that, the research developed a conjoined system inside (The Unit) that can adopt eight main aspects: Thermal, Visual, Solar, Acoustical, Form, Life cycle assessment, Computational fluid dynamics, and Energy. These aspects are mainly the factors that directly affect the quality of the internal space (Indoor Environmental Quality (IEQ)) which will be discussed further in the next chapter besides another important aspect like the Form and LCA.

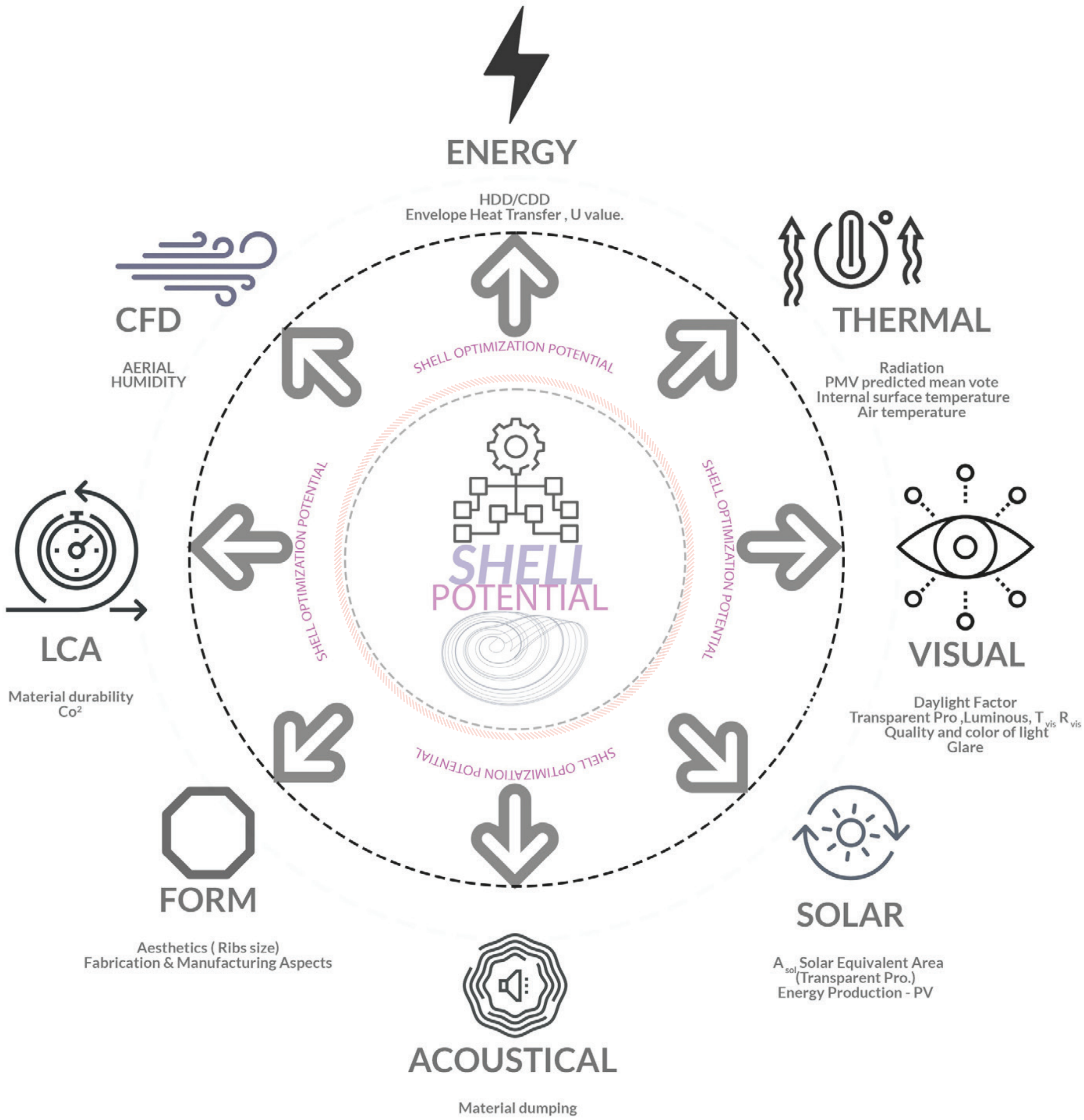


Fig.54: Unit Potential: eight main aspects to mainly handle IEQ. (Some will only studied as individual objective and others will enter the optimization process)..

3•2•2 Unit Structure

The envelope unit must be versatile and adaptable amongst many possibilities with the scope of digital investigations, simulations, generative outputs, and the shape itself to be aesthetically pleasing to the user. Therefore, the idea is to create a pattern or a sequence to build the shape of the unit, this pattern or sequence must be applicable to any regular geometric shape, which will be the base (unit) for the entire envelope as the brick is the basic element for constructing a full wall.

To clarify the unit's structure logic which is based on a layered installation consisting of several moving and fixed parts on the polygon ribs, this installation sequence could be delivered in any number of ribs, an example of the Trinary case (Plan Triangle shape) unit as shown in Figure 55 with its shutters (curtains) in the fully opened and full closed positions.

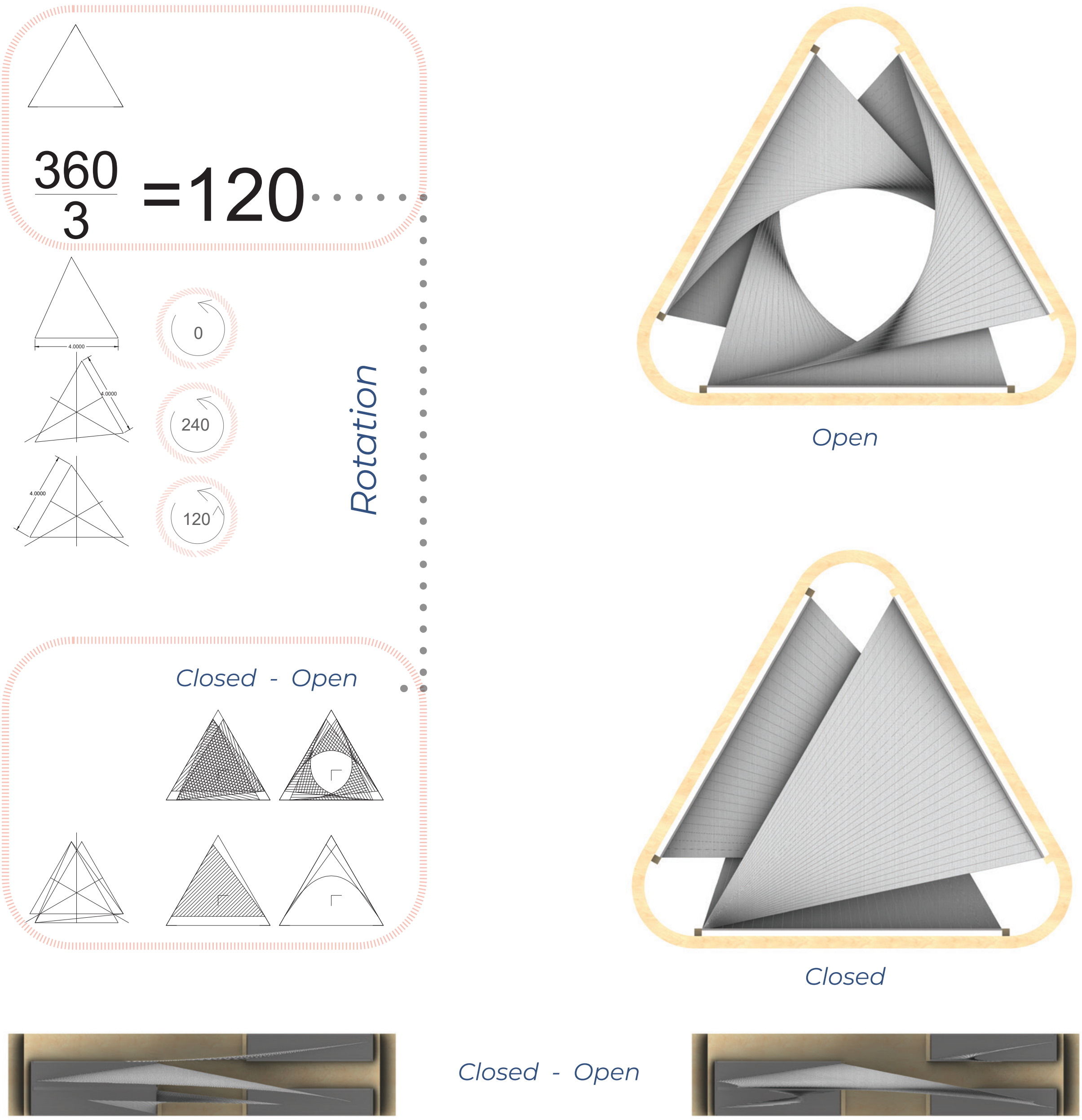
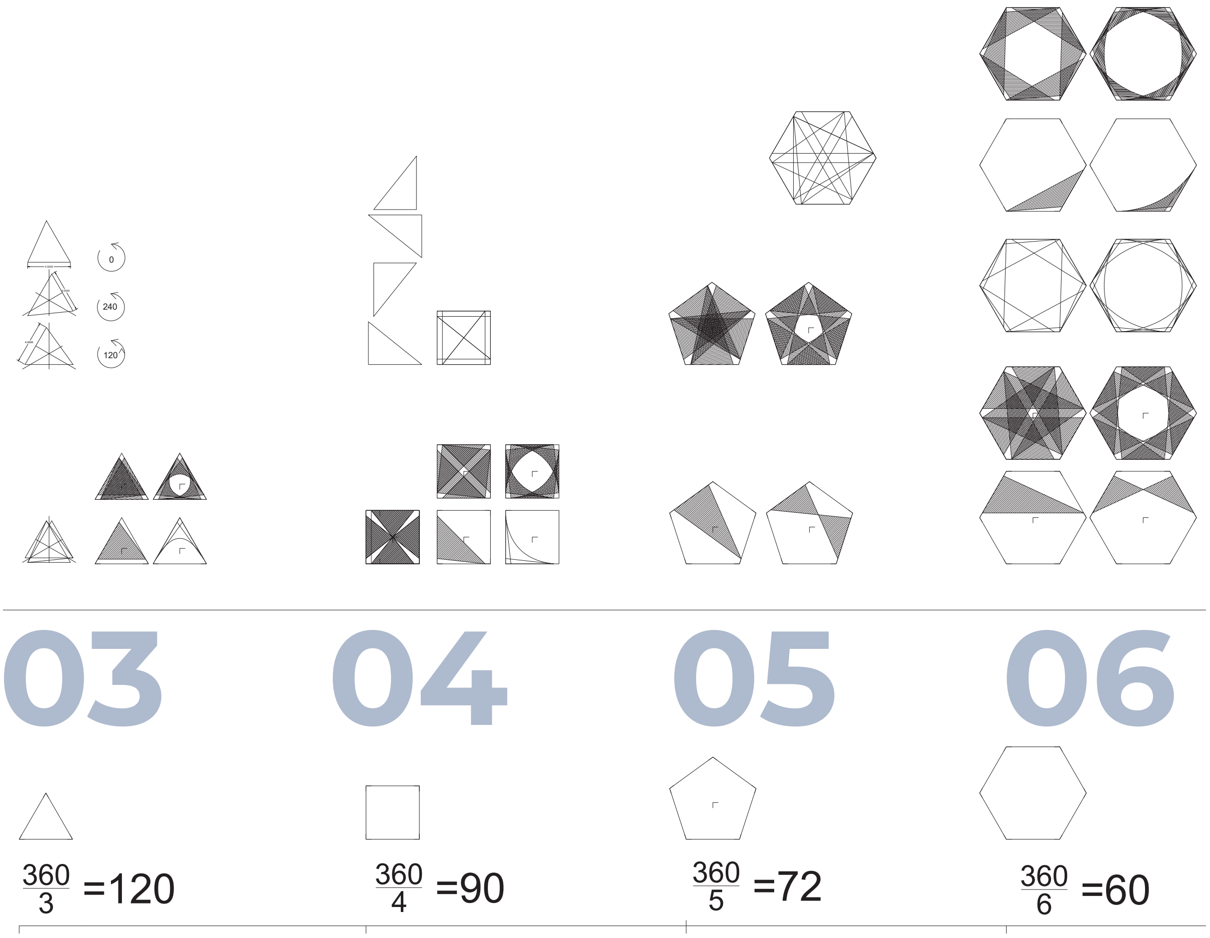


Fig.55: Trinary case (Trinary unit) structure logic and components - plans and sections.

•Structure logic

The structural logic of the unit creation could be applied to any polygon shape and any ribs numbers as it regular and complete a closed range of radial degrees. to understand this logic; first of all, divide the complete range of 360 degrees by the polygon ribs number to have the value of the rotation, and then connect two contiguous ribs with a linked curtain to two followed layers, one side is fixed to the polygon rib and the other has the ability to move across the other rib on a (rail) which allows this specific curtain to move and open or close the (Shutter). Finally rotate this (connected curtains with its rails) and repeat these curtains in their closed or moving position on the polygon frame accordingly in followed layers where could every movable curtain side overlap the other curtain fixed part till it covers all the range of 360 degrees as (figure 56) shows.

Thus this pattern is repeated whenever the number of sides increases or decreases, which makes it possible to transform this logic into a mathematical algorithm. After checks, the research found that the effectiveness is limited after Hexagon so the selection settled on the Triangle, Quadrilateral and hexagon units of the design proposals and developing them to be self-contained units that represent the basic element of the building envelope.

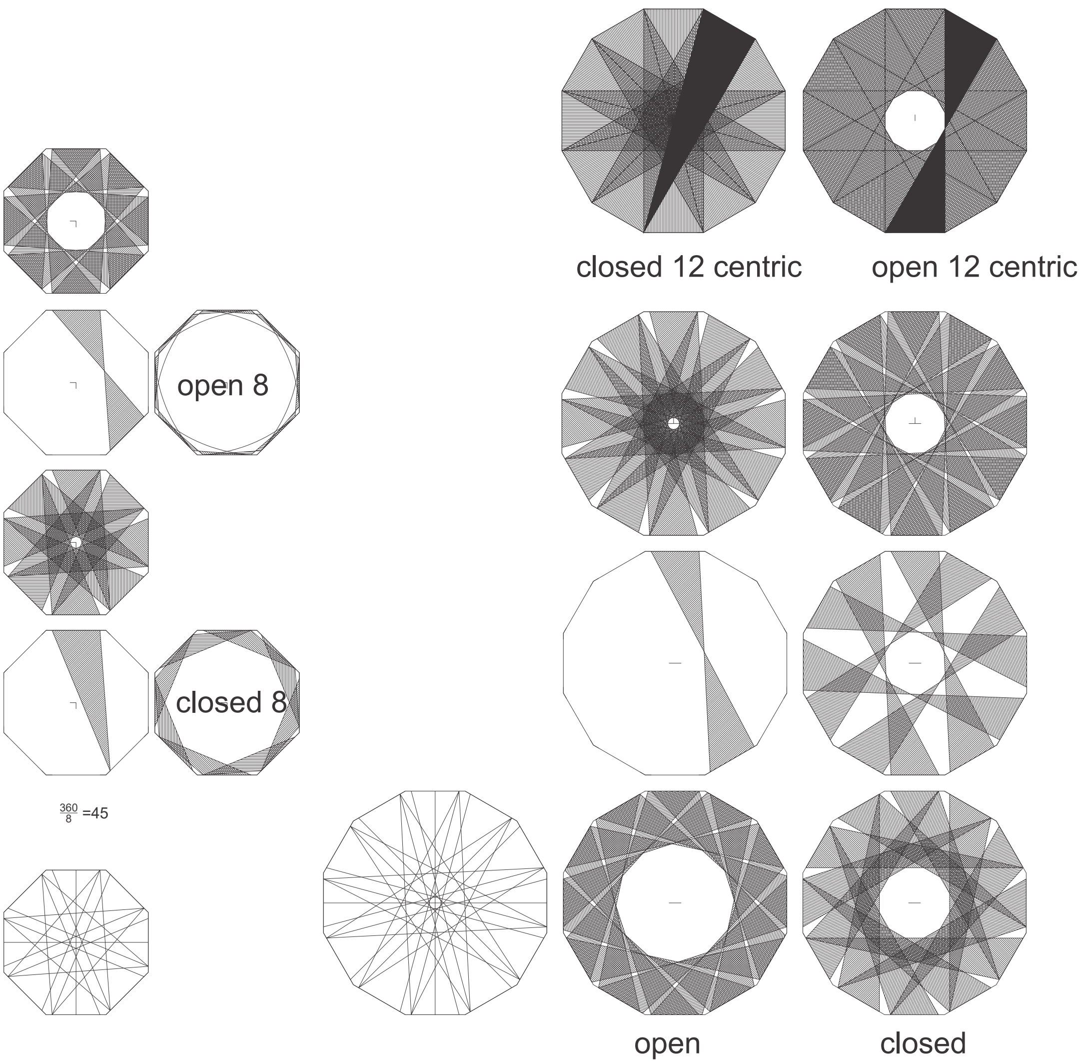


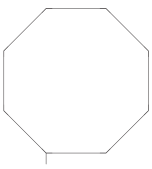
Trinary case	Quaternary case	Quinary case	Senary case
Triangle	Quadrilateral (Square)	Pentagon	Hexagon

Fig.56: Unit structure logic in different polygons scenarios

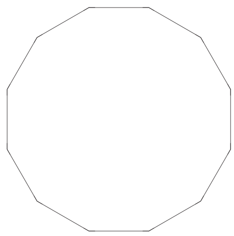
08

12

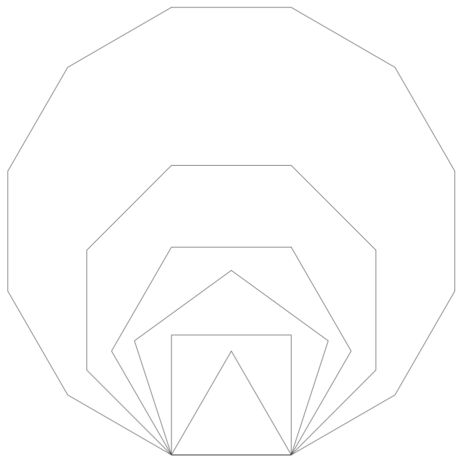




$\frac{360}{8} = 45$



$\frac{360}{12} = 30$



Octonary case

Octagon

Duodenary case

Dodecagon

The same sequence...........

3•2•3 Unit's Studied Features

As described previously in the capabilities of the unit (Unit Potential), the proposed design of the unit can influence many factors related to the control of the indoor environment, some of these factors will be studied separately and others will be included in the process of optimization in the next chapter during the research methodology where the measured objectives focused more on solar and visual means while there is a potential to handle many other factors such as aerial, acoustical, material, and form consideration.

From a theoretical point of view, it is possible to integrate the full capabilities of the units into the multi-objective optimization process, but due to the limitations of computing capabilities, Only three main elements representing three factors (**THERMAL, VISUAL, and SOLAR**) will be included in the optimization process together as it will be sufficient to prove the method, while the others will be studied separately (Figure 57) in this chapter (**FORM, ENERGY, CFD, and ACOUSTICAL**) and later on, another one in the Application chapter (**LCA**) which is based on the case study project (**Trio**).

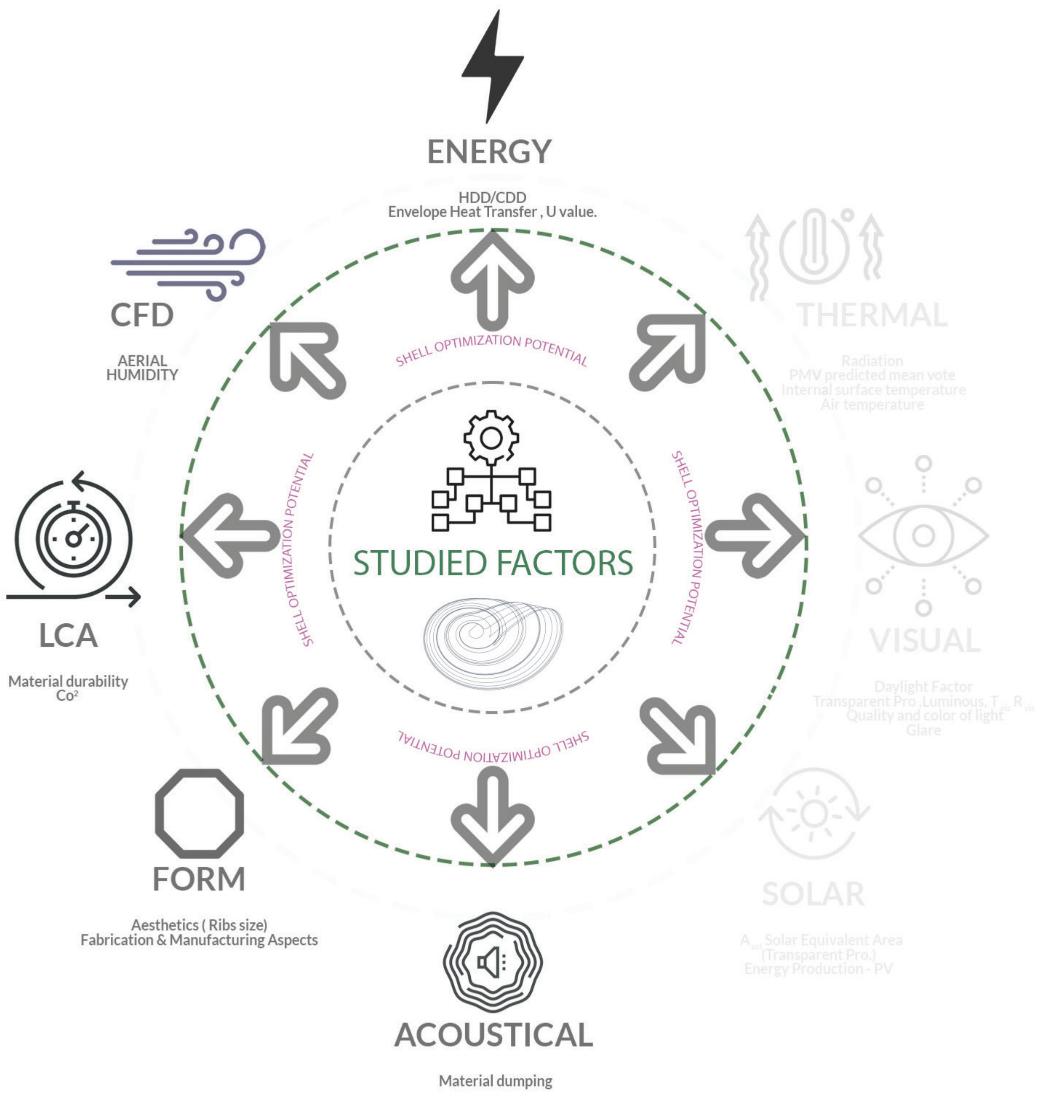


Fig.57: Studied features out of the unit potential which is not included in the optimization process.

•Form Study & Technological Design

Structure logic could be considered the approach to the (Form) characteristics. While the form relies on the envelope's base unit and how it will look when all the units are combined on a seamless pattern through the facade either or in the envelope (Figure 62), Also (Appedix 05) shows the pattern of the three chosen cases (T**rinary, Quaternary, and Senary**) cases.

The form is based on the units' physical features (Figure 59 -Table 1) which come with five main features four of which are represented graphically in (figures 63,64), beside the material variables and the photovoltaic addition. the envelope itself it could be fixed or kinetic which means some features could be abled or disabled depending on the used case.

Unit's Form Features

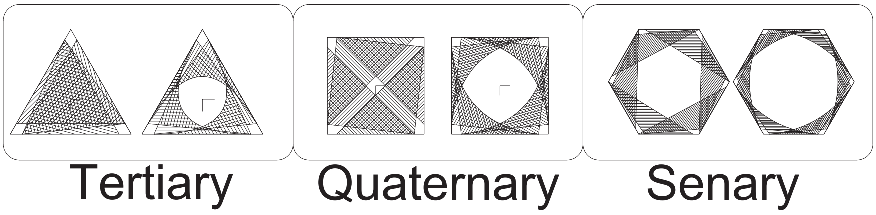


Fig.58: *Plan view for the three chosen cases from the structure logic (Left: closed, Right: Open)*

1. Unit's Typology (Ribs size), (Figure 60)

The design offers three main cases (Trinary, Quaternary, and Senary).

2. Opening shutters, (Figure 63)

This option imitates the camera shutter movement and the iris as well, where the internal curtains could slide simultaneously to achieve a certain opening value which allows mainly light and air to pass with a specific value and for a determined period.

3. Curtain Depth (Figure 64)

This option gives the ability to the movement of the internal parts (curtains), and it does only work in the (Kinetic) scenarios with a fixed outer frame.

4. Framework depth (External), (Figure 64)

This option allows different thicknesses for the panel itself (The outer framework), but In contradiction to the last option, this one works only on the (Fixed) scenarios which means that the targeted envelope or face will be manufactured in this way and without any movement during the operation time, it is useful as it simulates the shading devices with hundreds of varieties

5. Curtain translucent degree (Figure 64)

Transparency is the physical property of allowing light to pass through the material without an appreciable scattering of light, while translucency allows light to pass through, but with a limited value, which means that translucent material is made up of components with different indices of refraction while a transparent material is made up of components with a uniform index of refraction. This option controls the curtains' fabric translucent degree and also it works in the (Fixed) Scenarios as the fabric could be manufactured in this way.

While it could also be an addition in the (Kinetic) scenarios where a specific material could be used a flexible (polymer - dispersed liquid crystal) (PDLC) produced as a film with a graphene layer as transparent electrodes. The material is flexible and performed normally when bent without suffering any damage, but the research preferred not to utilise it because to cost considerations and because it would interfere with the usage of Photovoltaic option (option 7) which will need a synchronizing to maximize the benefits and to reach its fullest potential. Additionally, because the unit is mounted atop a glass window, the technique of controlling translucency might be used by Liquid Crystal Windows (LCW). However, that is outside the purview of this study.

6. Material (life cycle assessment) (Chapter 5)

The material has a huge impact in different aspects, a set of materials for the unit components discussed in the chapter 5 in the life cycle assessment on the case study of Trio's tower envelope.

7. Photovoltaic

Electricity generated from solar energy in kinetic scenarios is another addition that could be used to ensure maximum benefit of the unit. The general concept is to use Monocrystalline Silicon (ex: KOLON flexible photovoltaics) screens that could be integrated inside the curtain fabric to benefit from solar energy during closed situations that match with high radiation values to collect the energy in internal batteries that could power the movement of the unit itself, allowing the unit to be independent in a more substantial way. However, there needs to be more consideration given to the technology utilized to enable tenting the cells during curtain movement, as well as further calculations to determine whether the exposed area can actually generate the required amount of power.

Features	*Objective*	*Var.*	*Characteristic*	*Genes*
Ribs size	V, S, F	3	Polygon typologies: Trinary, Quaternary, Hexa-units	Fixed
Opening shutter	S, V, A, Ac	15	Controlled movable curtains like the camera shutter.	-
Curtain Depth	S, A	10	Internal X-axis curtain expansion-unified frames	-
Framework Depth	S, V, A	10	External/Internal X-axis expansion-various frames	Fixed
Translucency	S, V	15	Curtain material density in 15 grades.	Fixed
Curtain Material	A, Ac, M	5	Curtain materials variables (5 options)	Fixed
Photovoltaic	M	-	Policristalline Silicon wires (Addition)	Neglect
No. of Variables			*Potential of 337500 different variables (Trinary)*	

Fig.59: *(Table 1) Units Features and characteristics*

Units' features affect: {visual(V), Solar(S), Aerial(A), Acoustic (Ac), LCA material (M), Form(F)} properties and factors, with some applicable genes in either only (fixed) or both fixed and kinetic scenarios

Units Typologies

The units' features developed for two main scenarios, firstly the (Annual fixed case), it is suitable for lower operating costs and low-tech fabrication modules. It depends on prefabricated units as the best generative option based on averaging yearly measurements. The other scenario (Instantaneous Kinetic case) introduces (adapts to comfort) solutions by modifying the envelope continuously on an immediate, hourly, or daily basis in accordance with computational and technical capabilities.

As the unit structure and features demonstrate, there is a strong possibility to construct multiple typologies using the same structural logic. The research deduced it to three various typologies based on a triangle, square, and hexa, considering that a larger polygon size will diminish the efficiency of the shutter.

Trinary case (Triangle Unit).

The first typology is the trinary unit which built by a modifiable algorithm definition and developed by starting with a Trinary polygon shape (the size of triangle edges = 4.620m, Height = 4 m height as the height of the floor in our case, fillet corners = 0.4m, Inner offset = 0.1 m to achieve 0.2 m between panels, Basic depth extrude = 0.75 m) all values are adaptable. The following step is to divide the frame depth into four equal sections for the adaptable and flexible curtain (*more details in Page 86*).

(Figure 61) and as (Figure 62) shows trinary units in both fully opened and fully closed scenarios.

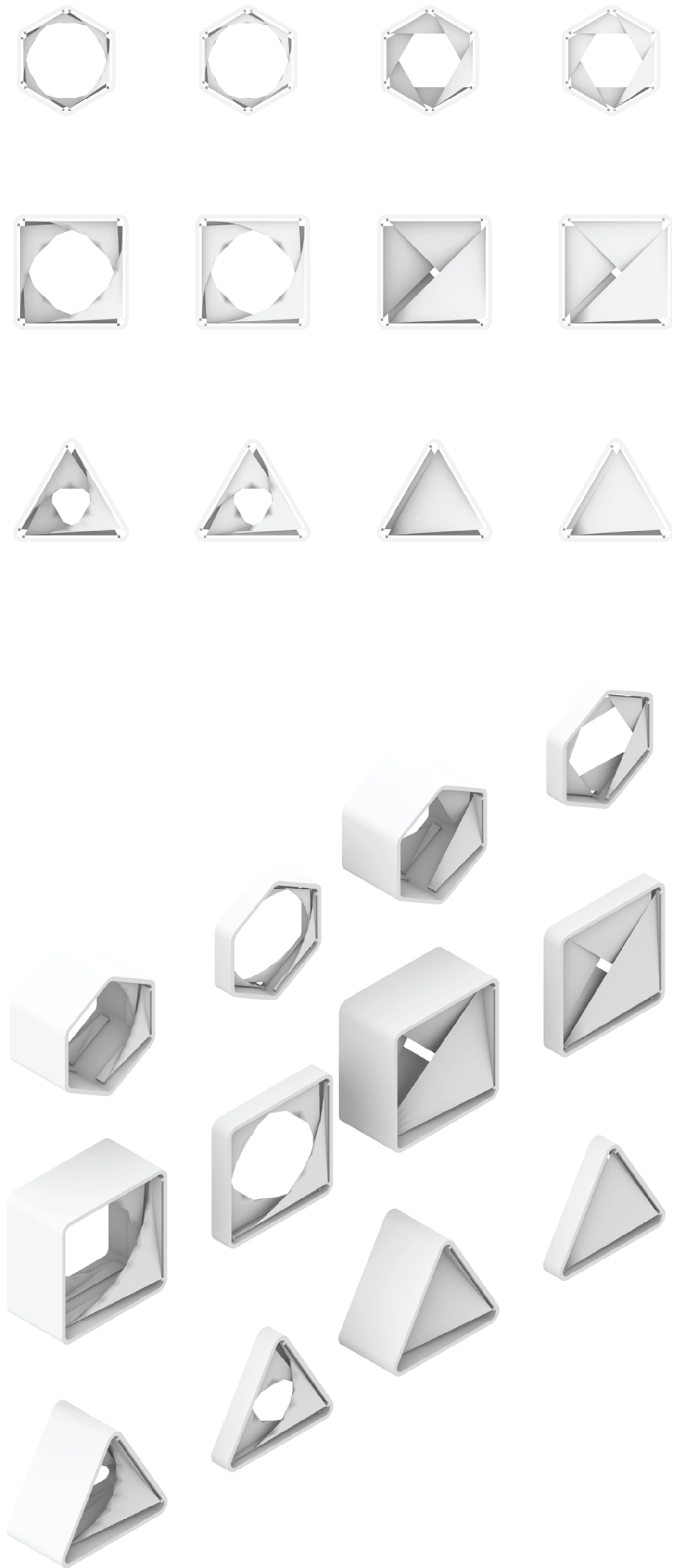


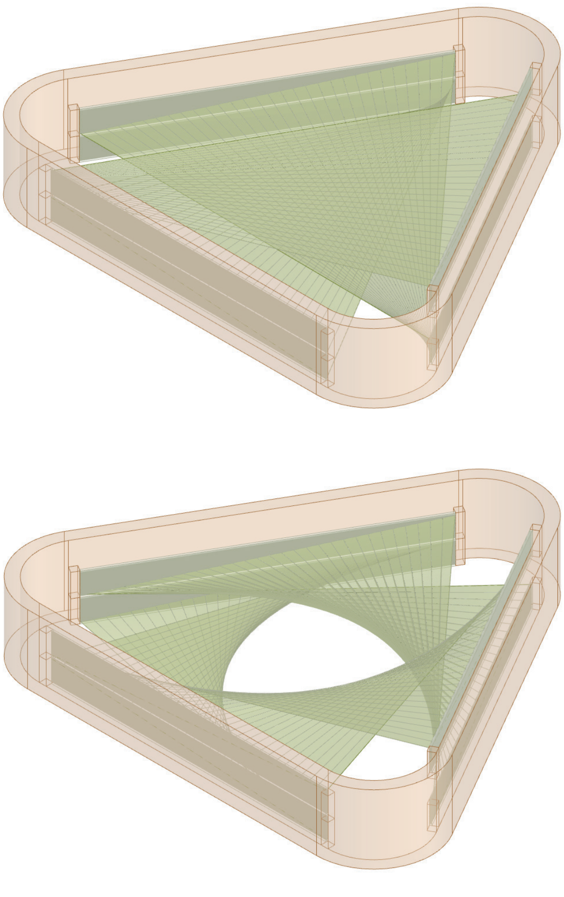
Fig.60: *three unit typologies in plan and an axonometric views*

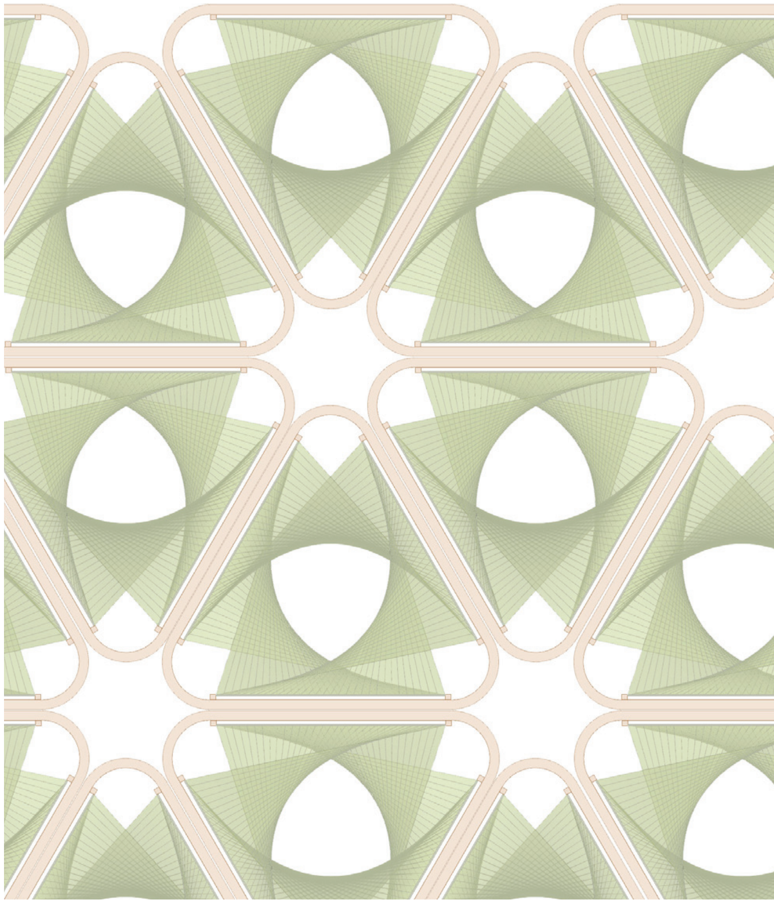
Quaternary case (Square unit)

Both Quaternary and Hexa-units follow the same algorithmic logic of the trinary unit. The quaternary unit is based on a square shape with five overlay layers to connect the internal curtains, the unit has more shutter exposure capacity and easier installation techniques, The unit's findings revealed the highest resistance to the wind rates while the lowest rate of aerodynamic flow (Figure 82, 83).

Senary Case (Hexa-Unit)

based on a hexagonal shape with six ribbed polygons divided into seven overlay layers to connect the curtains (the highest shutter exposure level). The unit is more suitable for free forms as it has an aesthetic repetitive beehive form (**Appendix 5**), but it is hard to coordinate with the normal façade-floor distribution.





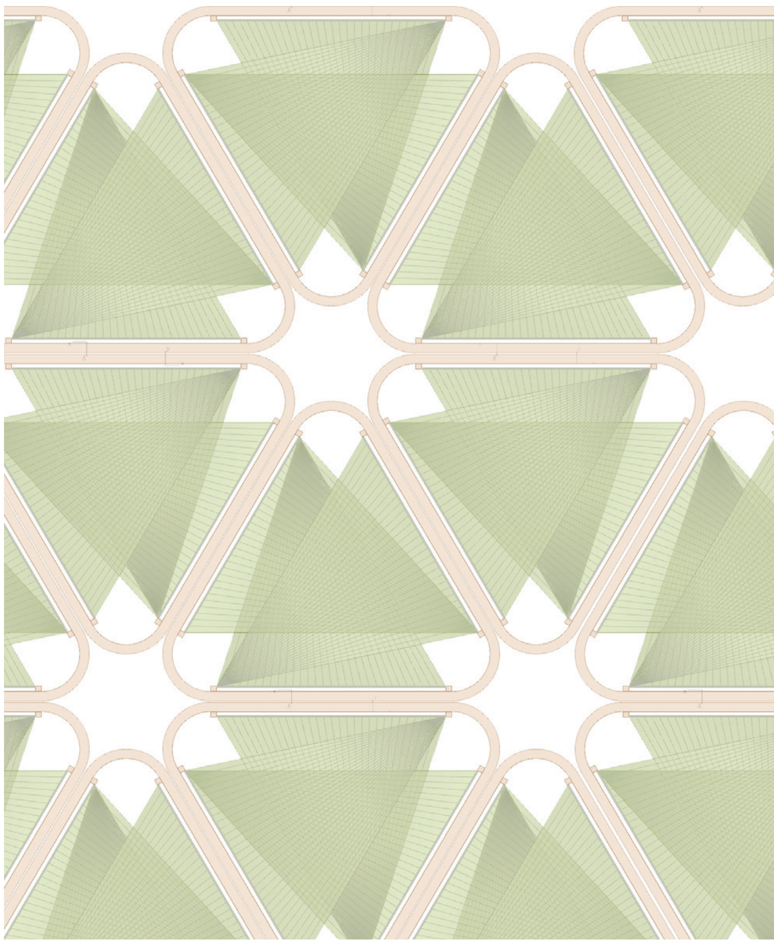


Fig.61: *Envelope unit (Triangle Shape) used in the trinary case (Open and closed shutter positions).*

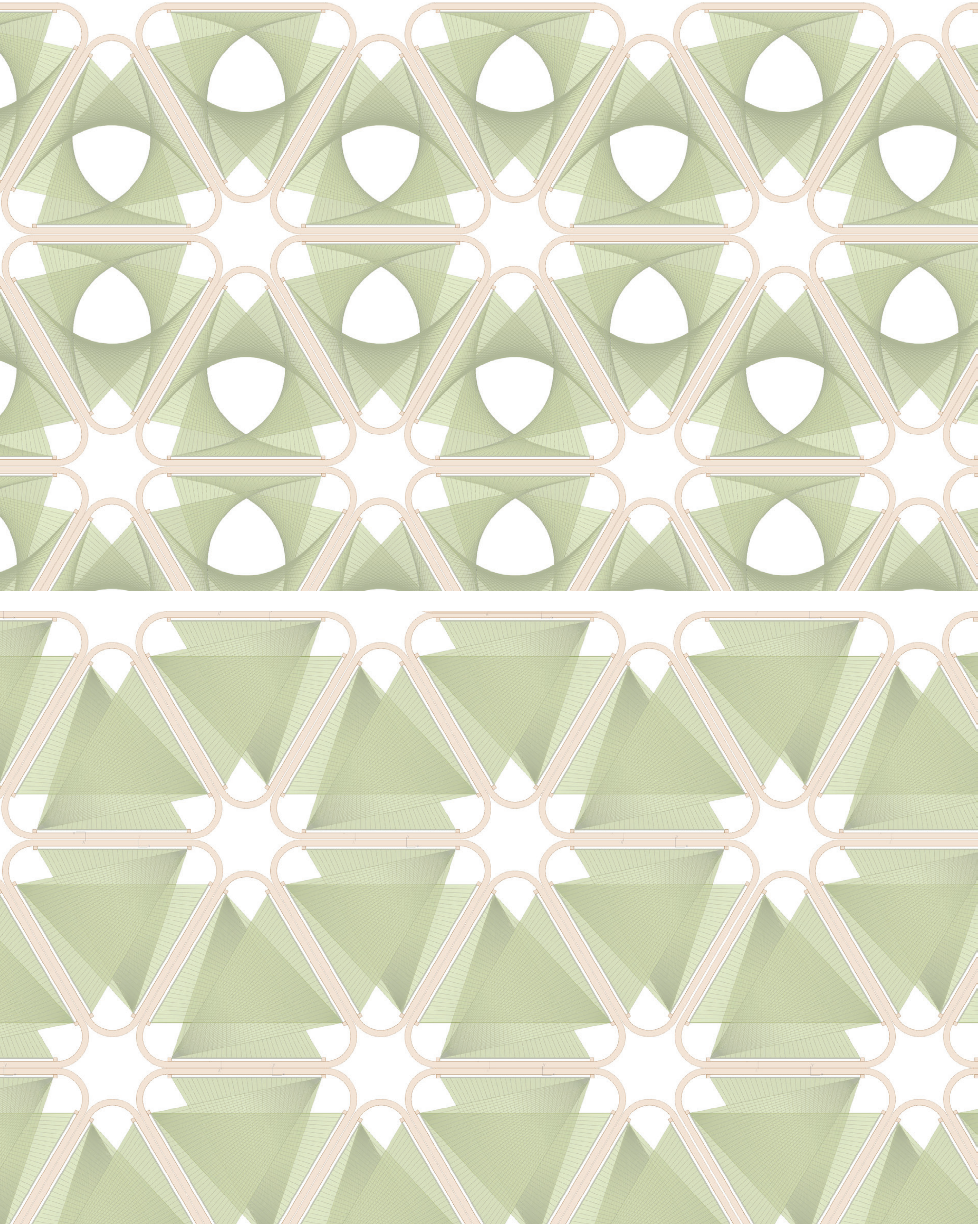


Fig.62: *Trinary unit array fully closed and fully open scenarios shows the texture of the matrix to form the envelope's outside appearance.*

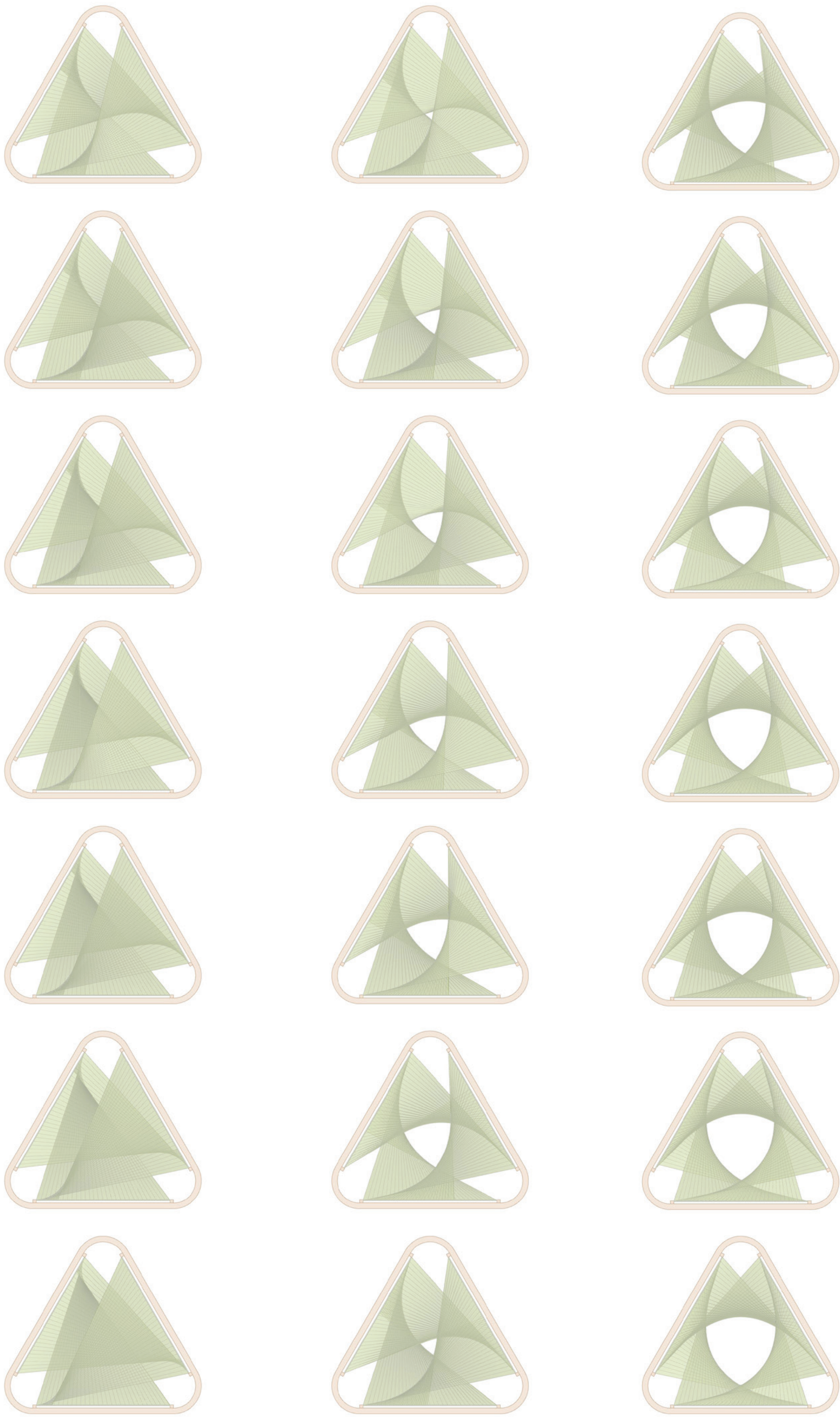


Fig.63: Trinary case (Triangle unit) shutter control positions (fully closed case (Left), and a fully open (Right)).

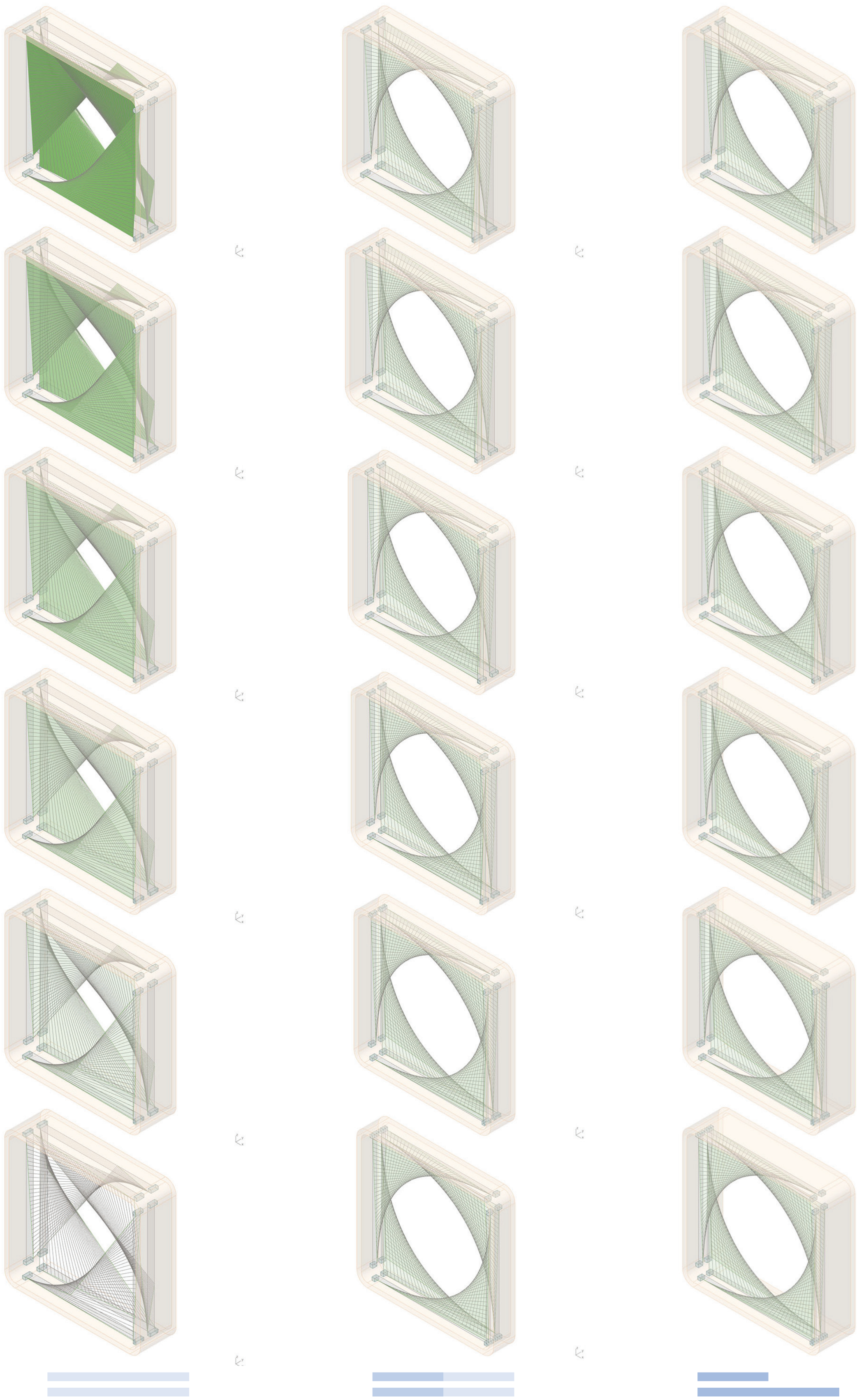
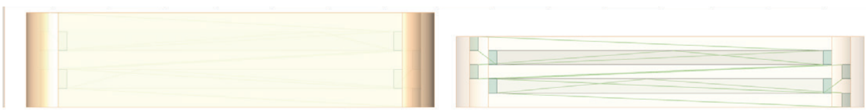


Fig.64: *Quaternary case (Square unit) three features positions Curtain translucent degree (Left), Framework depth -External- (Middle & Down) internal Curtain Depth (Right).*



Technological Design

The technological design part is help to understand better how this design proposal could be implemented during the construction phases. The blow-up axonometric views (Figure 66) show the disassembled units and their main components, for the material details, refer to table 02 (P.87) and (**Table 10) (P. 198)**.

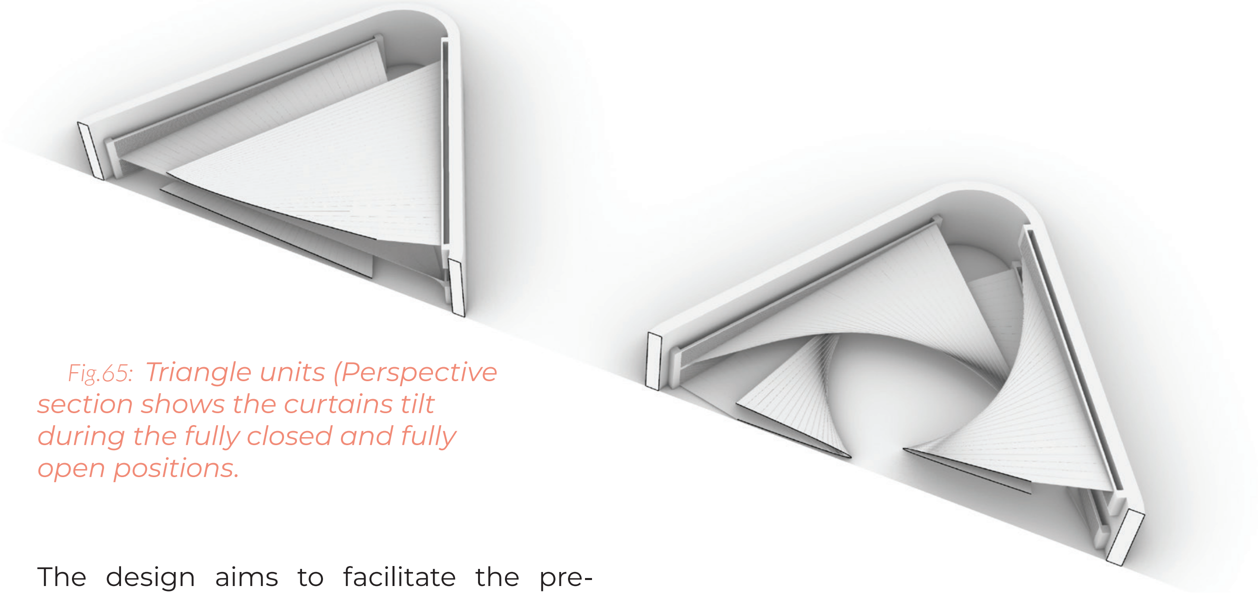


Fig.65: *Triangle units (Perspective section shows the curtains tilt during the fully closed and fully open positions.*

The design aims to facilitate the pre-fabricated process of the units and then be installed on the construction site. The recommended size or the used dimensions was for the application while it could be applicable for another size depending on the designer's prefrences.

To create the trinary unit, first of all, the polygon (size of triangle edges = 4.620m, Height = 4m height as the height of the floor in our case, fillet corners = 0.4m, Inner offset = 0.1 m to achieve 0.2 m between panels, Basic depth extrude = 0.75 m) all values are adaptable. The following step is to divide the frame depth into four equal sections for the adaptable and flexible curtain.

The curtain shading is twisted and connected by two layers to two adjacent edges of the polygon, the curtain is fixed from one side while the second is connected to a rail with a roller controller to move the curtain between its completely opened and closed positions in 15 different grades. In the same way, the second and third curtains rotate (360/Polygon size) 120 and 240 degrees counterclockwise respectively to lower layers to achieve 3 adaptable curtain shadings open and close as a camera shutter mechanism.

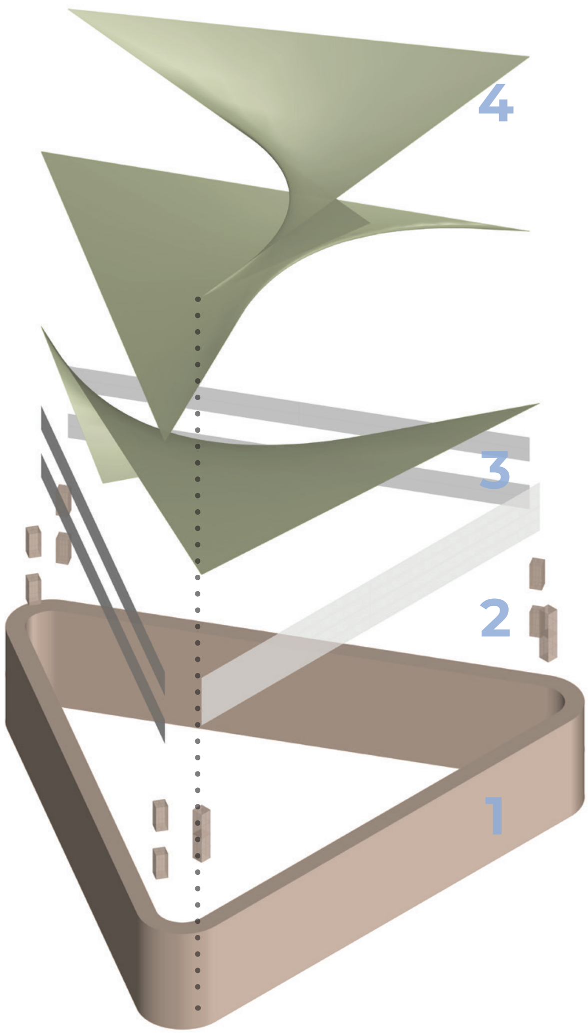
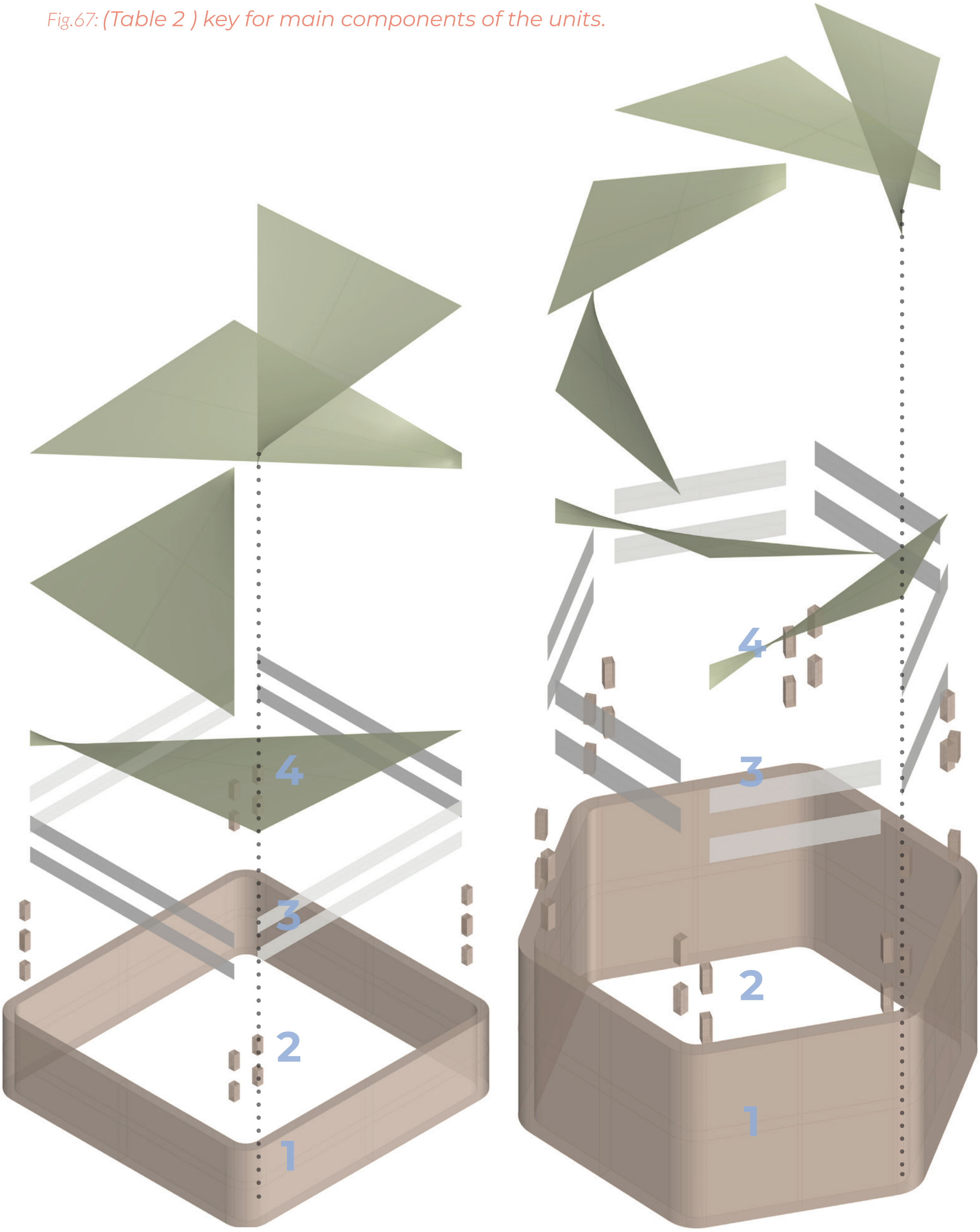
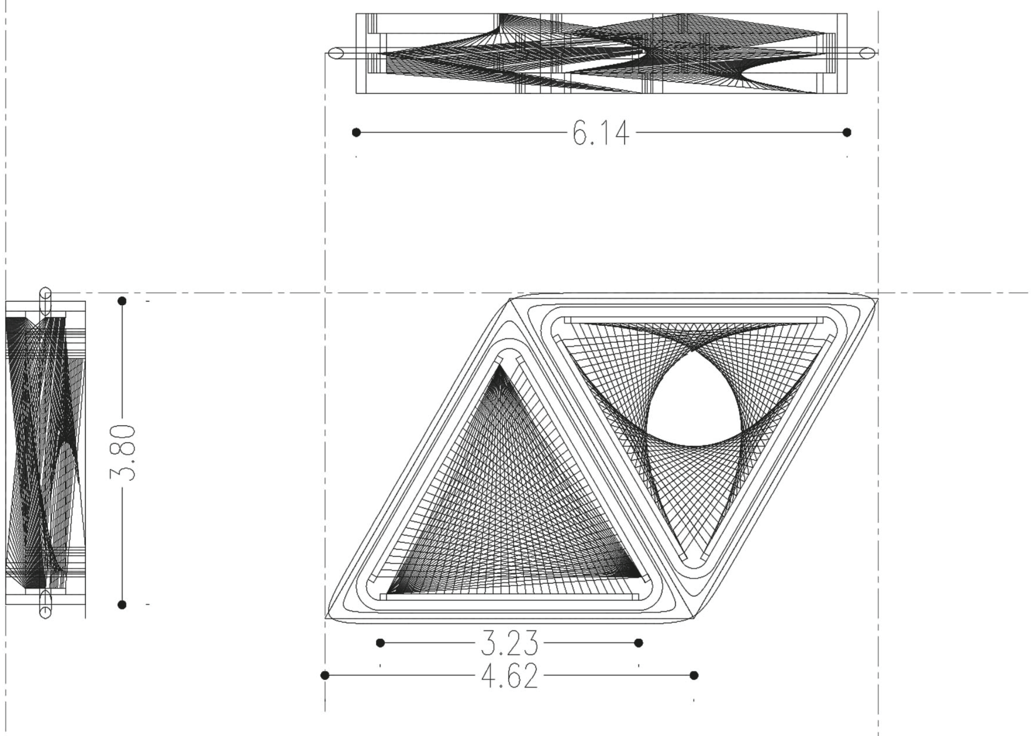


Fig.66: *Blow-up layered axonometric diagram (Triangle unit (Left), Square Unit (Middle), and Hexa- Unit (Right) with their internal main components.*

No.	Objective	Function	Material
01	Unit Frames	Connection back to the building with sub structure	Aluminum
02	Unit Roller	Controlling the movement of the fabric in kinetic case.	Stainless steel
03	Unit Rails	Support the mechanism movement in Kinetic case.	Aluminum
04	Unit Curtains	Fabric mesh with a predefined translucent degree - PTFE material : Poly- tetra-fluoro-ethylene flexible	PTFE

Fig.67: *(Table 2) key for main components of the units.*





Trinary Unit

Quaternary Unit

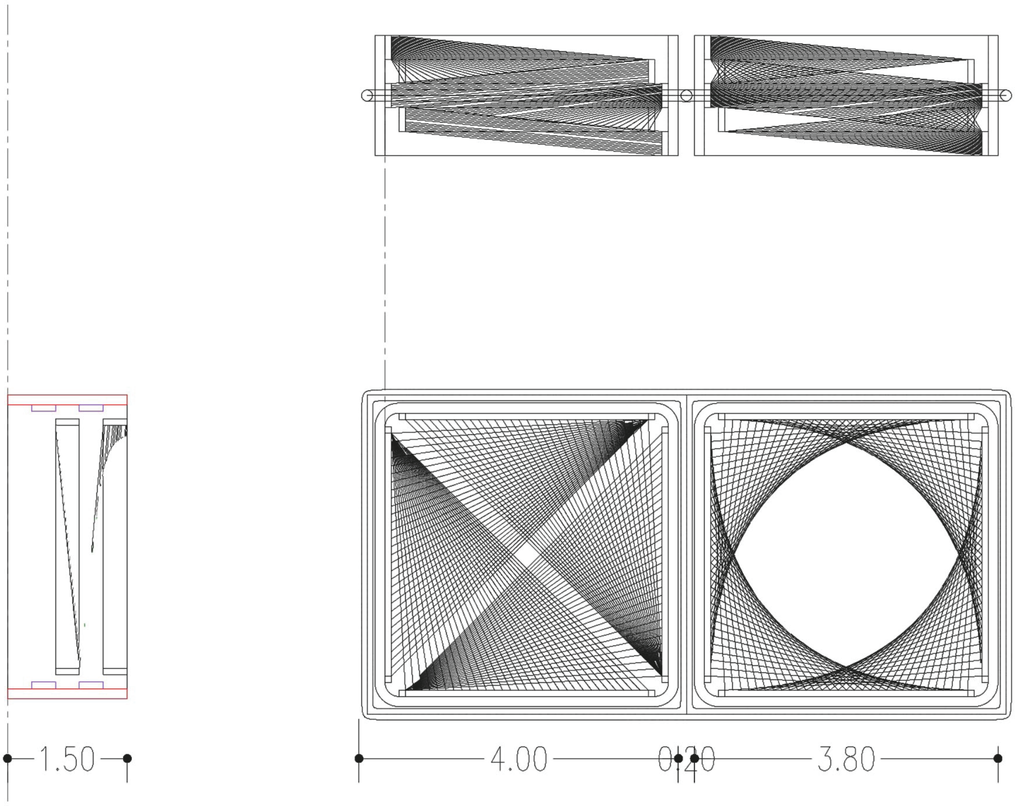
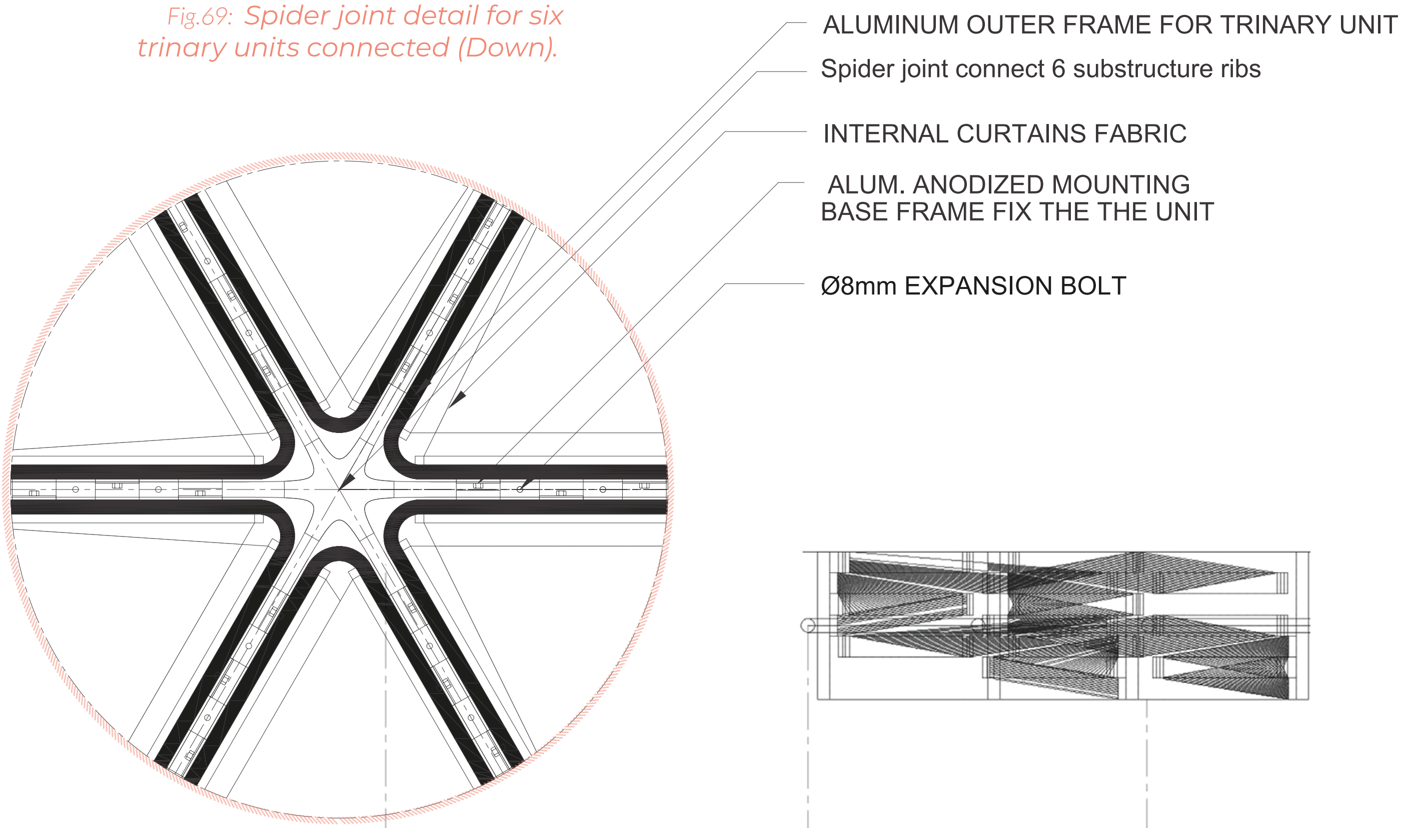


Fig.68: Trinary unit and Quaternaty unit three main views, (Front, Side and Top)

Fig.69: Spider joint detail for six trinary units connected (Down).



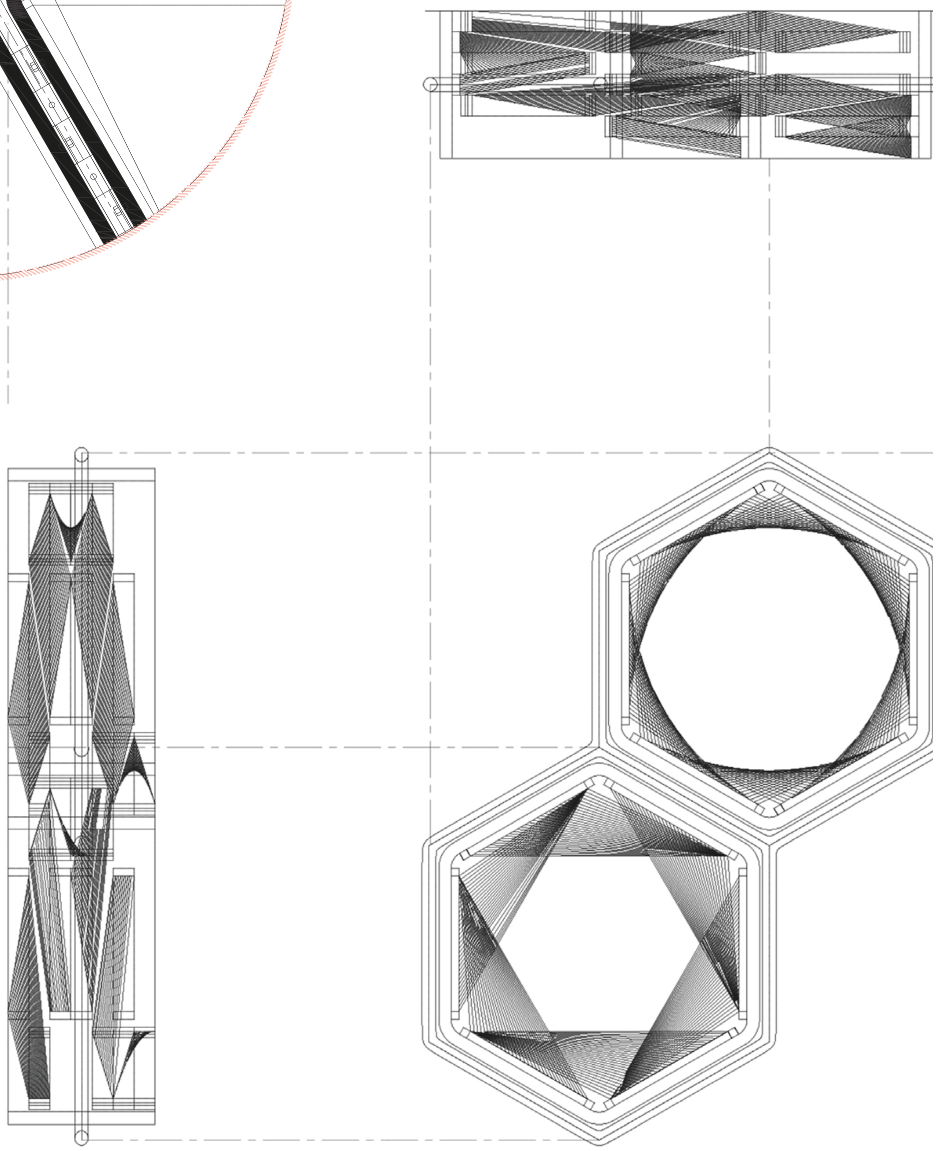


Fig.70: Two Hexa-Units connected on a diagonal way with their three main views (Front, Side and Top).

During the Methods Chapter, a mockup (the Prototype) or a small room will be needed to test the unit's different scenarios results, in this case, this prototype small building had been used also to apply the technological design on it.

In this section, the quaternary (Square) unit was used to illustrate how it might be installed on a one-story building as a shading device on the façade from the external part to cover the glazed wall. Air control is also possible with curtain motion once the unit is located in the center of the window behind it (Figures 70, 71, and 72).

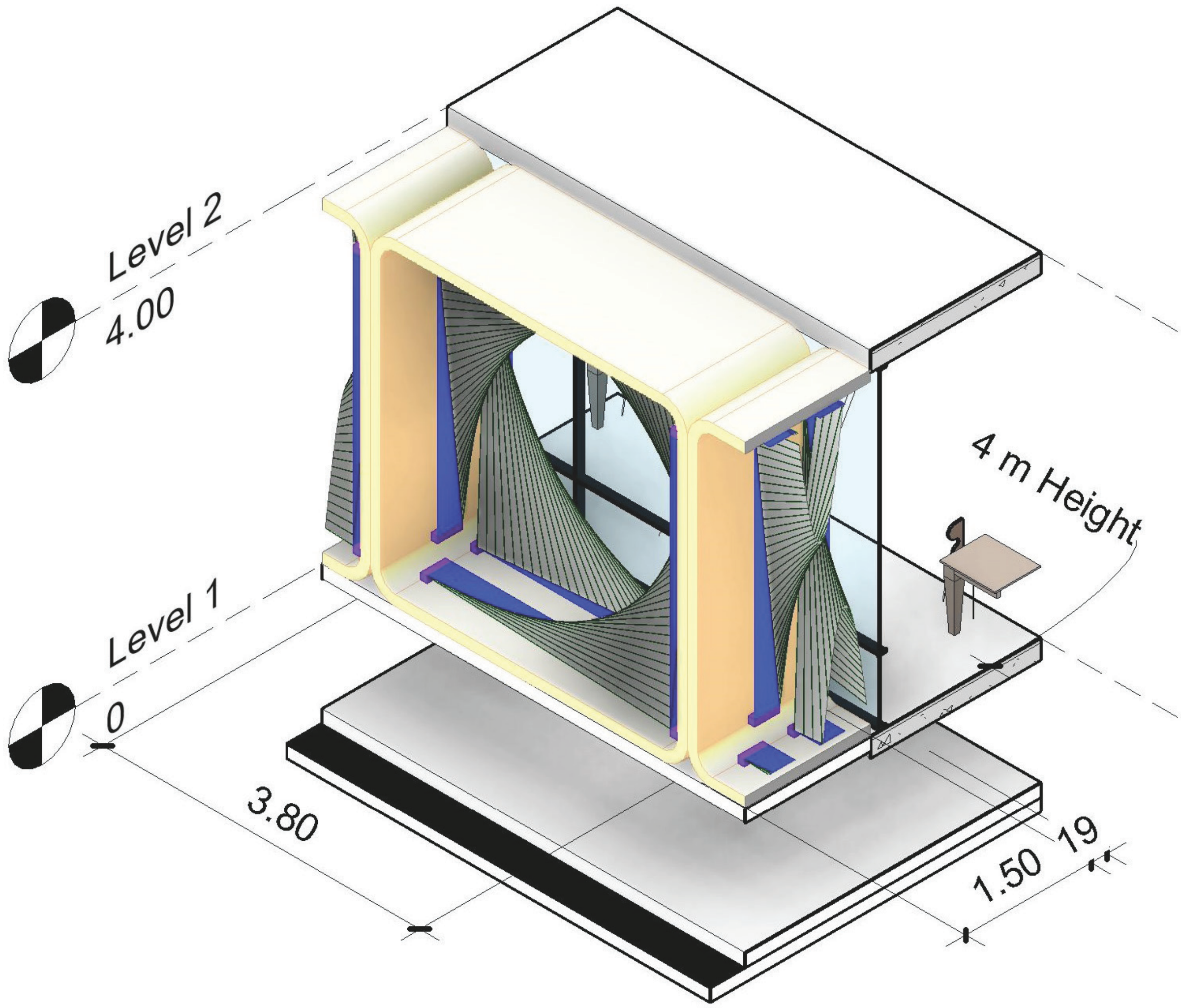


Fig.71: Perspective represents the installment of the Quaternary unit on a one-story building facade

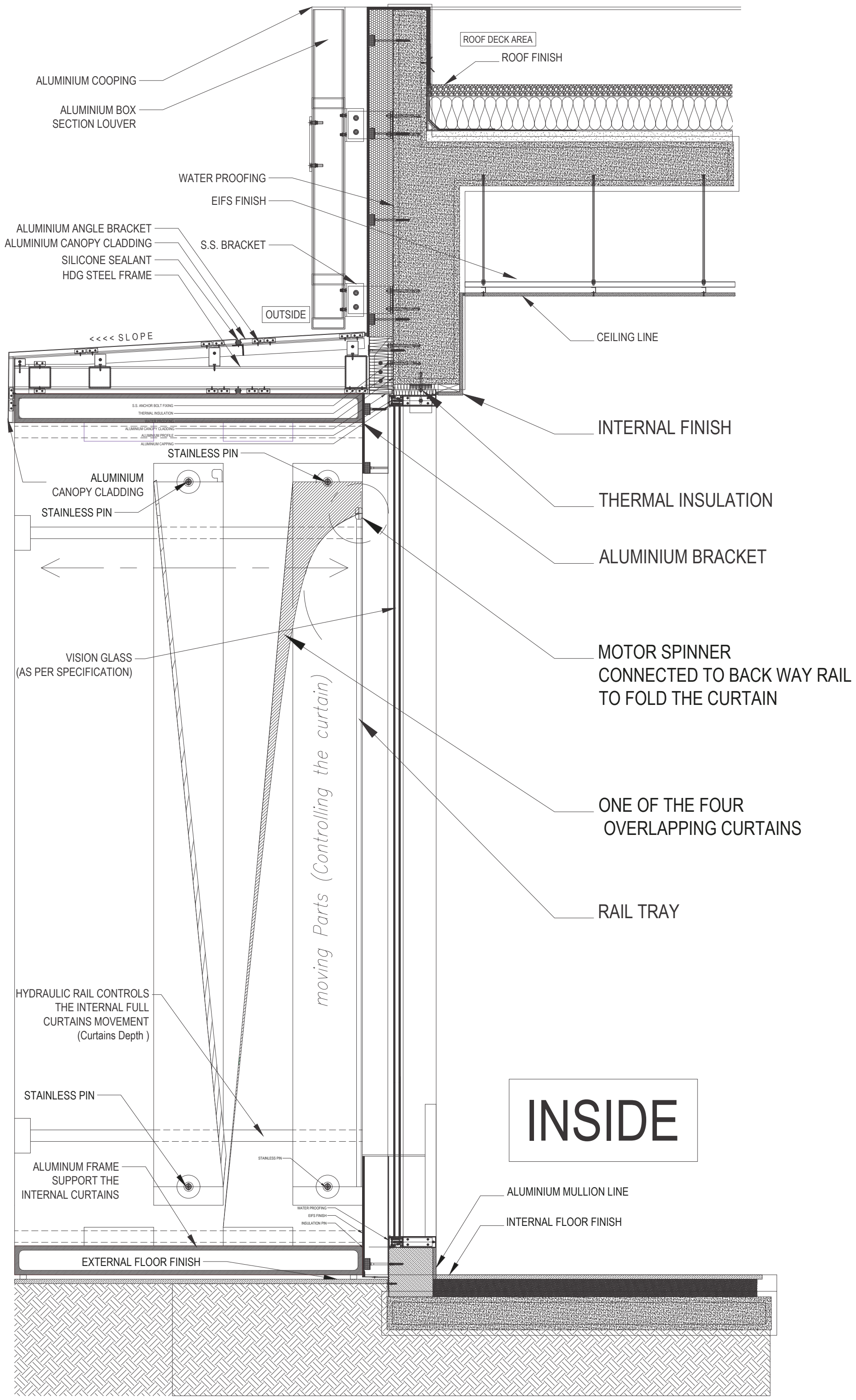
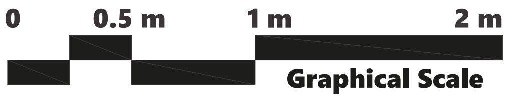
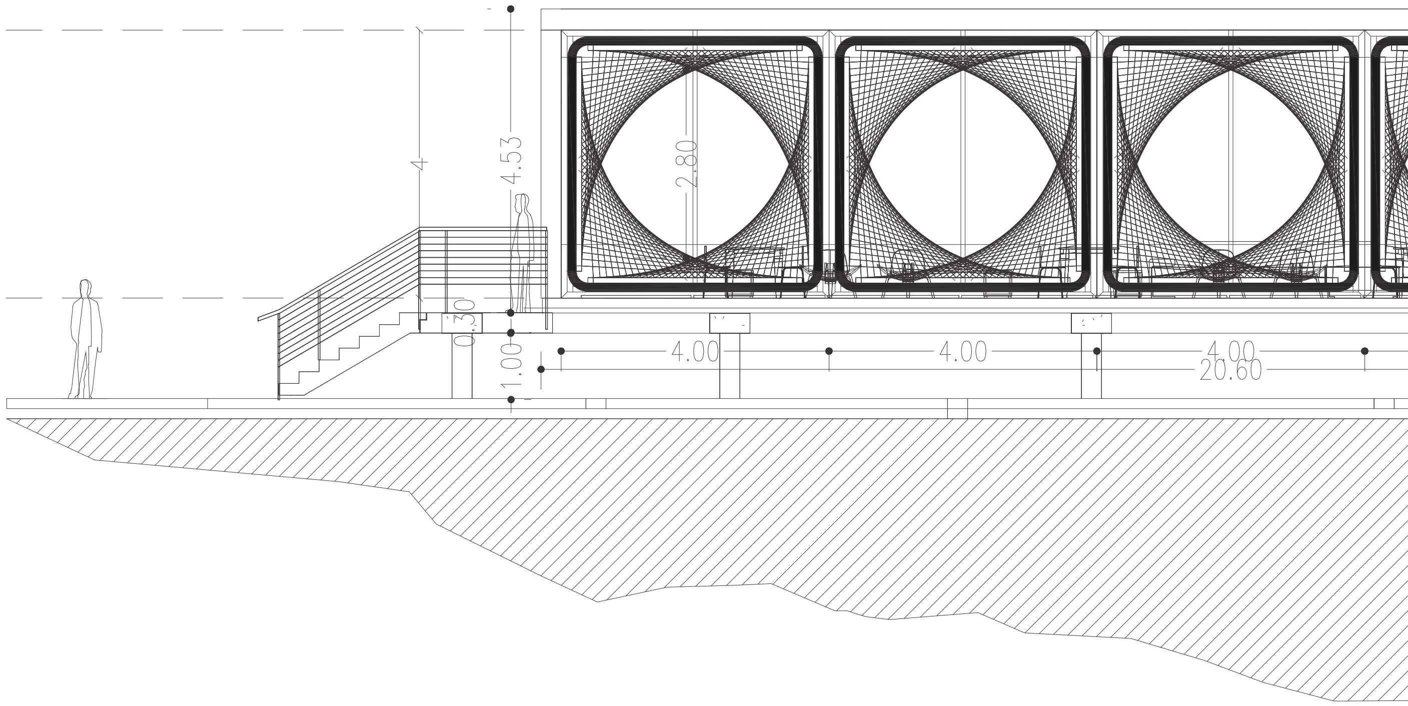


Fig.72: *Wall-section represents the installment of the Quaternary unit on a one-story building facade.*



The quaternary unit's longitudinal section (wall section) shows the movement technique in the kinetic scenario of two internal curtains in the open situation and also the hydraulic beams which also allows the full curtains to be spread in all the framework depth or shrink on a small part. This unit is installed on one storey building. Another wall section for a multi-story building represents the trinary units connected and applied on the envelope could be found on p.183 (Figure 146).



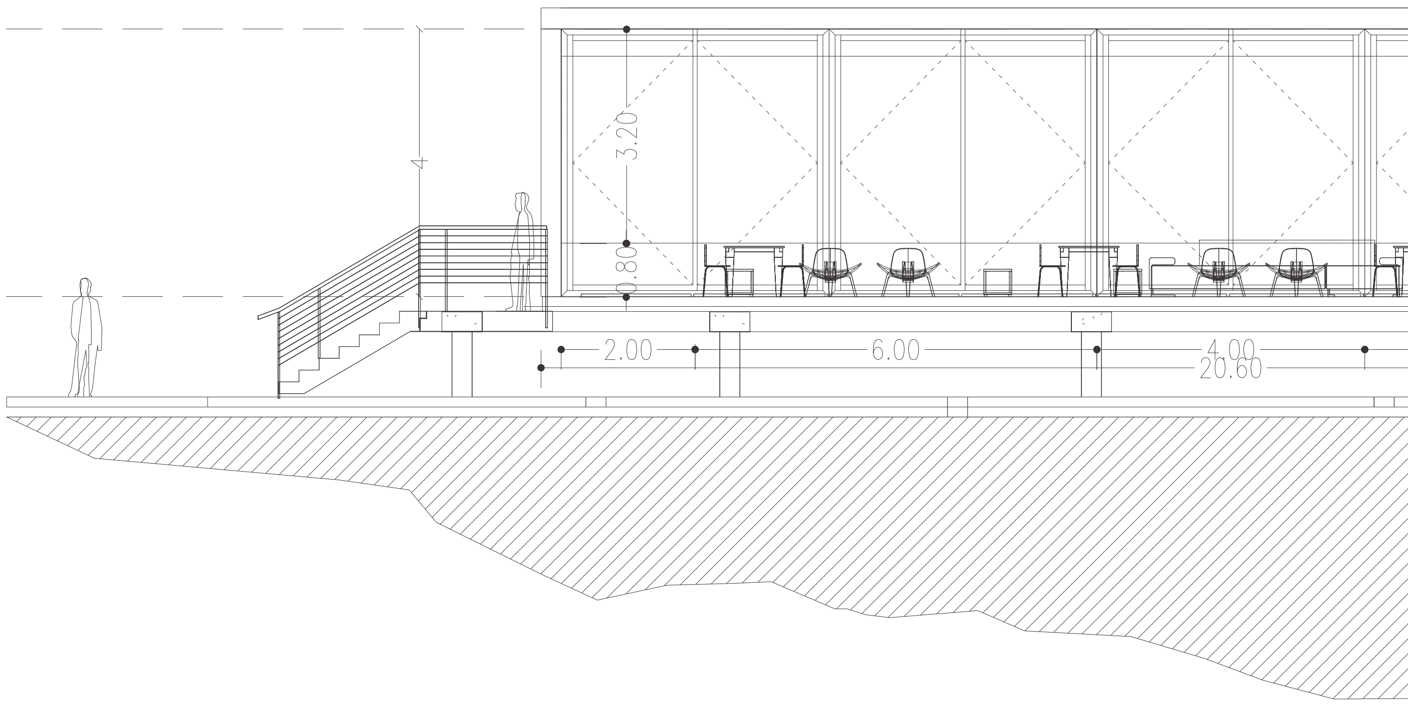
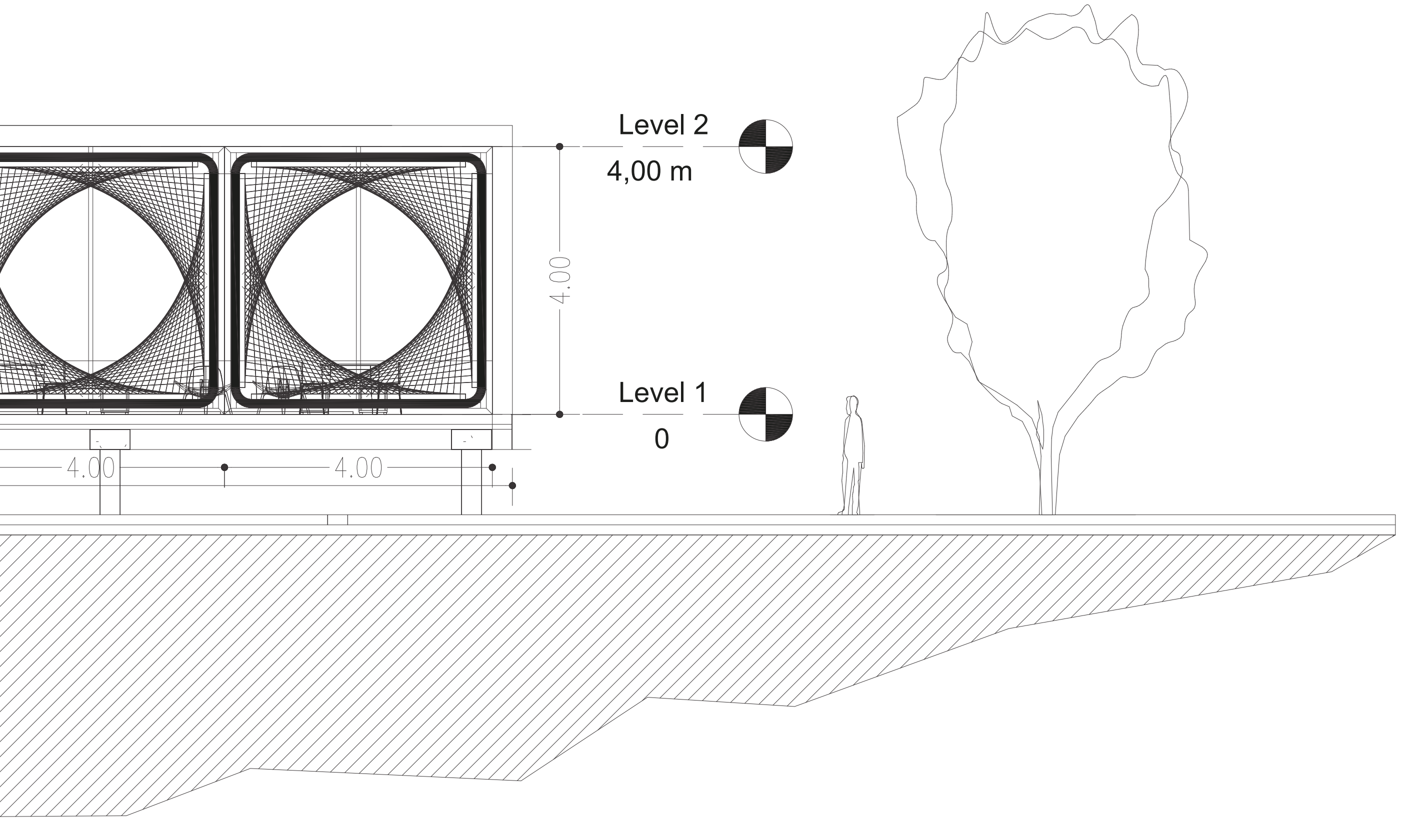


Fig.73: The mock-up (prototype) façade of a one-story building with quaternary units installed (up), as well as the glazing-only façade without the units (Down)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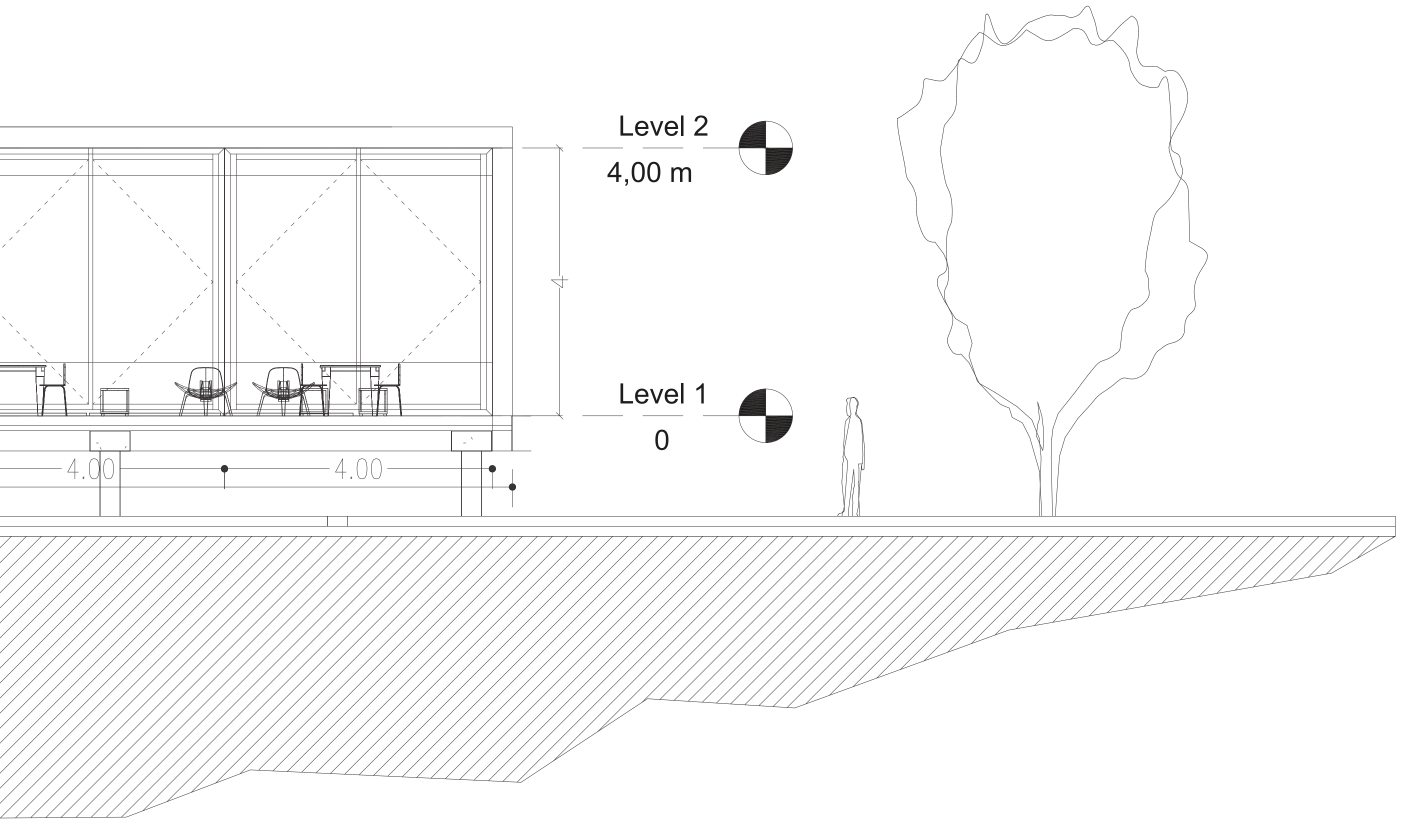
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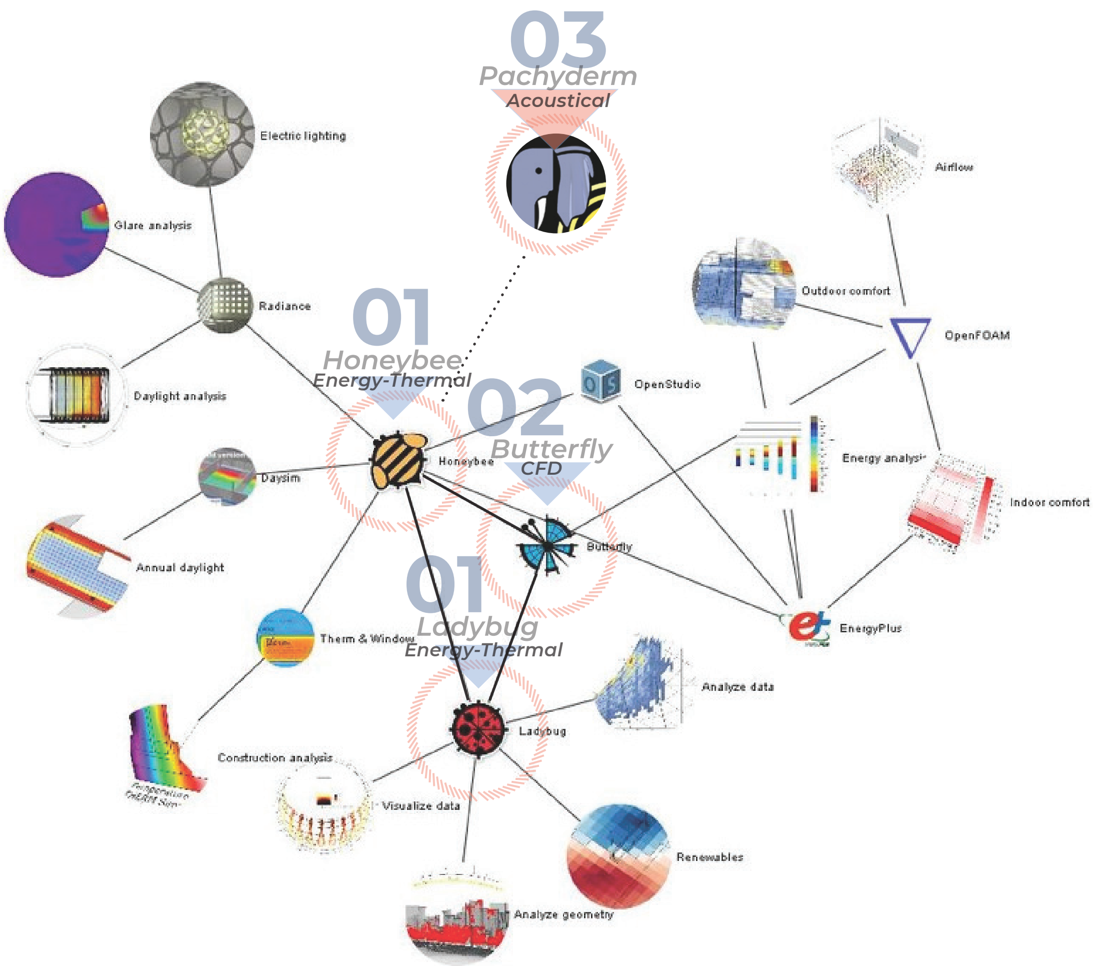
•Energy Study

Before moving on to the method in the next chapter, there were still three additional factors that should be tested independently after the Form study to guarantee the effectiveness of our design proposal (Energy, Fluid Dynamics, and Acoustical aspects).

This research uses visual programming tools and builds algorithms for the design proposal. For that different simulation tools were chosen to conduct these separate studies based on the Grasshopper program, to integrate them later in future works during the merged optimization process.

Simulation tools play a major role in the design of high-performance buildings, This part uses different Building Performance Simulation (BPS) tools to verify the initial results of the proposed unit design. All the Eneregy aspect, Computational Fluid Dynamics, and Acoustical aspects use different tools and plugins for the simulations inside the Grasshopper sofware eco system as the the (Figure 74) shows.

Regarding the Energy study, two different test applied. First of all, two sites one in the northern hemisphere (Abu Dhabi) and the other in the southern hemisphere (Johannesburg) have been tested for the shutter openings respond installed on basic facade towers with shading from the surrounding context. The openings got to respond to different radiation levels (Figure 76, 77).



Mian graph source: www.ladybug.tools

Fig.74: *The used Building Performance Simulation BPS tools (Ladybug, Honeybee, Butterfly, and Pachyderm) inside Grasshopper Ecosystem.*

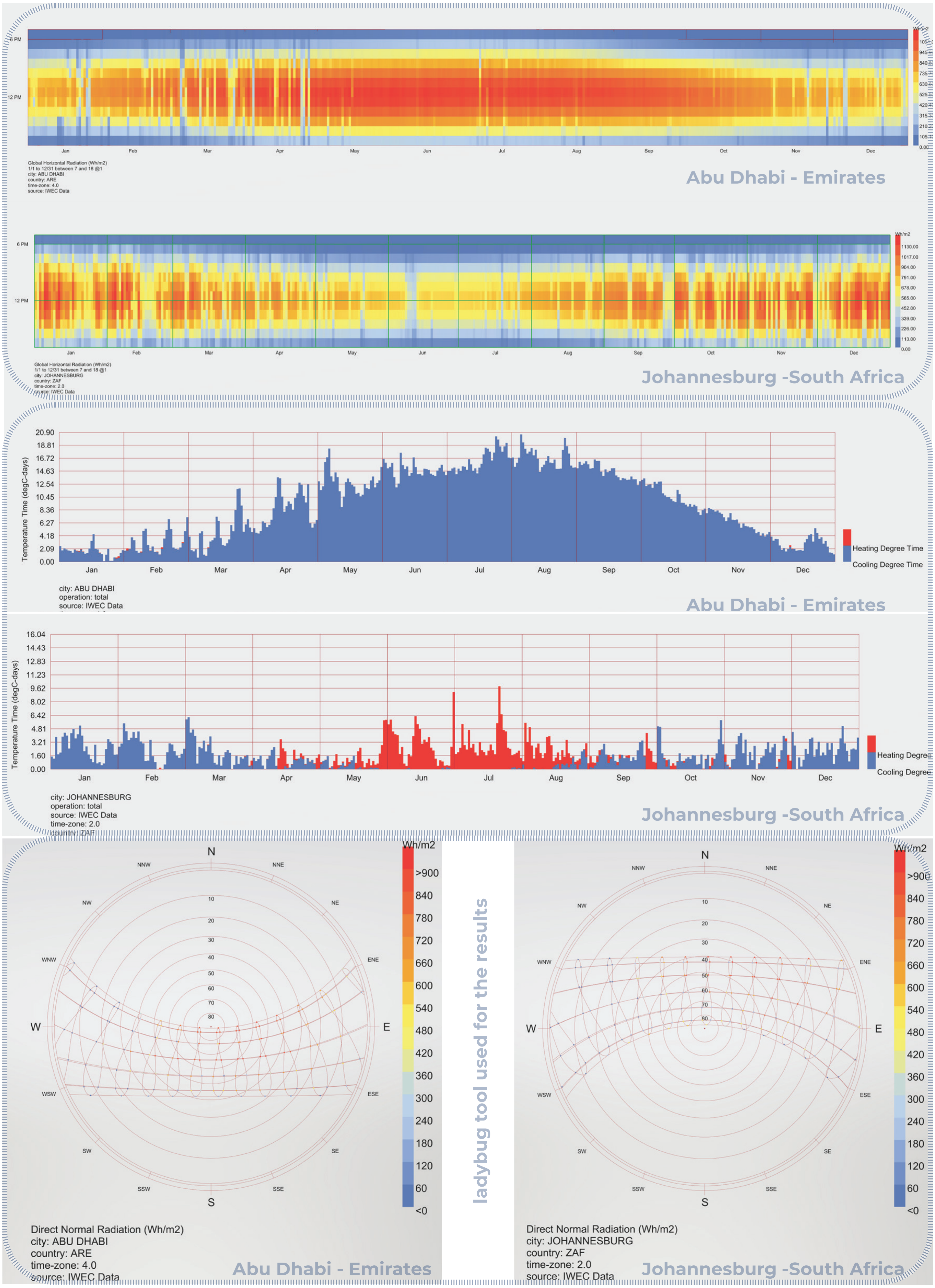


Fig.75: Global horizontal radiation and Heating degree days and cooling degree days, Abu Dhabi (up) and Johannesburg (Down) were used to test and compare the simulation results.

01
Ladybug
Energy-Thermal

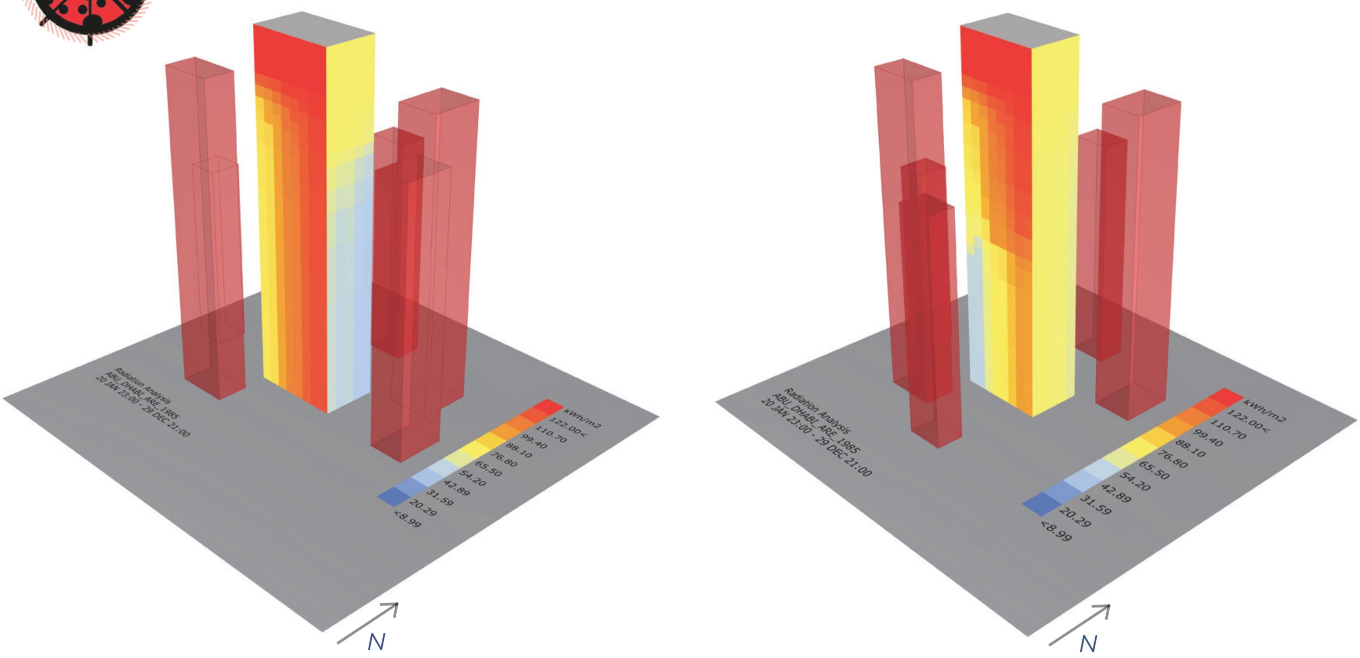
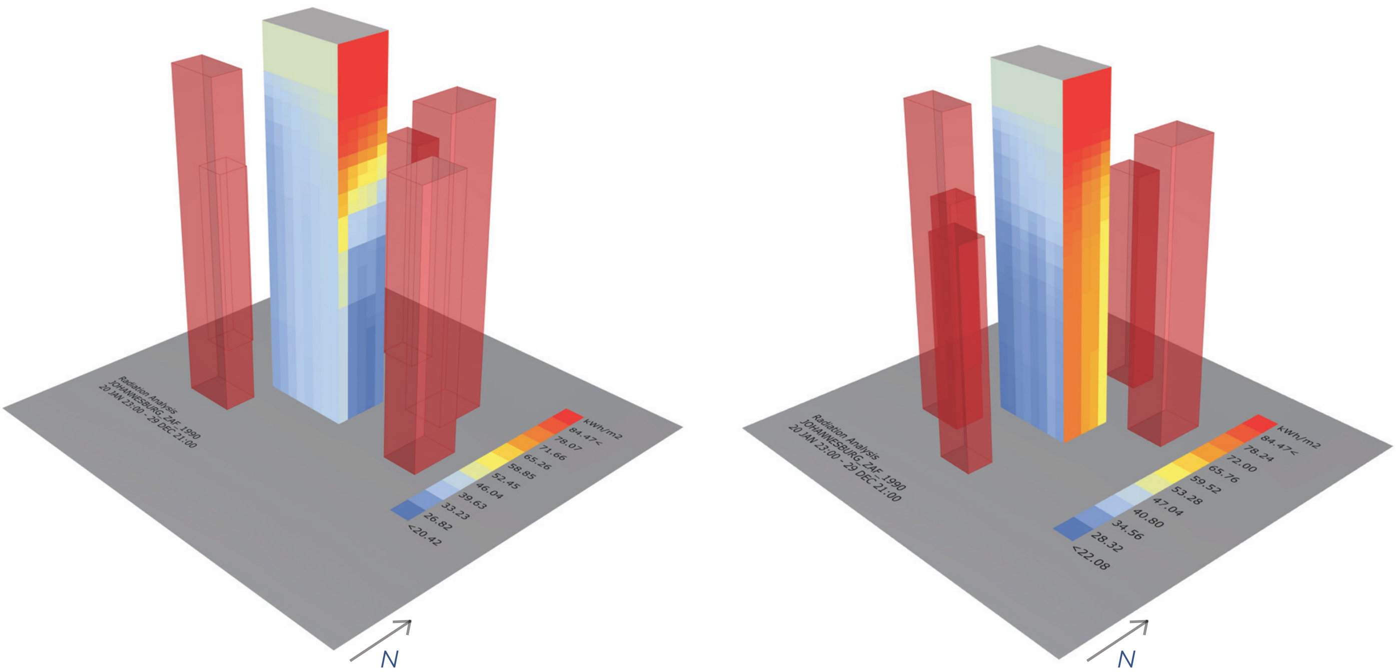


Fig.76: Radiation analysis over one year and different context scenarios Abu Dhabi (up) and Johannesburg (Down) using ladybug tool.



*01 Ladybug simulation tool: The name 'Ladybug' was originally chosen due to the ladybug's weather forecasting ability. Ladybug allows you to import standard EnergyPlus Weather files (*epw) into Grasshopper and provides a variety of 3D interactive graphics/metrics, including Sun-path, wind-rose, radiation-roses, radiation analysis, shadow studies, and view analysis.*

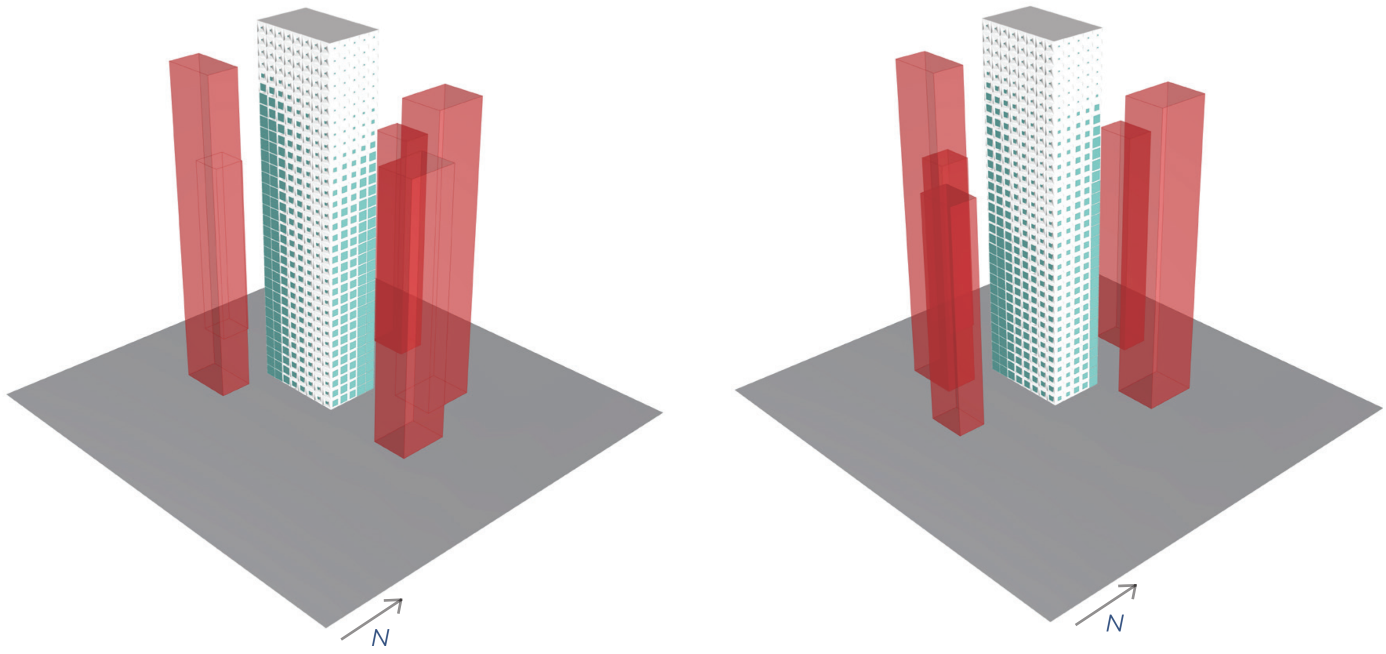
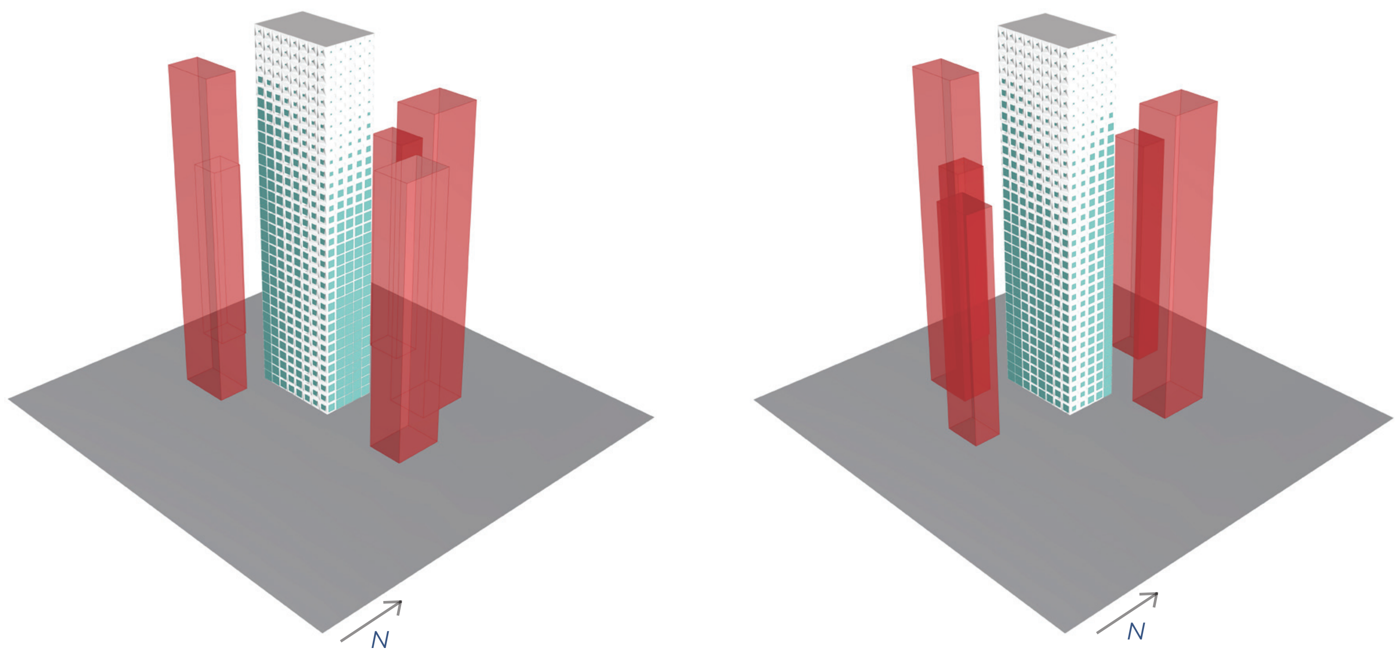


Fig.77: *Facade openings adaptation, Abu Dhabi (up) and Johannesburg (Down).*



01 Honeybee simulation Tool Honeybee, on the other hand, connects Grasshopper to EnergyPlus, Radiance, Daysim and OpenStudio for building energy and daylighting simulation. The Honeybee project intends to make many of the features of these simulation tools available in a parametric way. The name 'honeybee' derives from their ability to collect nectar from a flower.

01
Honeybee
Energy-Thermal

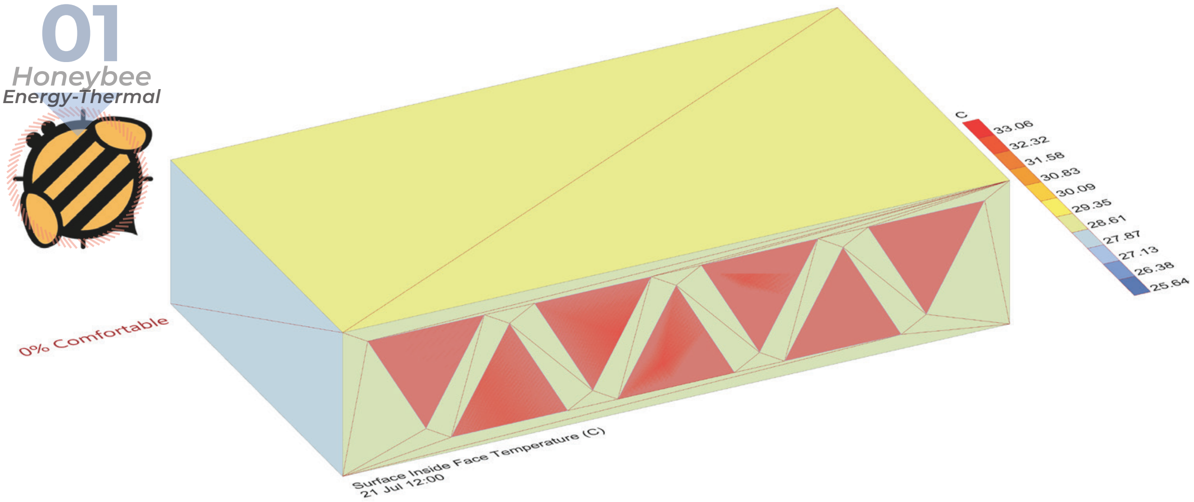


Fig.78: Mockup room (Prototype) WITHOUT units to test the total end use energy (Up) and its loads supply total cooling energy graph (Down).

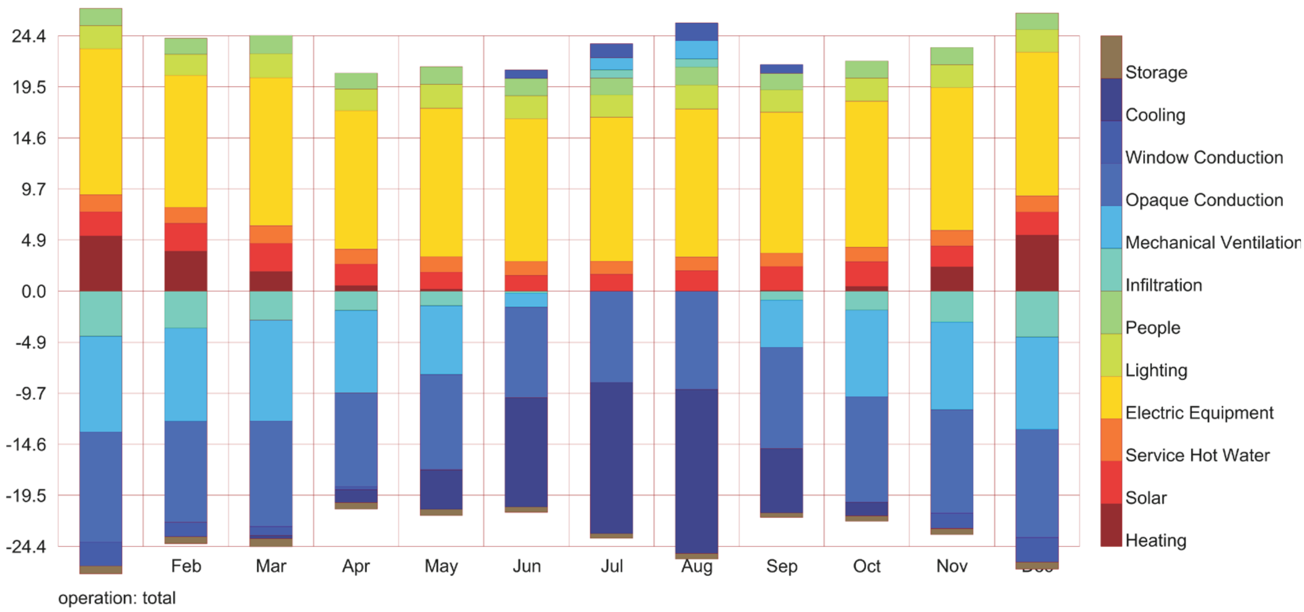


Fig.79: Total Energy Intensity for the mokup (Prototype) room without the panels in Climate zone of Milan city.

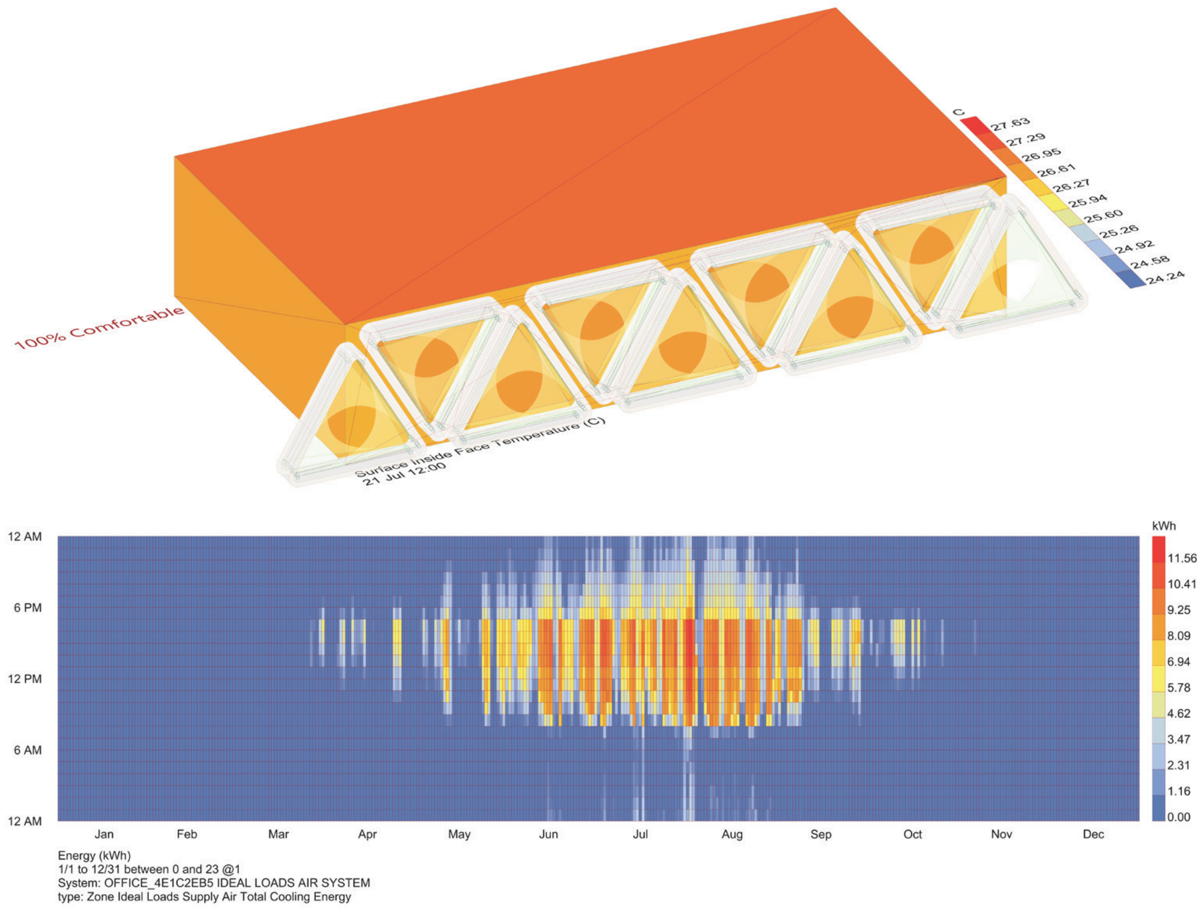


Fig.80: Mockup room (Prototype) WITH trinary units to test the total end use energy (Up) and its loads supply total cooling energy graph (Down).

Then the other test was then conducted in the climate zone of Milan city, Italy, where a mock-up small room had been created for this purpose. In order to compare the needs for heating and cooling and also the total end-use energy, the honeybee program was utilized. The annual Loads supply total cooling and heating energy graph shows a reduction of cooling in the summer period by 17.5 % after applying units (44. 943 kWh/m2) in comparison with the result before applying units (54.443 kWh/m2), and an increased in heating 4% (20.743 kWh/m2),(19.886 kWh/m2) respectively.

This shows how adding units to the façade can improve a building's ability to handle cooling demands. While the heating loads have undesirable effects, albeit in minor amounts.

Without Units	*Broken down each use*	*With Unit*	*Broken down each use*
Heating	19.886	*Heating*	20.743
Cooling	54.443	*Cooling*	44.943
Interior Lighting	26.094	*Interior Lighting*	26.094
Electric Equipment	164.111	*Electric Equipment*	164.111
Water system	17.677	*Water system*	17.677
Total End use energy	***282.212 Kwh/m^2***		***273.569 Kwh/m^2***

Fig.81: (Table 03) Comparison results of End-use energy consumption in the (prototype) mock-up room, with and without the designed unit installed on its glazed façade.

•Computational Fluid Dynamics Study

Obtaining computational fluid dynamics (CFD) simulations of the unit's performance in various contexts is the next step in evaluating the unit's performance.

CFD is a branch of fluid mechanics that uses numerical analysis and data structures to study and resolve problems that involve fluid flows.

In our case, the performance of the unit had been tested using two separate software programs. The first one is flow design from Autodesk, which offers a virtual wind tunnel where you can evaluate your product's performance at different velocities.

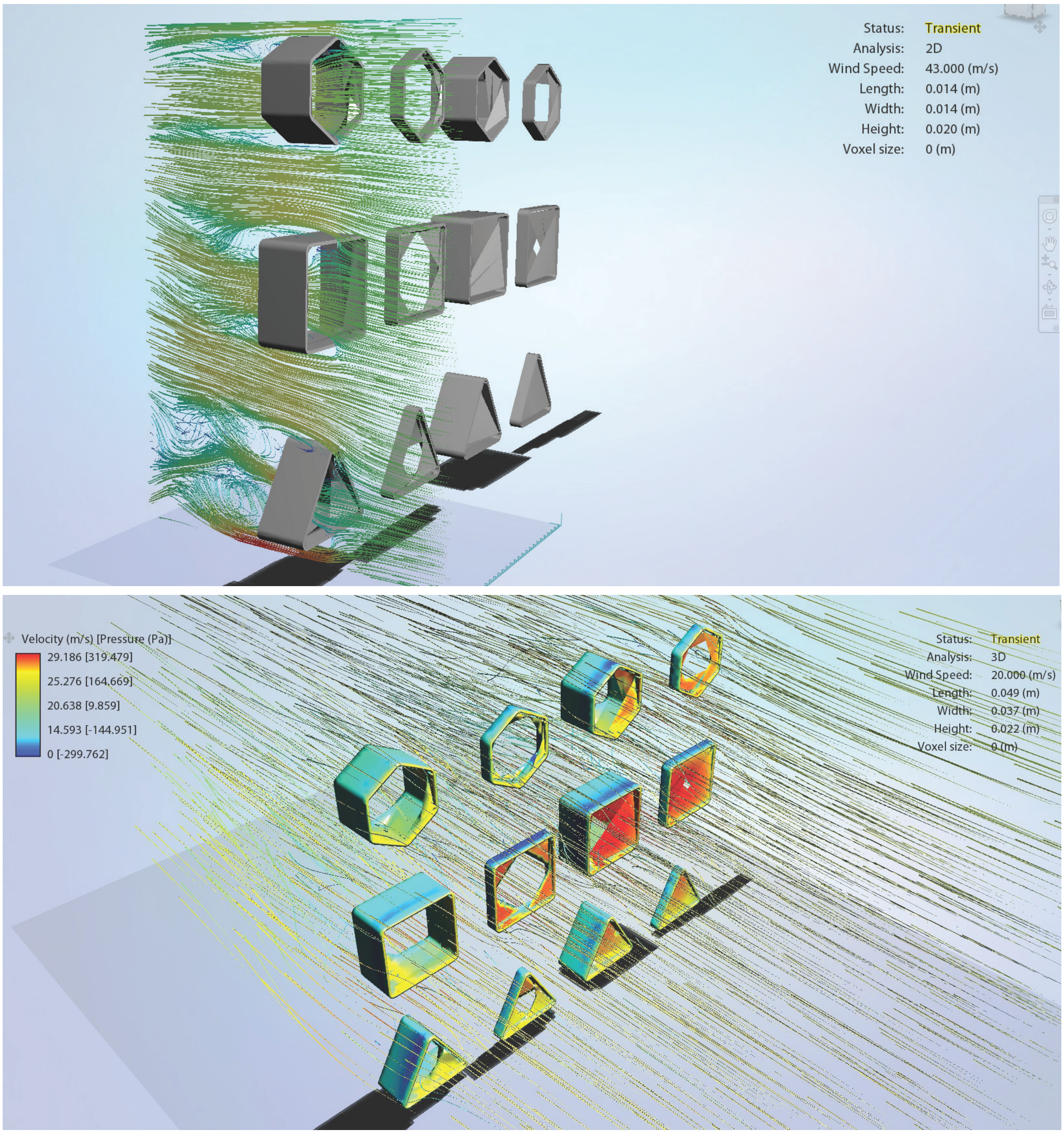


Fig.82: Quaternary, Hexa-units' structure and the aerodynamics simulation

Fig.83: Quaternary, Hexa-units' structure showing the tilted curtains and define the overlapped layered with colors

The internal helical form of the units accelerates air velocity in the open positions, particularly at the deeper curtain depths, as seen in (Figure 82) and with the layered curtains tilt (Open positions) (Figure 83), this allows proportional control of air quantity within the internal space and assists in the cross ventilation as well.

The same mockup room (prototype) was subjected to a second computational simulation using the Butterfly plugin to examine the outcomes before and after adding the units to the façade, obviously with opened windows behind.

The butterfly is a plugin with a python library to create and run advanced CFD simulations using OpenFOAM. In three cases (Figure 85), a Grasshopper GH definition (Figure 84) had been set up using the Butterfly plugin to conduct the indoor airflow simulation with the mock-up room (the prototype) :

1- Without units.
2- With units and fully opened curtains.
3- With units and fully closed curtains.

in the first case, the pressure of the wind is 0.8 pa in the second case, the pressure of the wind is 0.3 pa showing a reduction of 62.5% in the third case, the pressure of the wind is 0.2 pa showing a reduction of 75% the following script studied the effect of the air-flow according to different cases (with and without units).

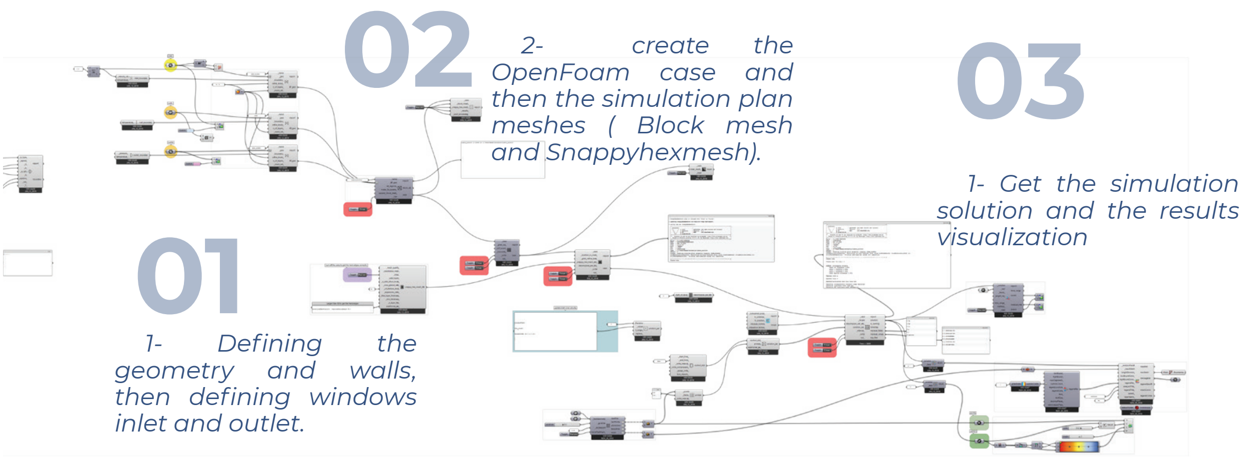


Fig.84: GH and Butterfly script definition to run CFD simulations.

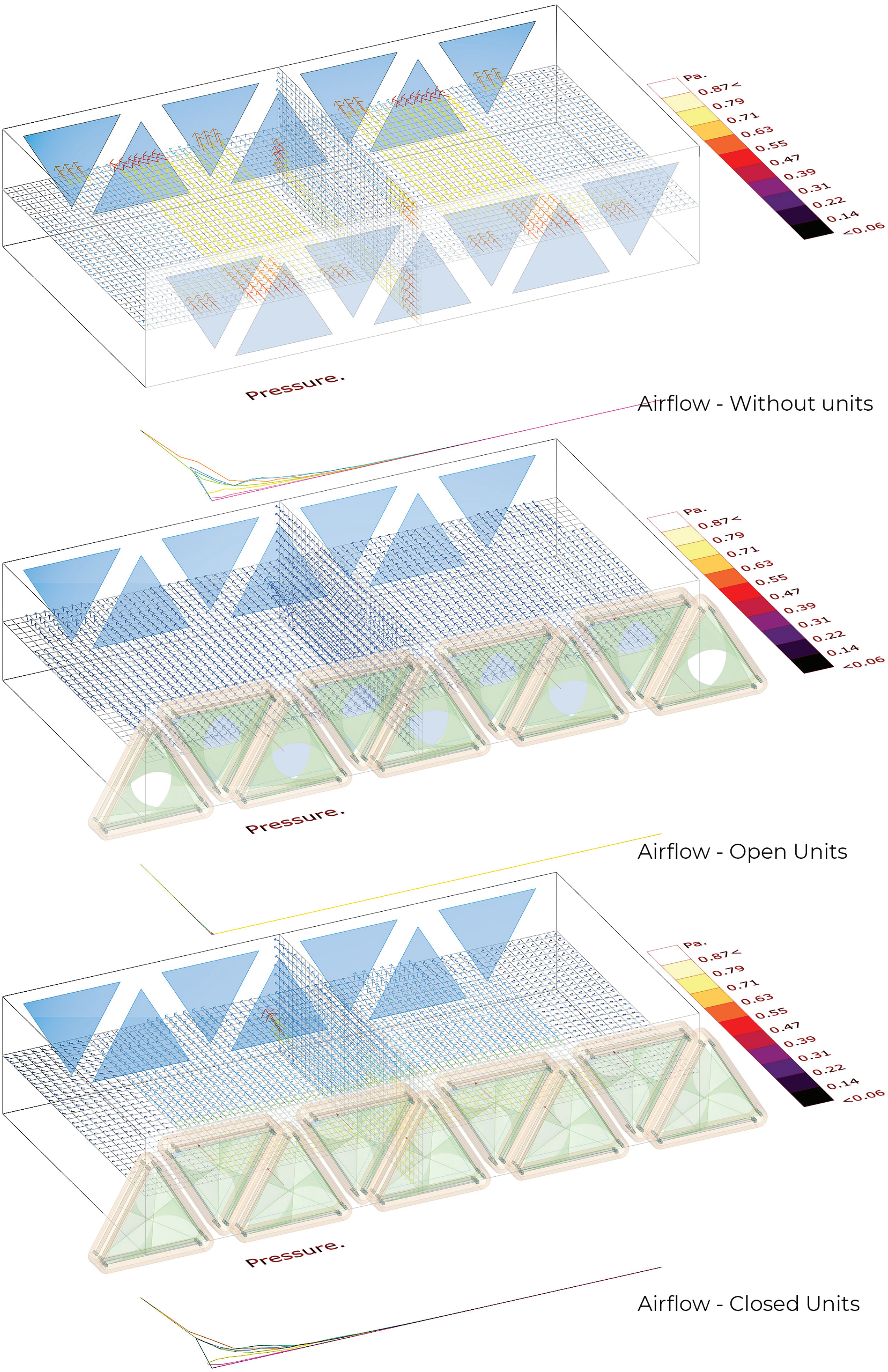


Fig.85: *Airflow pressure simulations results on the mockup room in three different cases (Without units (Up), with installed trinary units in open positions(Middle), and with closed units (Down).*

•Acoustical Study

The science of managing sound in buildings is known as building acoustics. Noise transmission between areas should be minimized or controlled at least. Different aspects can achieve this with the use of different types of Materials or by achieving a specific design that can handle acoustics level in the indoor environment.

The final study applied in this chapter for the unit was an acoustical investigation that made use of another plugin called PACHYDERM using Grasshopper ecosystem as well.

Pachyderm Acoustic Simulation is a collection of acoustics simulation algorithms that can be used to predict noise, visualize sound propagation, and critically listen to designed spaces.

Exactly as the CFD simulation, In three cases (Figure 87, 88), a Grasshopper GH definition (Figure 86) had been set up using the Pachyderm plugin to conduct the acoustical simulation with the mock-up room (the prototype) :

1- Without units.
2- With units and fully opened curtains.
3- With units and fully closed curtains.

It could observe from the side plan views (Figure 87) the acoustic suppression that occurred in the case of complete closure of the trinary units installed on the facade, While the open curtains have a much smaller impact on the sound-representing rays' movements than they would have if the units hadn't been installed.

01

1- Construct a scene with an existing geometry and then define the voice source (Geodesic source)

02

2- Visualize the sound directions (Pachyderm rays) to cast specular rays on the geometry.

03

3- Display the acoustics results and extract their visualization types.

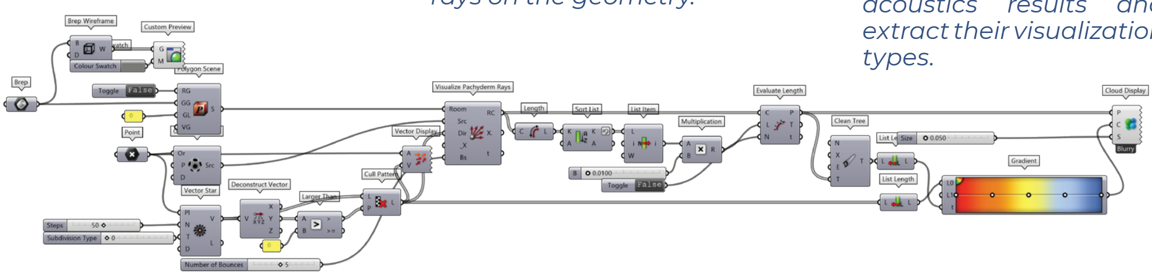


Fig.86: *GH and PACHYDERM script definition to run acoustical simulations.*

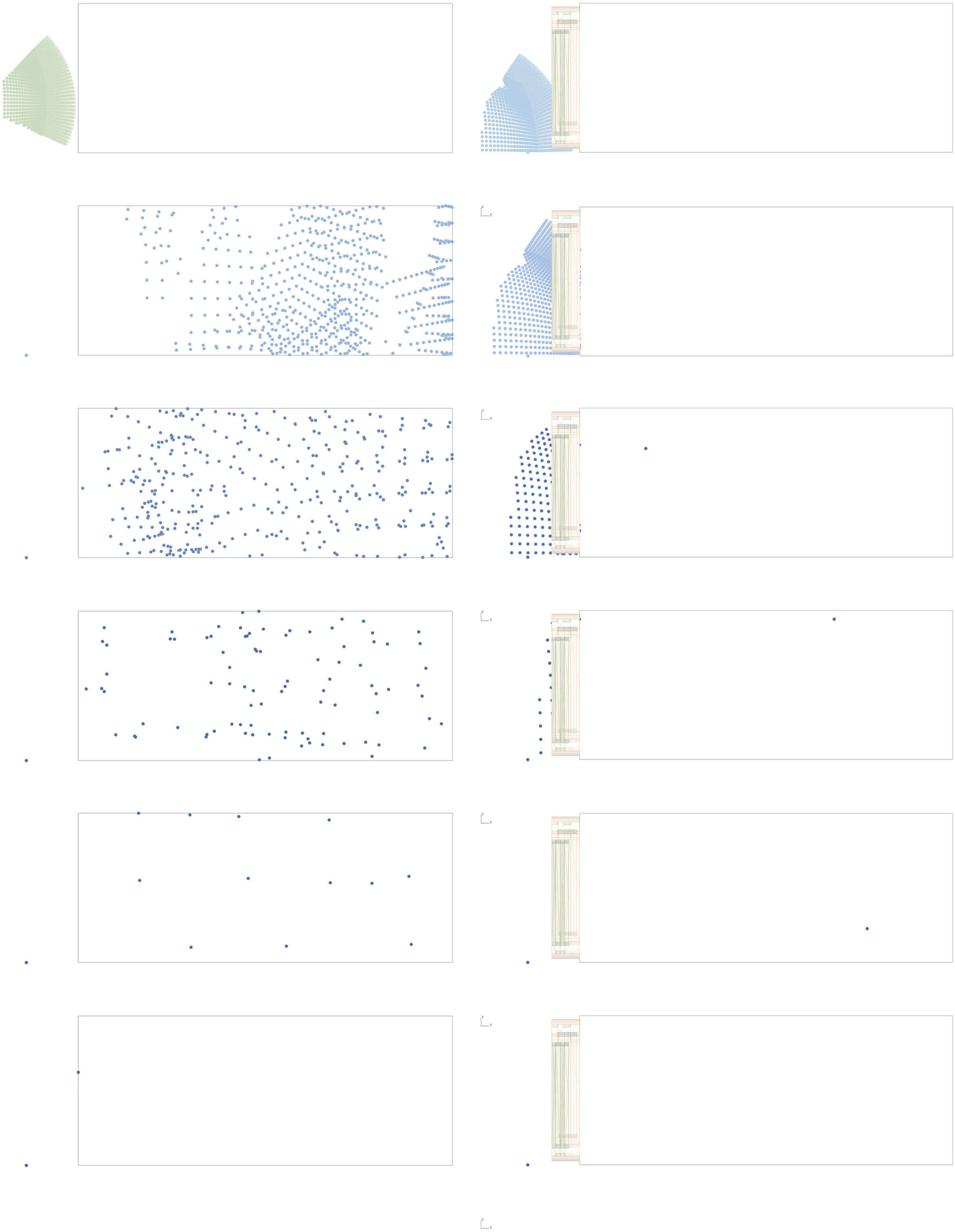


Fig.87: *Side plan view of the acoustical simulations on the mockup room during a run time (Start on the top), Without units (Left), with installed trinary units in* ***closed*** positions (Right).

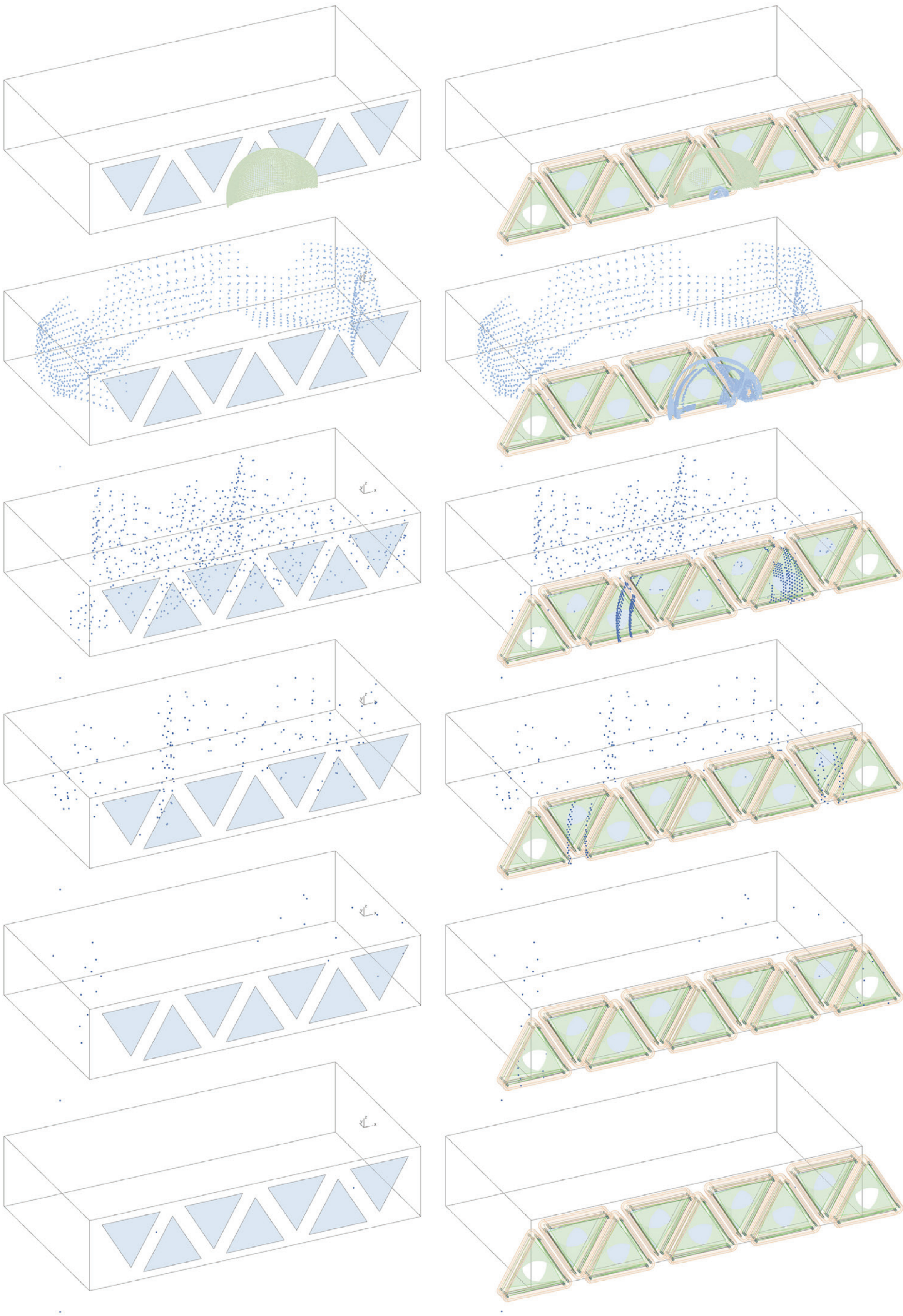


Fig.88: *Prespective view of the acoustical simulations on the mockup room during a run time (Start on the top), Without units (Left), with installed trinary units in* ***open*** *positions (Right).*

HIGHLIGHTS : #Building Physics
#Methods
#Optimization
#Empirical (Prototype)

P O L I T E C N I C O

METHOD
CHAPTER IV

0 4

4. METHODS

"Modern builders need a classification of architecture factors irrespective of time and country, a classification by essential variation. Some day we shall get a morphology of the art by some architectural Linnaeus or Darwin, who will start from the simple cell and relate to it the most complex structures."

William Lethaby 1857 - 1931, (England).

To have a (mass-customization) product of low-cost manufacturing, the design needs to be fully automated with interchangeable parts, a moving assembly line, and machinery systems (Koren 2010, chap. 4). To apply such principles a method developed along two main avenues: (1) Unit structure and (2) Framework with a prior overview of building envelopes.

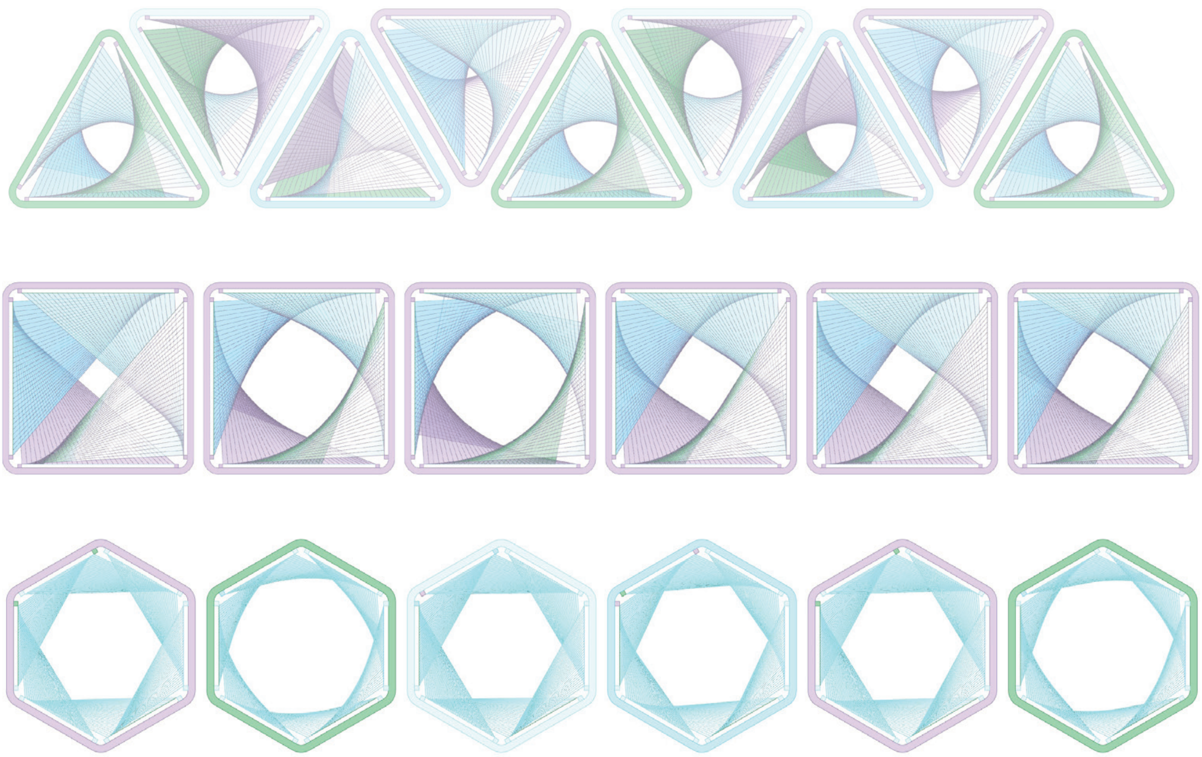


Fig.89: The adaptive innovative units (Authors).

4.1 Building Envelope

Transparent building envelopes have a lot of functions including providing a view out, daylight, ventilation, and protection from radiation and solar gains in winter...etc. Kinetic facades could enhance the envelope performance but it is challenging to create adaptive facades, In fact, as evidenced by research papers and test results, they provide a significant technical potential, but low real-world uptake (Loonen et al. 2017). This study aims to offer advanced techniques with useful criteria that can be applied to achieve them.

The Building Performance indicators are:

Total Energy Performance, Thermal Comfort, Visual Comfort, Aural Comfort, View Out, Productivity Operational Costs /Energy (including Maintenance), and LCA (Construction, Operation, and Disposal).

While Facade Performance Indicators are:

H't (*Overall Envelope Heat Transfer Coefficient), U value (opaque/transparent, CoP, Frame), Psi value (Thermal bridging), Cm and position, g value, Asol (Equivalent Solar Area), Tvis, Color Rendering (transmission/reflection*).

The Facade performance indicators more oriented to physical meaning for steady state boundary conditions and easily comparable as it is not directly providing a performance information (KPI). While the Building performance indicator are non direct physical meaning and more context specific, as they considers dynamic operations and actual building. while they are directly providing a measure towards a certain overall performance. We can use them for design effort by means of simulation tools, being able to assess from early design stage the whole building performance of many possible design alternatives.

The current research scope on the optimized solutions during the methods is the solar and visual indoor-related aspects while other factors are adiabatic.

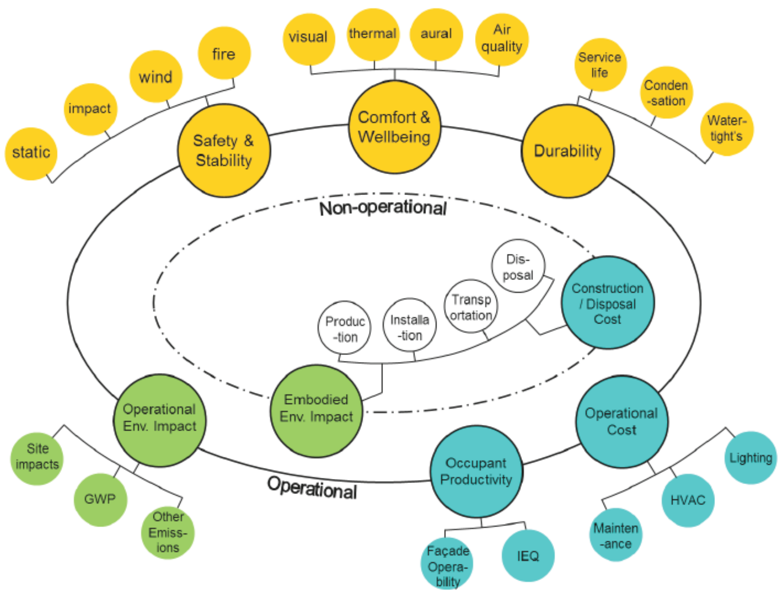


Fig.90: Facade Key Performance Indicators (KPIs), Credits: Prof. Fabio Favino, Prof. Mauro Overend.

4•1•1 Façades systems

Emerging Various terms of adaptive definitions of facades show that scientific research on dynamic skins is developing towards innovative design solutions by utilizing the possibility of integrating mechanical, and automated actuators, material sciences, and IT systems. Thus, technological solutions are moving from static elements to adaptive elements capable of rapidly changing function and configuration in relation to physical requirements.

In the literature, a long list of similar 'adaptive' terms has been used which confuse many researchers in the context of building façade interchangeably, including: passive, dynamic, active, kinetic, intelligent, switchable, responsive, interactive, movable, smart , biomimetic, plant-inspired, and so forth (Tabadkani et al. 2021).

Fig.91: Figure, Kinetic facade systems, Albahar Towers (Left), Kiefer technic showroom (Right).

•Adaptive Facades (AF)

In the traditional way, Spaces in the perimeter zones can receive daylight through windows, as traditional daylighting feature, but only up to a certain distance away from windows or skylights.

Integrated adaptive façade systems are designed through a dynamic process, and more specifically, these systems are evaluated according on how effectively they accomplish the stated objectives. Contrary to prescriptive functions for traditional shading systems like roller shades (open/close) or venetian blinds, performance-based functions for Adaptive Facades (Afs) allow for the prospective use of innovations (such as different configurations) and alterations based on user requests (height or slat angle). In the end, several methodologies are used to assess and classify more than a hundred adaptive building skins and concepts.

•Kinetic facades

These kinds of envelopes are described as complicated mechanical systems that are kinetic and have changing geometries thanks to specific actions like displacing, sliding, expanding, folding, or morphing. As a result, the definition incorporates additional terms that are frequently used in the literature, such as retractable, dynamic, and transformable, even though kinetic facades need to be effectively tuned to outdoor boundary conditions rather than an indoor environment and require actuation force to produce movement. Helio Track is a hypothetical prototype for kinetic facades that uses a kinetic curtain wall to trace the journey of the sun through time as an unconventional example, Arab World Institute and Al-Bahar Towers, which use 1049 hexagonal panels to manage daylight and glare, include 30,000 photosensitive diaphragms that are activated by an iris mechanism.

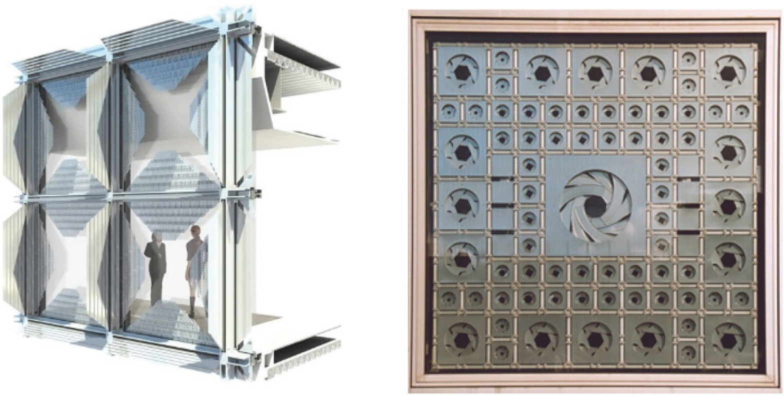


Fig.92: *Helio Trace in New York (USA) (Left), Arab World Institute in Paris (France) (Right).*

•Passive façades

An architectural passive design solution that responds to climatic changes as a weather protection layer of a structure that enhances overall interior comfort is a passive façade. The types of double skin facades (DSF), such as multistory, trombe wall, buffer, and opaque ventilated facades, are included in this calculation.

as apathetic façades. The passive facade is therefore the outcome of a "passive design" rather than being made up of "intelligent components," and its thermophysical characteristics depend on operational procedures like the timing of window openings. For instance, the multi-story DSF in the Morvaian Library can be converted to a single skin in the cooling season by opening the louvers, while the louvers are closed to use the pre-heated space in the heating season.

•Biomimetic or bio-inspired facades

The easiest imitation source for unconventional adaptive systems in either a problem-based or solution-based fashion is plant and human skin. Top-down or specifically problem-based approaches like solution-based or, specifically, bottom-up approach follows the biological principle in combination with a translation system towards building envelope technology. It translates the observed principle into a façade technology that performs the same action, such as responding to light or sun as phototropism and heliotropism, respectively, or responding to humid. As described in the second chapter, bio-inspiration might be included into several levels, scenarios, and elements, such as the facade's performance or the material utilized, as seen in the instances using fiber (figure 93)

•Interactive or media facades

Fig.93: Right to left, BUGA Fibre Pavilion, Rojkind pavilion, Maison Fibre.

By combining technological components like sensors, microprocessors, or building automatic management systems with human input to trigger a response, the façade can be made interactive. However, these types of façade present adaptive aspects of the building but lack the ability to affect indoor comfort. As a built example, Hypo surface is made up of movable triangulated metal plates that can be transformed. This surface deforms in real-time in response to a variety of human-based inputs, including sounds and gestures.

•Intelligent facades

Initial sensing, reasoning, and action functions that can adapt and react quickly are controlled by intelligent facades. Therefore, an intelligent facade combines automatic and occupant control as controlling strategies that, its enable a dynamic ability to allow changes based on environmental conditions through optimizing its usage pattern, whether individually or cumulatively based on predictive models with little user intervention. Building automation, such as computational protocols for the HVAC system and envelope, actuators, and physical adaptive devices like sunshades, blinds, or smart materials that allow variety in the building envelope to maintain desired indoor comfort, are often used to achieve this.

•Movable facades

These facades are equipped with technology systems that can quickly adapt to local environmental circumstances and geographic location using movable technologies like tracking sun position to produce renewable energies at various scales. Therefore, the objectives of this type are to control the indoor atmosphere or user comfort. There are numerous examples of photovoltaics being used on a façade. EWE Arena is a large-scale example, consisting of 200m2 photovoltaic panels that slide 200 degrees along the edge of the envelope to produce nearly 27 MWh annually (Tabadkani et al. 2021, 8).

Façade type	Requirement(s)	Limitation	Potential	User interaction	Upgraded version
Active	active technologies without sophisticated electronics	controlling indoor environment is not the aim	self-adjustment of façade that can be controlled by internal and external environment	No	–
Passive	passive design	a passive design makes it an adaptive façade	weather-protective layer that can improve indoor comfort condition	No	Intelligent façade
Biomimetic	mimicking natural inspirations	only responds to outdoor environmental condition and certain thresholds	uses biomimetic principles of nature with least energy involvement	No	–
Kinetic	complex mechanical or electro-mechanical mechanisms	corresponds only to outdoor environment	allows a wide range of possible motions	No	Responsive façade
Intelligent	Integrating automated and manual controlling through intelligent components	requires sensors, actuators and controllers to control indoor environment and computational technology to predict	has the ability to learn and respond over time either by learning facilities or real-time controllers	Yes	Responsive façade
Interactive/ Media	sensors, actuators and controllers in combination with direct human interventions	do not influence indoor comfort	responds in real-time by human-based signals	Yes	–
Movable	mobile systems in façade scale to quickly respond to climatic changes	user comfort is not the aim	has the ability to produce energy	No	Kinetic façade
Responsive	sensors, actuators and controllers to control indoor environment	need an act to response	allows real-time environmental perception and user-oriented operations	Yes	–
Smart	smart materials for intrinsic control	limited to materials with specific physical properties that are time-dependent	no need for external energy to generate movements	No	Intelligent façade Responsive façade Switchable facade
Switchable	adaptive materials for intrinsic control	limited to transparent components with specific physical properties	can be controllable either actively by users or passively by outdoor environmental condition	Yes	–

Fig.94: (Table 04)Characteristics of adaptive façade's typologies (Tabadkani et al. 2021).

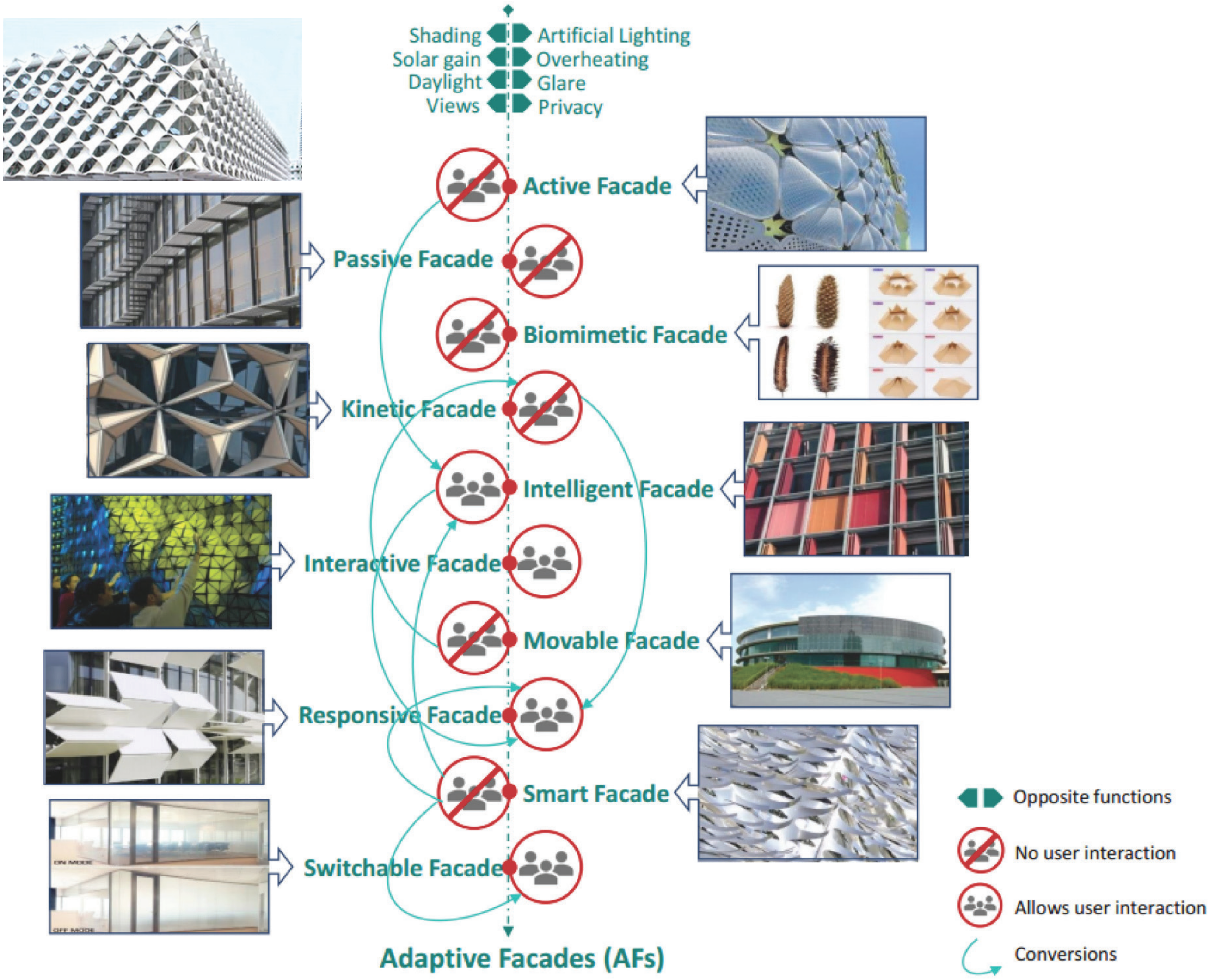


Fig.95: Interactions between existing AF's typologies (Tabadkani et al. 2021).

4•2 Indoor environment Quality

Generally, the outdoor environment refers to (atmospheric pollution, solar radiation, and climate), while the indoor environment quality refers to (thermal comfort, indoor air quality (IAQ), and lighting/Visual aspects). To address the conditions of thermal comfort there are six conditions (Metabolic rate, Clothing insulation, Air temperature, Radiant temperature, air speed, and Humidity) ("ANSI/ASHRAE Standard 209-2018 - Energy Simulation Aided Design for Buildings Except Low-Rise Residential Buildings" n.d., 7). There are no thermal environmental factors such as air quality, acoustics, illumination, or other physical, chemical, or biological contaminants that could affect comfort and health levels. Controlling these factors may affect thermal comfort levels as well.

4•2•1 Green Systems

There are a lot of green systems discussing the indoor environment and the occupants well being. According to the American Green system (LEED), the Indoor Environmental Quality (IEQ) refers to the quality of the air and environment inside buildings, based on pollutant concentrations and conditions that can affect the health, comfort, and performance of occupants. Indoor air can be two to five times more polluted than outdoor air. The Variables that affect the indoor environmental include: (Temperature, Humidity, Lighting, Acoustics, Air quality, and Control systems (U. Green Building Council n.d., 192). It's generally means the entire interior experience.

IEQ difficulties may result in liability concerns, poor tenant health, lost workdays, and costly fixes to fix the issue. Imagine selling a house and having a prospective buyer find black mold in the basement. That cleanup will either be covered by the seller or the house won't sell. When it comes to proper IEQ, all facets of the construction process are involved: design, building techniques, material selection, housekeeping, operations, and maintenance, staff training, tenant behaviors, etc. The indoor environment and regular building residents are impacted by each of these aspects.

with health benefits there are some other economic benefits regarding improving the IEQ such as reduced liability, reduced employee absenteeism, Reduced employee turnover, reduced occupant complaints, reduced vacancy costs, increased tenant satisfaction and retention, and increased marketability of the property, Which could be achieved through two strategies include Improve indoor air quality and increase occupant comfort (U. S. Green Building Council n.d., 607).

It is complicated and still not fully understood how the indoor environment affects building inhabitants' comfort and health. It can be challenging to quantify and assess the direct effects of a structure on its occupants because of a variety of factors, including the occupants' activities, local norms and expectations, and the location, design, and construction of the building. In light of this, the EQ section strikes a compromise between the need for prescriptive metrics and more performance-based credit criteria.

The EQ category combines traditional approaches, such as ventilation and thermal control, with emerging design strategies, including a holistic, emissions-based approach (Low-Emitting Materials credit), source control and monitoring for user-determined contaminants (Enhanced Indoor Air Quality Strategies credit), requirements for lighting quality (Interior Lighting credit), and advanced lighting metrics (Daylight credit). A new credit covering acoustics is now available for all projects using a BD+C rating system(U. S. Green Building Council n.d., 607). and comes in the following credit:

EQ Prerequisite Minimum Indoor Air Quality Performance

EQ Prerequisite Environmental Tobacco Smoke Control

EQ Prerequisite Minimum Acoustic Performance

EQ Credit Enhanced Indoor Air Quality Strategies

EQ Credit Low-Emitting Materials

EQ Credit Construction Indoor Air Quality Management Plan

EQ Credit Indoor Air Quality Assessment

EQ Credit Thermal Comfort

EQ Credit Interior Lighting ,

EQ Credit Daylight

EQ Credit Quality Views

EQ Credit Acoustic Performance.

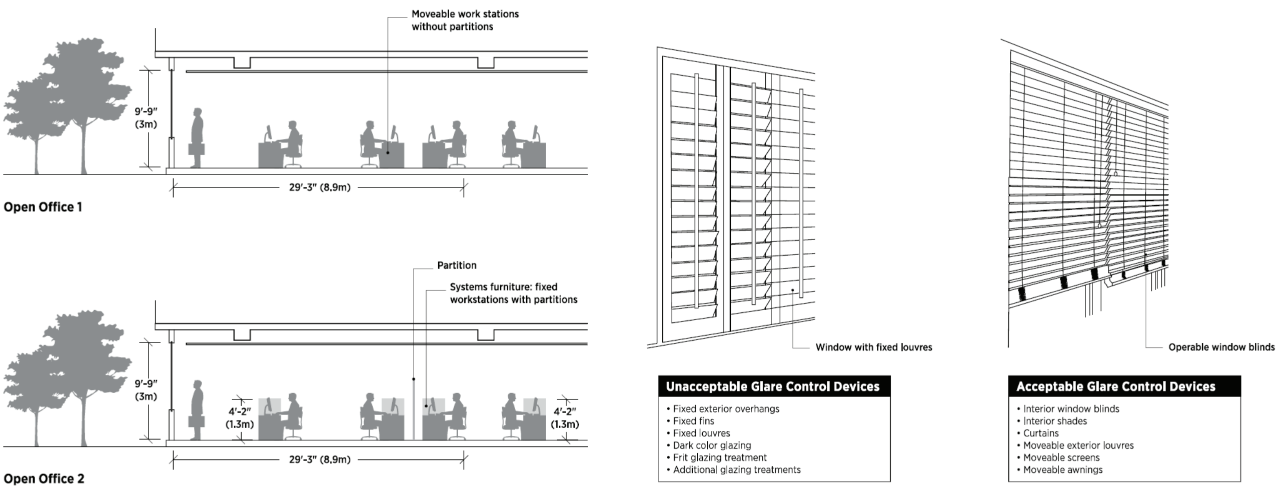


Fig.96: Samples of LEED green systems regarding to IEQ credits. Compliant and noncompliant oice spaces (Left), Glare control devices (Right).

4•2•2 Building Physics requirements.

The current building regulations in different countries defining the prescriptions and minimum requirements for buildings and required to measure performance as well, this section lists the associated calculated factors, which are described in the algorithmic definitions as equations and measured according to the EU-Italian regulations.

4•2•3 Controlling factors

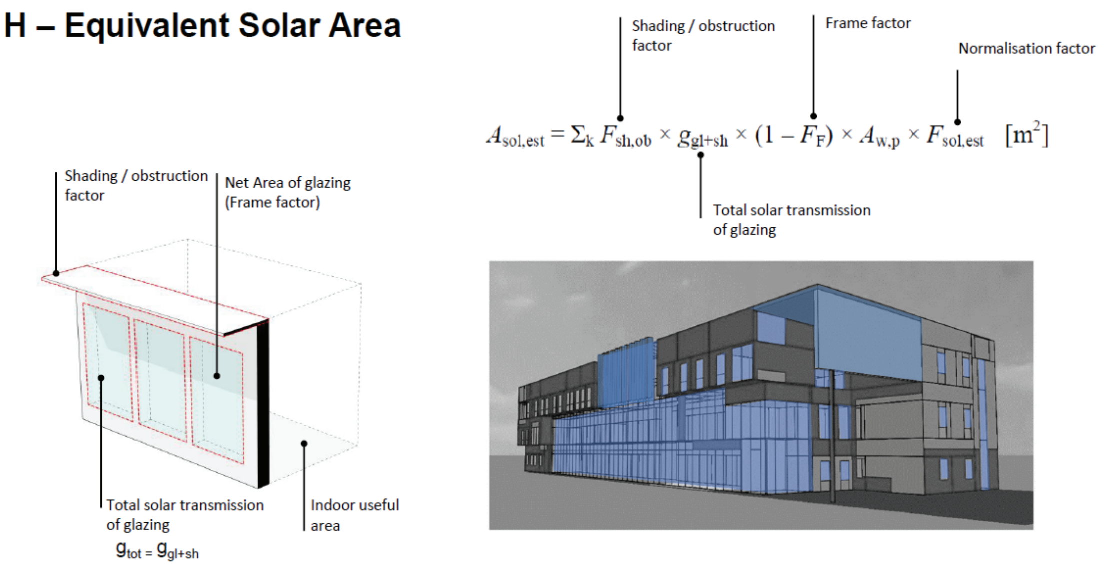
In a typical scenario for designing a façade, the designer would have information including the location, orientation, and the surrounding context and the program of the building where he can guess the occupant's capacity and other useful information. In the case of designing a definition and building an algorithm, it needs to define the controlling factors. There are three factors dedicated to highlight solar and visual comfort.

•Equivalent solar area (A sol, east)

The formula for the calculation of the summer equivalent solar area.

$$A_{sol,\,est} = \sum_k F_{sh,\,ob} \times g_{gl+sh} \times (1 - F_F) \times A_{w,\,p} \times F_{sol,\,est} \quad [m^2]$$

In the formula, F sh, ob represents the shading and obstruction Factor, while g_{gl+sh} represents the total solar energy transmittance of the window in July, F_F is the fraction of the area relative to the window frame, $A_{w,\,p}$ is the window opening area while $F_{sol,\,est}$ represents the building location as a (Normalization Factor) and average annual irradiance of Rome on the horizontal plane (4.4 Kwh/m2).
($A_{sol,\,est}/A_{useful}$) does not exceed the maximum value that is allowed. In office buildings it is recommended to be ≤ 4% (Favoino, Giovannini, and Thiebat 2021).



$A_{sol,est}/A_{useful}$

	#	Categoria edificio	Tutte le zone climatiche
Residential buildings	1	Categoria E.1 fatta eccezione per collegi, conventi, case di pena, caserme nonché per la categoria E.1(3)	≤ 0,030
All others (office, schools, retail ,etc.)	2	Tutti gli altri edifici	≤ 0,040

Fig.97: Equivalent Solar area equation.

•Daylight Factor (DF)

The daylight factor (DF) represents the ratio between the average indoor illuminance (at the center of the room) and the outdoor horizontal illuminance (unobstructed view, only due to diffuse radiation, not direct radiation). The formula as presented (figure 98), The standard EN 10840 indicates the minimum values of DF required inside different building types, for offices it needs to be ≥ 2% (Asdrubali and Desideri 2019, 599).

$$DF\ (FLD_m) = \frac{E_i}{E_{e,o}} = \frac{A_f \tau_l}{(1-\rho_{l,m})A_{tot}} * \varepsilon * \psi$$

Fattore di Luce Diurna Medio – FLDm or Daylight Factor – DF

Destinazione d'uso	***Valore minimo del fattore medio di luce diurna***			
	FLD_m >= 1%	***FLD_m >= 2%***	***FLD_m >= 3%***	***FLD_m >= 5%***
Dwellings [DM1975]	/	all rooms	/	
Educational buildings [UNI2007]	offices, staircases, restrooms	gymnasiums, canteens, common rooms	classrooms, laboratories	gamerooms for kids, kindergardens
Hospitals [CIRC1974]	offices, staircases, restrooms	gymnasiums, canteens	patient rooms, laboratories	

A_f = net glazing area [m²]

τ_l = visible transmittance [-]

$\rho_{l,m}$ = area-weighted average room visible reflectance [-]

ε = window factor [-]

A_{tot} = total area of room surfaces, included windows [m²]

ψ = correction factor of window factor [-]

$\varepsilon = 1$ for unobstructed skylights
$\varepsilon = 0.5$ for unobstructed windows
$\varepsilon < 0.5$ for obstructed windows

Fig.98: *Daylight equation and the range in different buildings types.*

•Radiation Analysis

It is the amount of solar radiation incident upon the test surface, expressed as (kWh/m2). Typically, solar radiation is combined with other elements to establish a particular level of comfort. In this case, the goal is to maximize or limit it depending on preferences. The incident radiation levels could be managed by window's shutter systems.

4•3 The Unit

Following the design proposal chapter, an innovative envelope unit should be designed to manage the various user-targeted scenarios and different envelope formulations in order to improve the practical envelope design model.

4•3•1 Unit Potential

The design of the unit needs to gather a lot of features that could affect the performance of the building and the envelope.

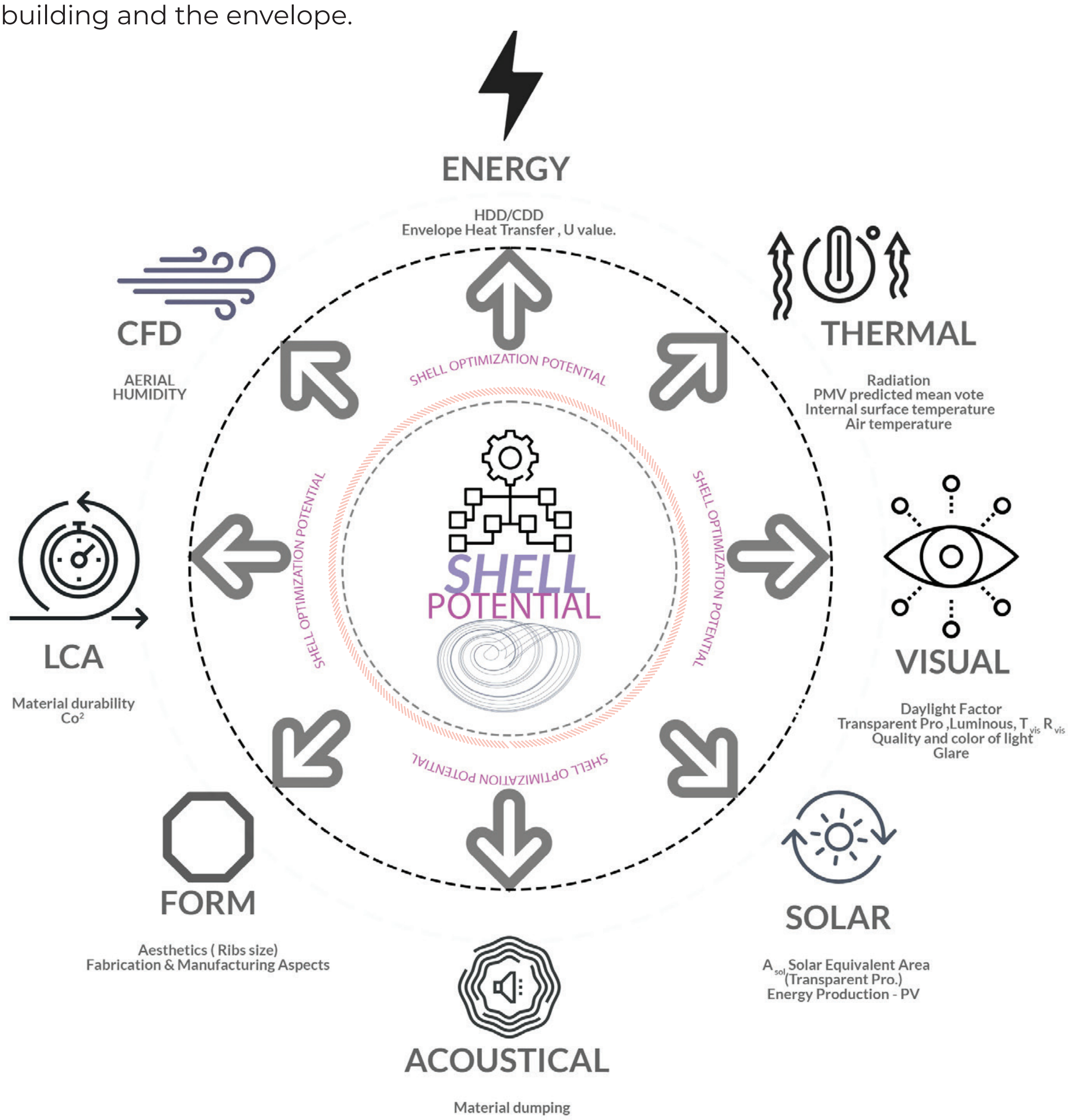
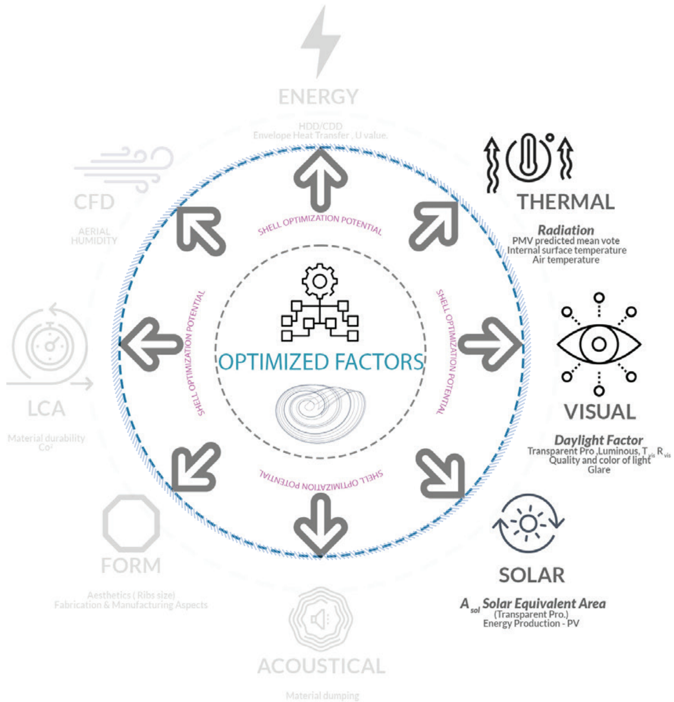


Fig.99: Shell Potential (eight different aspects).

for that the research developed a unified system that can adopt eight main aspects: Thermal, Visual, Solar, Acoustic, Form, Life cycle assessment, Computational fluid dynamics, and Energy.

The potential that units have can be integrated with an Evolutionary optimized approach using a Multi-Objective Evolutionary algorithm (MOEA), there are a lot of evolutionary engines to optimize different objectives and provide solutions. However, the Evolutionary optimization process needs relatively a huge computational capacity that can severely affect the simulation times.

or that the research divided the unit potential into two features groups the first one to be integrated in the optimization process which are (Solar, Visual, and Thermal) While the other five elements to be studied separately.



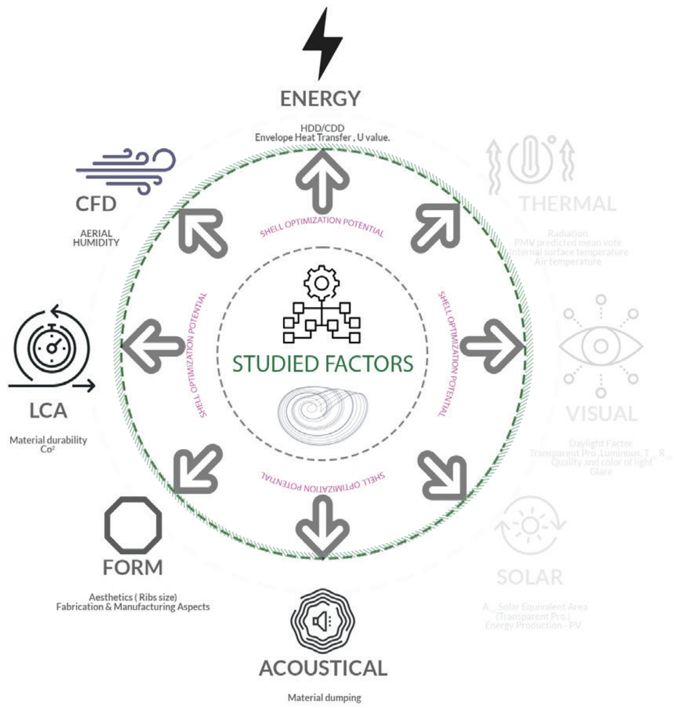


Fig.100: Two graphs shows the studeid factors and the three optimized factors integrated during the multi objective evolutionary process.

4•4 Framework

The development of the optimized design pipeline depends on addressing the areas of performance data-driven with its criteria (Shi and Yang 2013). To establish a methodology for integrating the existing building conditions, in a holistic design process.

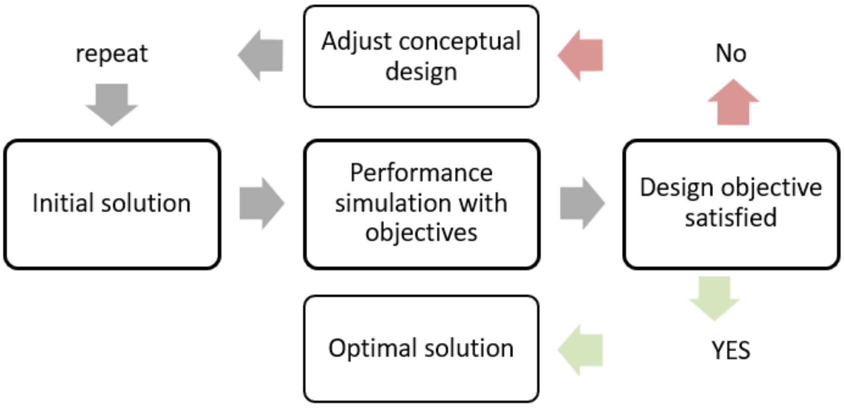


Fig.101: *Workflow of data driven.*

4•4•1 Fit to all - workflow.

After this research established the envelope units to achieve the desired pipeline for different types of envelopes (using Rhinoceros/Grasshopper softwares), a computational workflow integrated with all the performance conditions has been established, then defined as inputs for the optimization process.

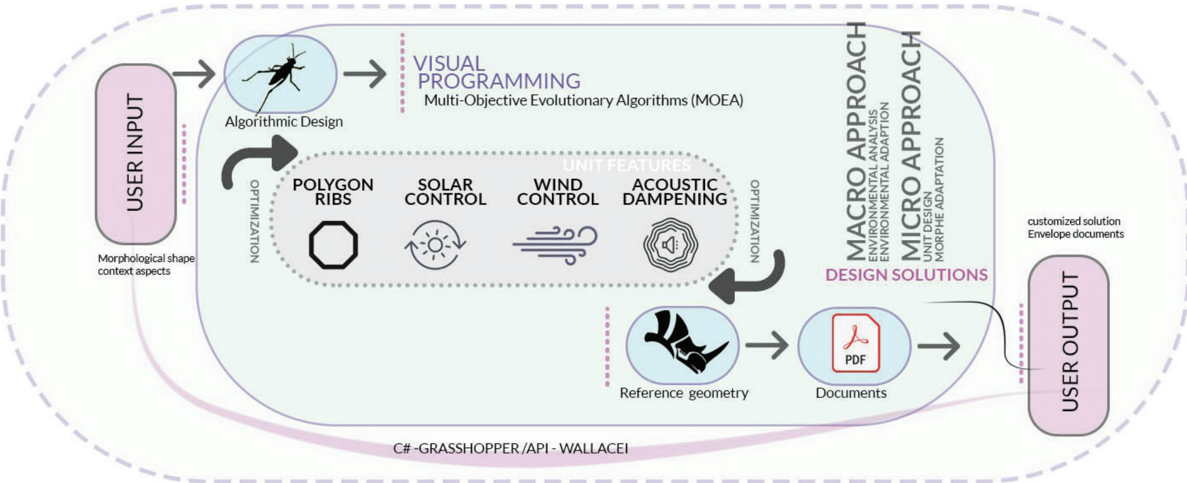


Fig.102: *(Fit to all workflow, from user input to user output.*

Main workflow (Fit to all - workflow) for the customized envelope solutions, The development of the optimized design pipeline depends on addressing the areas of performance data-driven with its criteriaing definitions to guide the design optimization in a loop controlled by certain algorithms.

The results of simulations can be automatically fed back to the modeling definitions to guide the design optimization in a loop controlled by certain algorithms (Figure 101).

4•4•2 Framework definition.

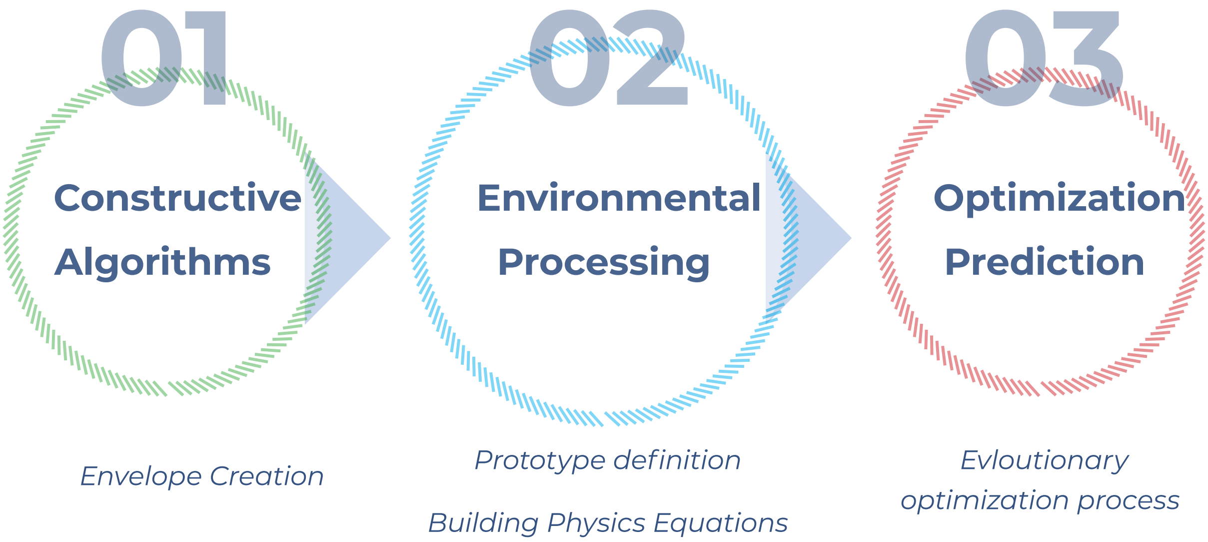


Fig.103: *Method three main steps (Construction - Environmental - Optimization).*

This section outlines the procedure followed when carrying out the research's experiments.

•Constructive algorithm (Units)

The methodological framework is divided into three main steps (Figure 103), the first one is to define the units as mentioned in unit construction, combined with the building model to create a prototype simulation.

•Environmental processing

This Part divided to two main parts, fisrt the **Building Physics** part to add the formulas according to the italian laws and secondly the **Prototype** to study the results on a specific and measured zones.

The Building Physics definitions and using (Ladybug) simulation tools to measure Incident Radiations, shading mask that generates orient view and sky view to calculate A_{sol}, DF factors with integrating the context.

•Optimization prediction.

As mentioned on the last part of the literatire review about the optimization process as the process of finding the best parameters in order to make a design as effective and functional as possible in relation to some specific performance indicators. It can be set to minimize or maximize these indicators, which may be related to various aspects of the design such as structural or climatic (energy or day light performance).

There are several optimization software ranging from optimization platforms , such as modeFrontier, Galapagos, Opossum, Optimus, Wallacei and Octopus.

Generally these engines can be divided into a number of categories on a range of functionality and results provided by them. The popular division is based on Optimization Criteria. In this research, the two categories used are Single-Objective Optimization only during a part of the LCA calculations and Multi-Objective Optimization during the methology and the software application in the next chapter.

Once the constructive and Environmental processing are defined, an MOEA methodology applied using the evolutionary and analytic engine to achieve the objectives from the third step,, by minimizing or maximizing them depending on the analysis period. Lastly export optimization results by Pareto front Solutions definition.

The optimization process is fundamental through this methodolgy, refering to the optimization on the last part of chapter two (Literature review), there different plugins or engines that handle thre process of optimization in Grasshopper software (*plugin / graphical algorithm editor*).

01

1. Constructive Algrithm.

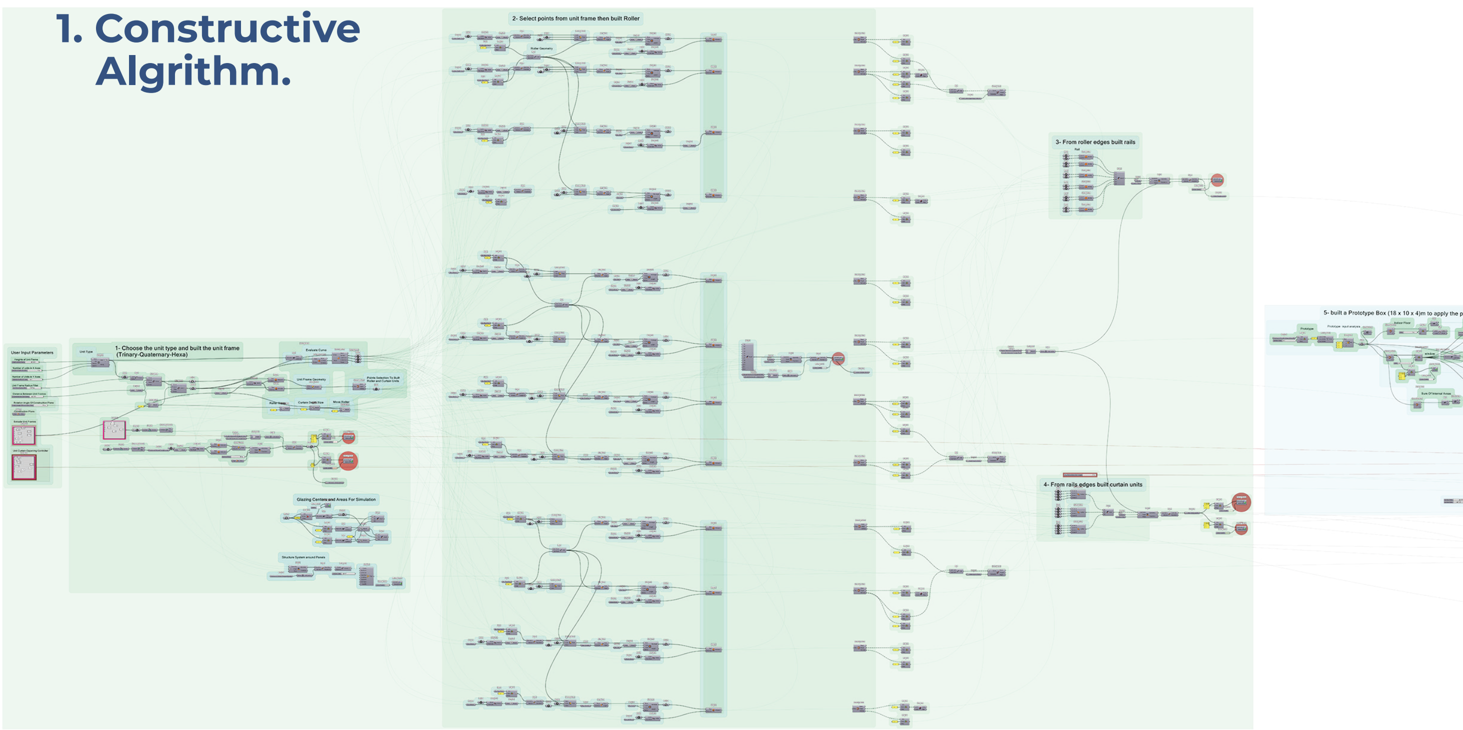


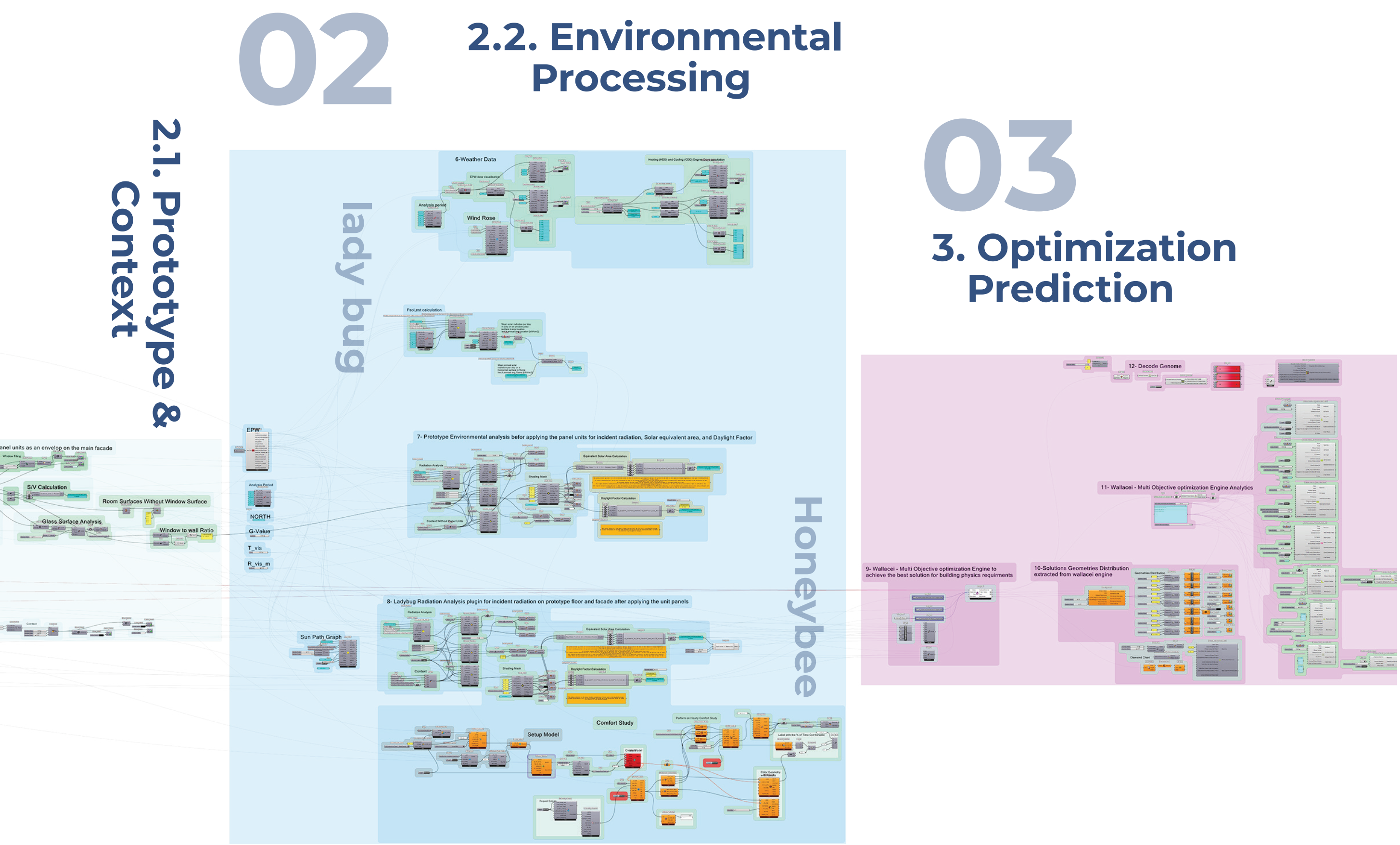
Fig.104: The method full Grasshopper definition through the three main steps.

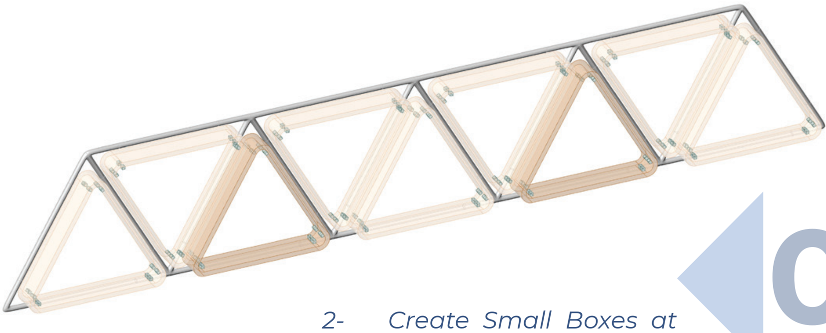
The first plugin and the used one in the method and during the application chapter (5) is WALLACIE which is an evolutionary multi-Objective optimization engine that allows users to run evolutionary simulations through utilising highly detailed analytic tools coupled with various comprehensive selection methods which encourage the research to use. This options assist users to better understand their evolutinary runs, and make more informed decisions at all stages of their evolutinary simulations.

Another Important plugin is GALAPAGOS which also used during the evolutinoary LCA calculations in Applications chapter. Galapagos is the native optimization engine for Grasshopper, developed by David Ruttem, but it is a single objective optimization engine hence it mainly works on either maximizing or minimizing the given single fintness criteria.

One more engine is BIOMORPHER which is an interactive Evolutionary Algorithms (IEAs) that allows designers to engage with the process of evolutionary development itseld. This creates an involved experience, helping to explore wide combinatorial space of parametric models without always knowing where you are headed.

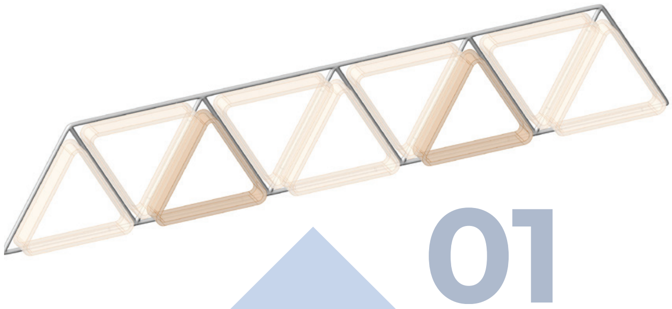
•SCRIPIT DIVIDING





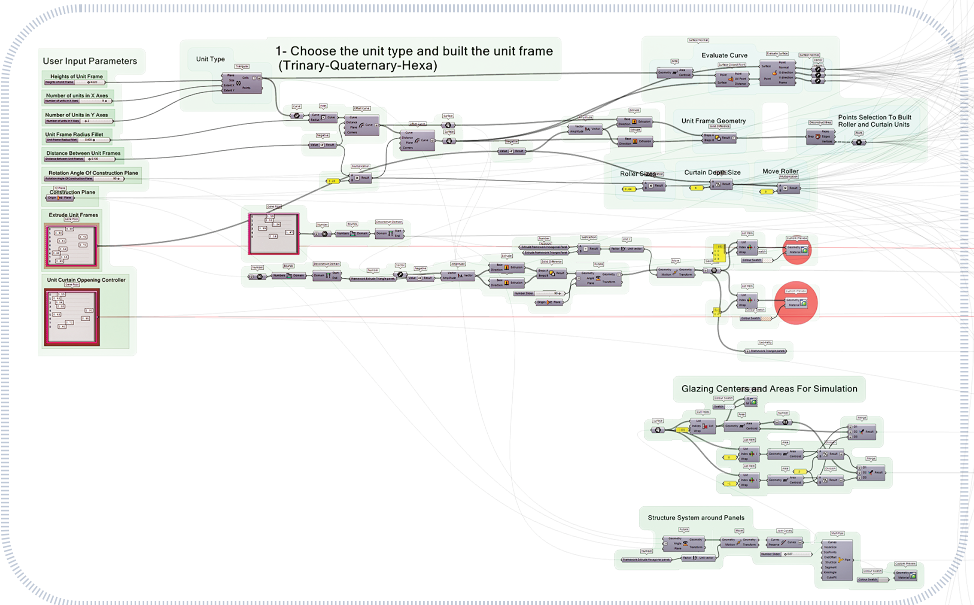
02

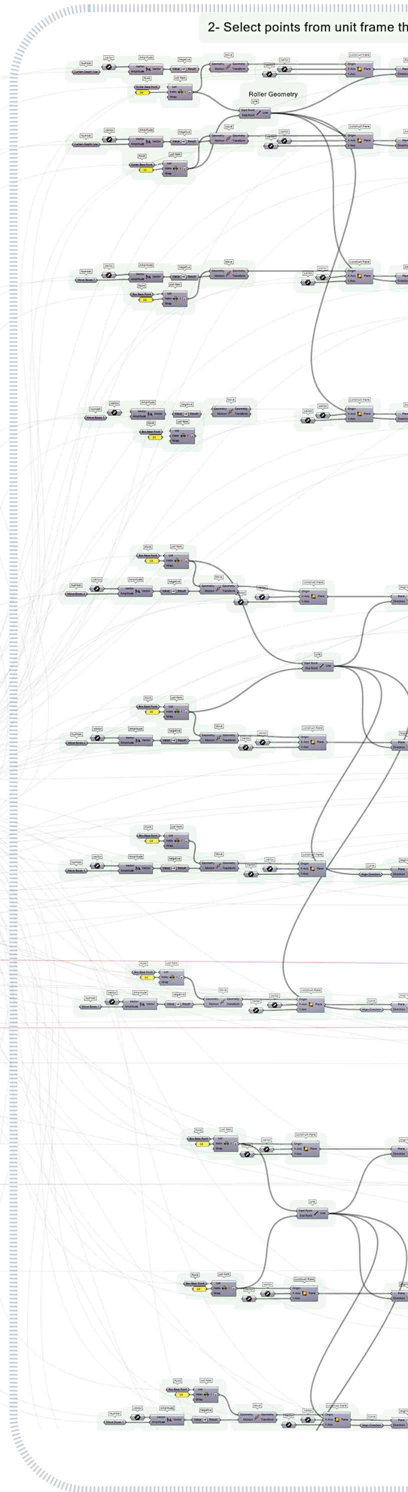
2- Create Small Boxes at each edge to hold the rails to open and close the curtains.



01

1- Triangular subdivision and fillet curves then extrude them to make the Panel Cadre





Constructive Algorithm:

user input parameters representing all features of unit panels. The geometry (unit type) of panel units, the size of units, frame extrusion, curtain unit opening controller, and the structure system around them taking into consideration the number of units that meet the size of the surface we apply the panels on it and insert the input parameters as gene pool components to allocate specific parameters for each unit alone to have an independent set of controls. the second step is to allocate the roller on unit edges that control the opening of curtains, for each edge, there are two rollers fixed to rail parallel to each edge and moved inside at a specific distance. finally, the curtain is connected between two sequential rails.

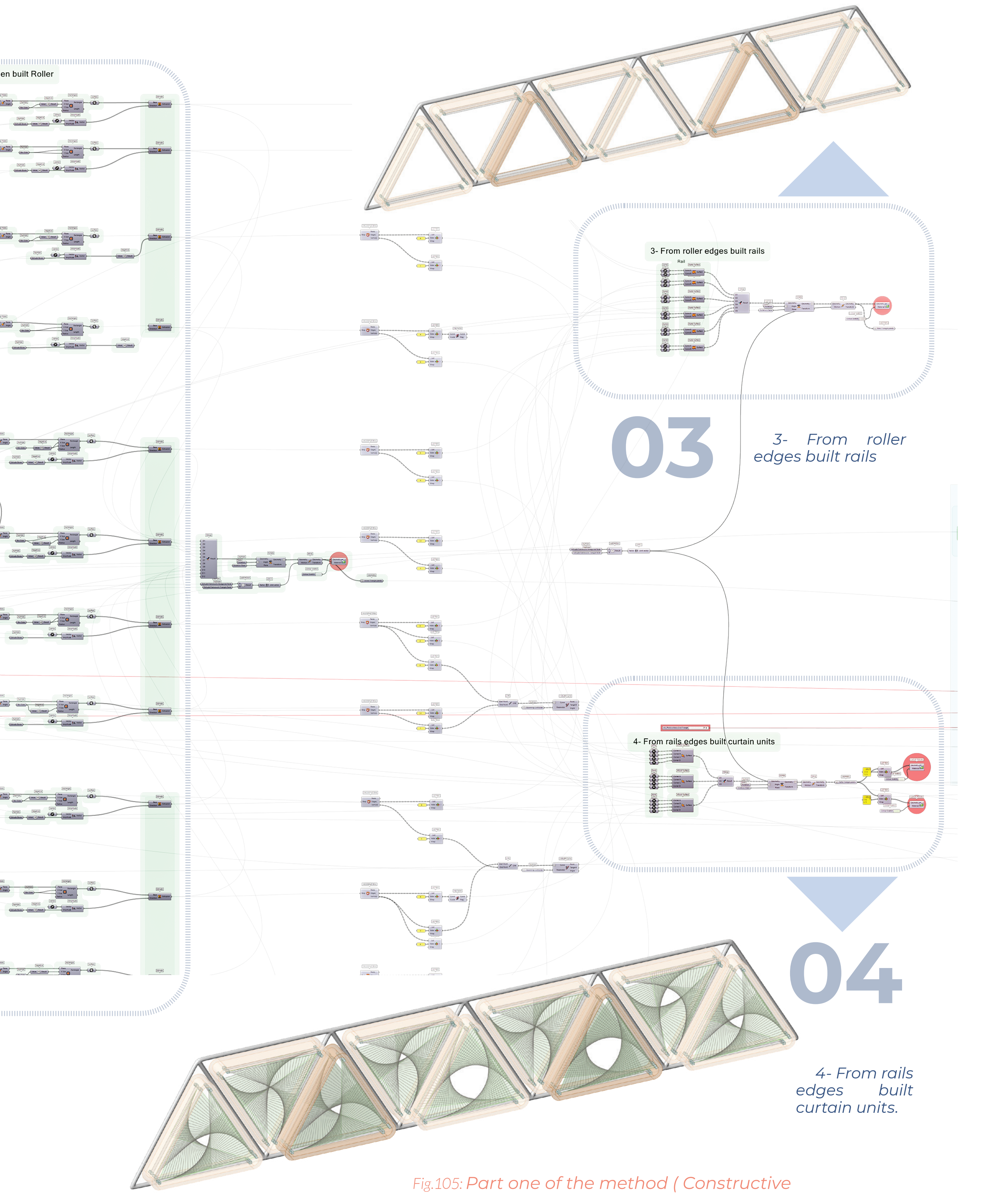
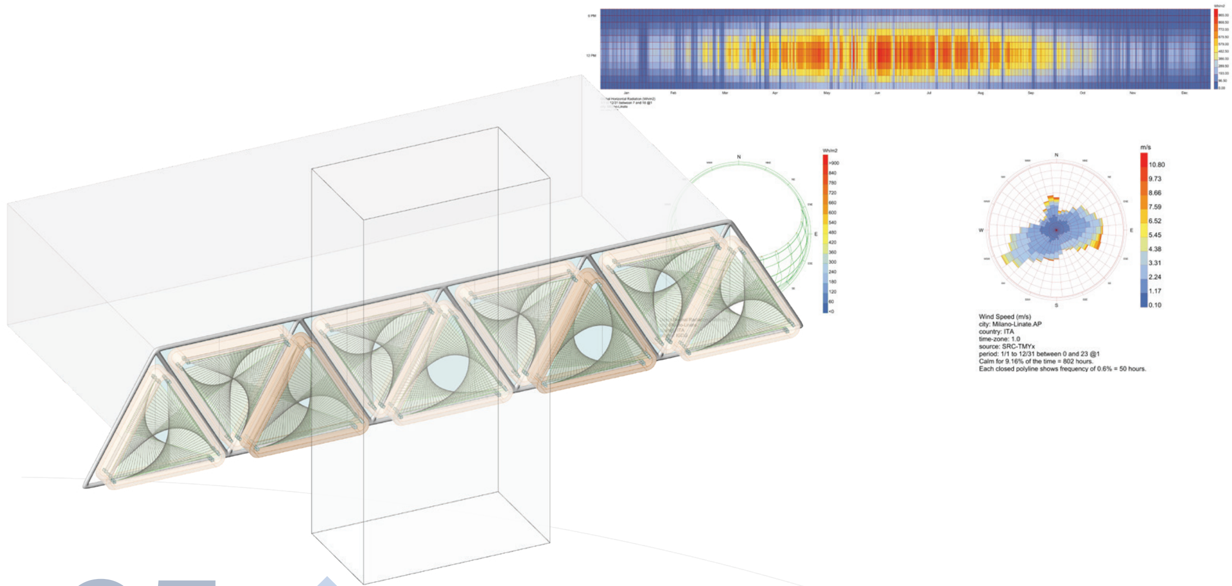
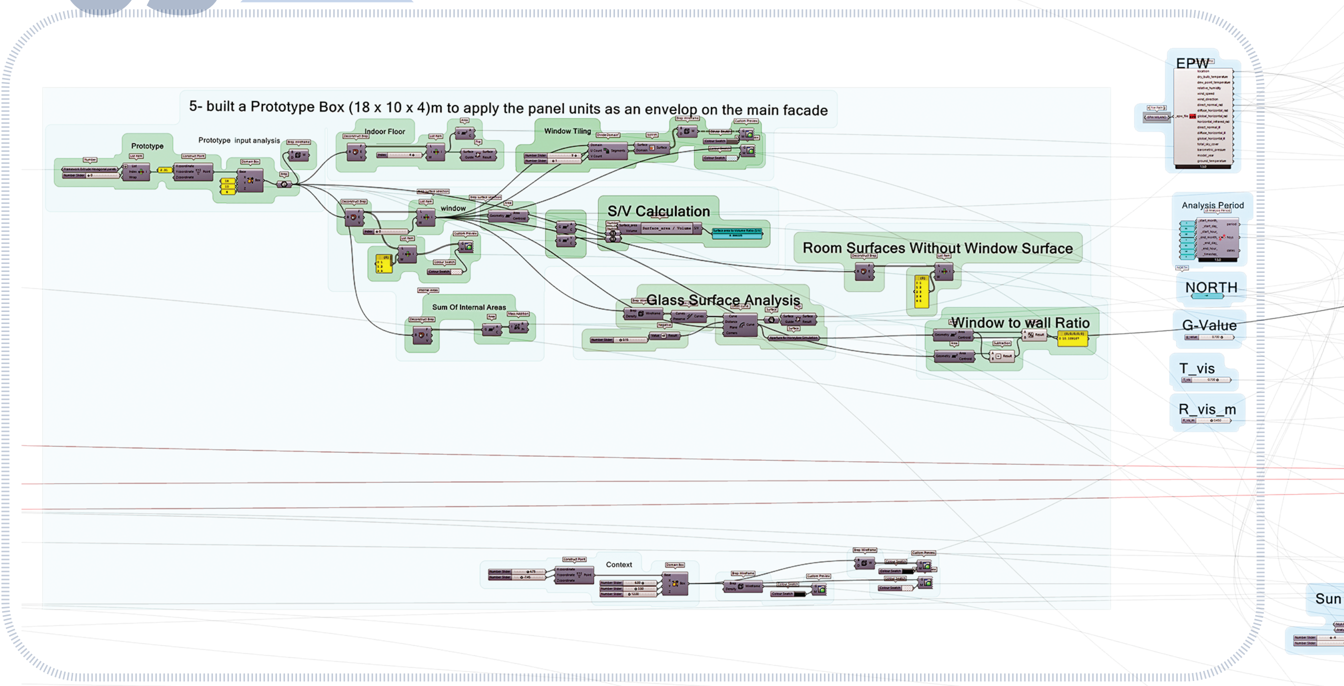


Fig.105: Part one of the method (Constructive Algorithms)- Grasshopper definition with its results.

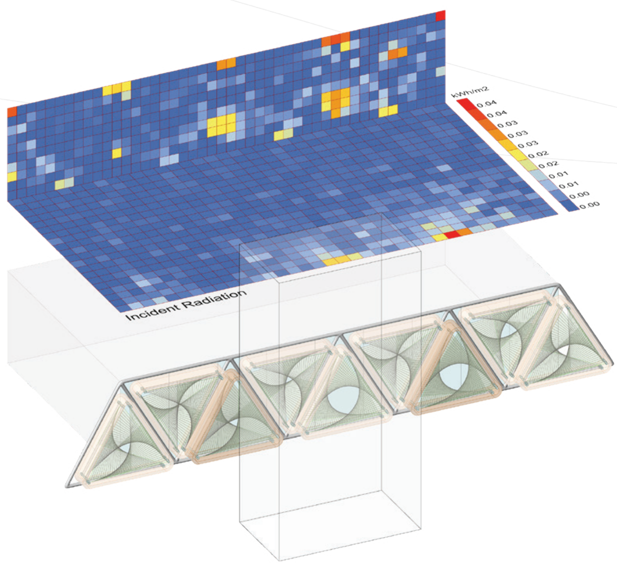


05

5- built a Prototype Box (18 x 10 x 4)m to apply the panel units as an envelop on the main facade



8- Ladybug Radiation Analysis plugin for incident radiation on prototype floor and facade after applying the unit panels



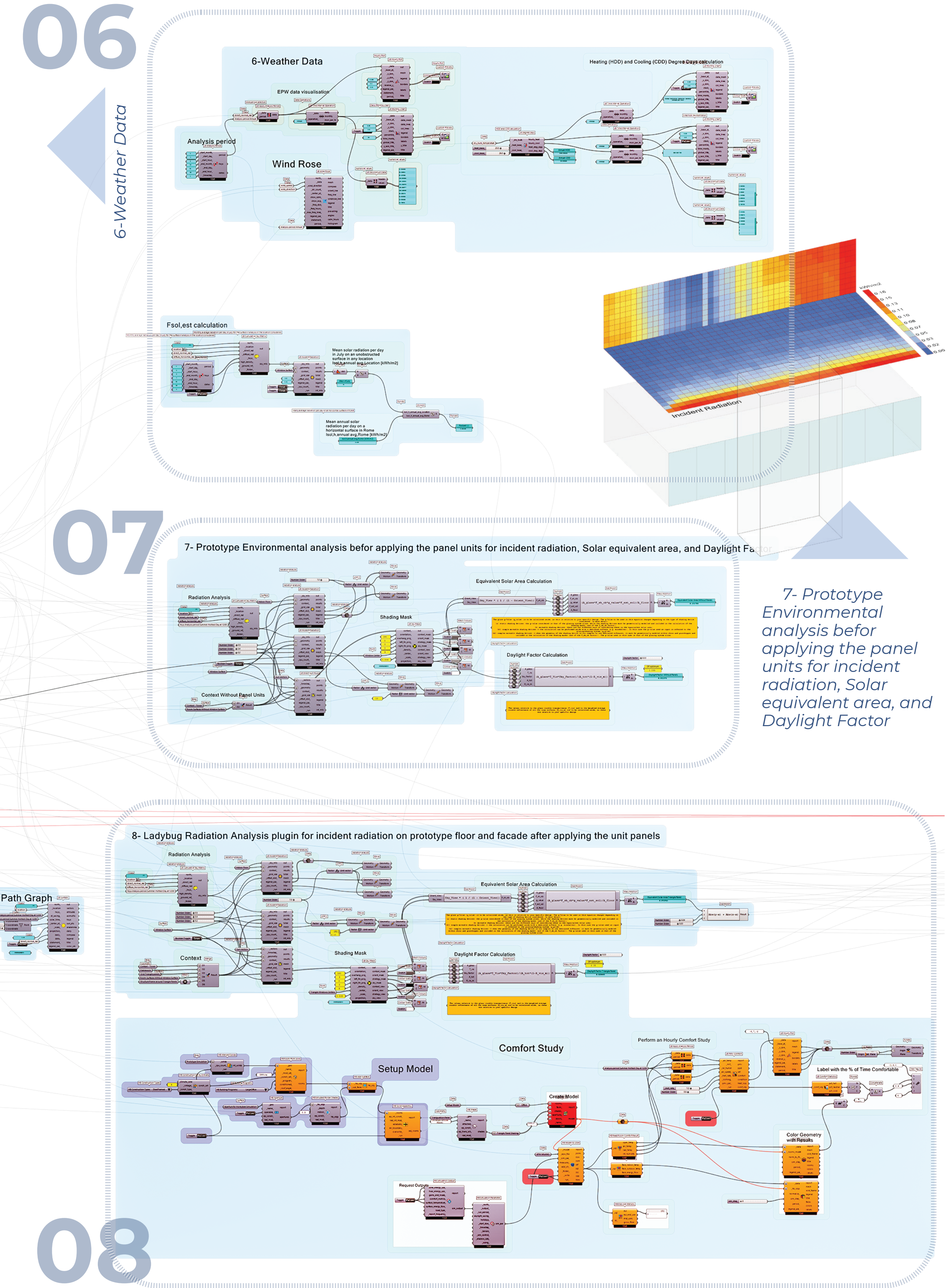


Fig.106: Part Two (Environmental and Prototype) of the method - Grasshopper definition with its results.

Environmental Processing

The (Environmental Processing) step consists of all the building physics rules and other simulations to manage the outcomes. To better comprehens this stage, the following definitions are necessary:

Prototype Geometry: It is a geometry sample (Mockup) to apply the unit types on a certain facade of it or skylight to make an initial simulation in order to choose which type of unit has fit the requirements then the user can input a surface with different shapes related to a design case study.

Context: Geometry represents the context in front of the prototype to study the impact on the curtain unit openings and frame extrusions because it affects the sky mask which has an impact on the solar equivalent area and daylight factor equations. This geometry should implement by the user relating to a case study.

Weather data: ladybug plugin is used to define the weather data which has an important part to collect the inputs of environmental analysis like EPW which plays the main role in calculating the cumulative sky matrix, incident radiation, and sky mask.

Environmental analysis: utilize the prototype as a case study in two phases of environmental analysis one before applying panel units to know the limits of building physics factors and one after applying them to compare the results. Extract the glazing panels to calculate the areas and center of them to allocate the sky mask for each one, also the area of the floor, and insert all those parameters in the Building physics definitions to calculate Solar Equivalent Area, Daylight Factor, and incident radiation by taking into consideration the context geometry from the previous step (Figure 106).

the ladybug and Honeybee was used through this part and they are environmental plug-ins for Grasshopper to help designers create an environmentally-conscious architectural design. They were initially developed by Mostapha Sadeghipour Roudasri but are open-source and maintained by several people, including Chris Mackey. Like many of the other Grasshopper plug-ins, they are both named after animals.

Optimization Prediction:

The aim of this crucial step is to extract solutions from sample space that meet the building physics requirements. multi-objective optimization engine tool (wallacei X) is the key with input parameters defined as follows:

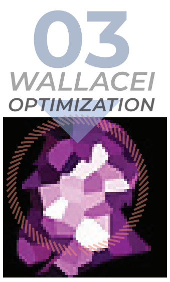
1- Genes: are representing the initial user parameter inputs that explained in the Constructive Algorithm phase.

2- objectives: to minimize or maximize requirements depending on the results from environmental treatment before applying the unit panels on the prototype to know if the requirements are below or above the acceptable ratio.

3- phenotypes are the geometries we need to extract from the engine. After simulation, the user can choose and extract solutions to choose the optimum one from Pareto front solutions, and decode genomes for each solution.

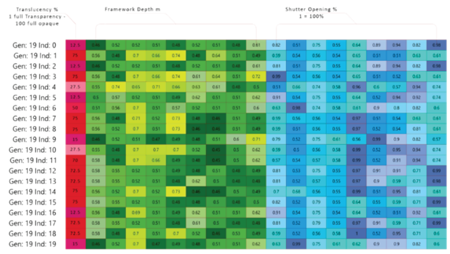
In Wallacei engine, there is a potential to extract analytics for solutions that represent their locations of them in sample space in graphs way and shows how the objectives of the solutions change through the simulation to help the user read if the engine process is close to the acceptance ratio.

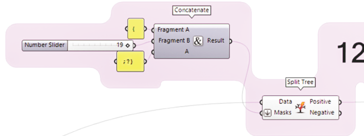
The final customised facade solution for all trinary, quaternary, and hexa-units is shown in **Appendix (5)** after a random objective has been applied to highlight the expected façade form in operation time instances (Figure 107).



Wallacei (which includes Wallacei Analytics and Wallacei X) is an evolutionary engine that allows users to run evolutionary simulations in Grasshopper 3D through utilising highly detailed analytic tools coupled with various comprehensive selection methods to assist users to better understand their evolutionary runs, and make more informed decisions at all stages of their evolutionary simulations; including setting up the design problem, analysing the outputted results and selecting the desired solution or solutions for the final output. Additionally, Wallacei provides users with the ability to select, reconstruct and output any phenotype from the population after completing their simulation.

12





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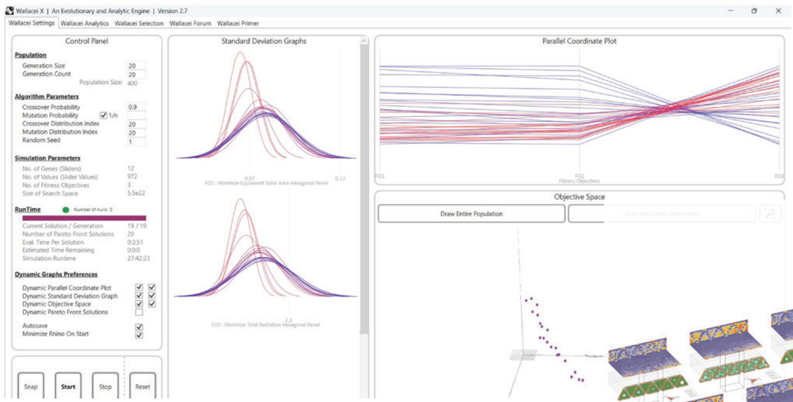
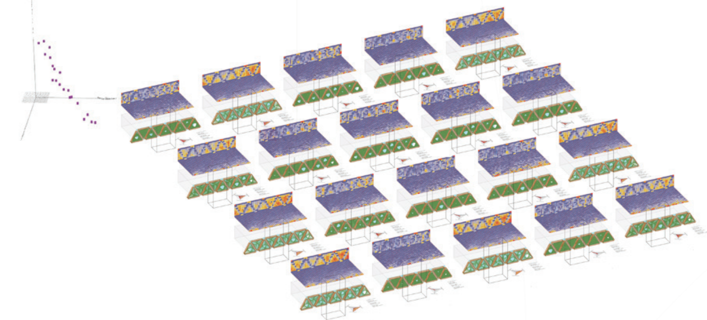


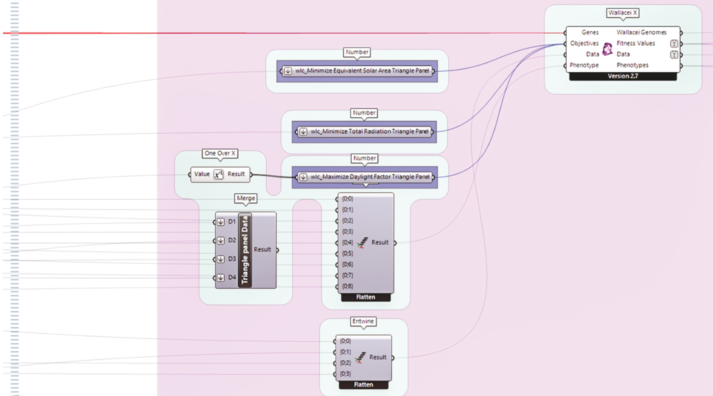


11- Wallacei

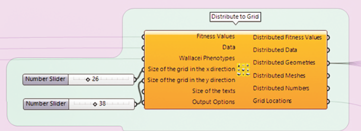
09

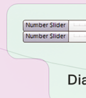
10

9- Wallacei - Multi Objective optimization Engine to achieve the best solution for building physics requirments



10-Solutions Geometries Distribution extracted from wallacei engine





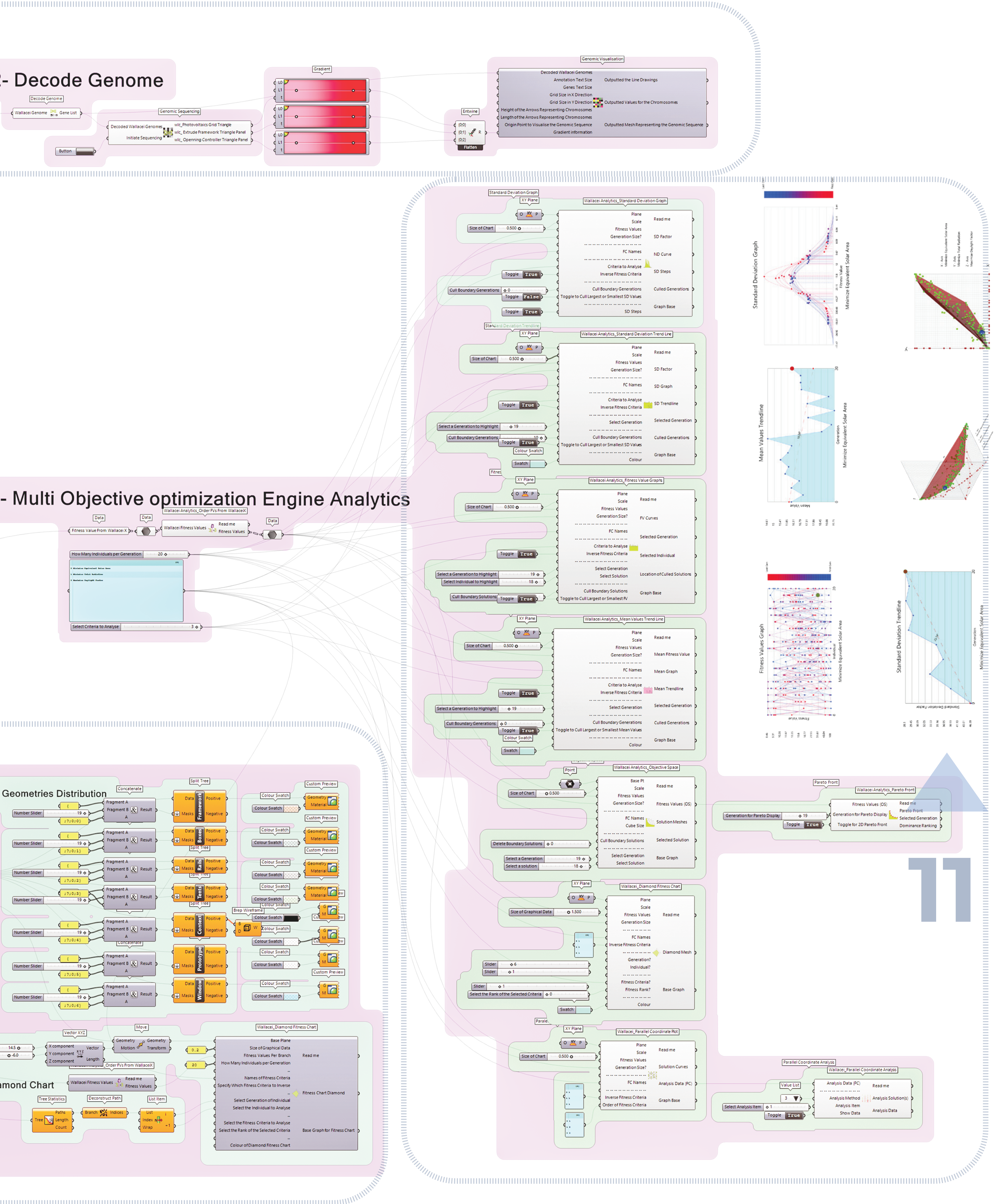


Fig.107: Part Three of the method (Optimization) - Grasshopper definition with its results.

4•5 Initial model (Prototype)

The Adaptive model is a method for determining acceptable thermal conditions in Occupant- Controlled Naturally Conditioned Spaces (“ANSI/ASHRAE Standard 209-2018 - Energy SimulationAided Design for Buildings Except Low-Rise Residential Buildings”).

To use the prototype, it needs first to understand the difference between Irradiance (Design condition): Specific moment of the Year (W/m2) and the Irradiation or Radiation (Representative condition): Specific Period of the Year(Kw/m2)

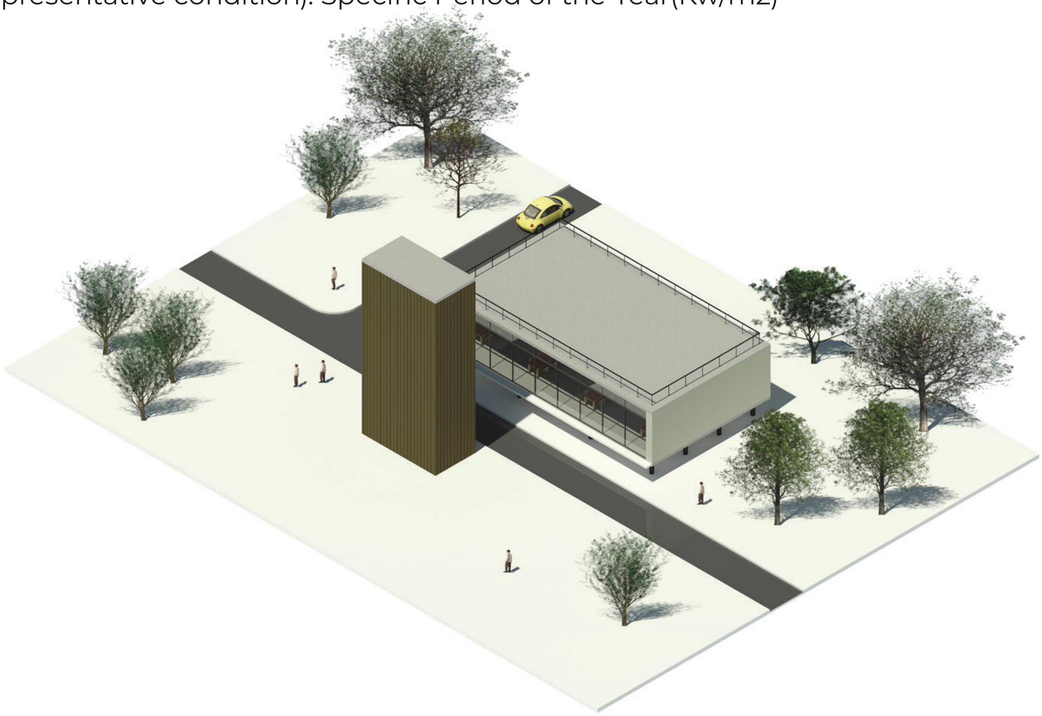


Fig.108: *Initial model (Prototype) detailed Architecture model (With units and without them)*

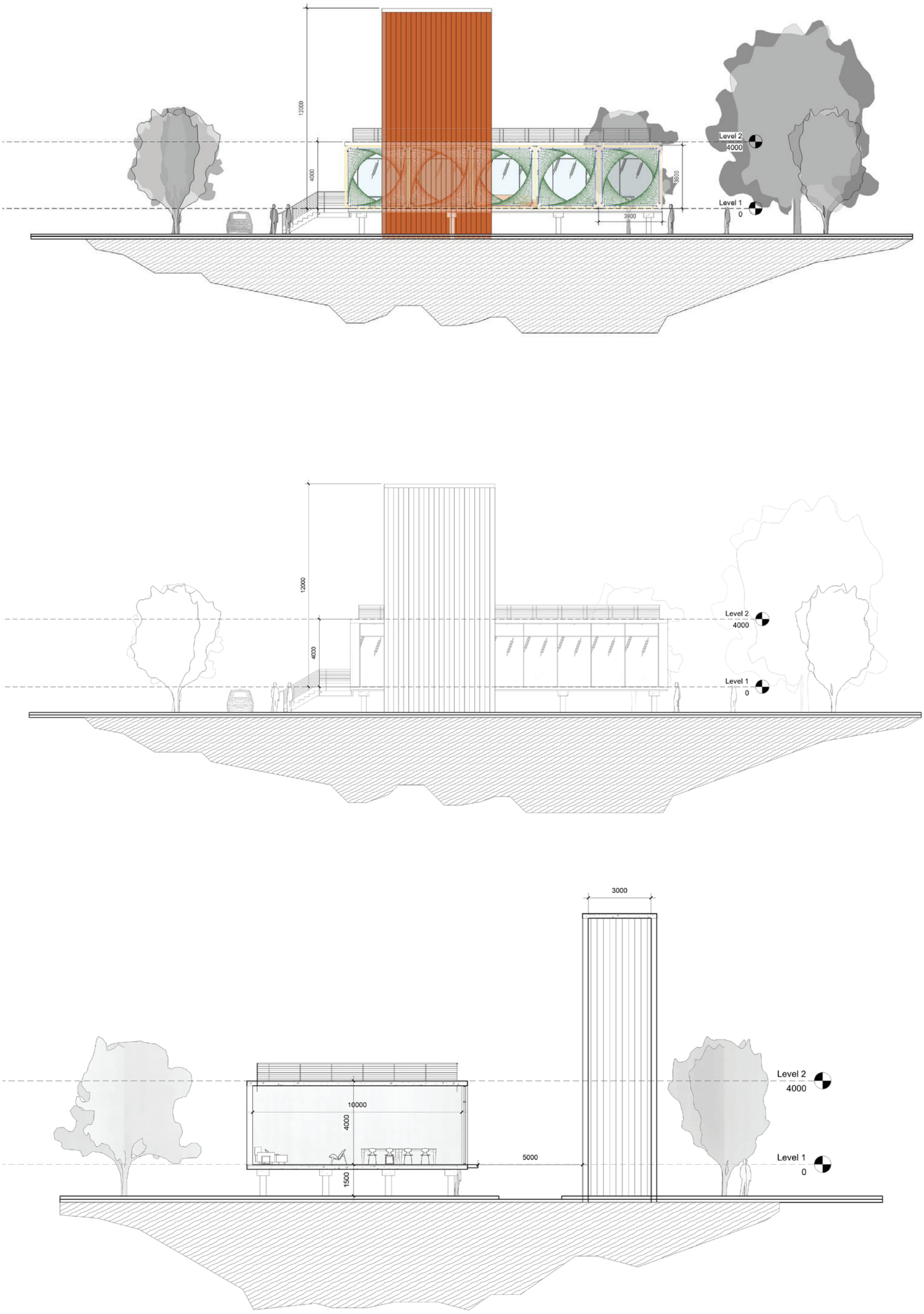


Fig.109: Initial model (Prototype) detailed Architecture model - elevations and section

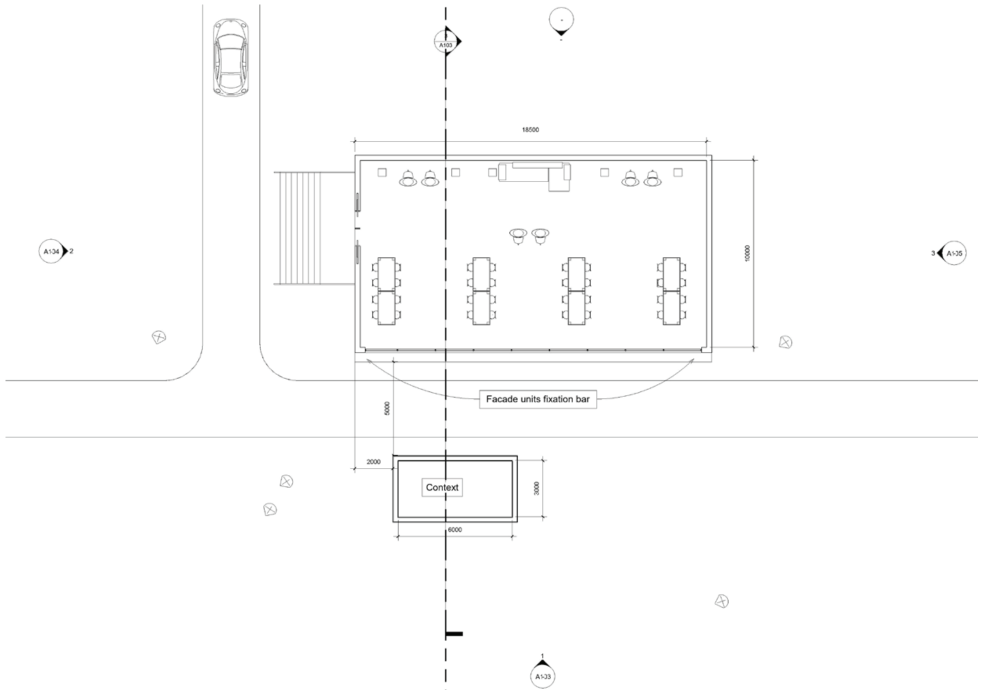


Fig.110: *Initial model (Prototype) detailed Architecture model - Plan (the small tower represent the context*

Initial model (Prototype) simulation

The Prototype simulation uses the same concept to better understand the revolutionary runs and to make more informed decisions.

The prototype is a large, typical office space with dimensions of 18.5*10* 4(h) m (Figure 108 , 109, 110).

A 12m height tower was added Infront of the room to represent the context, the outcome could be represented visually by two main units (Right and Left) to highlight the context effect. Wallacei used as the evolutionary optimization solver which is an engine that allows users to run simulations in Grasshopper with highly detailed analytic tools [11]. Nine simulations were run, three for the annual fixed cases with each of the three polygon: (trinary, quaternary, hexa), and six for the kinetic daily cases in both summer and winter to emphasize the probable outcomes.

Simulation size	*Objective*	*Algorithmic settings*	*Genes*
Generation size	20	Mutation Rate	1/n (n-No. of Var)
Generation Count	20	Crossover Probability	0.9
Population size	400	Mutation Distribution Index	20
No. of Chromosome	3	Crossover Distribution Index	20
No. of Variables	*7600*	*Simulation case studies*	9

Fig.111: *(Table 05) Optimization simulation and algorithm settings.*

4•6 Empirical Optimization Results

Following the optimization settings there are two studied cases beside the initial case (Without the units) (Only glazing results without the panels installed on the facade.

4•6•1 Without the units

The first case is outside the scope of the simulation, but it only shows the preliminary results without performing the optimization simulations, as well as without placing the units to know the initial numbers of building physics (DF, SEA, and Radiation) in the prototype.

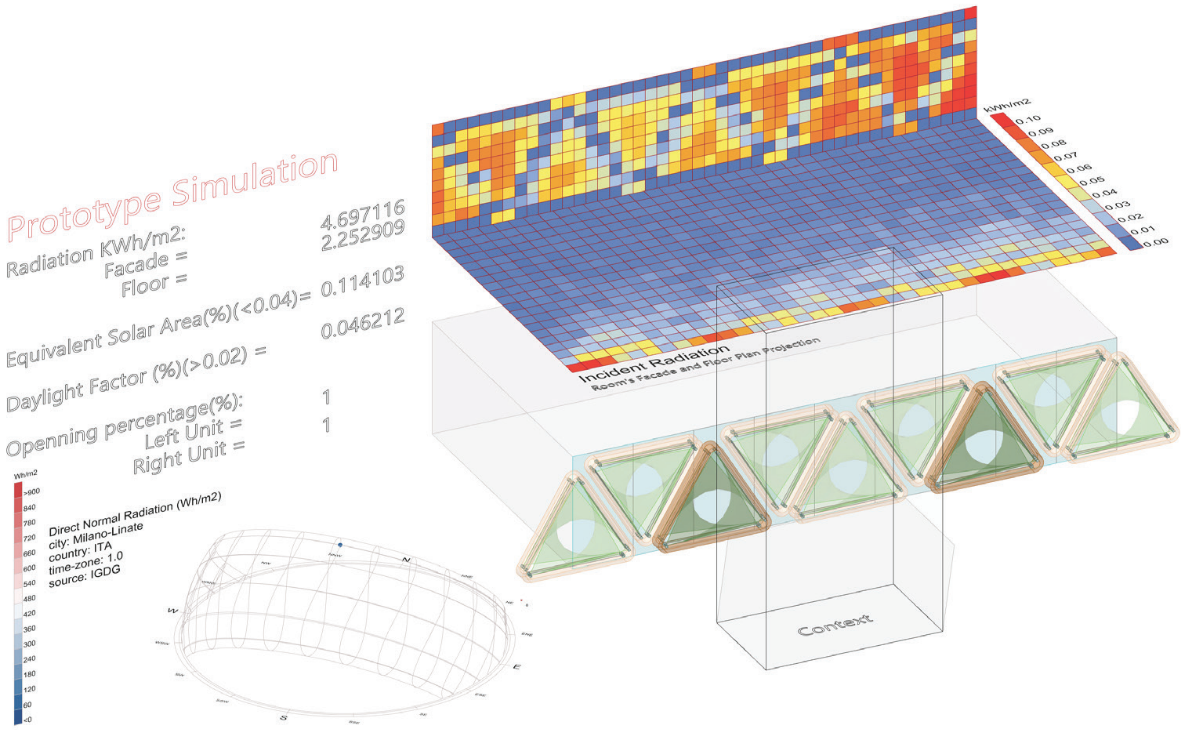


Fig.112: *The prototype in default case with trinary unit applied*

Ladybug plugin used to visualize the radiation on floor and facade, also the solar equivalent area, and Daylight factor before applying units in Summer period.

•Annual (Default case)

The normal statues (Figure 113):

Incident Radiation

Floor = 20703.798222 Kwh/m2

Window = 31704.780558 Kwh/m2

Equivalent Solar Area = 0.129818

Daylight Factor = 0.052577

Ladybug

Energy-Thermal

•Summer (21July, 12:00 pm)

(Figure 114)

Incident Radiation

Floor = 5.911707 Kwh/m2

Window = 9.505271 Kwh/m2

Equivalent Solar Area = 0.129818

Daylight Factor = 0.052577

•Winter (1January 12:00pm)

(Figure 115)

Incident Radiation

Floor = 4.836217 Kwh/m2

Window = 8.178335 Kwh/m2

Equivalent Solar Area = 0.129818

Daylight Factor = 0.052577

Front page

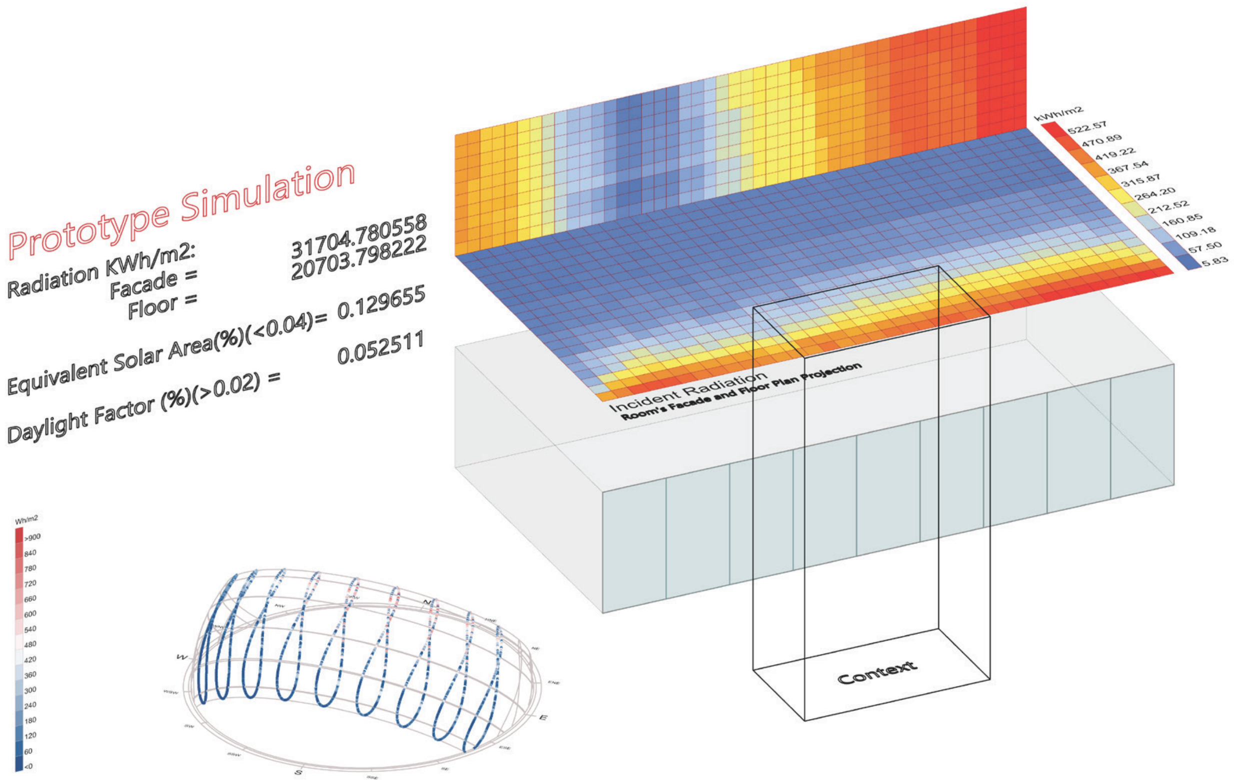


Fig.113: Figure, the prototype in Annual Period without units applied.

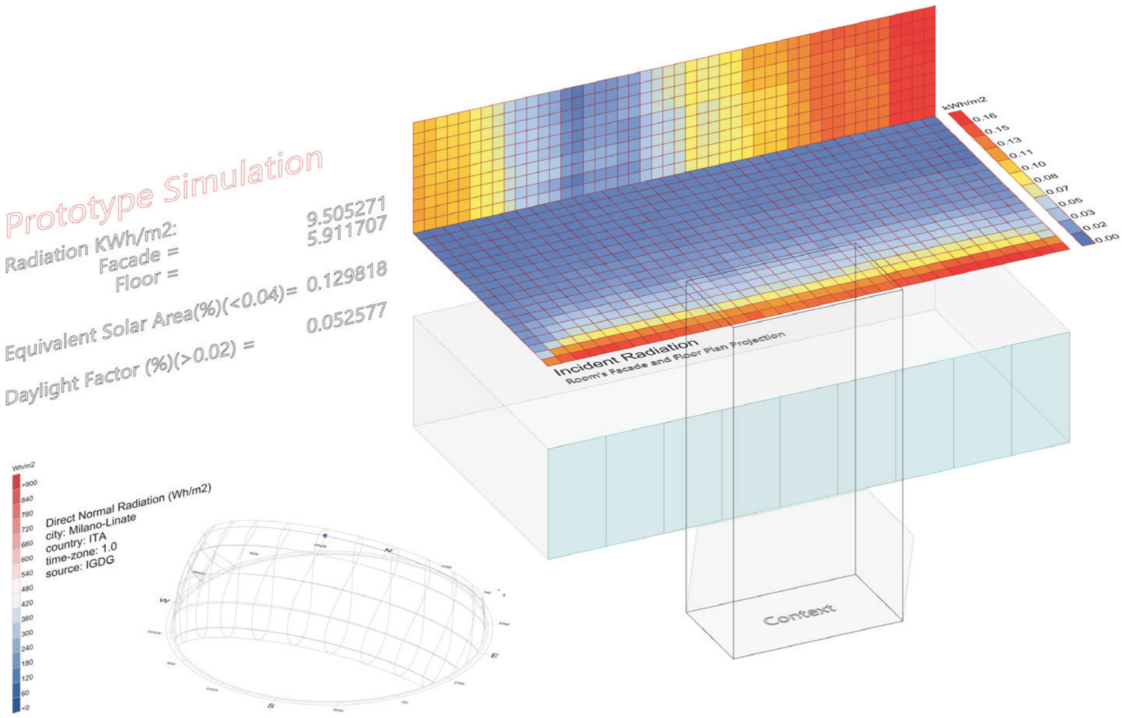


Fig.114: The prototype in default case with trinary unit applied.

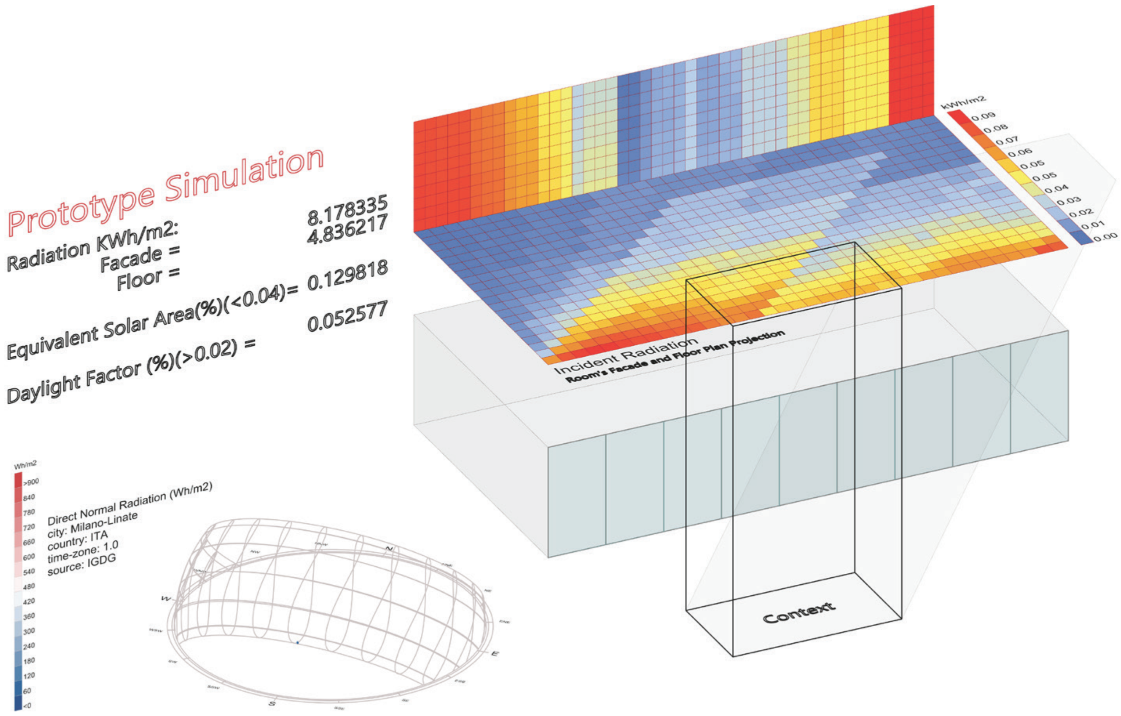


Fig.115: The prototype in Winter Period without units applied.

4•6•2 Annual (Fixed case)

•Annual fixed Trinary

. Incident Radiation

Floor = 4025.474395 Kwh/m2

Window = 7361.420207 Kwh/m2

Equivalent Solar Area = 0.046521

Daylight Factor = 0.018841

Opening Percentage

Left Unit =0.99, Right Unit =0.54

Framework Thickness:

Left Unit =0.48, Right Unit =0.61

Runtime = 20:15:5

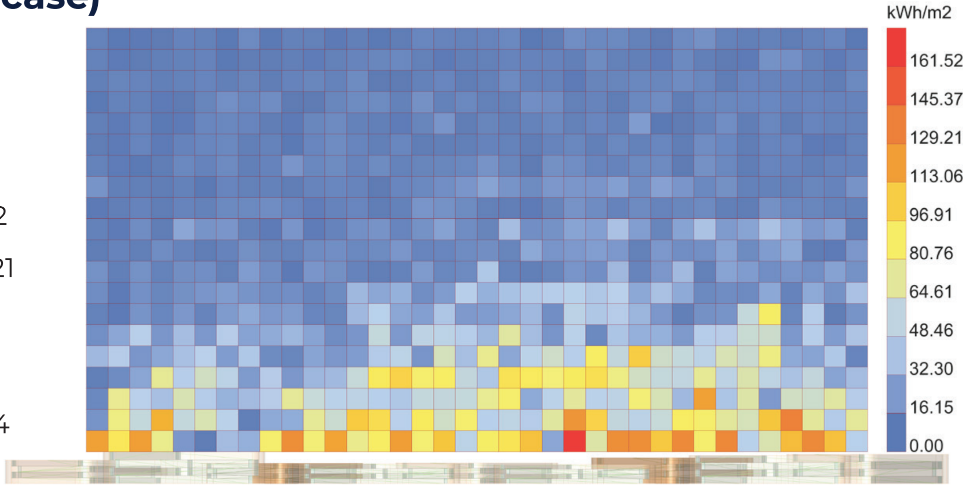


Fig.116: *The optimal solution for Trinary units in Annual period. Top View (Left), Perspective View (Right).*

•Annual fixed Quaternary

Incident Radiation

Floor= 4670.96279 Kwh/m2

Window = 7416.817062 Kwh/m2

Equivalent Solar Area = 0.056498

Daylight Factor = 0.022882

Opening Percentage:

Left Unit =0.23, Right Unit =0.05

Framework Thickness:

Left Unit =0.87, Right Unit =0.79

Runtime = 6:38:26

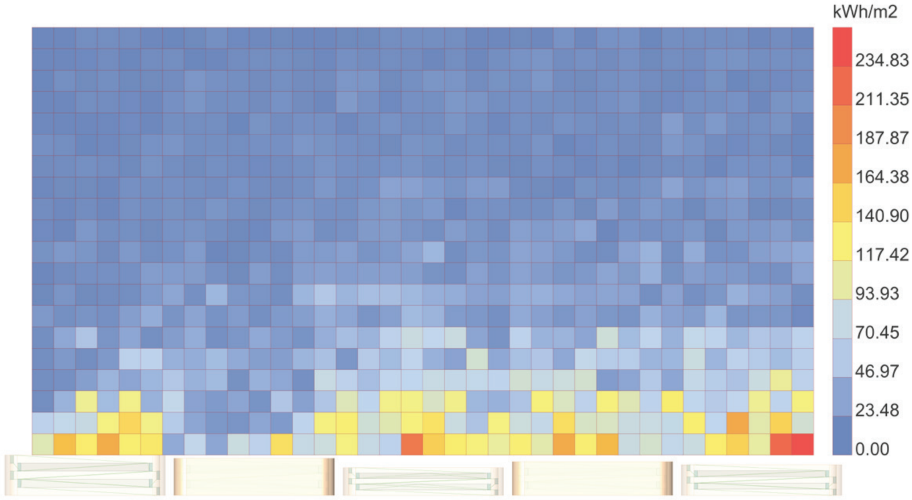


Fig.117: *The optimal solution for quaternary units in Annual period. Top View (Left), P rspective View (Right).*

•Annual fixed Senary

Incident Radiation

Floor = 4023.853171 Kwh/m2

Window = 7586.842001 Kwh/m2

Equivalent Solar Area = 0.081915

Daylight Factor = 0.033176

Opening Percentage:

Left Unit =0.11, Right Unit =0.17

Framework Thickness:

Left Unit =0.93, Right Unit =1.02

Runtime = 21:14:7

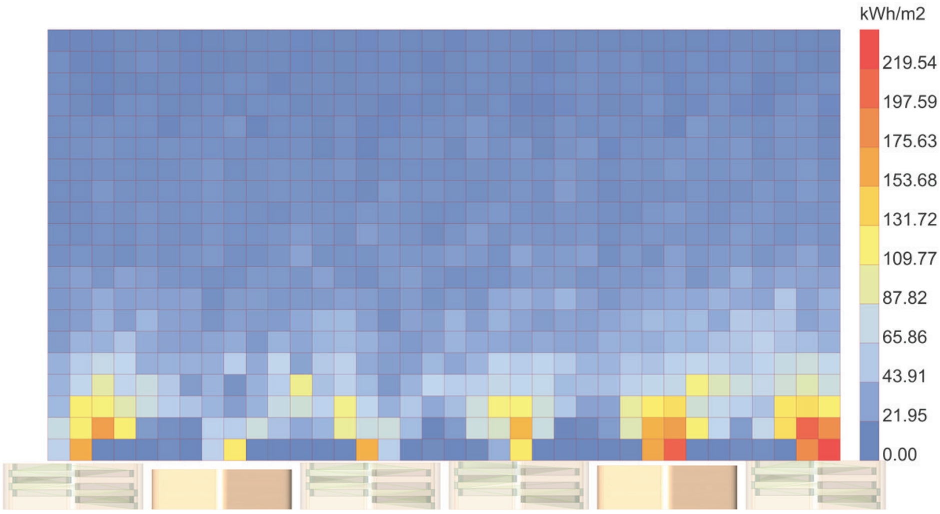
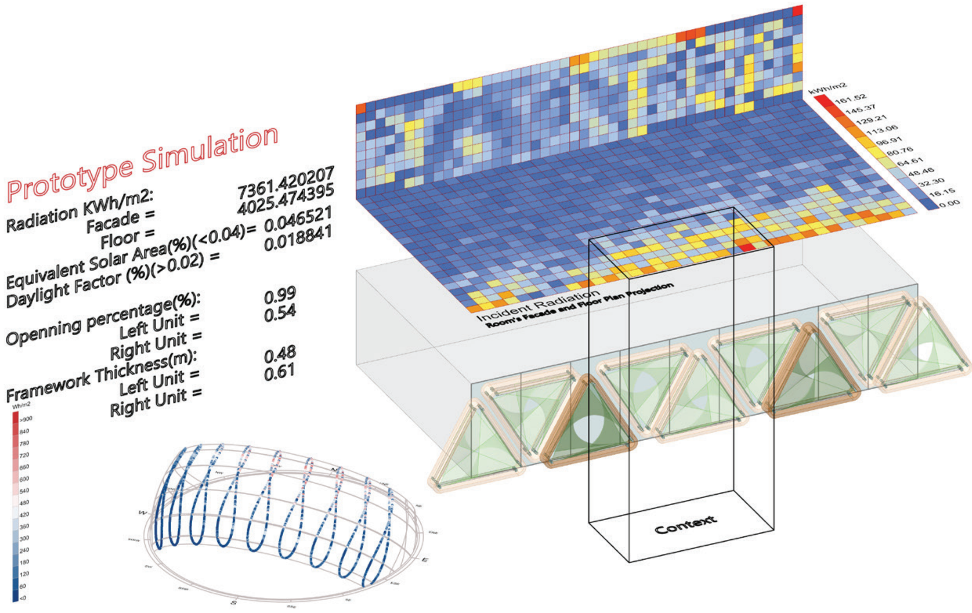
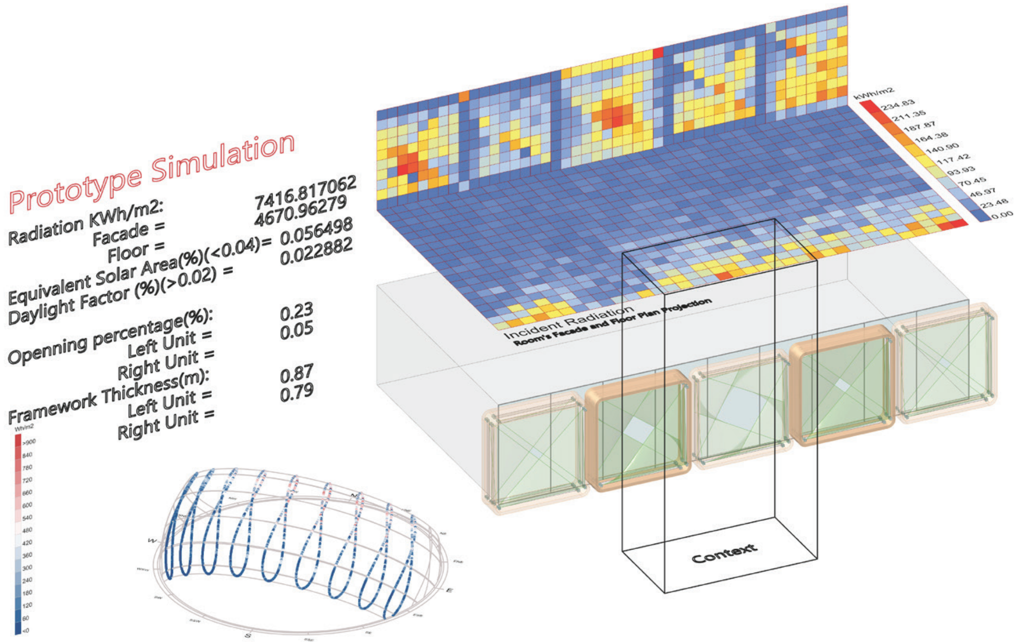


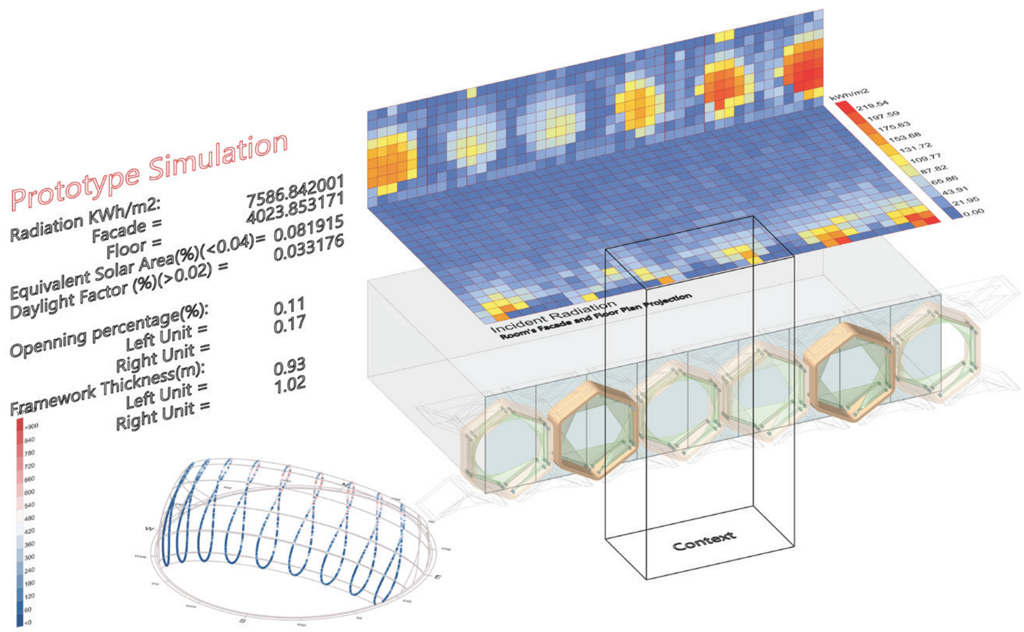
Fig.118: *The optimal solution for Hexa-units in Annual period. Top View (Left), Perspective View (Right).*



The optimal solution for Trinary units in Annual period. *(Results exported from wallacei simulation engine).*



The optimal solution for Quaternary units in Annual period. *(Results exported from wallacei simulation engine).*



The optimal solution for Hexa units in Annual period. *(Results exported from wallacei simulation engine).*

4•6•3 Instantons (Daily) Kinetic case

•Trinary unit - Summer (21July, 12:00 pm)

Incident Radiation

Floor = 0.912157 Kwh/m2

Window = 1.8477 Kwh/m2

E. Solar Area = 0.043943

Daylight Factor = 0.020753

Opening Percentage:

L-Unit =0.56, R-Unit =0.95

Runtime = 12:15:56

THE RECOMMENDED CASE (USED IN THE CASE STUDY (CHAPTER 5))

Analyses all the solutions in the population through comparing the fitness values for each solution across all fitness objectives.

The aim is to extract emergent behavior exhibited by the simulation and better understand how the solutions are optimizing throughout the simulation. Each line represent a solution linked between 3 points each point represent a value for an objective and the user can track each line behavior through each objective starting from FO1 (first objective) minimize equivalent solar area to FO2 (Second objective) minimize radiation FO3 (Third objective), maximize daylight factor.

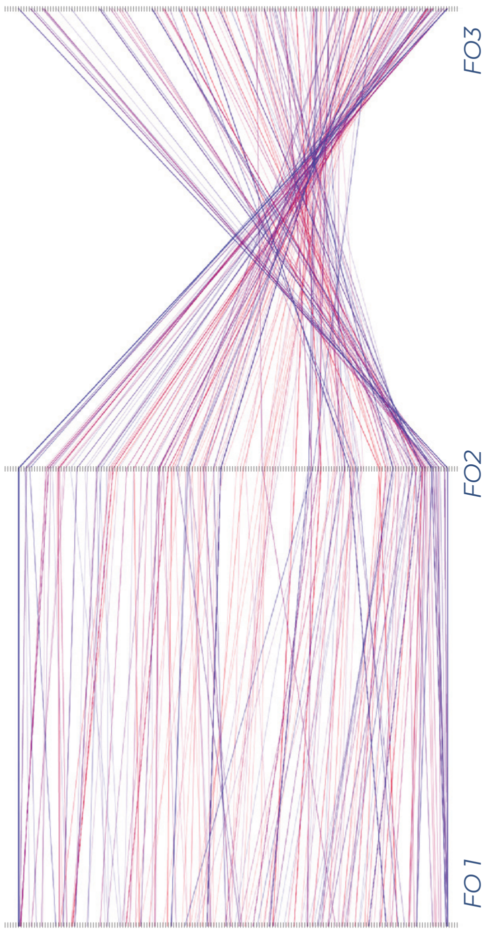


Fig.119: *The parallel coordinate plot (PCP) TRINARY SUMMER*

•Trinary unit - Winter (21January 12:00pm)

Incident Radiation

Floor = 1.146955 Kwh/m2

Window = 2.3884 Kwh/m2

E. Solar Area = Neglected

Daylight Factor = 0.028766

Opening Percentage:

L-Unit =0.75, R-Unit =0.88

Runtime = 14:32:14

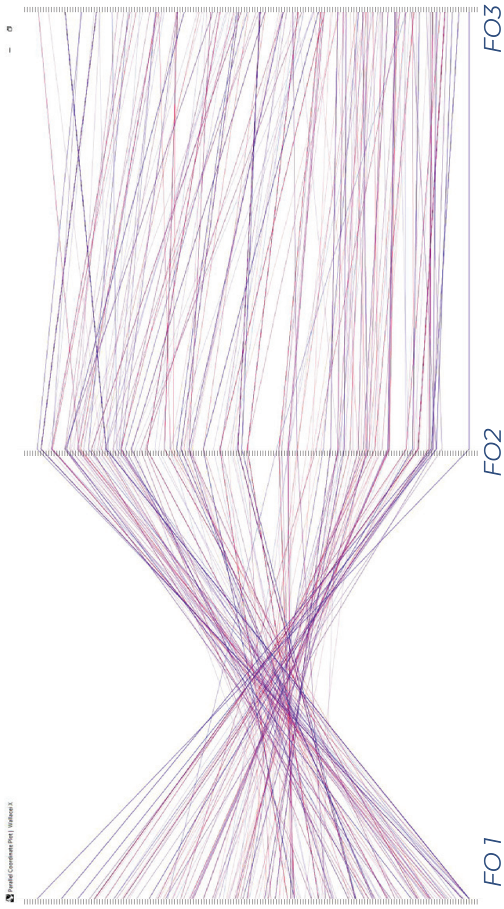


Fig.120: *The parallel coordinate plot (PCP) TRINARY WINTER*

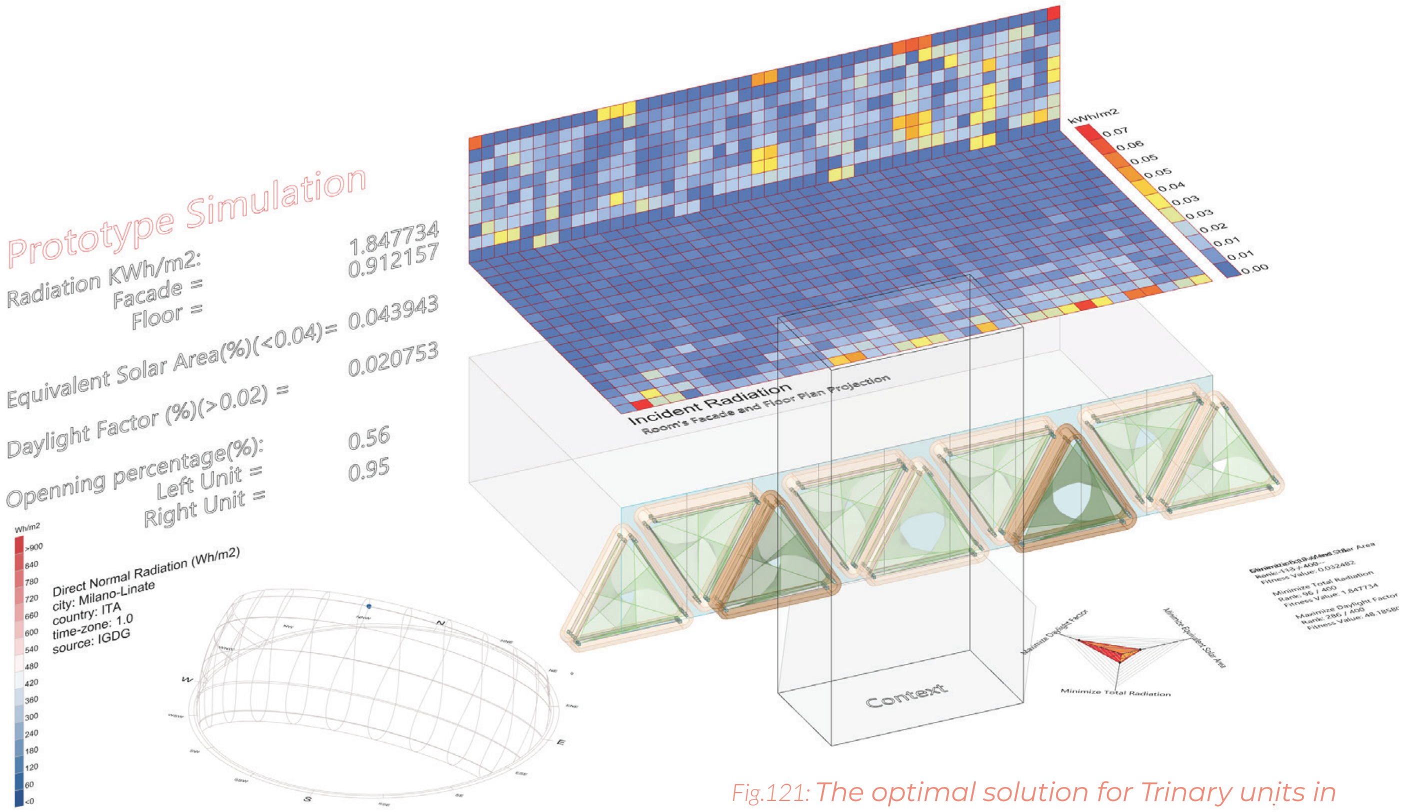


Fig.121: *The optimal solution for Trinary units in Summer 21 Jul, 12:00 pm Period. (Daily) Kinetic case*

The optimal solution for Trinary units in Summer 21 Jul, 12:00 pm period. (Results exported from wallacei simulation engine).

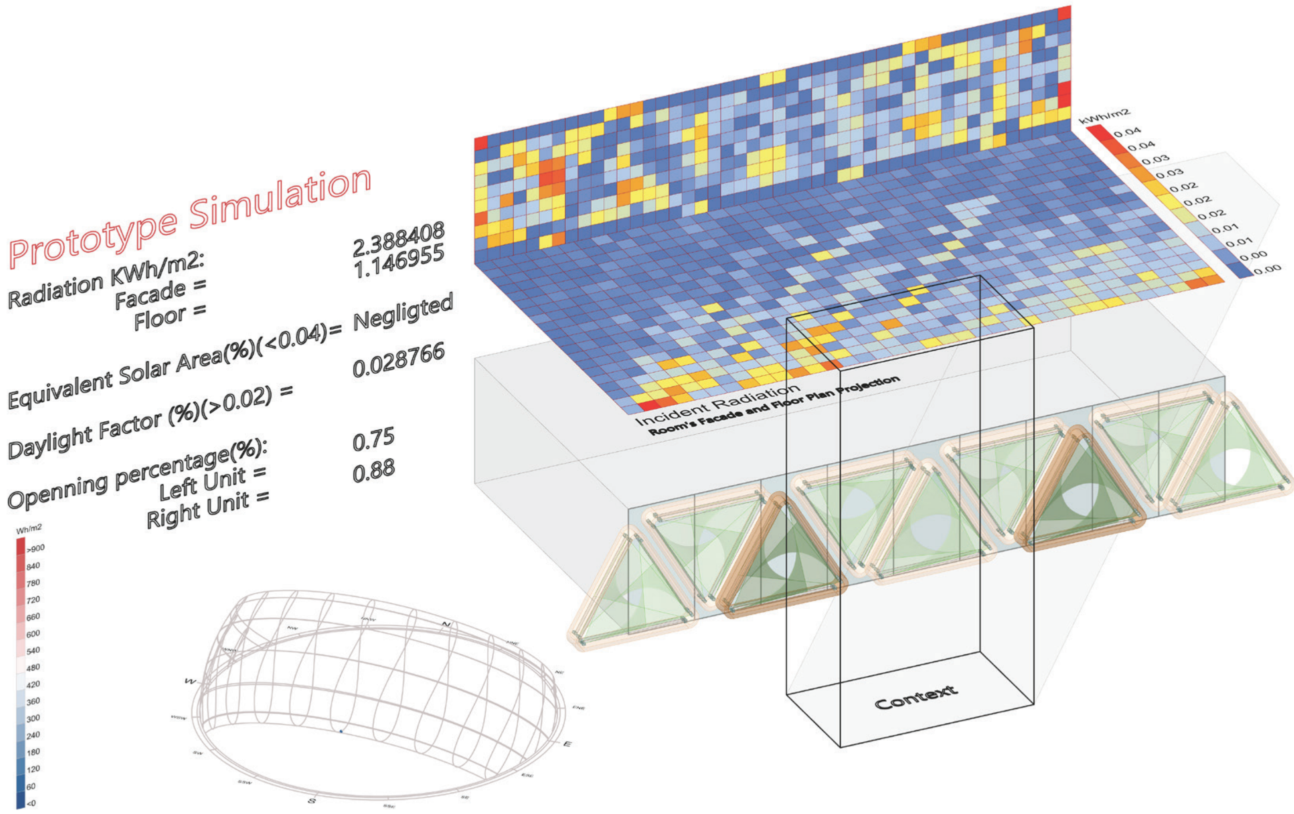


Fig.122: *The optimal solution for Trinary units in Winter 21 Jan, 12:00 pm Period. (Daily) Kinetic case.*

The optimal solution for Trinary units in Winter 21 Jan, 12:00 pm period. (Results exported from wallacei simulation engine).

•Quaternary Unit - Summer (21July, 12:00 pm)

Incident Radiation

Floor = 1.294174 Kwh/m2

Window = 2.2732 Kwh/m2

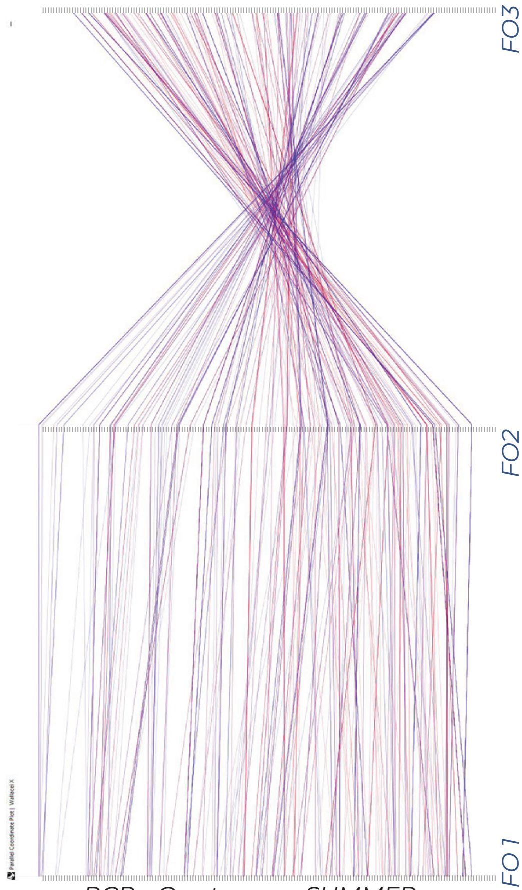
E. Solar Area = 0.069407

Daylight Factor = 0.02811

Opening Percentage:

L-Unit =0.13, R-Unit =0.98

Runtime = 24:46:2



PCP - Quaternary SUMMER

•Quaternary Unit - Winter (21January 12:00pm)

Incident Radiation

Floor = 1.621204 Kwh/m2

Window = 2.948 Kwh/m2

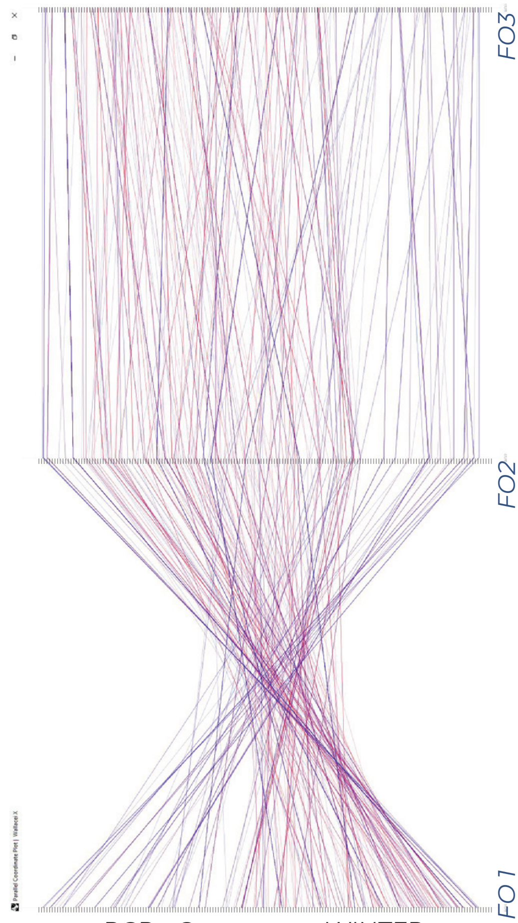
E. Solar Area = Neglected

Daylight Factor = 0.039017

Opening Percentage:

L-Unit =0.93, R-Unit =0.36

Runtime = 25:57:11



PCP - Quaternary WINTER

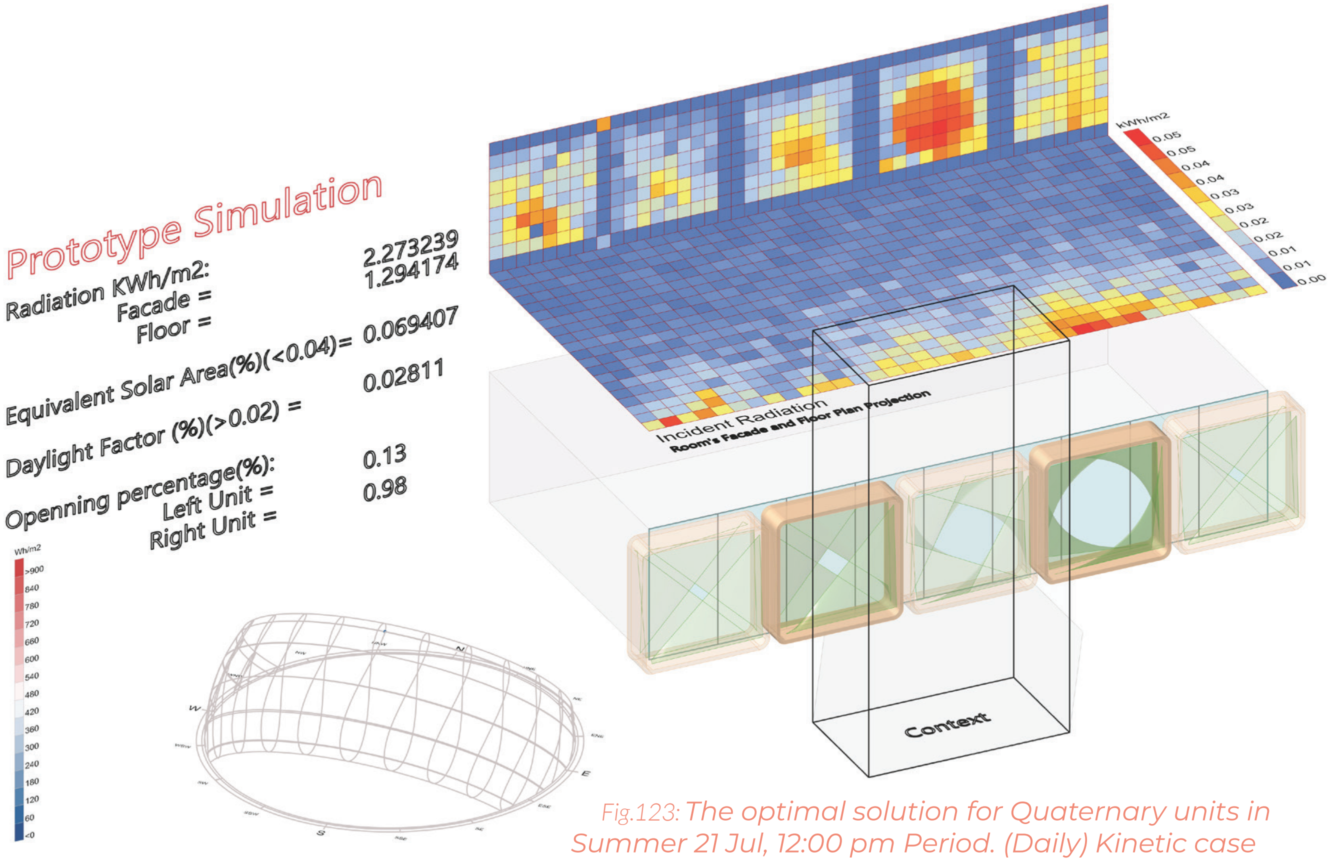


Fig.123: The optimal solution for Quaternary units in Summer 21 Jul, 12:00 pm Period. (Daily) Kinetic case

The optimal solution for Quaternary units in Summer 21 Jul, 12:00 pm period. (Results exported from wallacei simulation engine).

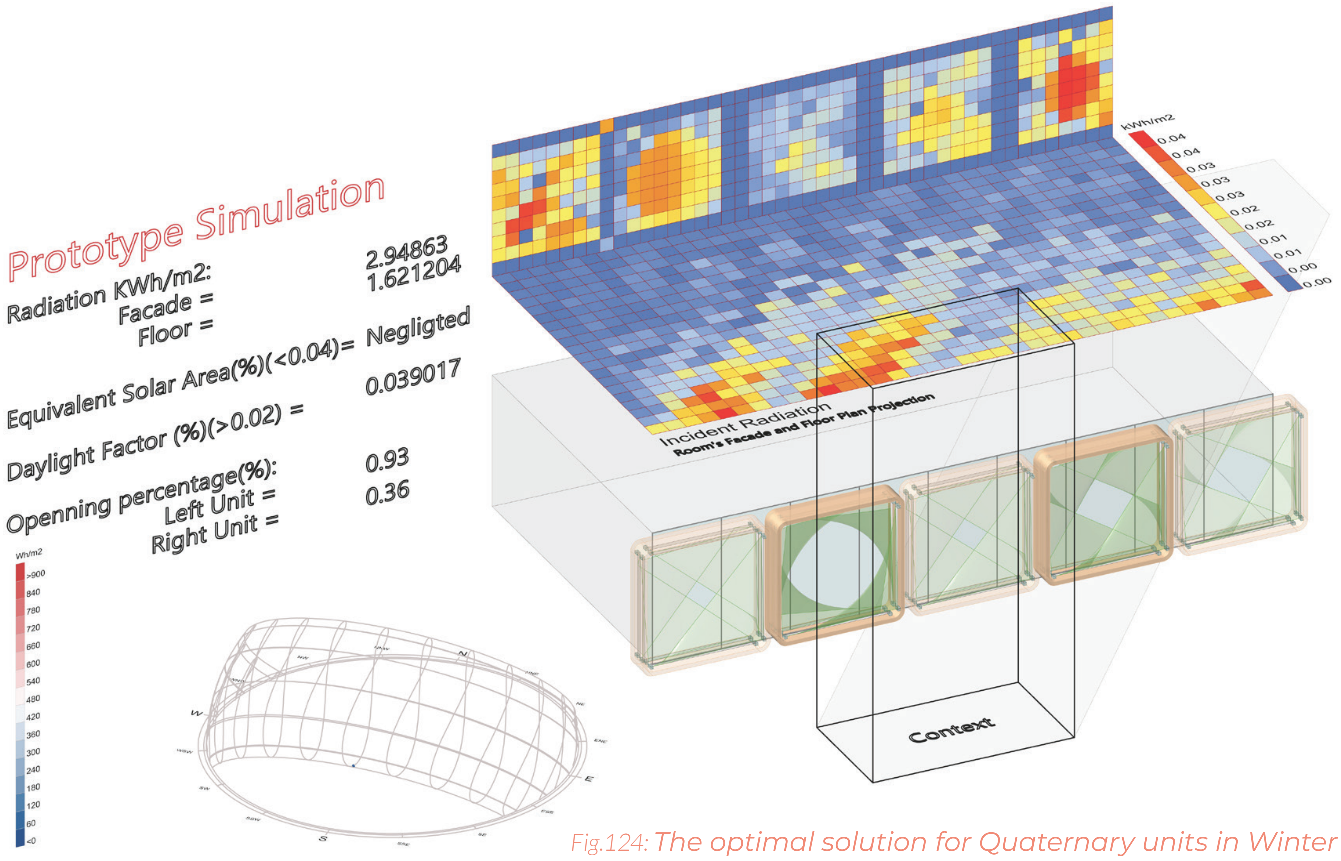


Fig.124: The optimal solution for Quaternary units in Winter 21 Jan, 12:00 pm Period. (Daily) Kinetic case .

The optimal solution for Quaternary units in Winter 21 Jan, 12:00 pm period. (Results exported from wallacei simulation engine).

•Hexa-unit - Summer (21July, 12:00 pm)

Incident Radiation

Floor = 0.812647 Kwh/m2

Window = 1.7830 Kwh/m2

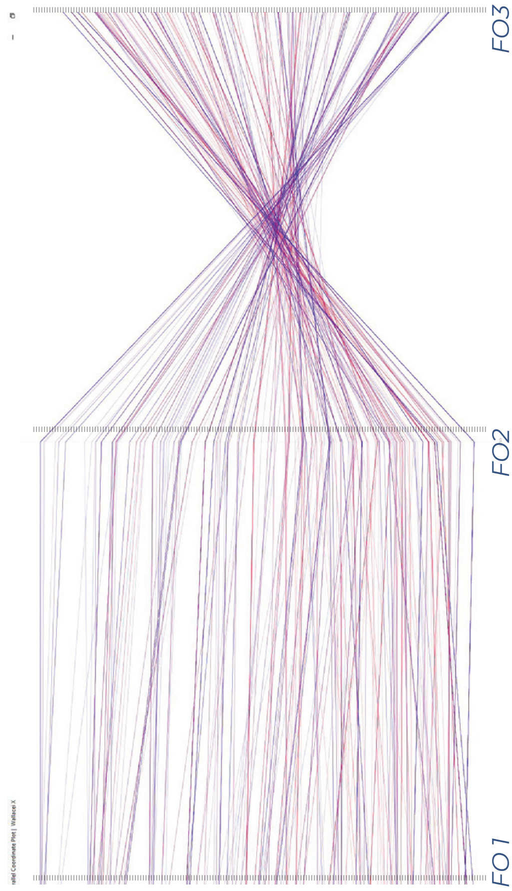
E. Solar Area = 0.063787

Daylight Factor = 0.025834

Opening Percentage:

L-Unit =0.13, R-Unit =1

Runtime = 27:42:23



PCP- Hexa /SUMMER

•Hexa-unit - Winter (21January 12:00pm)

Incident Radiation

Floor = 0.899237 Kwh/m2

Window = 1.9120 Kwh/m2

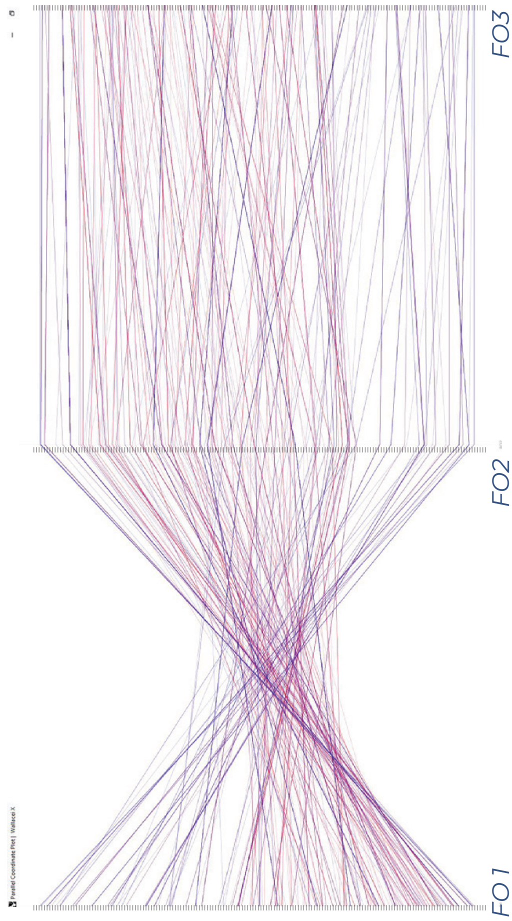
E. Solar Area = Neglected

Daylight Factor = 0.02752

Opening Percentage:

L-Unit =0.25, R-Unit =0.07

Runtime = 41:31:0



PCP - Hexa / WINTER

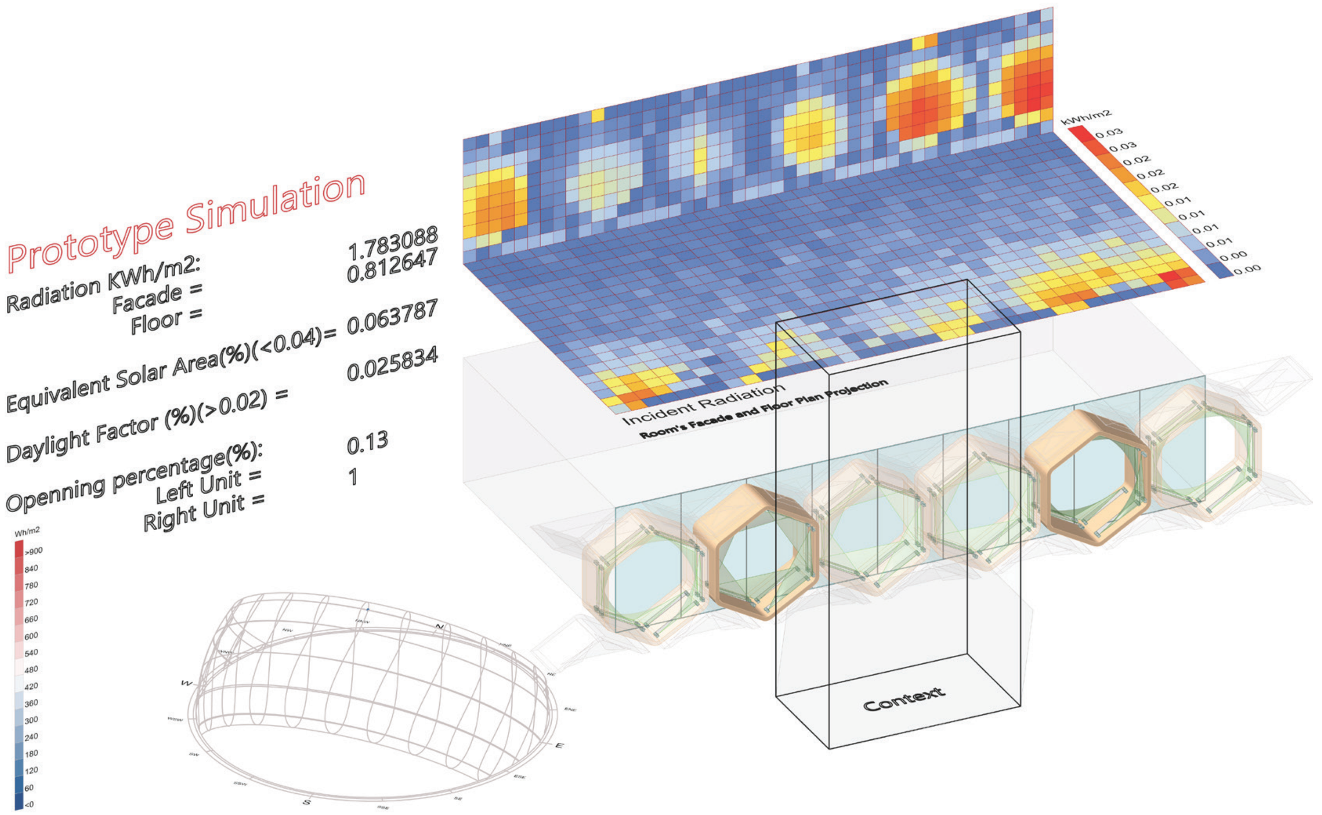


Fig.125: T he optimal solution for Hexa units in Summer 21 Jul, 12:00 pm Period. (Daily) Kinetic case

The optimal solution for Hexa units in Summer 21 Jul, 12:00 pm period.

(Results exported from wallacei simulation engine).

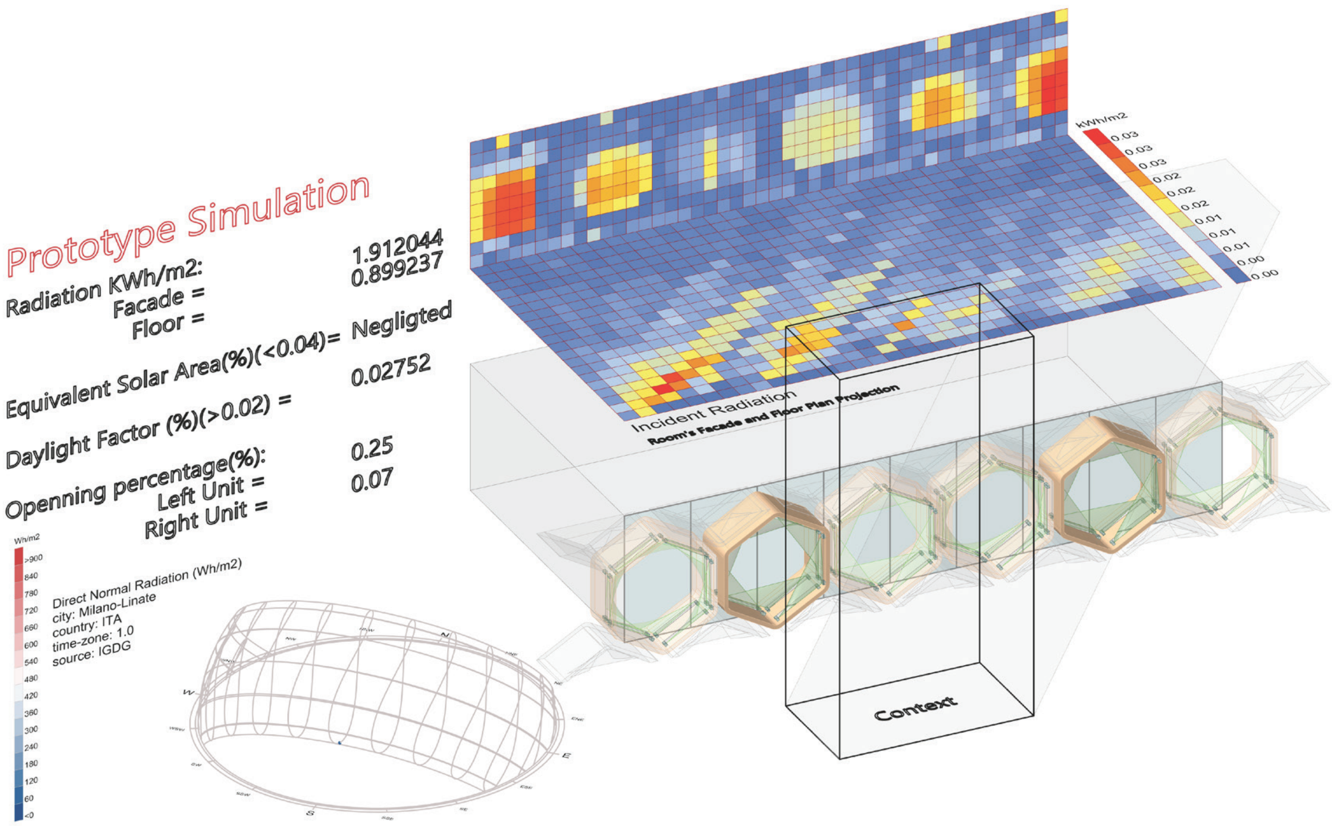


Fig.126: T he optimal solution for Hexa units in Winter 21 Jan, 12:00 pm Period. (Daily) Kinetic case

The optimal solution for Hexa units in Winter 21 Jan, 12:00 pm period.

(Results exported from wallacei simulation engine).

4•6•4 Opaque Curtains empirical simulation

Two distinct curtain material types were used for the simulation. A certain level of transparency was added to the curtains in the prior case and was also added during the evolutionary optimization process, allowing a certain amount of light to penetrate the space and producing the prior results.

On the prototype, a different simulation example was conducted, but for entirely blackout curtains. The outcomes Translucent curtains were recommended because the anticipated goals were not met in the improvement generations that were carried out.

When applied a full opaque material on the units the simulation results in most cases failed to acquire targeted numbers, Which prompted the research to add translucent factor to the curtains, the results of which were issued in the previous section.

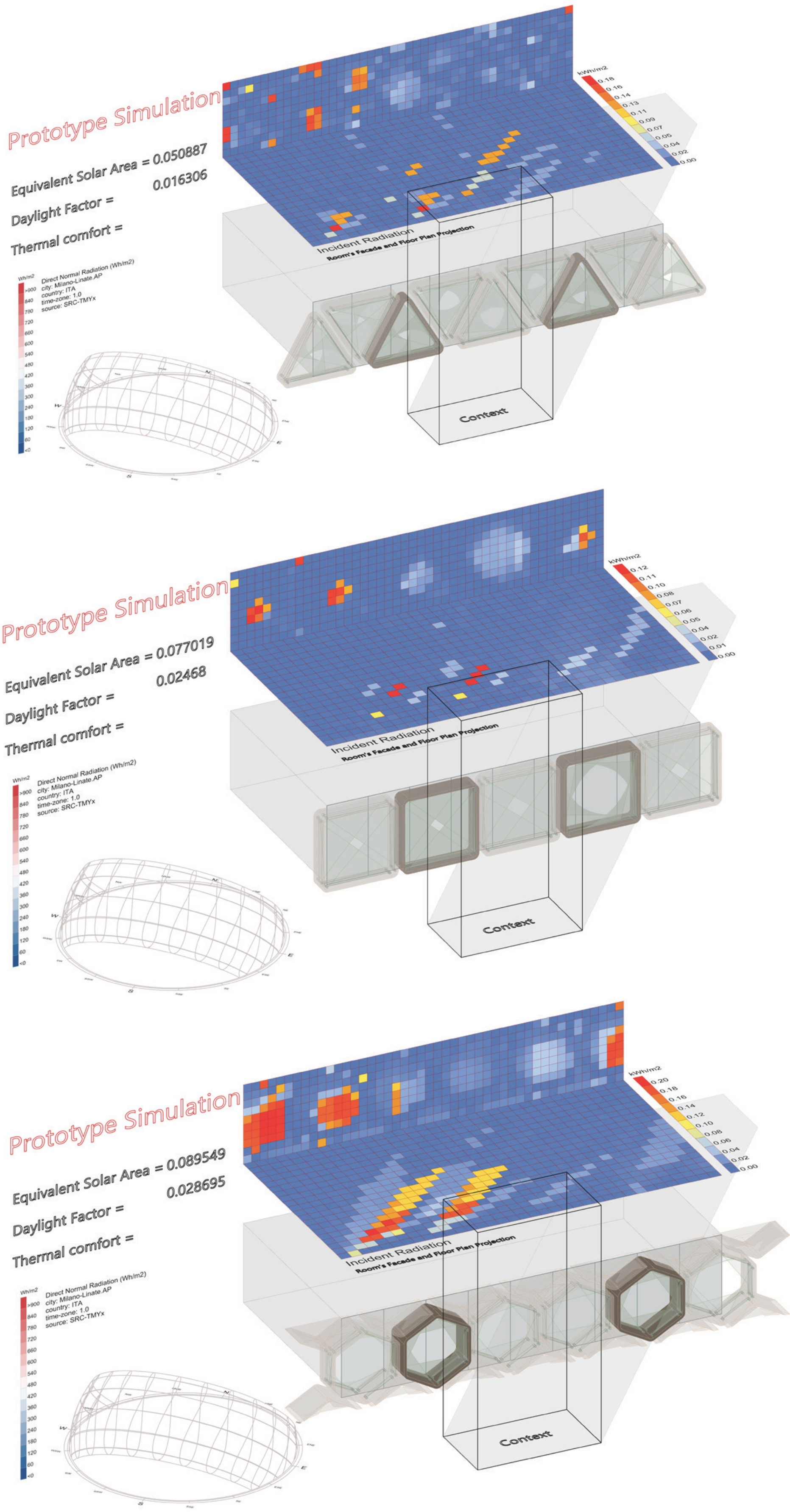


Fig.127: Trinary, Quaternary, and senary cases with opaque curtains, didn't achieve the required numbers (results comparison (Right)).

The optimal solutions for all the unit's typologies with opaque curtains.
(Results exported from wallacei simulation engine).

Fully opened panel with Minimum Framework extrude	**Fully Closed panel with Maximum Framework extrude**
Triangle Unit: Minimum extrude Framework 0.45 m *Fully opened panel with minimum Framework extrude* *Incident Radiation on Floor = 5.43 Kwh/m2* *Incident Radiation on Window = 9.8 Kwh/m2* *Equivalent Solar Area = 0.141622* *Daylight Factor = 0.045382*	Triangle Unit: Maximum extrude Framework 0.75 m *Fully Closed panel with Maximum Framework extrude* *Incident Radiation on Floor = 1 Kwh/m2* *Incident Radiation on Window = 1.3 Kwh/m2* *Equivalent Solar Area = 0.005192* *Daylight Factor = 0.001664*
Square Unit: Minimum extrude Framework 0.6 m *Fully opened panel with minimum Framework extrude* *Incident Radiation on Floor = 6.8 Kwh/m2* *Incident Radiation on Window = 10.5 Kwh/m2* *Equivalent Solar Area = 0.153861* *Daylight Factor = 0.049304*	Square Unit: Maximum extrude Framework 1 m *Fully Closed panel with Maximum Framework extrude* *Incident Radiation on Floor = 1 Kwh/m2* *Incident Radiation on Window = 0.8 Kwh/m2* *Equivalent Solar Area = 0.019332* *Daylight Factor = 0.006195*
Hexagonal Unit: Minimum extrude Framework 0.9 m *Fully opened panel with minimum Framework extrude* *Incident Radiation on Floor = 4.9 Kwh/m2* *Incident Radiation on Window = 9 Kwh/m2* *Equivalent Solar Area = 0.12186* *Daylight Factor = 0.039049*	Hexagonal Unit: Maximum extrude Framework 1.5 m *Fully Closed panel with Maximum Framework extrude* *Incident Radiation on Floor = 2.4 Kwh/m2* *Incident Radiation on Window = 4.7 Kwh/m2* *Equivalent Solar Area = 0.082025* *Daylight Factor = 0.026284*
Without Units	
Incident Radiation on Floor = 14.9 Kwh/m2 Incident Radiation on Window = 22.4 Kwh/m2 Equivalent Solar Area = 0.161528 Daylight Factor = 0.055176	

Fig.128: *(Table 06) Fully opened and fully closed units result from comparison when applying opaque curtains.*

HIGHLIGHTS : #Automation
#Software
#Case study
#LCA

APPLICATION
CHAPTER V

0 5

5. APPLICATIONS

"A person who never made a mistake never tried anything new"

Albert Einstein 1879 - 1955, (Germany- USA).

In this chapter, three different applications going to introduce, the first one is SHELL, an Add-in software created to be used on the computer (through Grasshopper software)that could process the users' envelopes and projects by optimizing them based on the user's preferences.

The second application is (TRIO) which is a case study application using the methodology discussed in the third chapter and using Shell to create the outer envelope of the skyscraper building.

Finally, and to follow the third chapter of the studied features that describes the potential of SHELL, the Life cycle assessment (LCA)had been studied on TRIO envelope to calculate the final embodied carbon. Also included simple alternatives to the materials that can be used for the units, which in turn can affect the acoustic aspect.

The Shell program has a number of internal experiences. You can choose first to use the prototype. In this option, a small building appears, which is a small administrative building with a small tower in front of it which represents the general context of the project. Then, as a user of the program, you can give your design inputs and perform the improvement process based on the goals you set. as previously explained. In the end, the program will show you the optimization results as those that appeared in the previous chapter, but for the best possible unit in this context. In the next step, you can test a different internal option for your favorite unit that was nominated by the prototype, or you can choose another form if you prefer a polygon and it is applied to the real interface to be studied, in the end, and based on the complexity of the site and the surrounding area, the program gives improvement results at the end, which are based on a fixed annual basis or a moving basis every specific period of time, and be it on a daily or hourly basis or in the form of Instantaneous, based on the user's preferences and computer capabilities. In the end, this process is supposed to take place continuously in a moving pattern, as the building continues to confront external variables.

Although the research approach can be applied anywhere in the world, this section introduces an experimental phase carried out in Milan City Climate Zone (Cfa). A simulation prototype was used and then applied in a skyscraper case study in Milan.

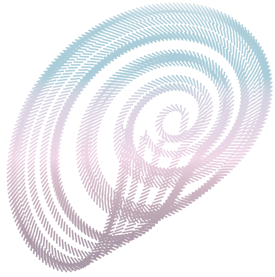
In the context of the research, the optimal solution was not chosen from the initial model directly, but a simulation was performed on all possible patterns (fixed and mobile) in the three different cases of the polygon, in order to compare the numbers finally and make sure that the model nominated by the program is indeed the best model to use. In the following pages, the results of the tests on the prototype completely, and then in the end, its application to the summer and mobile case as well as for a real architectural project that was designed specifically for this context, which is a skyscraper in the central area of Milan surrounded by a number of towers, which can affect the outer cover of the project and thus Testing the quality of the results. The architectural project is an outer cover project and a design idea that focuses on the building envelope and its design idea. We participated in the international competition for skyscrapers Skyhive in July 2022. The project was also shortlisted for this competition, after completing the studies for the cover of the skyscraper project. As-Sahab A construction life cycle analysis was conducted through two different models.

5•1 SHELL - Software Add-in

The following is the Add-in software to the grasshopper and the following workflow represents the summary of how it works and how the software user can use it to obtain his customized envelope:

How to use SHELL?

The Software



**The user can neglect the first phase if he has a preferred unit typology*

First Phase

Prototype

Initial model

Prototype -IN

01 set the user's preferences

STATIC Envelope	Type	KINETIC Envelope
Annual case	Features	*Instantaneous case*
Affordable		*More Accurate*

02 Set the user's Goal

Equivalent solar area (A sol, east) — Solar

Daylight Factor (DF) — Visual

Radiation Analysis — Thermal

Comparison of

Optimization Factors

Without Units

+ MAXIMIZE / **- MINIMIZE**

Verify the prototype's initial performance without the units (only glazing) Should they be maximized or minimized?

03 Run the Simulation

Evolutionary Optimization Process ...

Wallacei Settings

01 Constructive algorithm

02 Environmental processing

03 Optimization prediction.

Prototype -OUT

04 Intermediate Results

Depending on the analytics of all three different typologies which leads to the

Identification of the successful unit

Recommended Unit △ or □ or ⬡

Second Phase

Targeted Envelope

Real model

01 Choose the recommended unit

Trinary Envelope *or* **Quaternary Envelope** *or* **Senary Envelope**

STATIC Envelope — **Type** — **KINETIC Envelope**

Features

STATIC Envelope	KINETIC Envelope
Annual case	*Instantaneous case*
Affordable	*(Daily, Hourly,...)*
	More Accurate

02 Set the user's Goal

Equivalent solar area (A sol, east) — *Solar*

Daylight Factor (DF) — *Visual*

Radiation Analysis — *Thermal*

Comparison of

Optimization Factors

Without Units

+ MAXIMIZE — **- MINIMIZE**

Verify the envelope initial performance without the units (only glazing) Should they be maximized or minimized?

03 Run the Simulation

Evolutionary Optimization Process ...

Wallacei Settings

01 Constructive algorithm

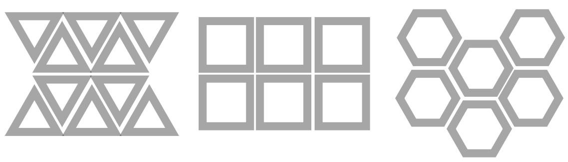
02 Environmental processing

03 Optimization prediction.

04 Final Results

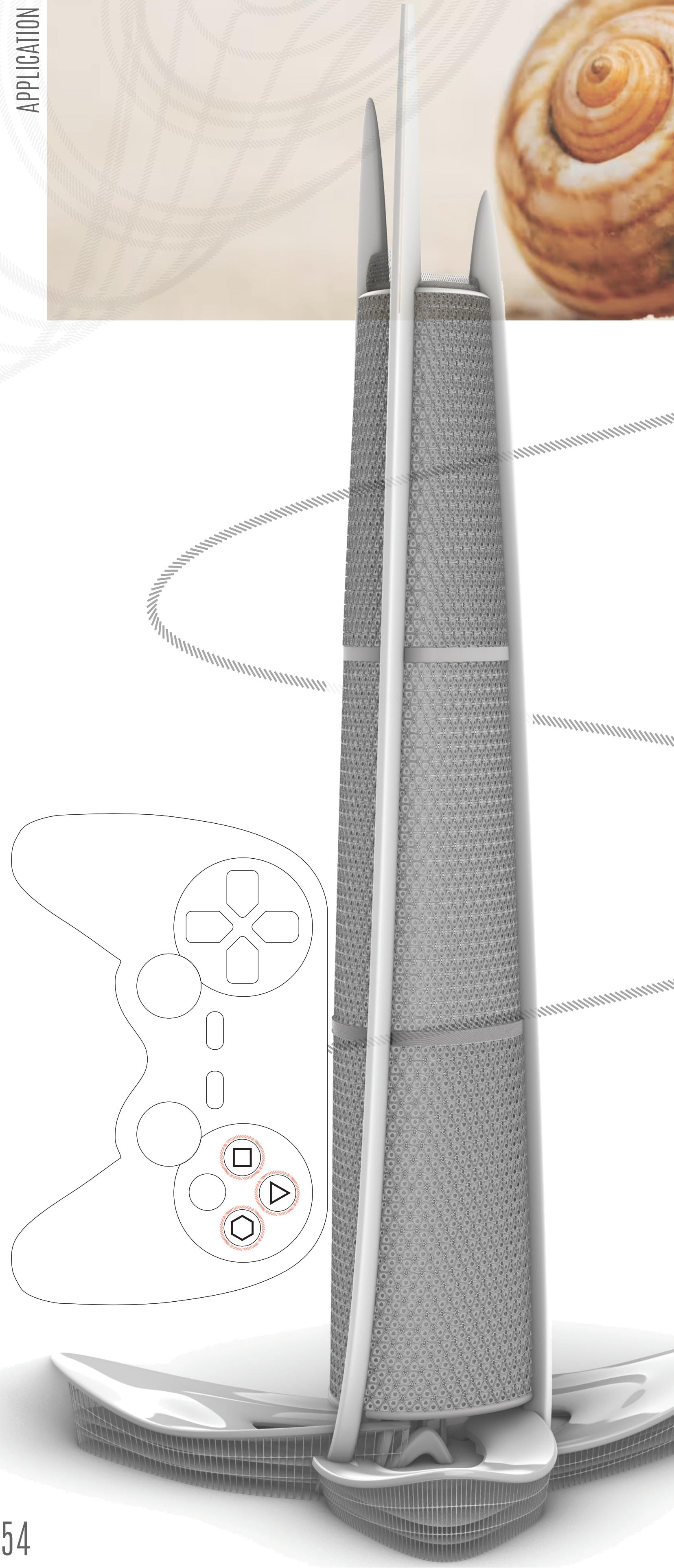
Outcomes

Dara for Operation — **Outcomes** — *Optimization Analytics*



Final Outcome

Optimized Envelope



5•1•1 Concept

Have you ever thought about how to use a Joystick or the console to control your favorite game on PlayStation or Computer? Have you ever tried putting a soccer game on auto-pilot so you could play against the computer or even watch the machine play?

This what we wish through ***SHELL***. but for building envelops. Tthrough the same simple commands such as pressing the square, circle, or triangle, the console transfer signals for processing to find the response in the game? The same is true for Shell. In Shell, the user interface is programmed through six different buttons (Clusters). This enables the user to control the aspect of his building envelope to reach the best possible values to ensure the quality of the indoor environment in terms of optimizing factors.

Likewise, the name SHELL came from the idea of the shell, Seashell or cortex that works to protect the internal environment of the living organism and provide a suitable environment for it, as does the building envelope for the internal space, separating it from external factors and controlling them.

Fig.129: SHELL concept, Automated envelope, and controlling units' features like a child playing with his (Joystick).

5·1·2 User Experience

Step 1 : Apply the simulation on the prototype to Obtain the optimal solution for the preferred unit type.

Step 2 : Apply the full evolutionary simulation on the real project Utilizing the unit components (Trinary,Quaternary,Hexa) depend on the result from step 1.

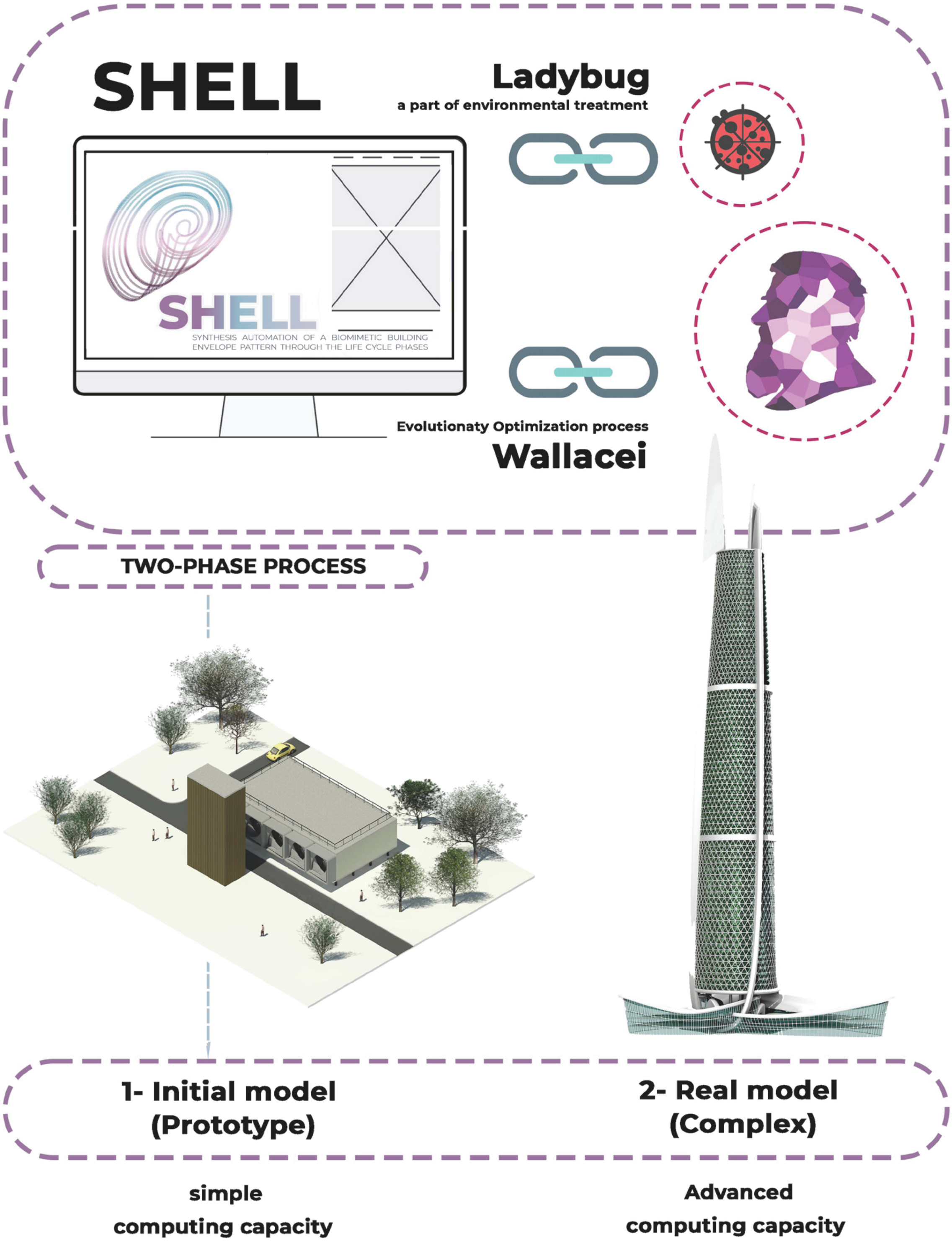


Fig.130: *SHELL Add-in two steps Initial model (Prototype) and Real model (Complex).*

5•1•3 Grasshopper Addin

SHELL consists of two separate groups working parallelly on the mentioned two phases, the first is for the prototype and consists of two inner clusters working with Grasshopper ecosystem (Figure 131), and the second is for the Envelope and consists of four inner Clusters.

The First phase group (Prototype)

1- ProtoType In

2- ProtoType Out

01

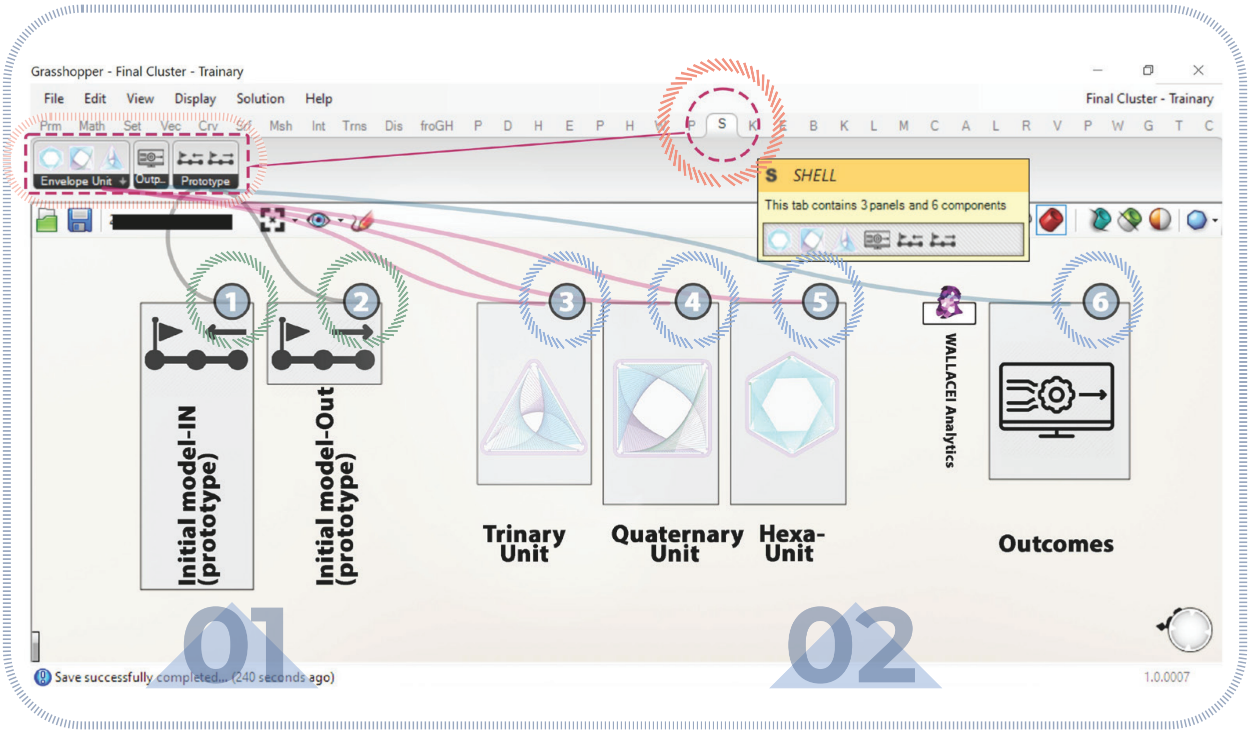


Fig.131: SHELL Add-in (Plugin / Software) inside GH ecosystem..

The Second Phase Group (Envelope)

1- Trinary case (Triangle Units)

2- Quaternay Case (Square Units)

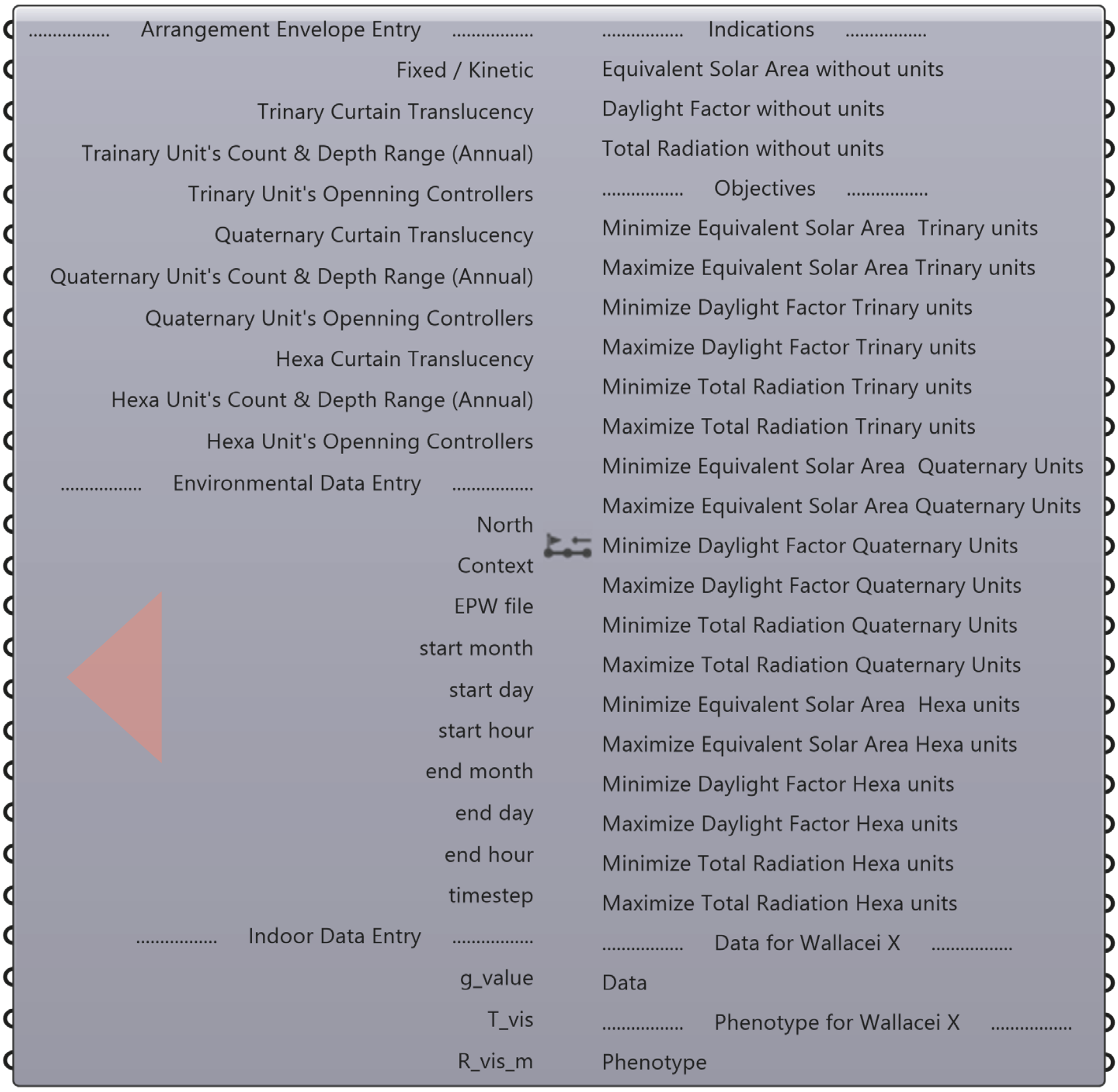
3- Senary Case (Hexa Units)

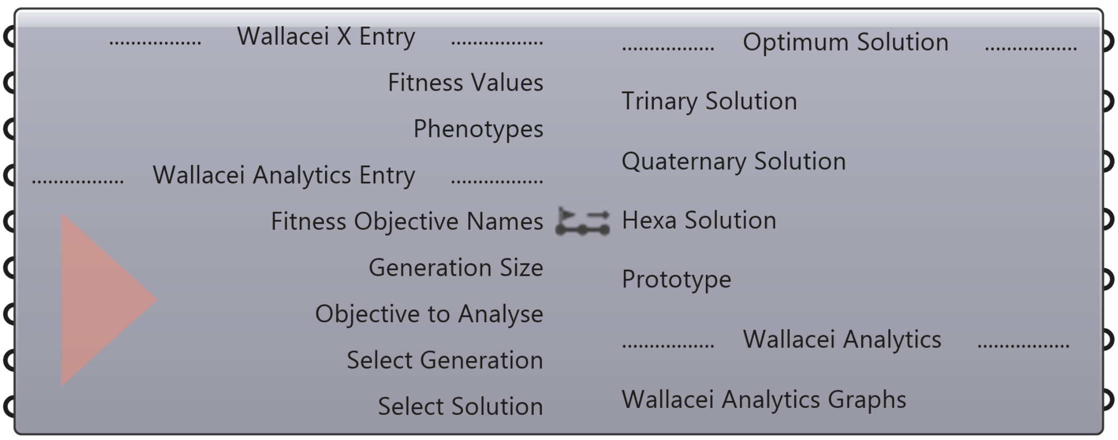
4- Outcomes

02

Both phases have a trial description using SHELL inside Grasshopper ecosystem (Figures 138, 139).

The Prototype - In component allows the user to apply unit types on a given prototype (box 18 x 10 x 4 m). 1- Input (left): divided into three parts - Arrangement Envelope - Environmental - Indoor data entries. 2- Output (right): divided into three parts - Indications - Objectives - Data - Phenotype. objectives to be linked with Wallacei X (minimize or maximize) depends on the indications results without units, also data and phenotype should link with wallacei X after finishing the simulation, to avoid program crush.

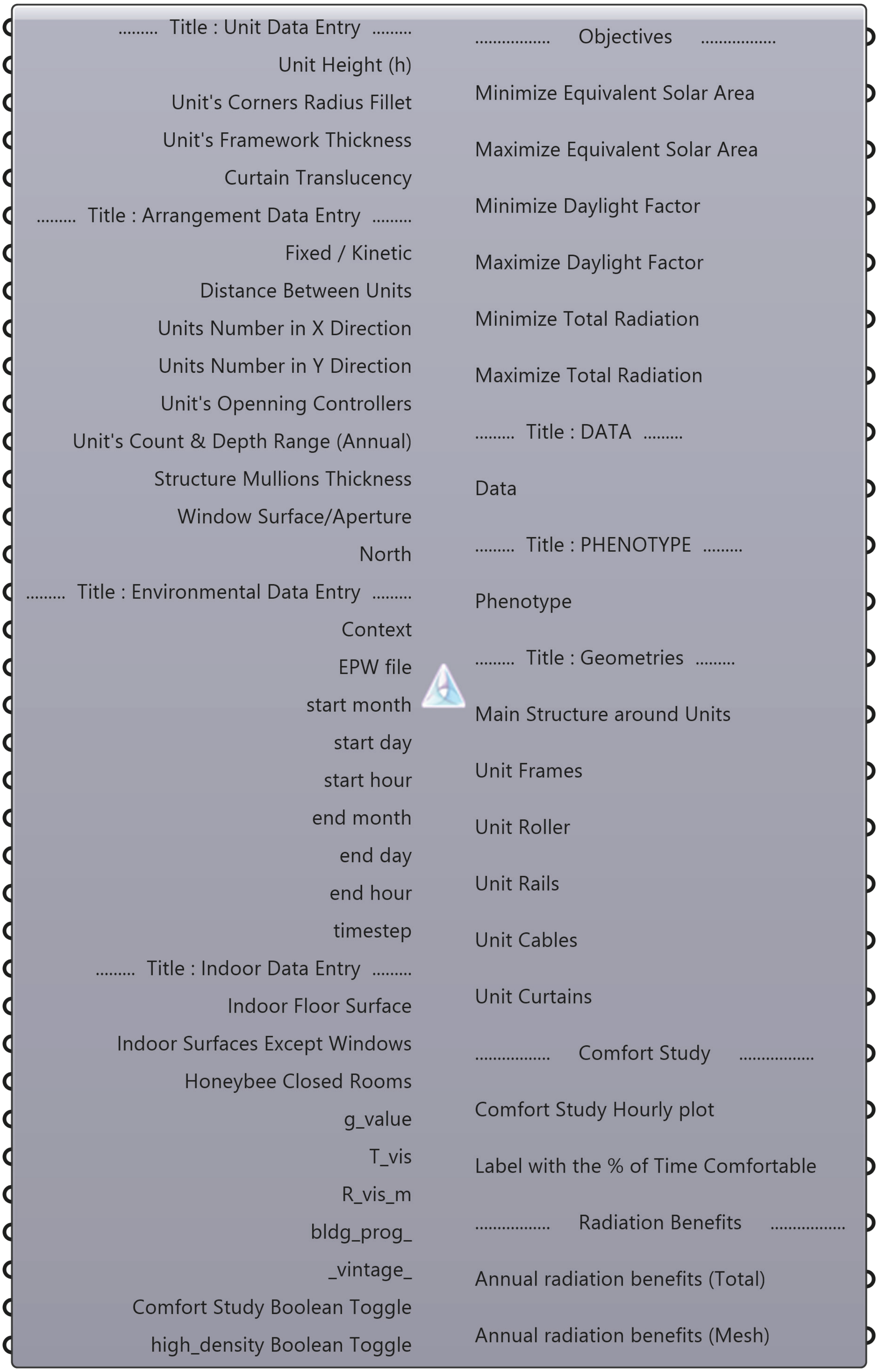




The Prototype - Out component allows the user to visualize Wallacei analytics graphs, and geometries after simulation with Wallacei X engine. 1- Input (left): divided into two parts - Wallacei X - Wallacei analytics data entries. 2- Output (right): divided into two parts - optimum solution - Wallacei analytics graphs.

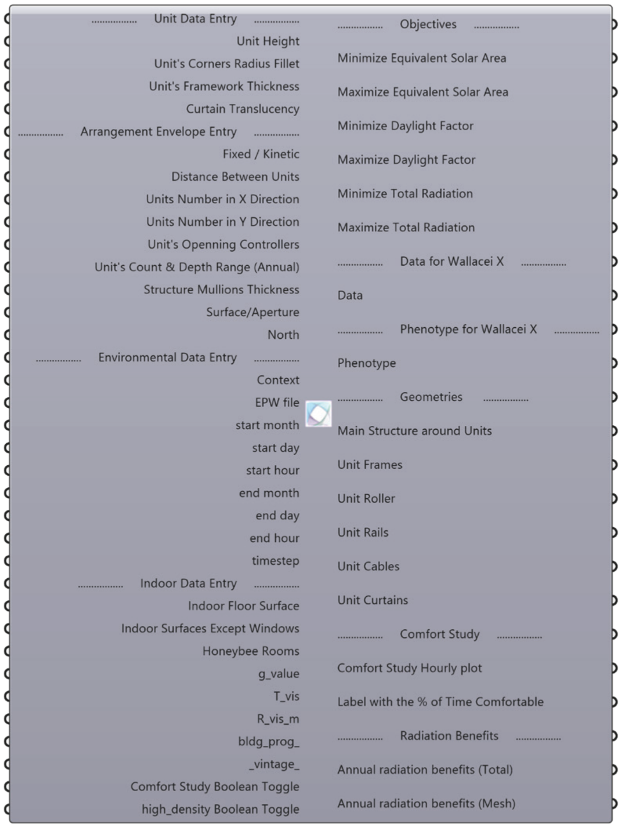
Fig.132: *Prototype-in and Prototype- out components*

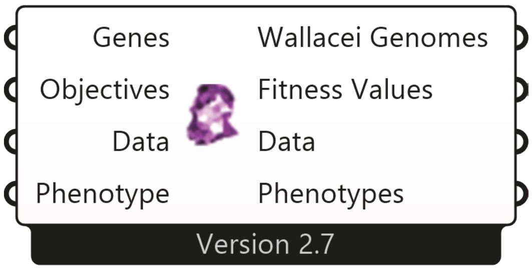
**Appendix 01 additionally includes backend visual code for these clusters components.*



This component allows the user to apply the Trinary units on a surface. 1- Input (left): divided into three parts - unit - Environmental - Indoor data entries. 2- Output (right): divided into six parts - Objectives - Data - Phenotype - Geometries - Comfort Study - Radiation benefits.

Fig.133: *Trinary component (Cluster) that the user can utilize in SHELL software.*





Wallacei X is an evolutionary engine that allows users to run evolutionary simulations by utilizing highly detailed analytic tools to assist users in better understanding their evolutionary runs, including setting up the design problem, analyzing the outputted results, and selecting the desired solution or solutions for the final output. Additionally, Wallacei provides users with the ability to select, reconstruct and output any phenotype from the population after completing their simulation.

Output component visualizes operation data, Wallacei analytics graphs, and geometries after simulation with Wallacei X evolutionary engine. 1- Input (left): divided into three parts - Wallacei X - Wallacei analytics - Giometries distribution entries. 2- Output (right): divided into five parts - Giometries exported solution - Operation Data- Checkup result data- Wallacei analytics output - Geometries distribution output.

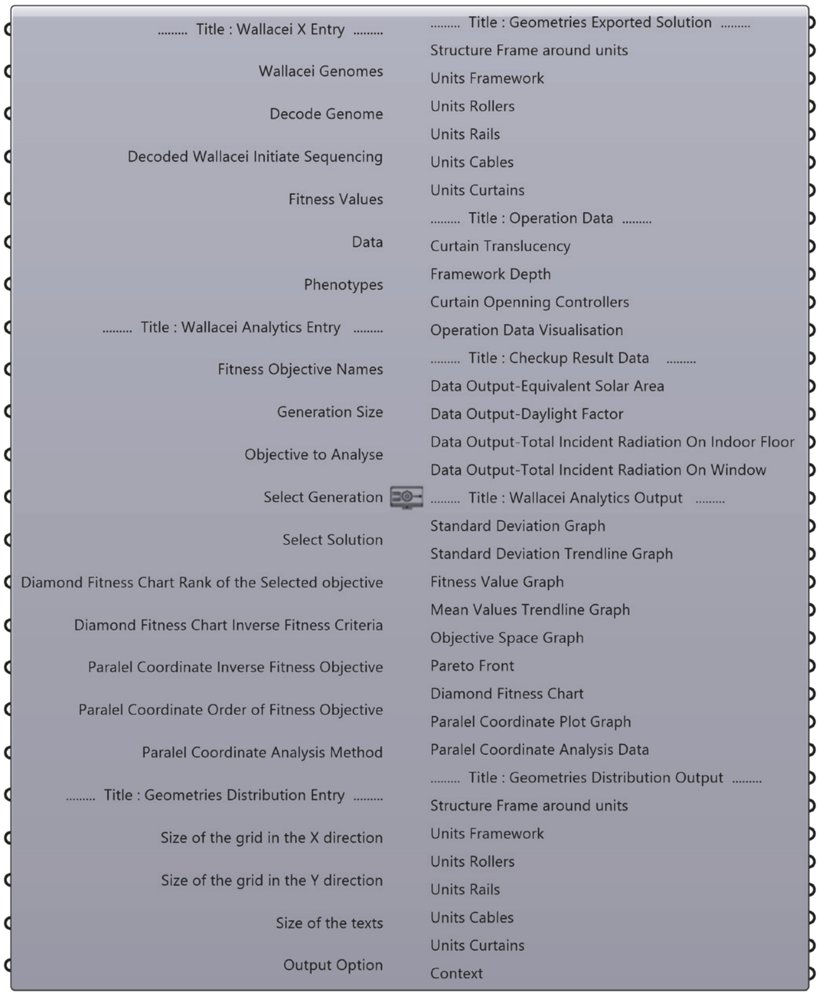


Fig.134: *Quaternary, and Hexa Components (Up), and Wallace analytics component (left) and Output component (Right down)*

Envelope unit Cluster Description (Ternary, Quaternary, Hexa)

		input	Input Discription
unit data Entry This inputs group to define unit morphology.	1	Unit Height (h)	This component represents the Unit Height which is recommended to be the floor height as well, which is following the next equation (Unit Rib Dimension = (2/sqrt(3))*Unit Height (h)). Dimensions in meter (m).
	2	Unit's Corners Radius Fillet	Units Framework Radius Fillet. Dimensions in meter (m).
	3	Unit's Framework Thickness (m)	Unit's Framework Thickness. Dimensions in meter (m).
	4	Curtain Translucency	It represents the transparency factor of curtain material which affects solar equivalent area and daylight factor. Insert an integer number slider between 4 and 30 (4 full transparency, 30 full opaque).
Arrangement Data Entry This inputs group to define unit arrangement.	5	Kinetic / Fixed	Insert an integer number (Kinetic = 0 / Fixed = 1), to choose between Periodic solutions (Instantaneously, Daily, Monthly ... etc.) or Fixed solutions for Annual scenarios.
	6	Distance Between Units (m)	Distance between units. Dimensions in meter (m).
	7	Units Number in X Direction	Number of units in X direction (cells in base plane X direction).
	8	Units Number in Y Direction	Number of units in Y direction (cells in base plane Y direction).
	9	Unit's Openning Controllers	Gene pool Between (0.3 - 1.0). Taking in consideration that the gene pool count should be the same amount of units applied on the input surface which is the result of multiplication Units Number in X Direction and Units Number in Y Direction.
	10	Unit's Count & Depth Range	In the case of the Kinetic (Instantaneous) scenario, insert the Gene pool component, its Max/Min values should be for the preferred unit thickness range, recommended (Minimum = 0.6 m - Maximum = 1.0 m). Taking into consideration that the gene pool count should be the same amount of units applied on the input surface which is the result of multiplication Units Numbers in the X Direction and Units Number in the Y Direction. In the case of a fixed (annual) scenario, insert only one number Slider (Minimum = 0.6 m - Maximum = 1.0 m) instead of a gene pool component.

output	Input Discription	
Minimize Equivalent Solar Area	This is to be link to the wallacei Objectives. according to your design scenario.	OBJECTIVES Those objectives to be inserted in the Objective Wallacei X component according to your design scenario.
Maximize Equivalent Solar Area	This is to be link to the wallacei Objectives. according to your design scenario.	
Minimize Daylight Factor	This is to be link to the wallacei Objectives. according to your design scenario.	
Maximize Daylight Factor	This is to be link to the wallacei Objectives. according to your design scenario.	
Minimize Total Radiation	This is to be link to the wallacei Objectives. according to your design scenario.	
Maximize Total Radiation	This is to be link to the wallacei Objectives. according to your design scenario.	
Data	This outputs the Data of (Equivalent Solar Area-Daylight Factor-Incident radiation on Floor and Windows). It is obligatory to link it with Data in Wallacei X evolutionary and analytic engine.	Data for Wallacei X This data to be inserted in the data Wallacei X evolutionary and analytic engine.

	11	Structure Mullions Theckness	Input a number of the structure mullions theckness. Dimensions in meter (m).
	12	Window Surface/Aperture	insert the surface to apply the units on. Also, the input surface in which incident radiation analysis will be conducted. if surface/brep is input, they will be subdivided using the _grid_size to yield individual points at which analysis will occur. If a mesh input, radiation analysis will be performed for each face of this mesh instead of subdividing it.
	13	North	A number between -360 and 360 for the counterclockwise difference between the North and the position Y axis in degrees. 90 is West and 270 is East.This can also be vector for the direction to North. (Default: 0)
Environmental Data Entry This inputs group to define Environmental Data.	14	Context	Rhino Breps and/or Rhino Meshes representing context geometry that can block the sky to the center of the sky mask.
	15	EPW file	An epw (Weather Data) file path on your system as a string.
	16	start month	start month (1-12)
	17	start day	start day (1-31)
	18	start hour	start hour (0-23)
	19	end month	end month (1-12)
	20	end day	end day (1-31)
	21	end hour	end hour (0-23)
	22	timestep	An integer number for the number of time steps per hours. Acceptable inputs include: 1,2,3,4,5,6,10,12,15,20,30,60.

Phenotype	This outputs the Phenotypes (Geometries) of the Units. It is obligatory to link it with Phenotypes in Wallacei X evolutionary and analytic engine.	Phenotype for Wallacei X This Phenotype to be inserted in the Phenotype Wallacei X evolutionary and analytic engine.
Main Structure Frame around units Unit's Frames Unit's Roller Unit's Rails Unit's Cables Unit's Curtains		Geometries : Unit's Geometries
Comfort study hourly plot Lable with % of time comfortable		Comfort Study
Annual radiation benefits (Total)	It calculate the total annual incident radiation benefits on the curtain units in (Kwh)	Radiation Benefits
Annual radiation benefits (Mesh)	It is a Mesh representing the the total annual incident radiation on the curtain units	

Indoor Data Entry This inputs group to define Indoor Data.	23	Indoor Floor Surface	Rhino surface in which incident radiation analysis will be conducted. if the surface is input, they will be subdivided using the _grid_size to yield individual points at which analysis will occur. If a mesh input, radiation analysis will be performed for each face of this mesh instead of subdividing it.
	24	Indoor Surfaces Except Windows	Insert the indoor room surfaces without the windows. (Floors, Walls Roofs).
	25	Honeybee Rooms	A list of Honeybee Rooms to be added to the model. Note that at least one room is necessary to make a simulate-able energy model. The added rooms should be a closed Breps, and the apertures are set from the same of windows surfaces.
	26	g_value	G-value, also known as total solar energy transmittance, is a coefficient used to measure the transmittance of solar gain through glazing. Or, how much heat is transmitted through a window from the sun's rays. The G-value is a scale between 0-1: A high G-value of 1 represents full transmittance of solar energy. A low G-value of 0 means that all solar energy is blocked by the glass. Insert = 0.7 as a suggested value for ignored use.
	27	T_vis	The values relative to the glass visible transmittance. Insert = 0.7 as a suggested value for ignored use.
	28	R_vis_m	the weighted average visible reflectance of all the room surfaces. Insert = 0.45 as a suggested value for ignored use.
	29	bldg_prog_	Text for the building program to search (eg. "LargeOffice", "MidriseApartment", etc.). The Honeybee "Building Programs" component lists all of the building programs available in the library. If None, all ProgramTypes within the library will be output (filtered by keywords_ below).
	30	_vintage_	Text for the building vintage to search (eg. "2019", "pre_1980", etc.). The Honeybee "Building Vintages" component lists all of the vintages available in the library. Default: "2019" (for ASHRAE 90.1 2019 | IECC 2015). Note that vintages are often called "templates" within the OpenStudio standards gem and so this property effective maps to the standards gem "template".
	31	Comfort Study Boolean Toggle	It is a boolean toggle to run a honeybee simulation for Comfort Study. It is recommended to run this simulation after exporting the optimal solution from wallacei X to check the indoor comfort.
	32	high_density Boolean Toggle	It is an optional boolean toggle to run a high_density for Cumulative Sky Matrix.

Fig.135: *(Table 07) Envelope (Trinary) cluster full description in SHELL software- Quaternary and Hexa units have the same description but with their adaptable results.*

Wallacei

	input	Input Discription	output	Input Discription
1	Genes	Variables (number Sliders and/or geenpools).	Wallacei Genomes	This outputs the genomes of all solution in the population.
2	Objectives	Fitness Objectives are values contained within a 'number' component.	Fitness Values	This outputs the fitness values of all solutions in the population. The list structure is as follows {A;B}[i], where 'A' is the generation number, 'B' is the solution number and 'i' is the fitness values for each fitness objective
3	Data	Any dat to be saved for every solution in the population.	Data	This output the inputted data of all solutions in the population
4	Phenotype	The phenotypes that will be exported from within the solver. Any data type is accepted such as Breps, Meshes or Numbers. It is recommended to be inputted after running the simulation.	Phenotypes	This outputs the phenotypes of the exported solutions in the population.

Fig.136: *(Table 08) Wallacei analytics cluster full description (Wallacei engine).*

Outputs shell component

		input	Input Discription
Wallacei X Entry : All Output Data from Wallacei X evolutionary and analytic engine.	1	Wallacei Genomes	This outputs the genomes of all solutions in the population. It is obligatory to link it with Wallacei Genomes in Wallacei X evolutionary and analytic engine.
	2	Decode Genome	It is a number slider represent the exact number of Generation that inputed in Wallacei X
	3	Decoded Wallacei Initiate Sequencing	Insert a button component to start calculation, as a result of this process, new components will be generated on the grasshopper canvas.
	4	Fitness Values	Fitness Values from Wallacei X of all solutions in the population. It is obligatory to link it with Fitness Values in Wallacei X evolutionary and analytic engine.
	5	Data	Data from Wallacei X of all solution in the population (Equivalent Solar Area-Daylight Factor-Incident radiation on Floor and Windows). It is obligatory to link it with Data in Wallacei X evolutionary and analytic engine.
	6	Phenotypes	Phenotypes from Wallacei X of the exported solutions in the population. It is obligatory to link it with Phenotypes in Wallacei X evolutionary and analytic engine.
Wallacei Analytics Entry : This inputs group to define Wallacei Analytics Graphs.	7	Fitness Objective Names	Insert fitness objective names as a panel list.
	8	Generation Size	How many individuals are there in a single generation? This is the same number of (Generation Count) in Wallacei X evolutionary and analytic engine.
	9	Objective to Analyse	Select the Objective to be ploted and analysed. It is a number slider to switch between objectives.
	10	Select Generation	Input a generation number to highlight it on the graph
	11	Select Solution	Input a Solution number in the selected generation to highlight it on the graph
	12	Diamond Fitness Chart Rank of the Selected objective	Select the Ranking of the solution to visualize. (0) is the highest rank.
	13	Diamond Fitness Chart Inverse Fitness Criteria	Boolean Toogle for Inverse Fitness objective in Diamond Fitness Chart, 1 = inverse / 0 = don't inverse.

output	output Discription	
Structure Frame around units	Structure Frame around units for a specific Solution exported from wallacei X evolutionary and analytic engine.	
Units Framework	Units Framework for a specific Solution exported from wallacei X evolutionary and analytic engine.	
Units Rollers	Units Rollers for a specific Solution exported from wallacei X evolutionary and analytic engine.	Geometries Exported Solution : Geometries for a specific Solution exported from wallacei X evolutionary and analytic engine.
Units Rails	Units Rails for a specific Solution exported from wallacei X evolutionary and analytic engine.	
Units Cables	Units Cables for a specific Solution exported from wallacei X evolutionary and analytic engine.	
Units Curtains	Units Curtains for a specific Solution exported from wallacei X evolutionary and analytic engine.	
Curatain Translucency	List of Numbers represent the operation data of Curtain Translucency.	
Framework Depth	List of Numbers represent the Framework Depth of the units for a specific Solution exported from wallacei X evolutionary and analytic engine. (Genomic Visualisation Outputted Values for the Chromosomes). It should be used to control the Framework Depth.	
Curtain Openning Controllers	List of Numbers represent the Curtain Openning Controllers of the units for a specific Solution exported from wallacei X evolutionary and analytic engine. (Genomic Visualisation Outputted Values for the Chromosomes). It should be used to control the Curtains oppening.	Operation Data : List of Numbers represent the operation data of the units for a specific Solution exported from Wallacei X evolutionary and analytic engine.
Operation Data Visualisation	Mesh represents the Operation Data Visualisation of the units for a specific Solution exported from Wallacei X evolutionary and analytic engine. (Genomic Visualisation Outputted Mesh Representing the Genomic Sequence).	
Equivalent Solar Area	Equivalent Solar Area after applying units system and Simulation.	
Daylight Factor	Daylight Factor Area after applying units system and Simulation.	Checkup Results Data: It is a List of Numbers represent the data of the units for a specific Solution exported from Wallacei X evolutionary and analytic engine.
Total Incident Radiation On Indoor Floor	Total Incident Radiation On Indoor Floor Area after applying units system and Simulation.	

	14	Paralel Coordinate Inverse Fitness Objective	Input Booleans as list. Number of Booleans should correspond to the number of fitness Objectives. 0 = don't inverse // 1 = inverse
	15	Paralel Coordinate Order of Fitness Objective	Input list of integers (1 to 5) in order you want to view the fitness Objective.
	16	Paralel Coordinate Analysis Method	Input value list component to choose between four different analysis methods. 0 = Repeated Fitness Values / 1 = Solutions with repeated Fitness Values // 2 = Relative Difference Between Fitness ranks // 3 = Average of Fitness Rank.
Geometries Distribution Entry : Geometries Distribution Inputs for Multi Solutions exported from wallacei X evolutionary and analytic engine.	17	Distribute to Grid in the X direction	Insert a number to define the Size of the grid in the X direction
	18	Distribute to Grid in the Y direction	Insert a number to define the Size of the grid in the Y direction
	19	Size of the texts	Insert a number to define the Size of the texts on the grid
	20	Output Options	input a value between 0 and 3 to select which data type to output from the Wphenotype. 0 = All, 1 = geometry, 2 = mesh, 3 = number
	21		
	22		
	23		
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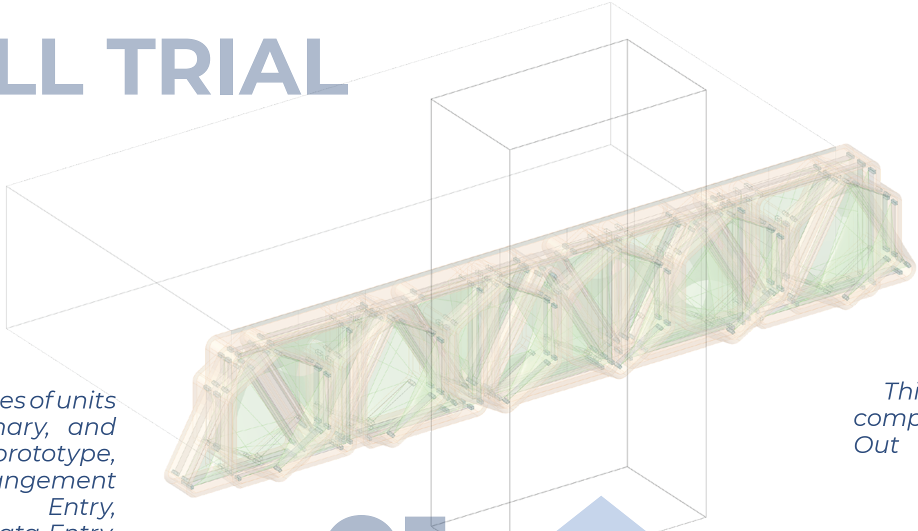
	30		

Fig.137: (Table 09) Outputs cluster full description in SHELL software.

Total Incident Radiation On Window	Total Incident Radiation On Window Area after applying units system and Simulation.	
Standard Deviation Graph	Calculate the standard deviation values and draws the normal distribution graph for each generation of data exported.	Wallacei Analytics Output : Wallacei Analytics is a group of components used to analyze the fitness values outputted by an evolutionary simulation. The aim is to provide users with a thorough understanding of the population's fitness values through their analysis and presentation by means of a range of methods, each highlighting a unique aspect of the outputted results.
Standard Deviation Trendline Graph	Plot the standard deviation factor for each generation and create the trendline for the entire simulation for data exported.	
Fitness Value Graph	Plot the Fitness Values for each solution per generation for data exported.	
Mean Values Trendline Graph	Plot the Mean Values for each generation and create the trendline for the entire simulation for data exported.	
Objective Space Graph	Display the objective space of the fitness values of the solutions.	
Pareto Front	Evaluates the data generated by the Wallacei X Objective Space and calculates the Pareto Front for a selected generation and plots the Dominance rank for each solution in the selected generation.	
Diamond Fitness Chart	Display the diamond fitness chart along with the fitness ranking for each solution for data exported from Wallacei.	
Paralel Coordinate Plot Graph	Evaluate the fitness values for each solution by comparing each fitness objective to one another in the form of parallel coordinayte plot.	
Paralel Coordinate Analysis Data	Analyse the data generated from (Wallacei-Parallel Coordinate Plot) by comparing the fitness values across the different fitness objective.	
Structure Frame around units	Structure Frame around units for a multi Solutions exported from wallacei X evolutionary and analytic engine.	Geometries Distribution Output : Geometries Distribution output for Multi Solutions exported from wallacei X evolutionary and analytic engine.
Units Framework	Units Framework for a multi Solutions exported from wallacei X evolutionary and analytic engine.	
Units Rollers	Units Rollers for a multi Solutions exported from wallacei X evolutionary and analytic engine.	
Units Rails	Units Rails for a multi Solutions exported from wallacei X evolutionary and analytic engine.	
Units Cables	Units Cables for a multi Solutions exported from wallacei X evolutionary and analytic engine.	
Units Curtains	Units Curtains for a multi Solutions exported from wallacei X evolutionary and analytic engine.	
Context	Rhino Breps and/or Rhino Meshes representing context geometry.	

SHELL TRIAL



01: Apply all types of units (Trinary, Quaternary, and Hexa) on the prototype, after insert (Arrangement Envelope Entry, Environmental Data Entry, and Indoor Data Entry)

This GH definition is a components prototype-In, Wa Out

01

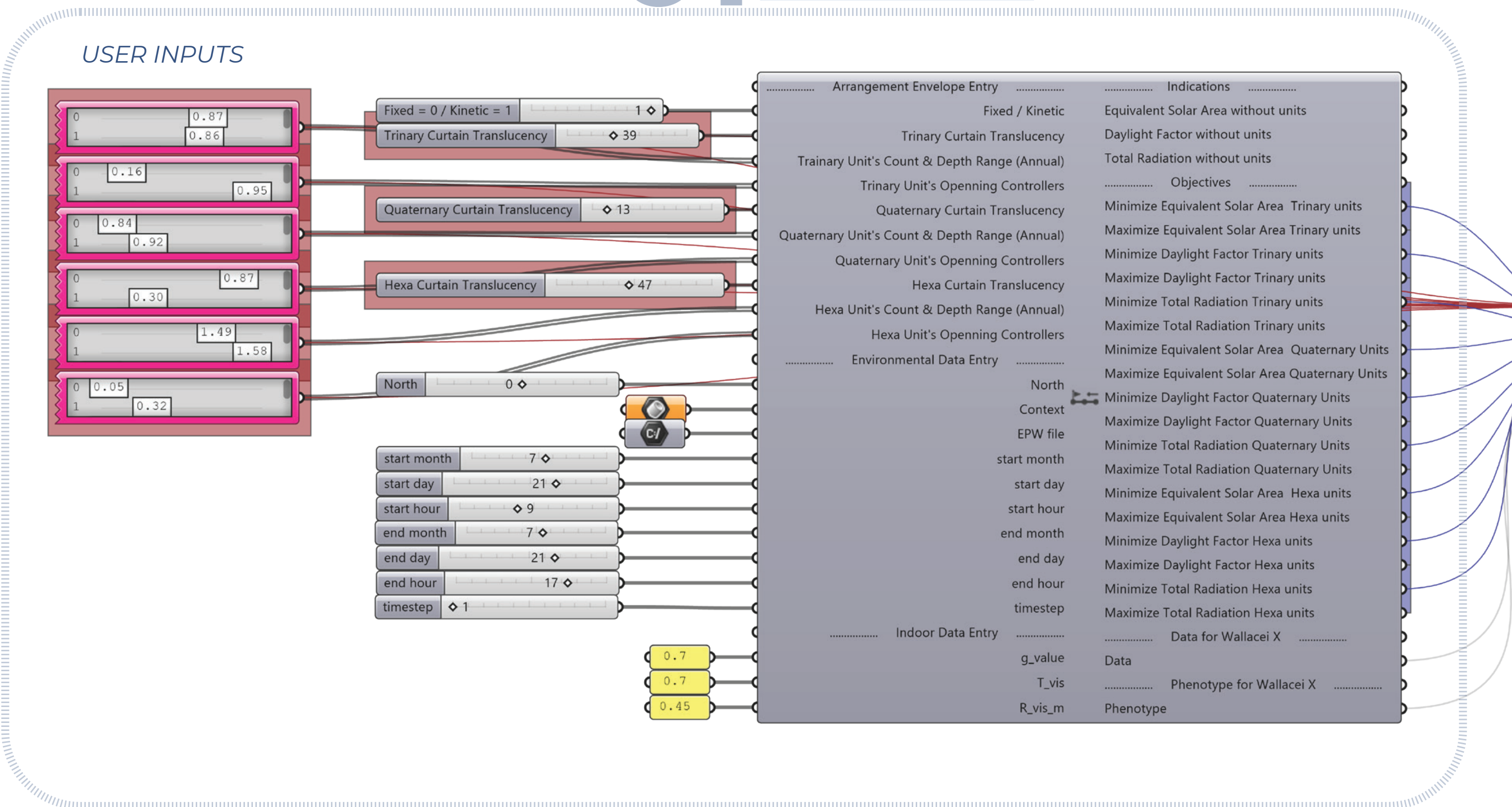
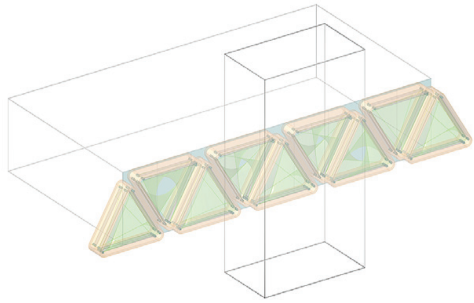
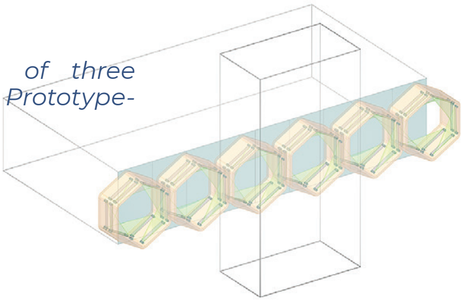


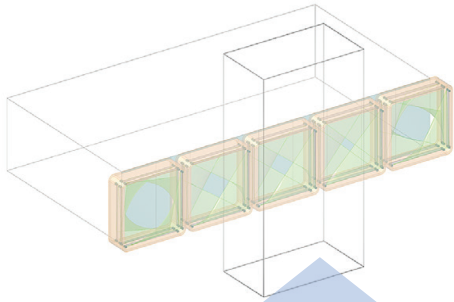
Fig.138: Prototype Cluster- Case study of using the Prototype component to run the initial simulation

Description: From the Prototype-in component, we have to read Indications (Equivalent solar area, Daylight Factor, and Total Radiation) without units in order to choose the minimize or maximize objectives, to meet the building physics regulations. Then link the appropriate ones to the Objectives in wallacei X component, also link the Data between the Prototype-in component and wallacei X component. Pay attention to link Phenotype from the Prototype-in component to Phenotype in Wallacei X after finishing the simulation to avoid software crashes. Finally, Start the simulation through Wallacei X, visualize the Data, and export the optimal solution that meets the regulations.



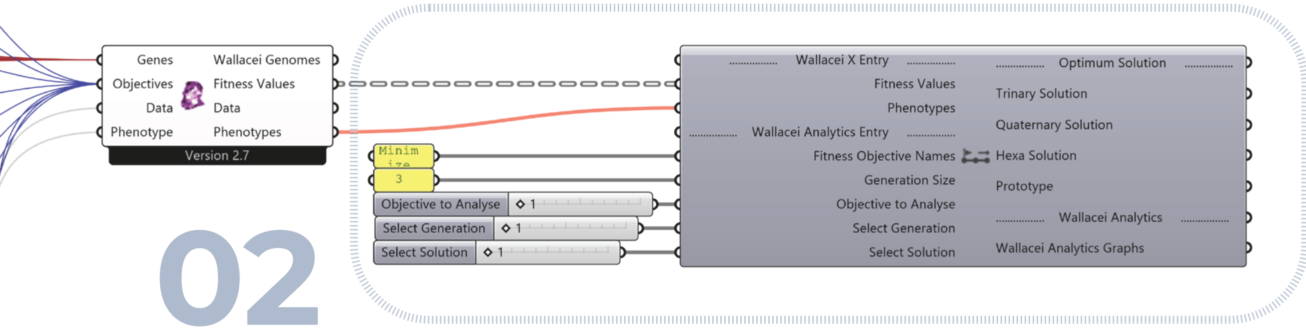


combination of three
allacei X, and Prototype-



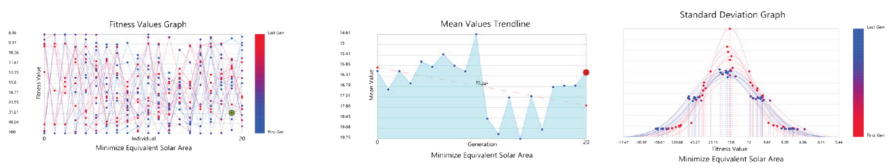
03: Visualize the optimal solution on the prototype after finishing the simulation. It could be (Trinary, quaternary, or Hexa), and visualize its analytics graphs.

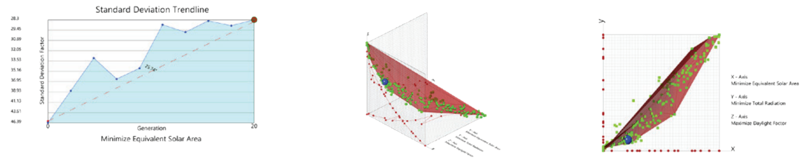
03



02

02: Run the simulation and export the optimal solution that meet Building physics regulation.

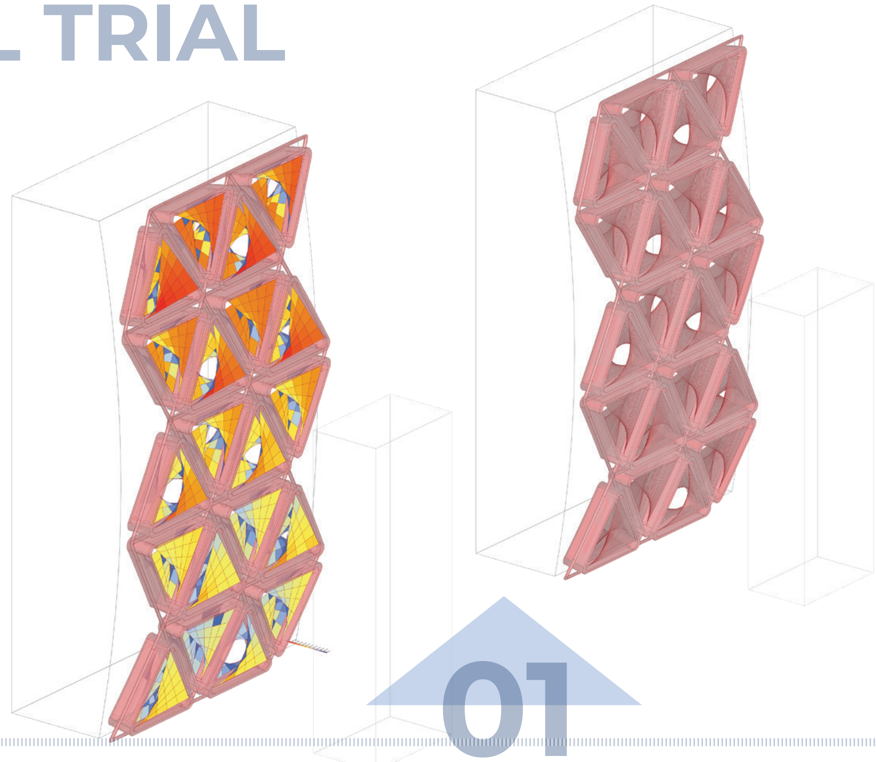




SHELL TRIAL

01 Apply the trinary units on a studied surface and read the annual radiation benefit on the curtains.

Also in order to calculate the energy derived from photovoltaic that could apply to the curtains if needed.



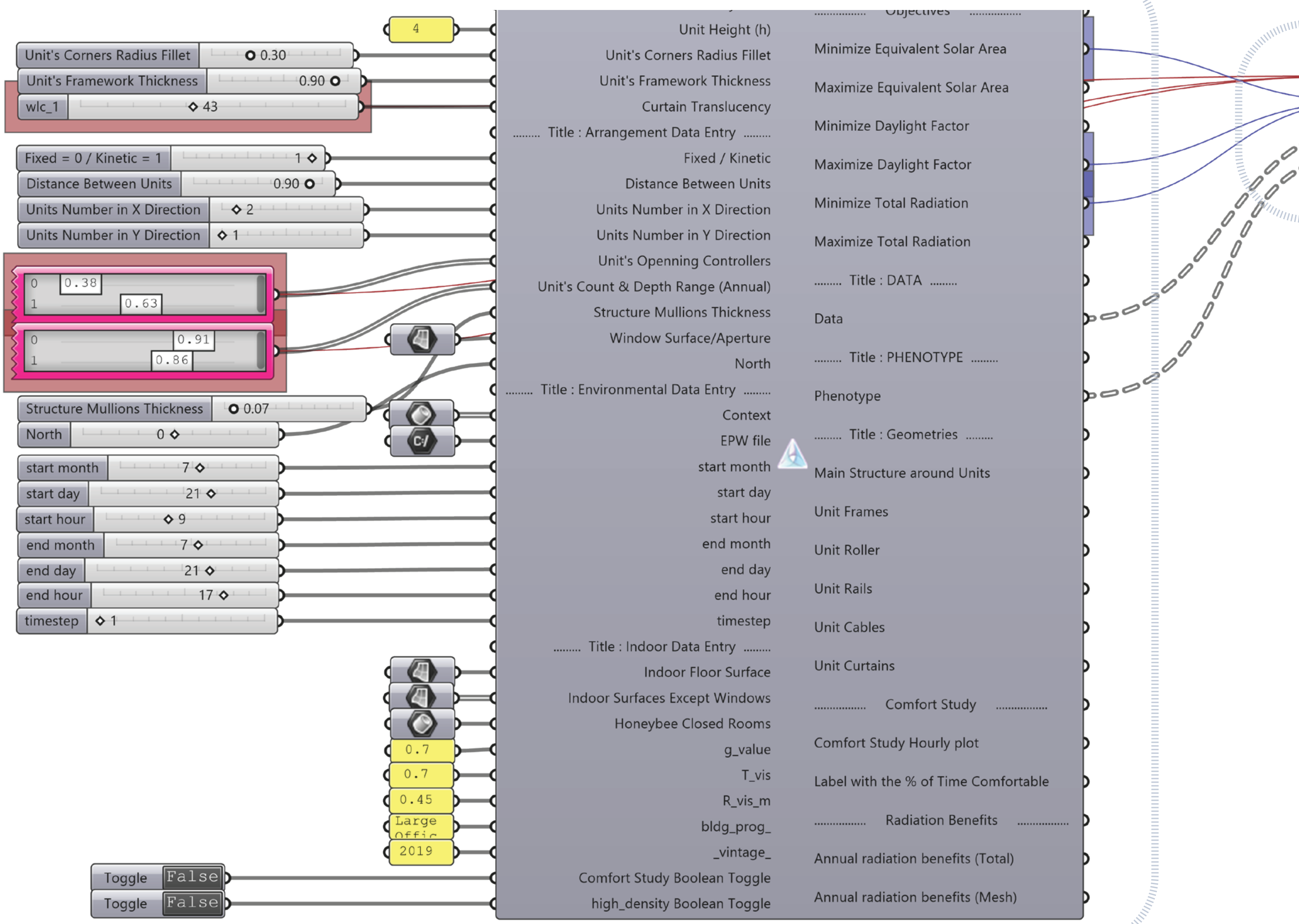
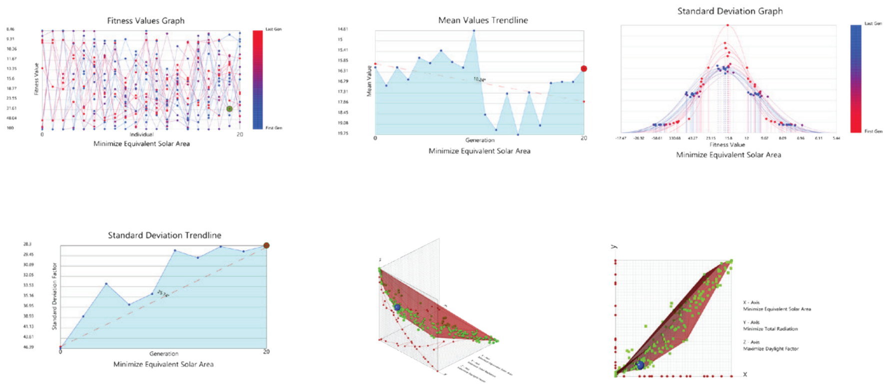
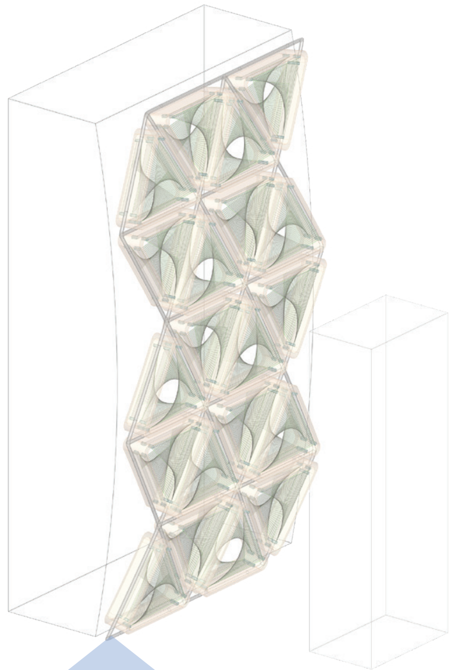


Fig.139: Trinary Cluster , Case study of connections in GH using the Trinary component connected to Wallacei X to run the complex simulation



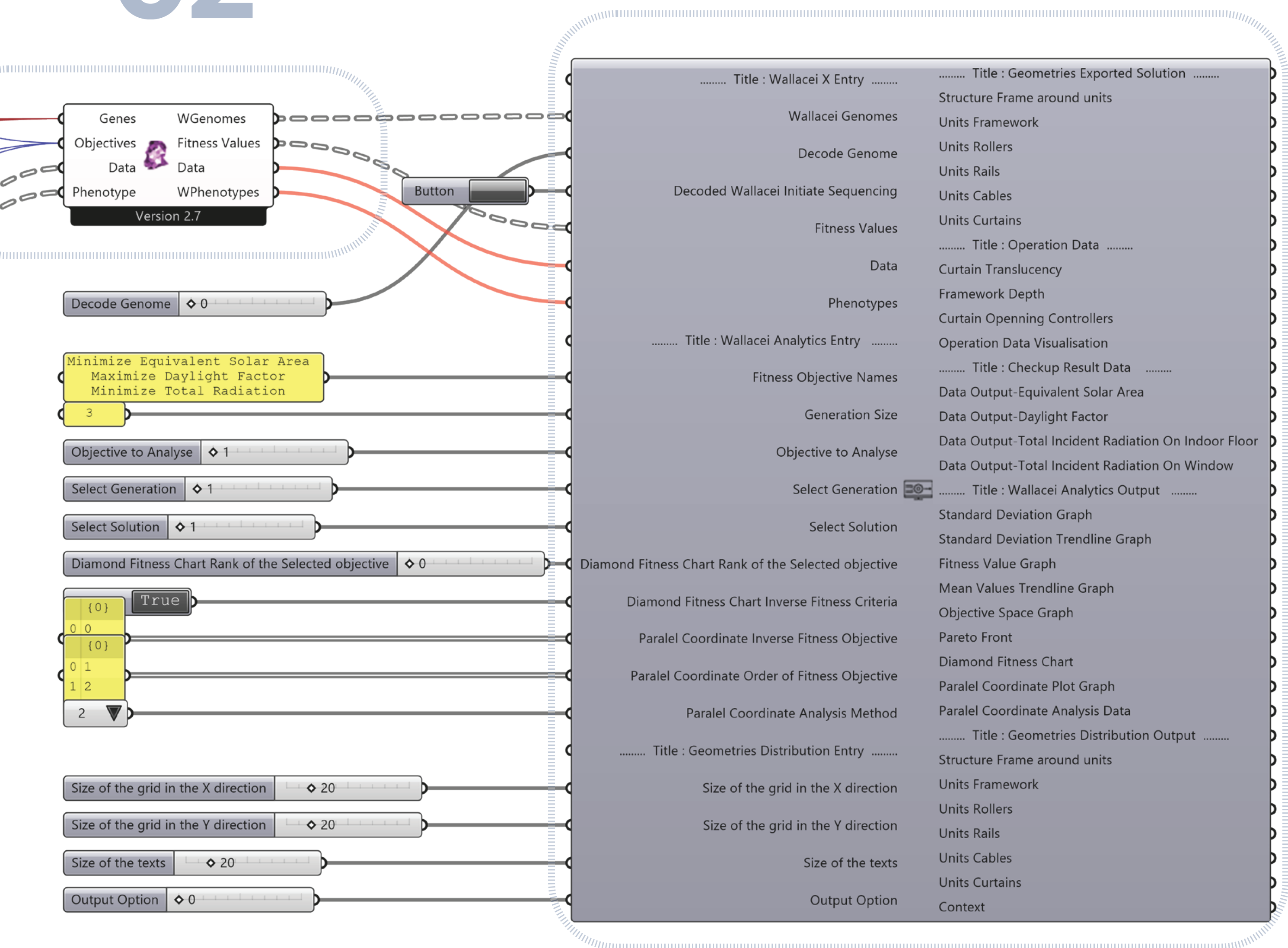
02: Run the simulation and export the optimal solution that meet Building physics regulation.

03: Export the optimal solution for Trinary units on the studied surface that meet Building physics regulations, and visualize its analytics graphs.



02

03



This GH definition is a combination of three components Trinary, Wallacei X, and Outcomes

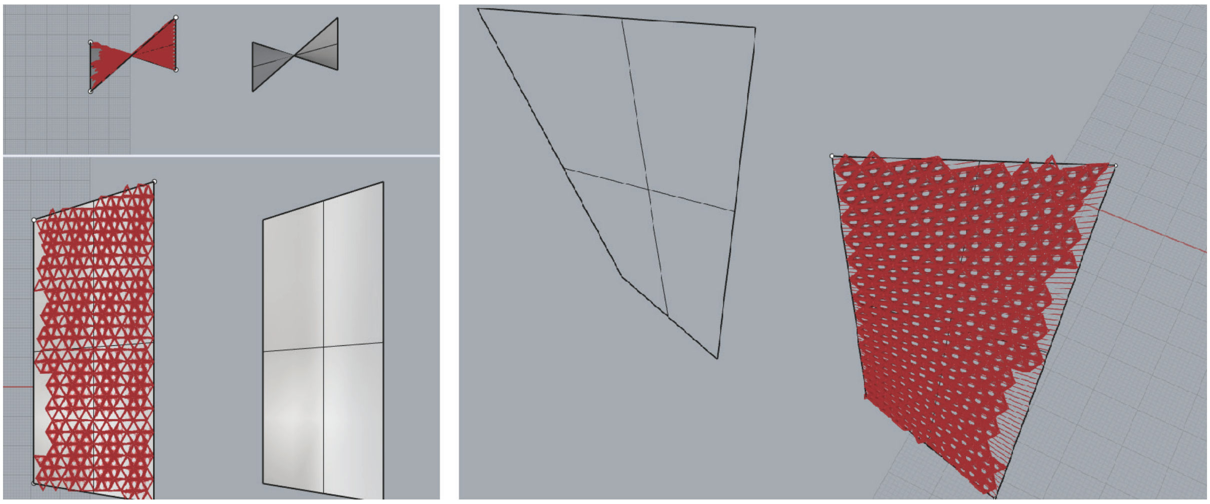
Demo Trial.

INPUTS - Trinary (Unit) CLUSTER:

- Choose the needed façade surface
- Choose the project location and connect the EPW files
- Choose the floor height – (unit height)
- Choose the project context building

Outputs

- the solved optimized tents groups
- the unit frame and its rails
- Indicating structure frame



Selected surface as a façade

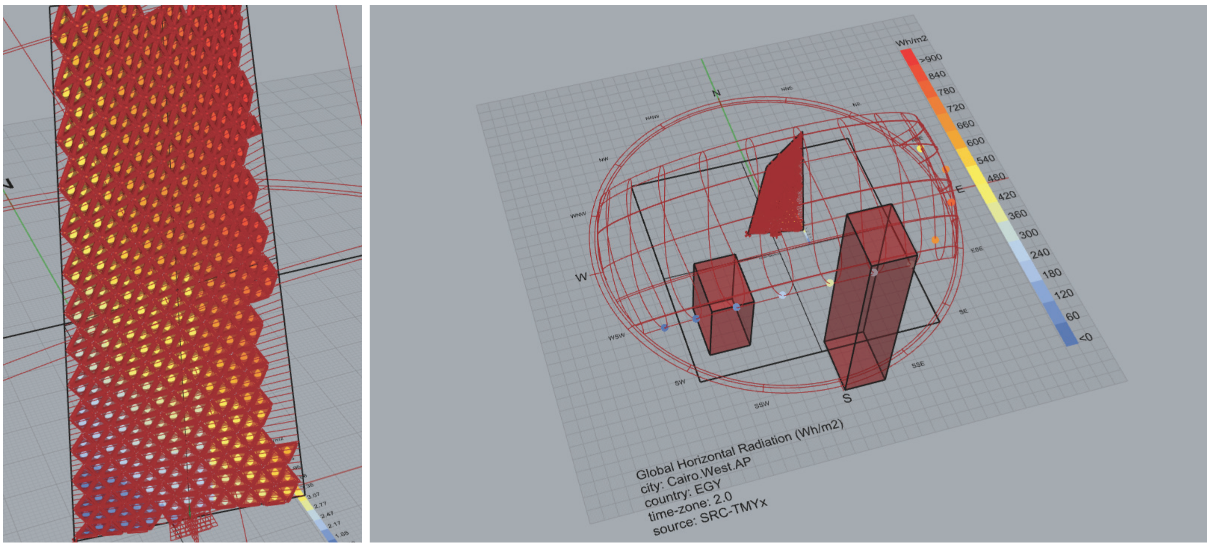
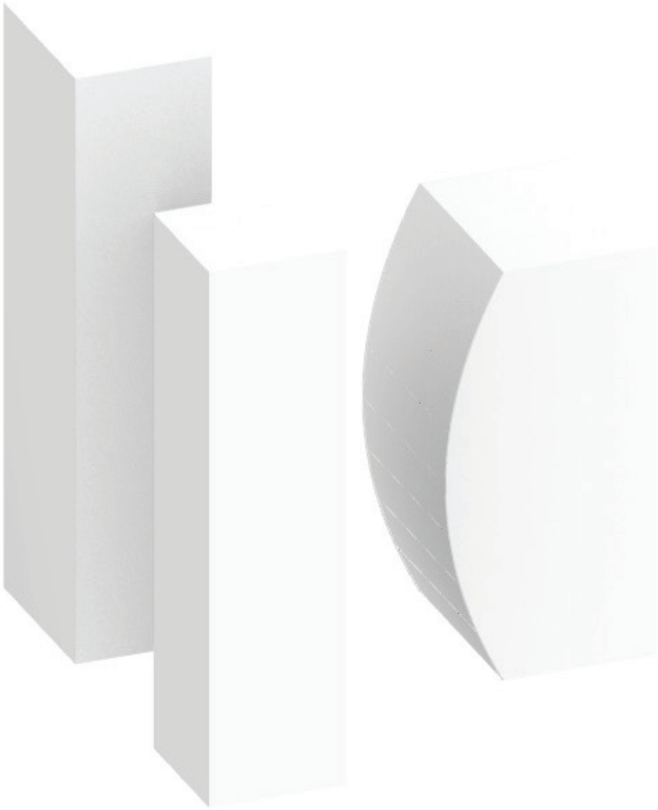


Fig.140: Initial results applied on different surfaces representing a facades in different contexts using SHELL addin.

•**Before & After**



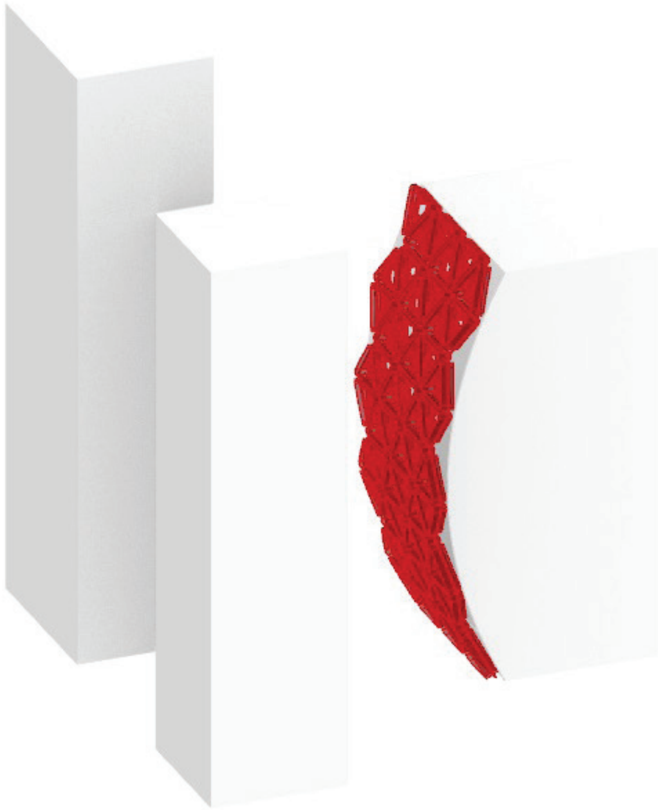
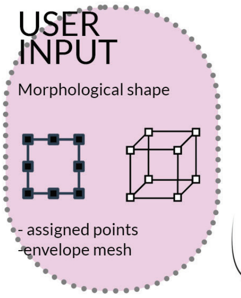


Fig.141: *Curved facade as a case study with its context (Up), apply Trinary cluster input applied on it using SHELL software (down).*

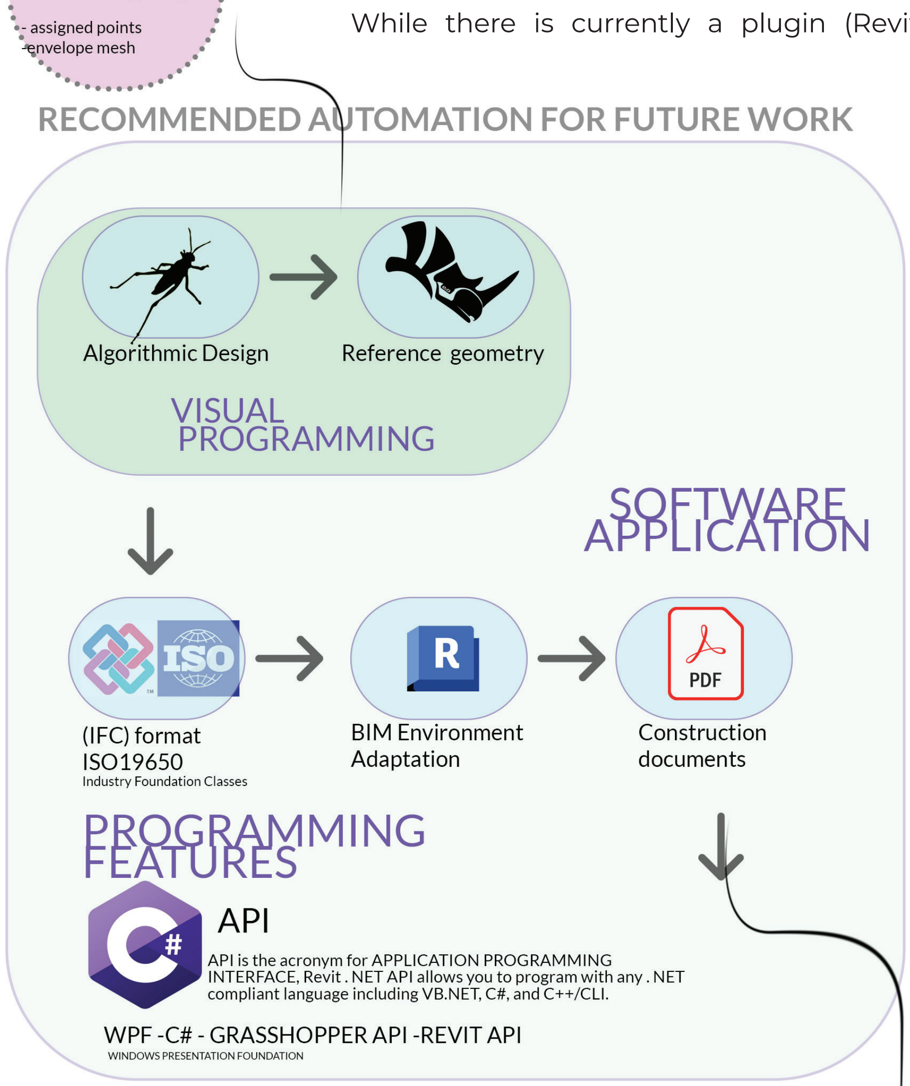
5•1•4 C# Addition

SHELL software requires a development with BIM environment in order to allow the final data and results to work likely and proceed to the construction



phase, which is necessary to guarantee full automation and full compatibility of SHELL with the current best practice in the AEC industry.

While there is currently a plugin (Revit



inside) that can be used to transfer data between Grasshopper and Revit, further bespoke solutions will be required to complete the transfer, also it could not be automated.

For upcoming work, Revit API and IFC schemes might be utilized to manage the data and be automated

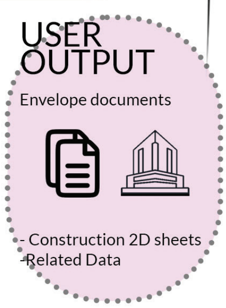
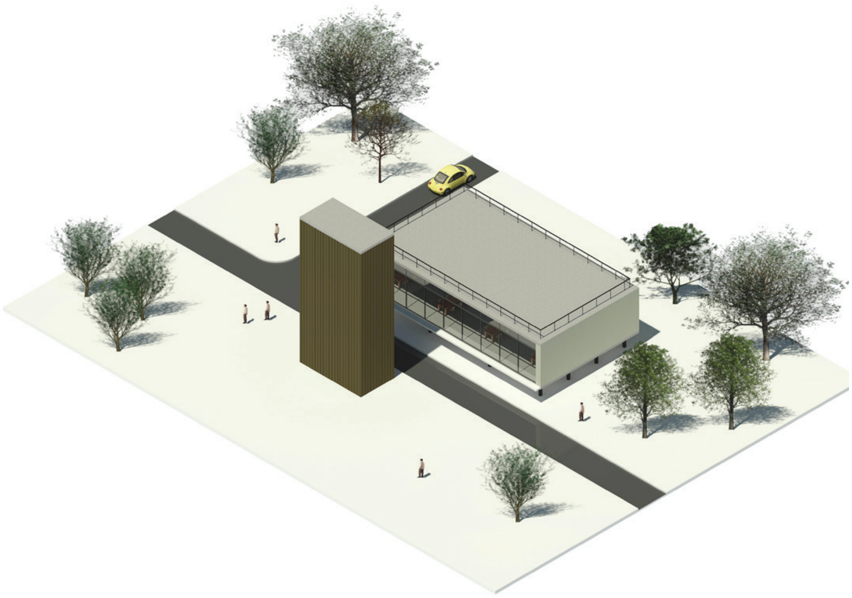


Fig.142: Recommended Workflow for SHELL to assure the full automation and full interoperability of the software with other commercial softwares.

directly in the BIM environment, allowing sheets and drawings for building sites to be quickly prepared. In Revit, a sample of automated sheets has been included (***Appendix 04***).

5•2 Initial model (Prototype) Result

After SHELL program's working mechanism has been explained, the results it achieved will now be released in the two steps that were previously explained, the prototype and an actual project.



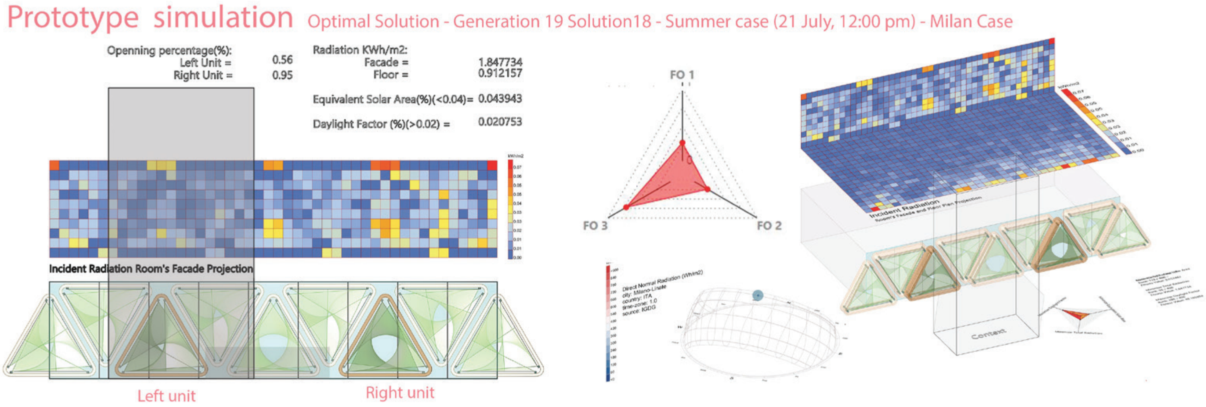
The results here come from the empirical findings from the method chapter which applied in the northern Italy climate zone.

The

	Translucency % 1 full Transparency - 100 full opaque	Framework Depth m									Shutter Opening % 1 = 100%								
Gen: 19 Ind: 0	12.5	0.46	0.52	0.52	0.51	0.48	0.52	0.51	0.48	0.61	0.82	0.51	0.75	0.55	0.64	0.89	0.94	0.82	0.98
Gen: 19 Ind: 1	75	0.56	0.48	0.7	0.66	0.74	0.48	0.64	0.51	0.49	0.59	0.54	0.56	0.54	0.65	0.51	0.51	0.63	0.61
Gen: 19 Ind: 2	12.5	0.46	0.52	0.52	0.51	0.48	0.52	0.51	0.48	0.61	0.81	0.51	0.75	0.55	0.64	0.89	0.94	0.82	0.98
Gen: 19 Ind: 3	75	0.56	0.48	0.7	0.66	0.74	0.61	0.64	0.51	0.72	0.99	0.54	0.56	0.54	0.65	0.51	0.52	0.63	0.61
Gen: 19 Ind: 4	27.5	0.55	0.74	0.65	0.71	0.66	0.63	0.61	0.48	0.5	0.51	0.66	0.74	0.58	0.96	0.6	0.57	0.94	0.74
Gen: 19 Ind: 5	12.5	0.5	0.57	0.52	0.51	0.49	0.62	0.51	0.51	0.62	0.91	0.54	0.75	0.55	0.64	0.52	0.94	0.92	0.74
Gen: 19 Ind: 6	50	0.51	0.56	0.7	0.51	0.57	0.52	0.51	0.51	0.6	0.63	0.98	0.74	0.58	0.61	0.9	0.8	0.82	0.6
Gen: 19 Ind: 7	75	0.56	0.48	0.71	0.52	0.73	0.48	0.46	0.51	0.49	0.59	0.56	0.56	0.54	0.97	0.51	0.54	0.63	0.61
Gen: 19 Ind: 8	75	0.56	0.52	0.7	0.51	0.73	0.46	0.46	0.51	0.49	0.59	0.51	0.56	0.55	0.97	0.52	0.54	0.81	0.61
Gen: 19 Ind: 9	15	0.46	0.52	0.51	0.47	0.49	0.48	0.51	0.6	0.71	0.79	0.52	0.75	0.61	0.56	0.99	0.9	0.82	0.57
Gen: 19 Ind: 10	27.5	0.55	0.48	0.7	0.7	0.7	0.52	0.45	0.5	0.62	0.59	0.5	0.56	0.58	0.99	0.52	0.95	0.94	0.74
Gen: 19 Ind: 11	70	0.58	0.48	0.7	0.66	0.49	0.48	0.45	0.5	0.62	0.57	0.54	0.57	0.58	0.99	0.52	0.91	0.94	0.74
Gen: 19 Ind: 12	72.5	0.58	0.55	0.52	0.51	0.49	0.48	0.51	0.48	0.49	0.81	0.53	0.75	0.55	0.97	0.91	0.91	0.71	0.99
Gen: 19 Ind: 13	72.5	0.58	0.55	0.52	0.51	0.48	0.62	0.5	0.48	0.48	0.81	0.52	0.57	0.55	0.97	0.9	0.59	0.71	0.98
Gen: 19 Ind: 14	75	0.56	0.52	0.7	0.52	0.73	0.46	0.46	0.5	0.49	0.7	0.68	0.56	0.55	0.99	0.51	0.95	0.81	0.61
Gen: 19 Ind: 15	75	0.58	0.55	0.52	0.51	0.48	0.48	0.5	0.48	0.5	0.82	0.52	0.79	0.55	0.64	0.55	0.59	0.71	0.99
Gen: 19 Ind: 16	12.5	0.56	0.48	0.69	0.51	0.49	0.62	0.51	0.51	0.62	0.91	0.54	0.75	0.54	0.64	0.52	0.51	0.92	0.61
Gen: 19 Ind: 17	72.5	0.58	0.55	0.52	0.51	0.48	0.61	0.5	0.48	0.48	0.81	0.52	0.79	0.55	0.97	0.91	0.59	0.71	0.99
Gen: 19 Ind: 18	72.5	0.58	0.48	0.7	0.51	0.7	0.52	0.46	0.53	0.49	0.59	0.52	0.56	0.58	1	0.52	0.95	0.71	0.6
Gen: 19 Ind: 19	15	0.46	0.52	0.7	0.47	0.49	0.48	0.51	0.51	0.62	0.63	0.99	0.75	0.61	0.62	0.9	0.9	0.82	0.6

Closed shutter — Full Opening

Prototype simulation Optimal Solution - Generation 19 Solution18 - Summer case (21 July, 12:00 pm) - Milan Case



The final chapter will include a detailed explanation of these findings (Results)

Fig.143: *Prototype (Mockup) architecture model and tnd the Trinary unit-based as the optimal solution based on the simulation results (down).*

ADAPTIVE

TRIO

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type based on the simulation of the prototype is the ternary unit which has more clarification in the results chapter, Therefore, the trinary unit was used in the case

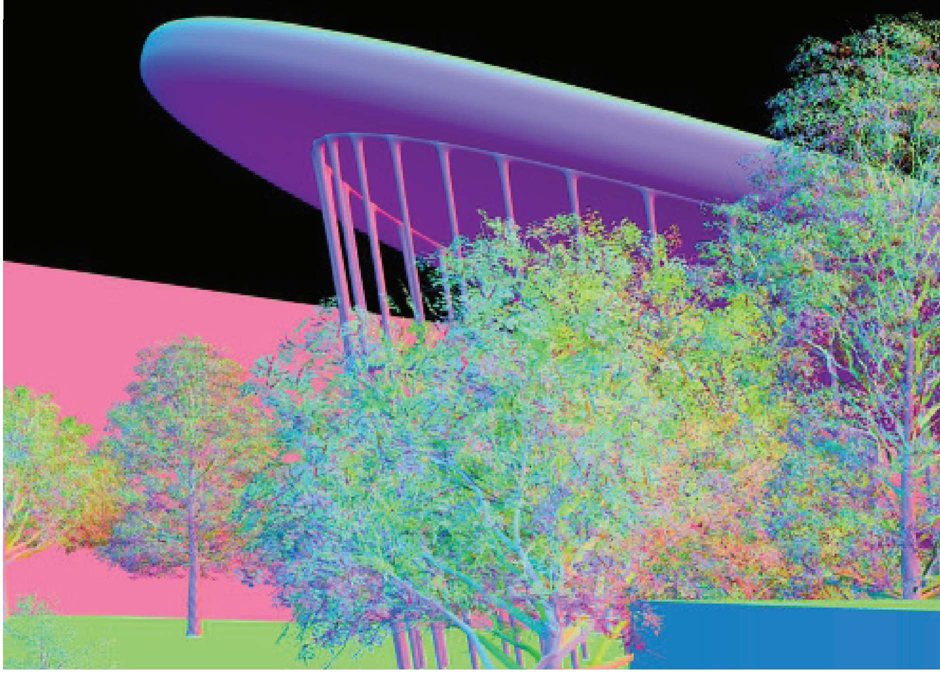
Between chaos and order you find TRIO (the Triad) is a hybrid of several triads, The formation followed the Rössler rule and relied in the envelope on a pattern of improvement that changes over time.

study (Trio).

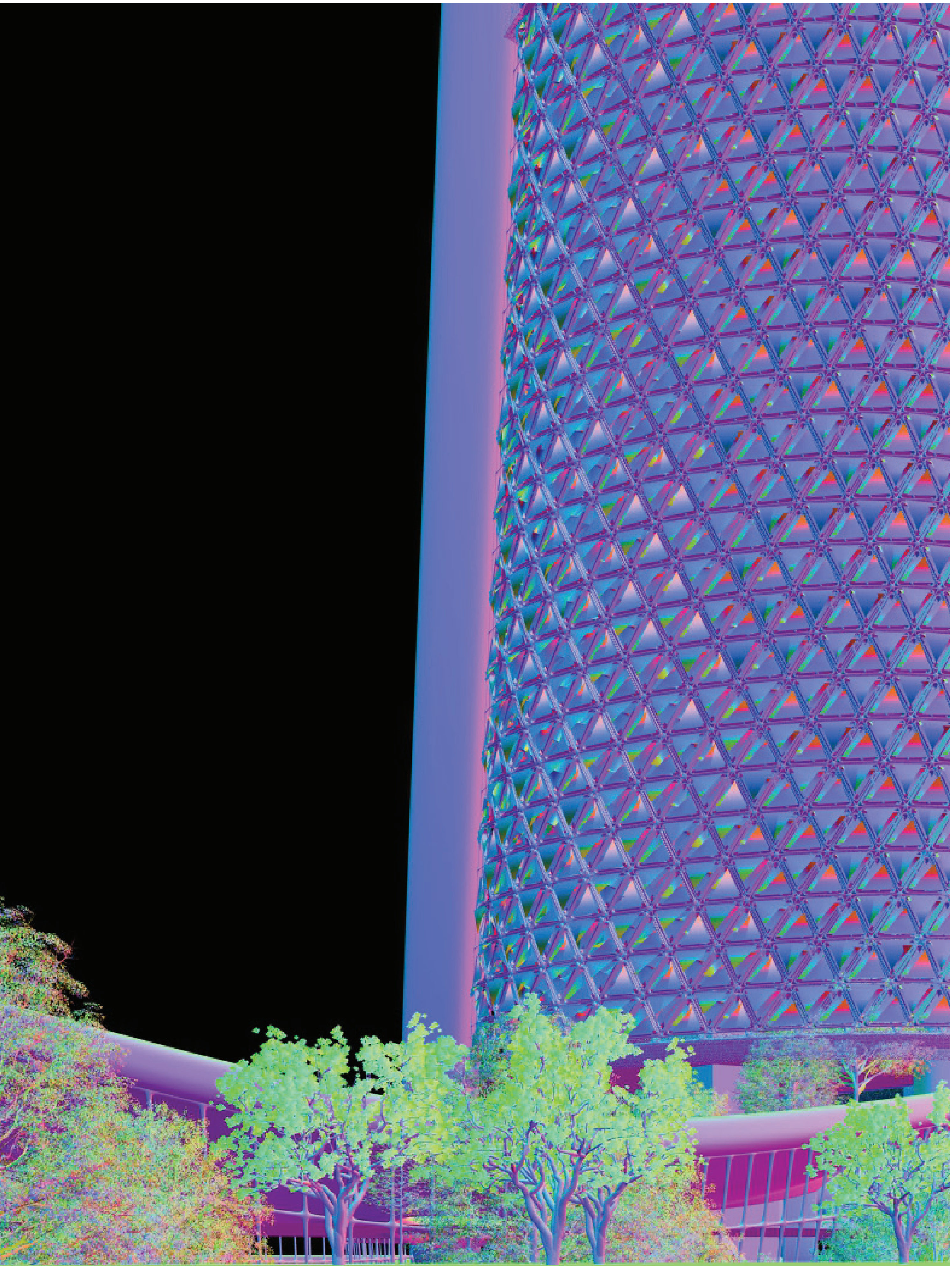
RIO - Cas

Milan’s Skyscraper case study

MILAN SKYLINE



TRIO was included in the shortlist of the SKYHIVE competition by Buildners for its fifth edition in July 2022.



While the methodology can be applied to any site globally, a case study was conducted in the climate zone of northern Italy, where the optimization method was used and interpreted in the context of Milan city. by fixing the thermal transmittance factors (H'T) in the dedicated face and applying an adiabatic in the other parts, then optimizing to adapt the Equivalent solar area (Asol,est), Daylight factor (DF), and radiation levels with their internal parameters to achieve the targeted comfort values.

The case study is a typical commercial-office tower represents a realistic solution that tries to integrate creative ideas with the determinants of reality, it based on a morphological concept beside an environmental solution, as it follows the municipality's rules and adapts to its surrounding t

5•3•1 Objectives

owers depending on the units' optimized features. As the surrounding factors remain in dynamic change, these consequences may be chaotic or systematic, Therefore, the envelope function is to respond to these variations.

According to the UN estimations, by 2022 the world population hit 8 billion. These legions of new generation basically attracted to the cities and city centers and main metropolitans seeking for development and better opportunities causing the rural-urban migration.

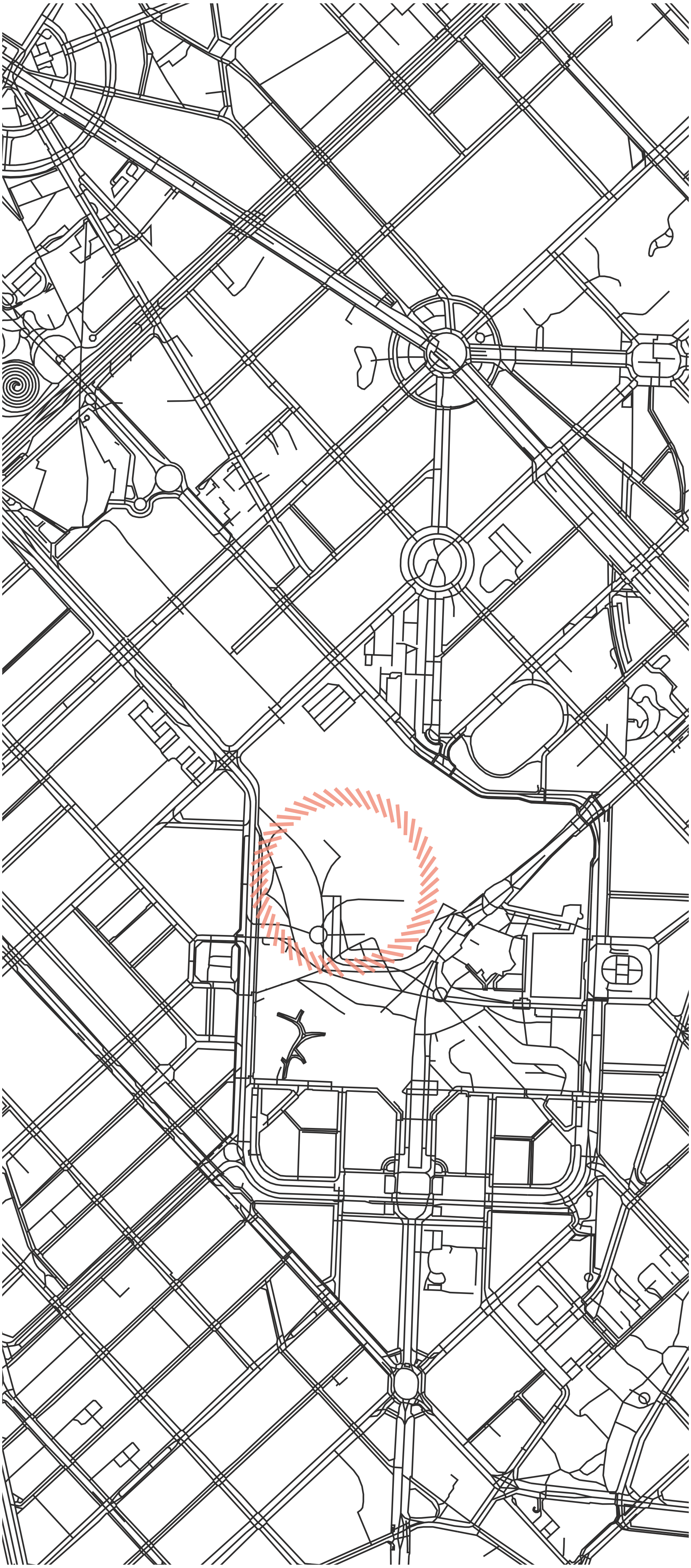
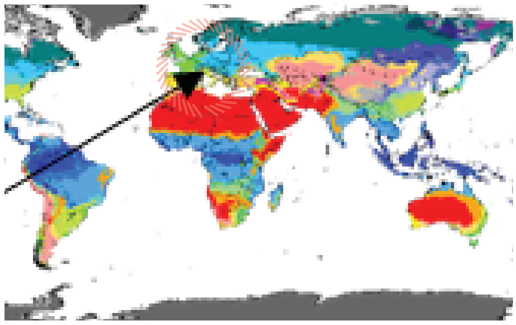


Fig.144: MILANO City (Right), TRE Torri- Fiera / CITYlIFE (Left) Google street maps.

MAIN PROBLEMS



Case study climate zone according to Köppen climate classification.

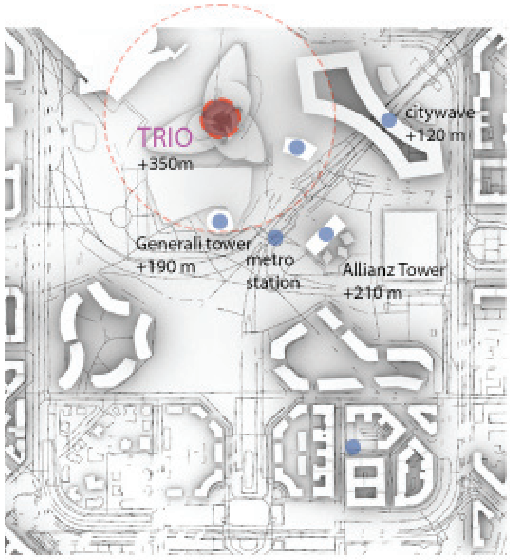
5•3•2 Site Analysis

•CityLife

Milan, as a large metropolitan city, attracted a large population, particularly in the city center, where a complex of Citylife is located, including a hub of skyscrapers, in the northern-west remaining part we have shaped (Adaptive TRIO).

Otherwise, rapid urban development beside many other factors cause the climate change which adds a new challenge for the proposed solution.

TRIO Followed by the three previously mentioned superposition challenges. commercial, residential, administrative, farming .... etc.) activities or whatever a human activity it is which we need to respond and occupy; vertical solutions in heart of urban zones will represent a dominant solution in the coming era.



CITYLIFE MILAN

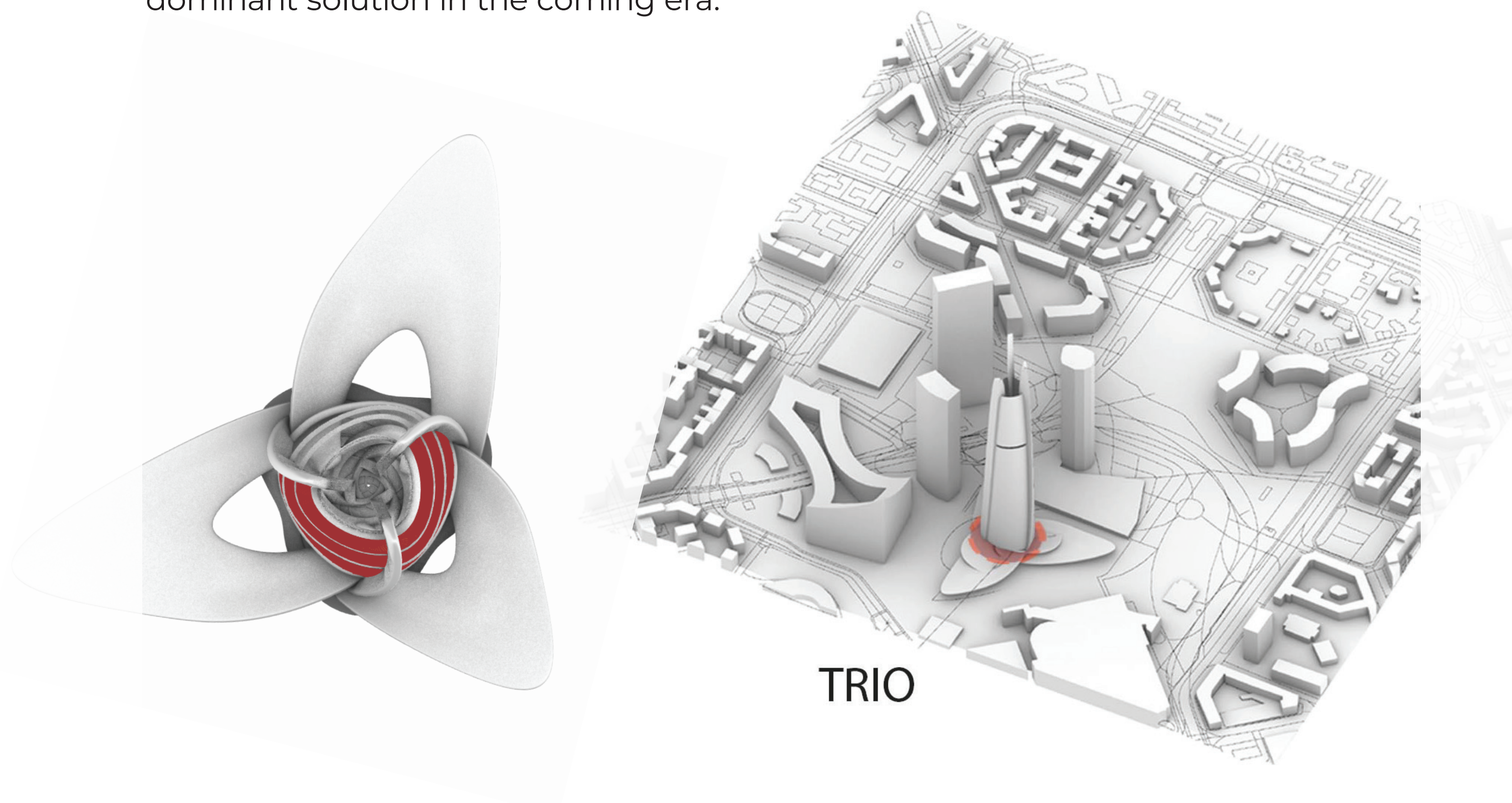


Fig.145: Right: Perspective image of the CityLife site with the integrated Trio tower. Left: Plan view of the tower with the targeted two south-facing facades indicated in red for SHELL software use (to add trinary units).

5•3•3 Concept

ADAPTIVE TRIO is a typical commercial-office tower to represent a realistic solution that tries to integrate creative ideas with the determinants of reality, as it follows the municipality rules and adapts to its surrounding towers.

Surrounding factors remain in dynamic change, Climate Change and its consequences may be chaotic or systematic, or perhaps chaos contains a system, as in the case of the Rössler equations!, TRIO based on a morphological concept beside an environmental solution, mainly as follows:

•Rössler three equations

These differential equations formed the base of the tower shape. Rossler attractor is a system of three nonlinear ordinary differential equations originally studied by Otto Ressler in the 1970s which define a continuous – time dynamical system associated with the fractal properties of the attractor, it is a response to a chaotic-systematic dynamic change and its graphic representation was the base of the concept to define the tower form and its main structural frames, the inspiration leads to the form which continues to influence the environmental solution in order to have a direct response to this dynamic change, both based on ternary aspects.

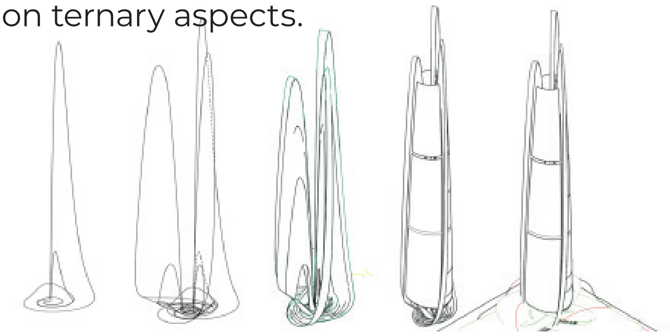


Fig.147: *Mass development through Rossler three differential equations formed the base of the tower shape.*

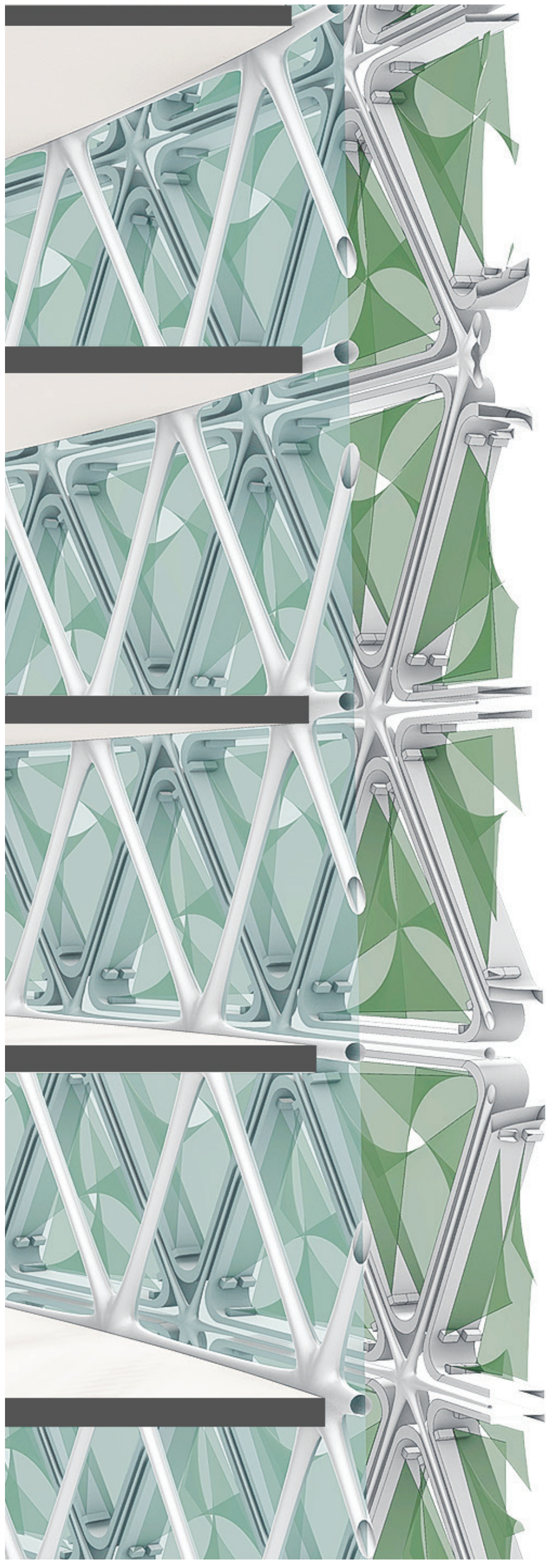
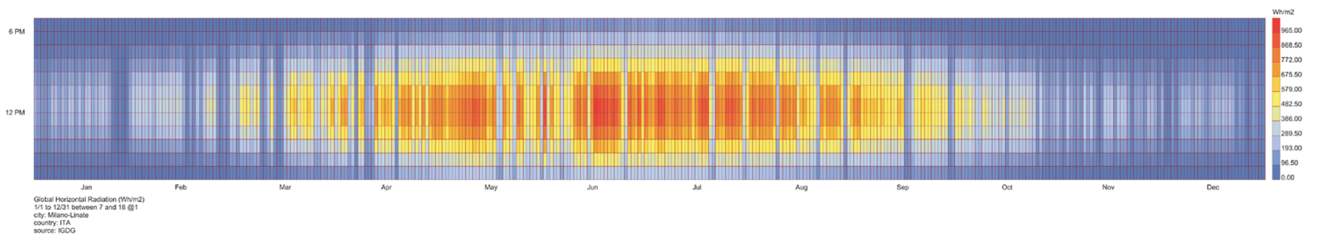
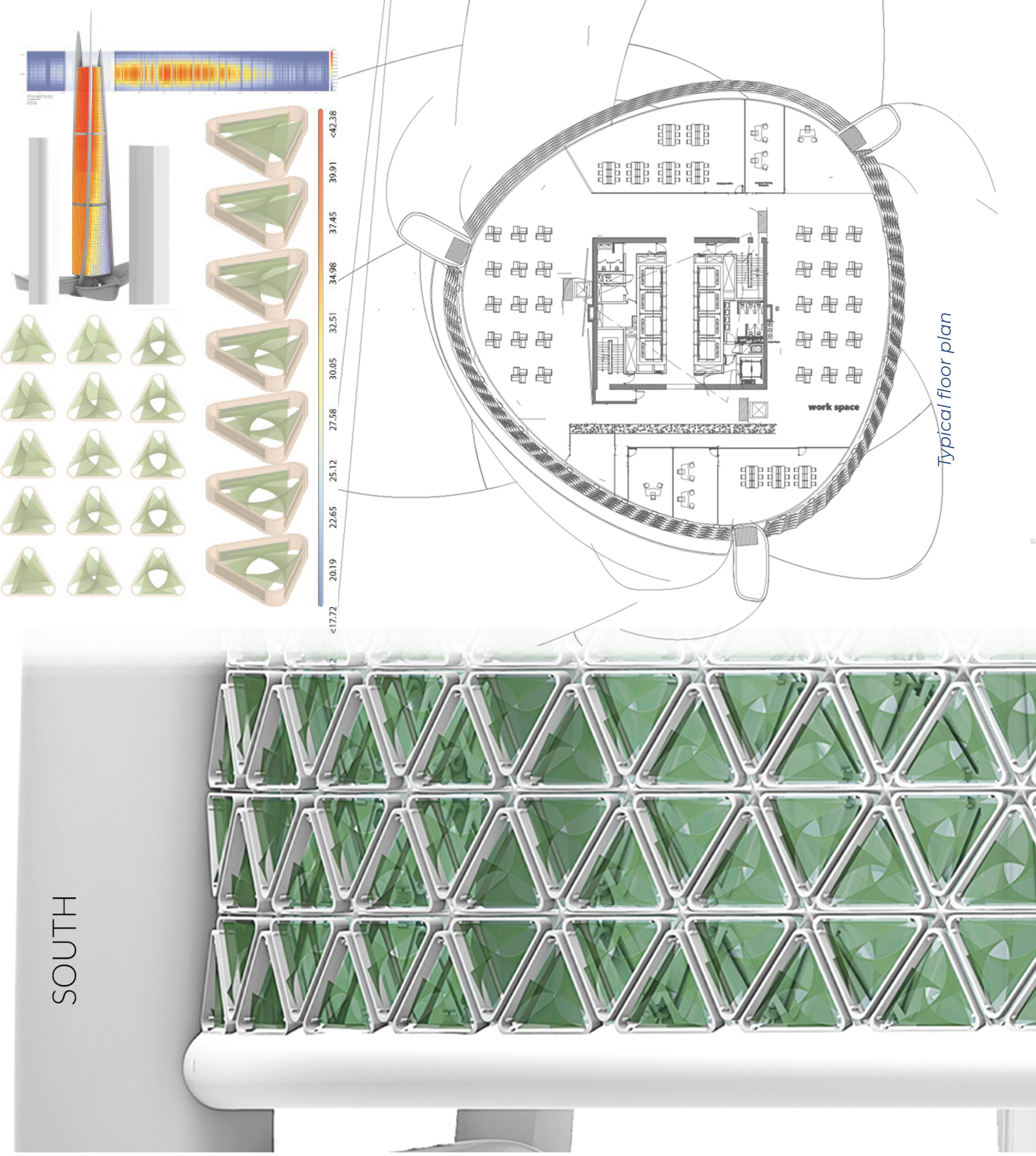


Fig.146: *Perspective wall section in Trio tower (Up), Global Horizontal Radiation diagram in Milan climate zone (Down).*



The adaptive envelope unit with built-in sensors adapting to context factors (Sun radiation, wind, context shading ...etc) is shown in all of its corresponding shapes in a plan view, down there are two perspective views for the unit in its maximum and minimum opening values.



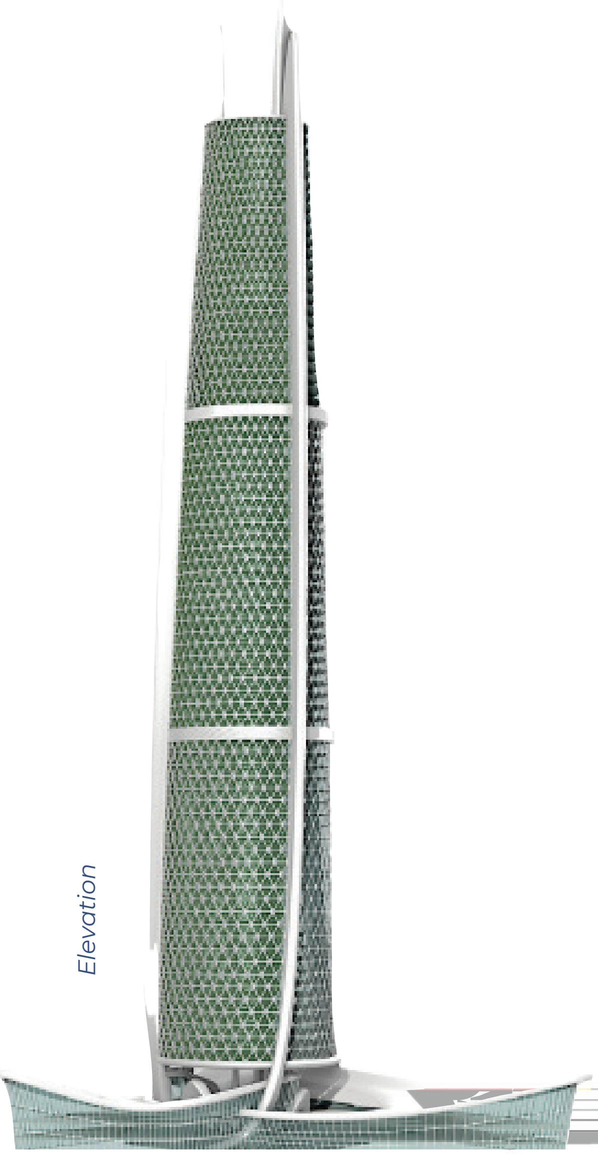
++

ADAPT TO COMFORT - GLAZIN

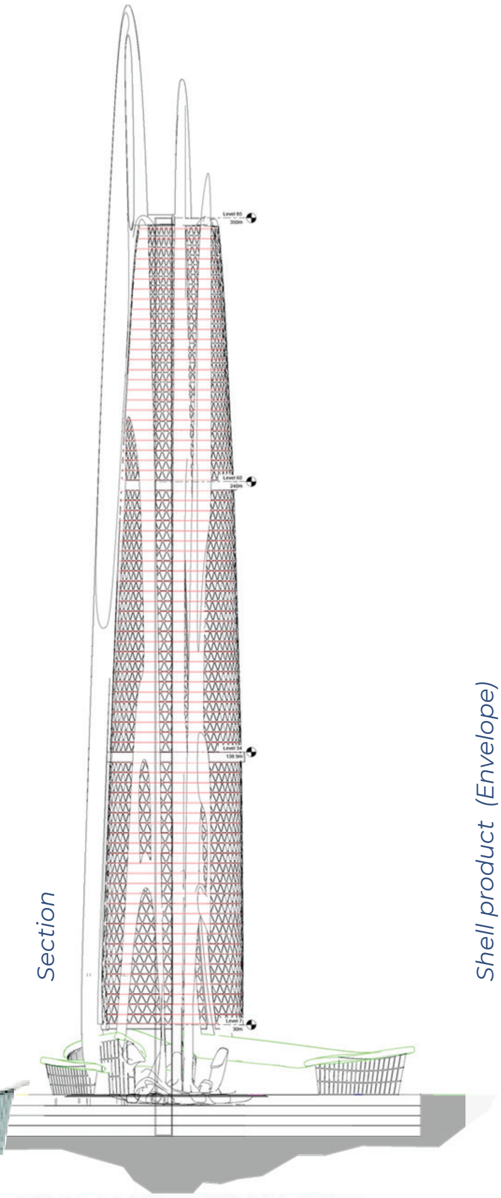
INCREASE

RADIATION

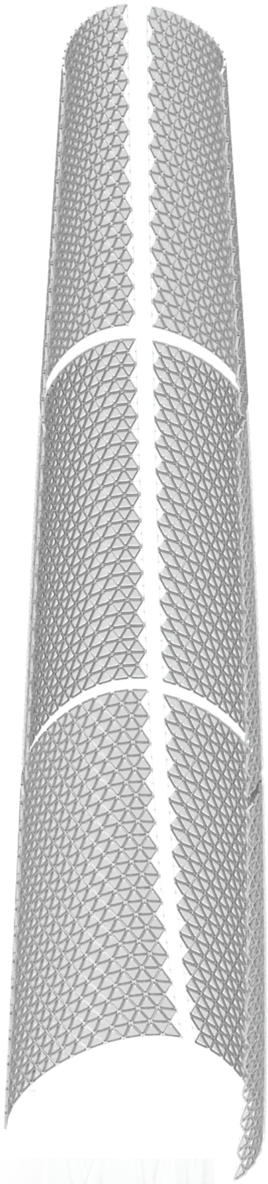
Fig.148: The Trinary unit arrangement over an envelope (fully closed case (UP), respond (10:00 am , 02:00 pm)(Right).



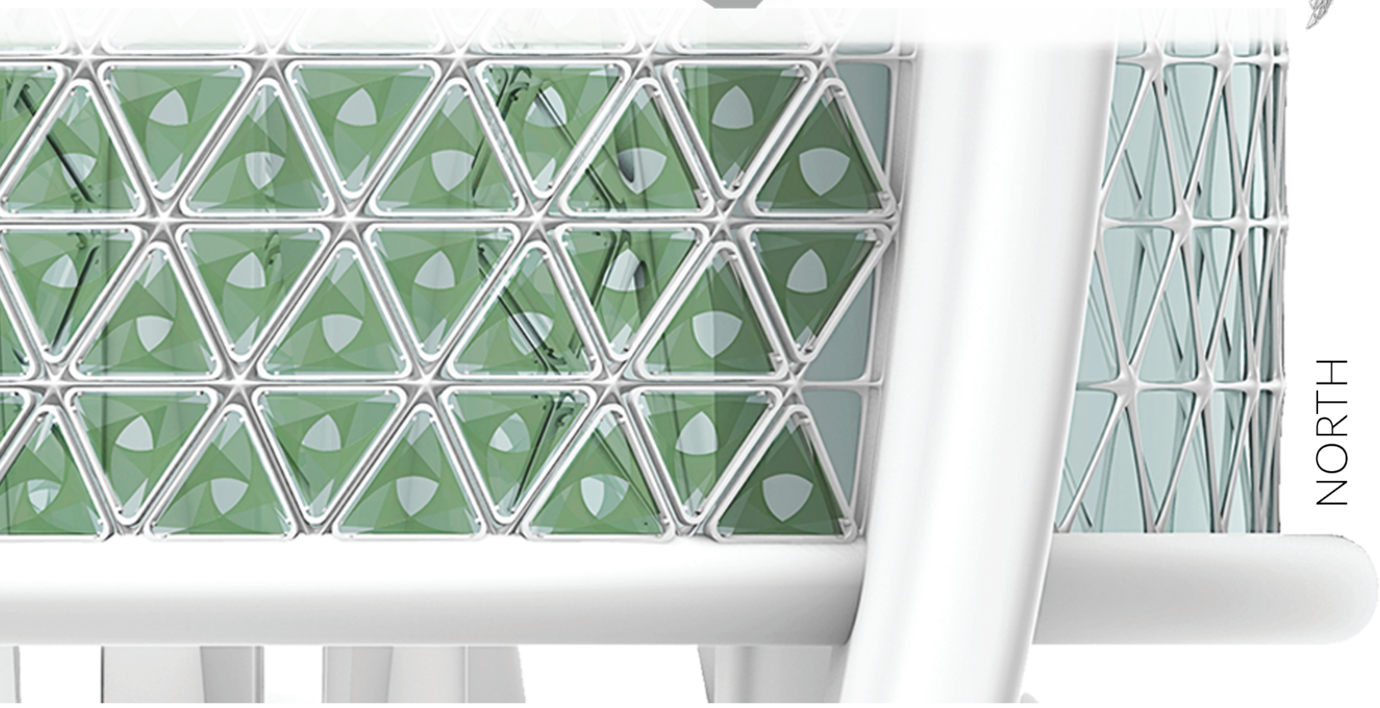
Elevation



Section



Shell product (Envelope)



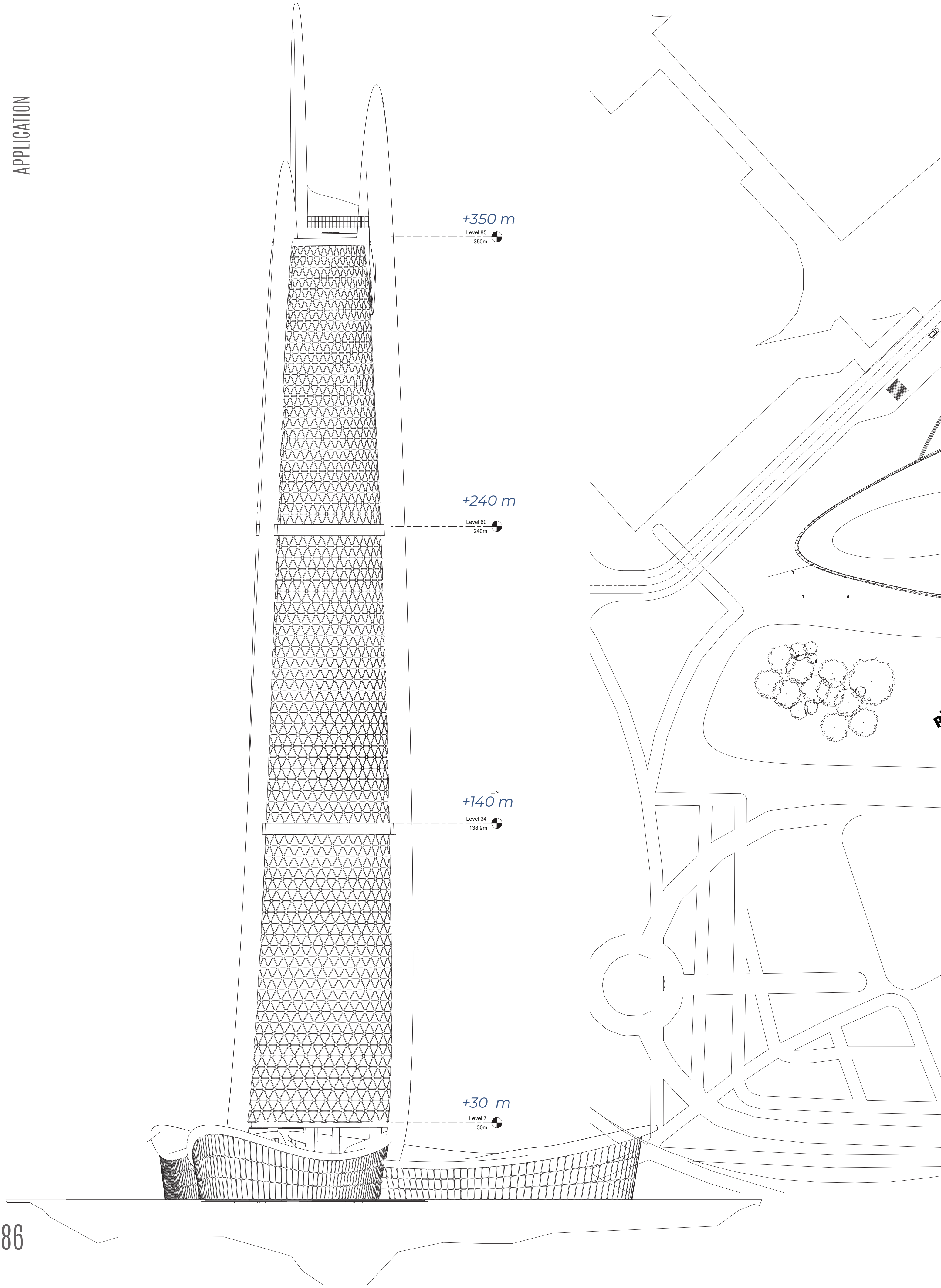
G + KINETIC FACADE

ONLY GLAZING --

DECREASE

and a fully open (Down)). Radiation levels indicated on facade with units'

RADIATION


+350 m
Level 85
350m
+240 m
Level 60
240m
+140 m
Level 34
138.9m
+30 m
Level 7
30m

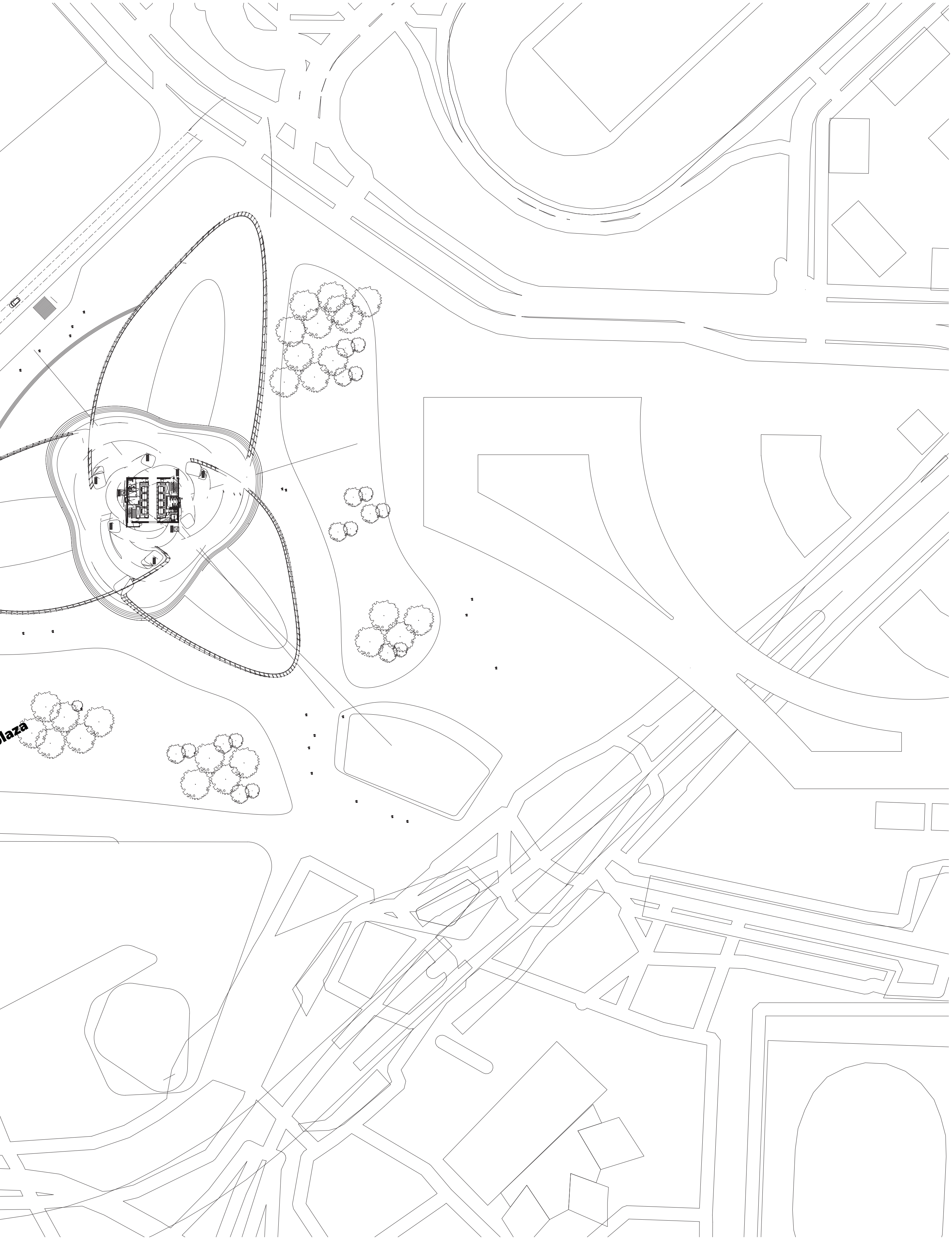


Fig.149: *Trio elevation and Layout in CityLife Milan. Italy.*

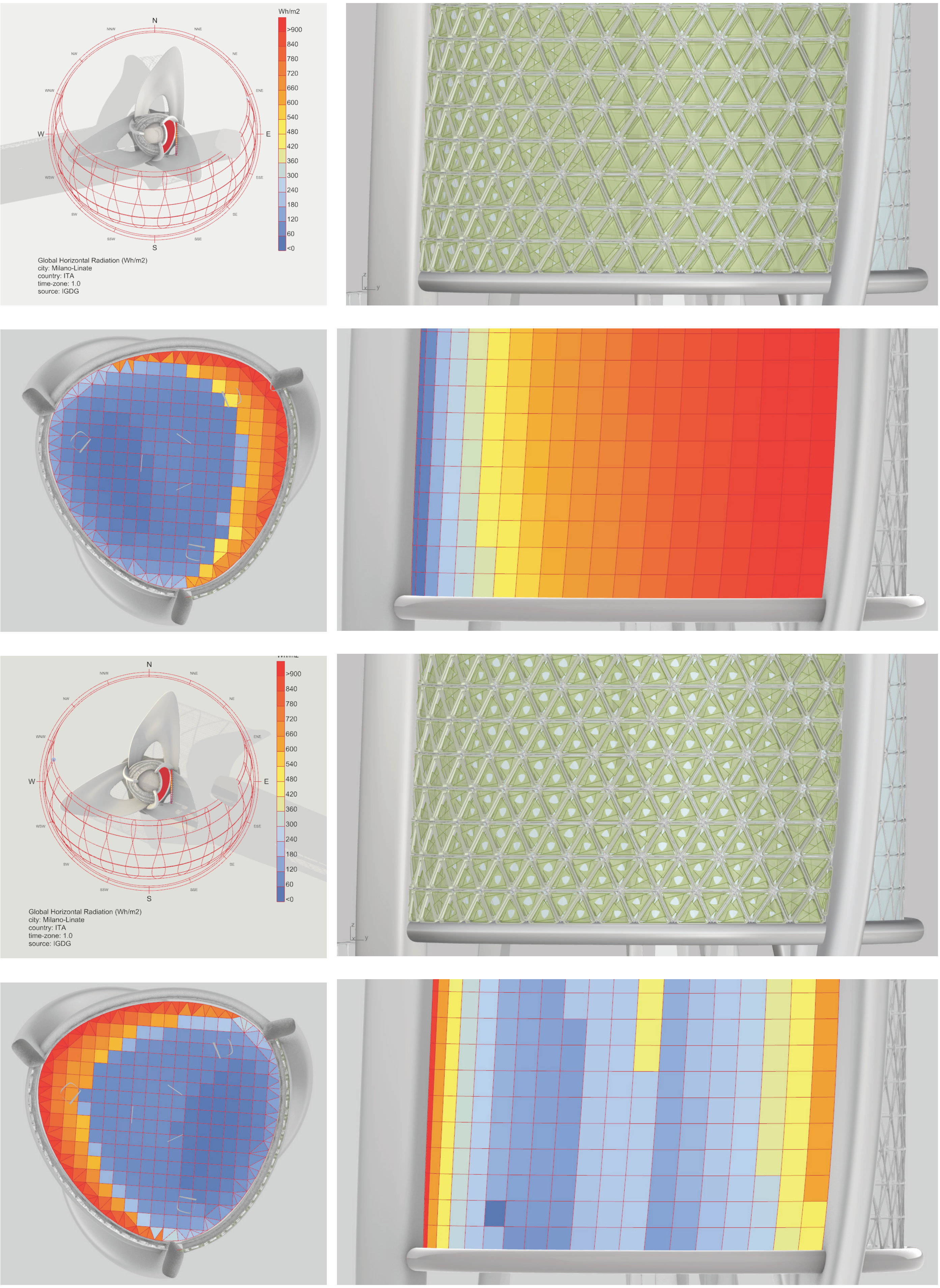
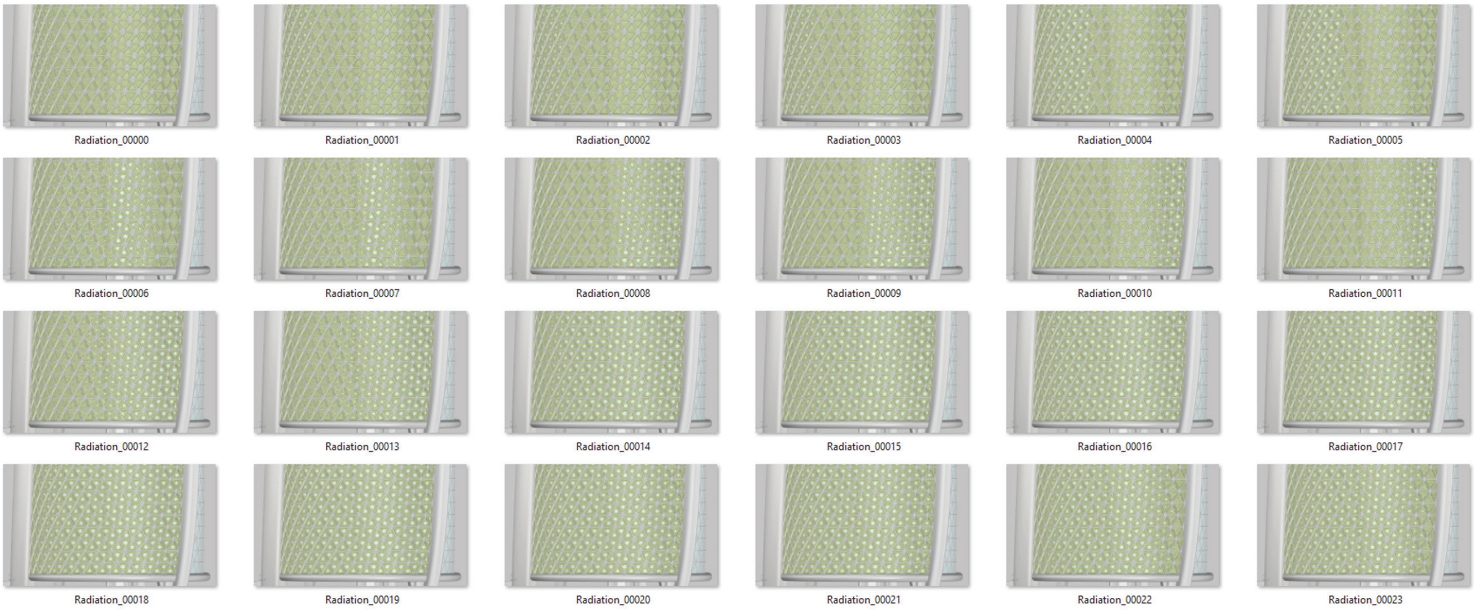
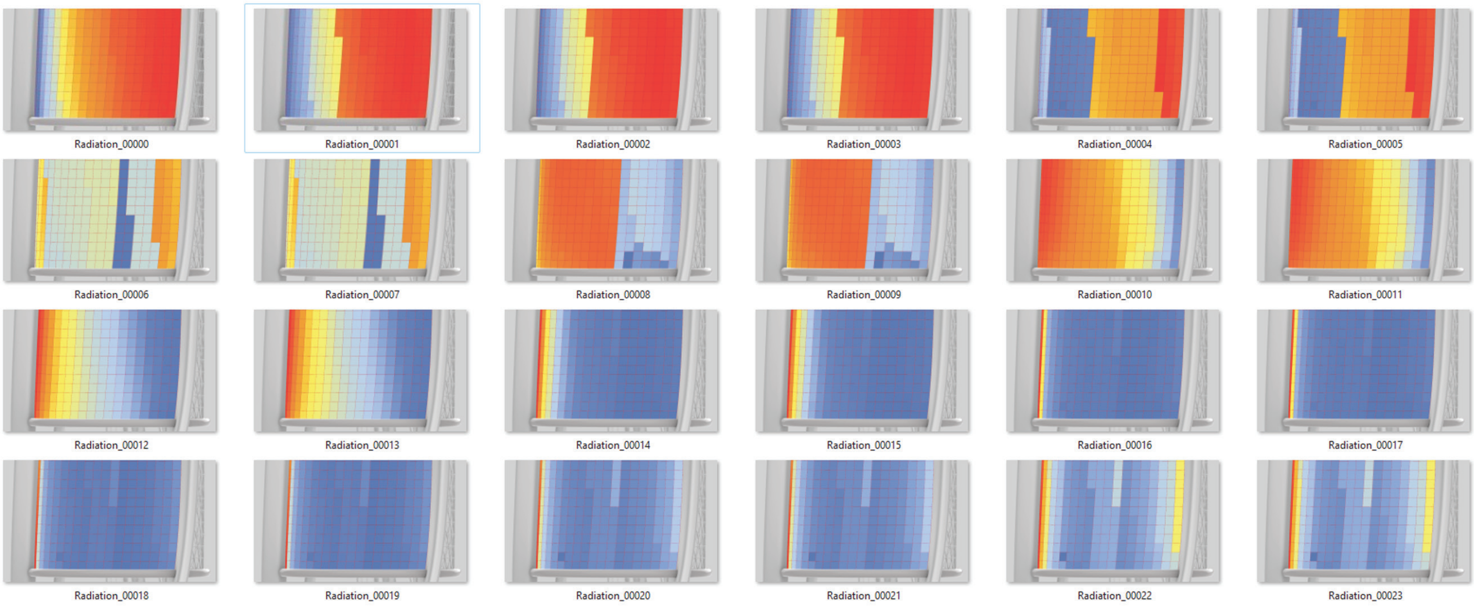


Fig.150: *The Trinary units arrangement over an envelope (fully closed case (UP), and a fully open (Down)). Radiation levels indicated on facade with units' respond (08:00 am , 05:00 pm)(Right).*


Radiation_00000
Radiation_00001
Radiation_00002
Radiation_00003
Radiation_00004
Radiation_00005
Radiation_00006
Radiation_00007
Radiation_00008
Radiation_00009
Radiation_00010
Radiation_00011
Radiation_00012
Radiation_00013
Radiation_00014
Radiation_00015
Radiation_00016
Radiation_00017
Radiation_00018
Radiation_00019
Radiation_00020
Radiation_00021
Radiation_00022
Radiation_00023


Radiation_00000
Radiation_00001
Radiation_00002
Radiation_00003
Radiation_00004
Radiation_00005
Radiation_00006
Radiation_00007
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Radiation_00009
Radiation_00010
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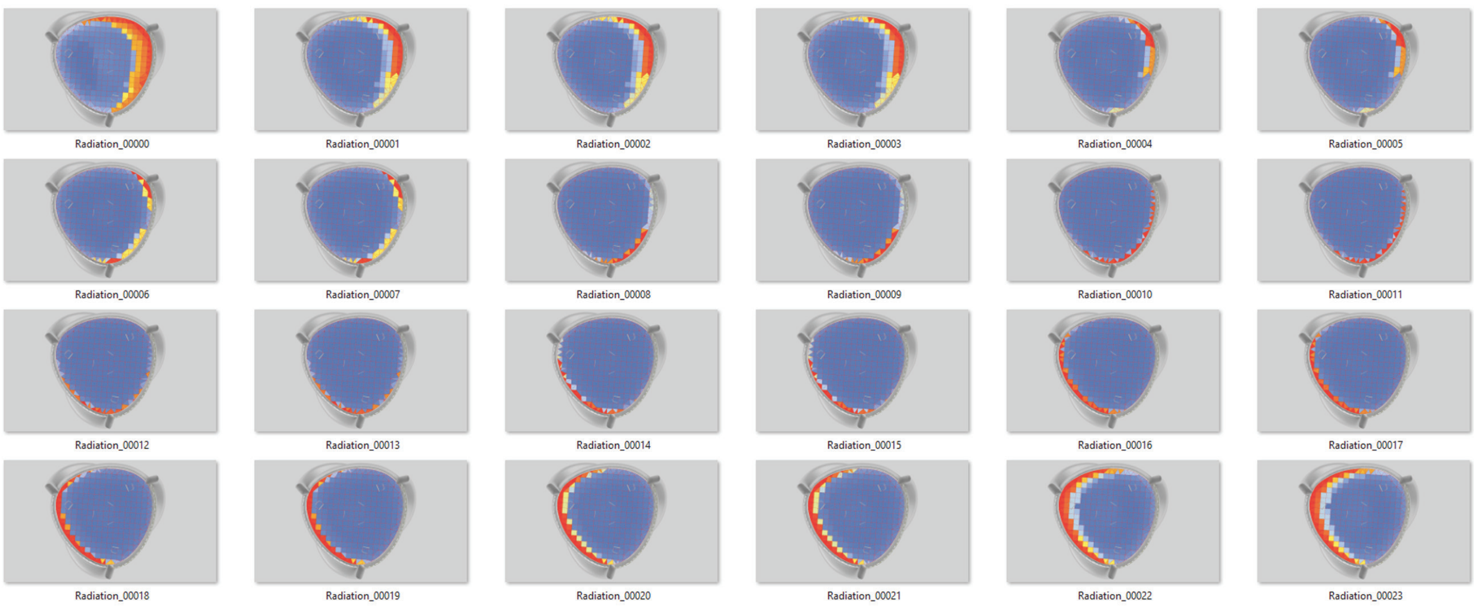
Radiation_00021
Radiation_00022
Radiation_00023


Radiation_00000
Radiation_00001
Radiation_00002
Radiation_00003
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Radiation_00011
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Radiation_00014
Radiation_00015
Radiation_00016
Radiation_00017
Radiation_00018
Radiation_00019
Radiation_00020
Radiation_00021
Radiation_00022
Radiation_00023

Fig.151: *Southern facade with its adaptive panels , chime with Generali tower*


GENERALI

Fig.152: *Birds Eye view shows TRIO tower included in CityLife Milano context*


TRIO
GENERALI
ADAPTIVE
TRIO
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5•4 Life Cycle Assessment

5•4•1 Introduction

The Life Cycle Assessment (LCA) is important for assessing a building's environmental impact since building industry has an enormous impact on the environment and accounts for the world's resource and energy consumption. Global co2 emission for construction and material was 11% in 2017 and is expected to reach 90% by 2050 (Van Gulck, Wastiels, and Steeman 2022).

In order for sustainability to be effectively incorporated into architecture in the modern day, the project's actors must have the same vision, which necessitates a "long-term" approach that focuses on a number of strategic goals, like:

•minimizing the use of natural resources.

•maintaining efficiency for a pre-established period of time (durability).

•ensuring adaptability to changes in use over a period of time (flexibility).

•ensuring the deconstruction and recycling of building components.

Thus It is our responsibility to reduce the impact of embodied carbon energy (Thiebat 2019, xi).

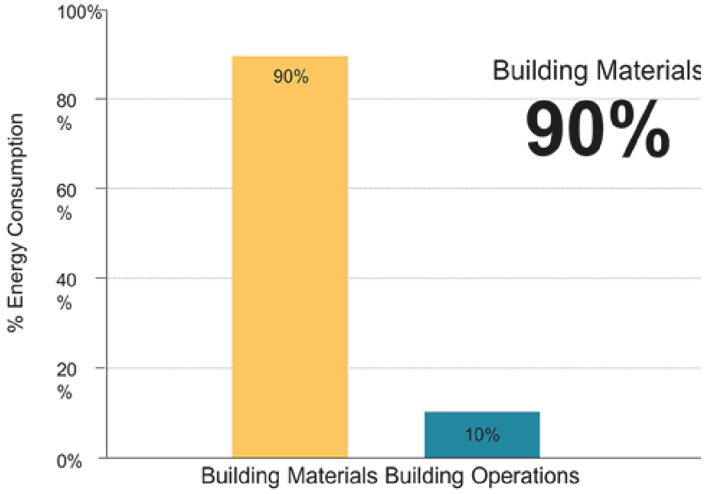


Fig.153: 900 Bilion Sq. Ft. Energy Consumption Footprint 2015-2030 (EIA,2011).

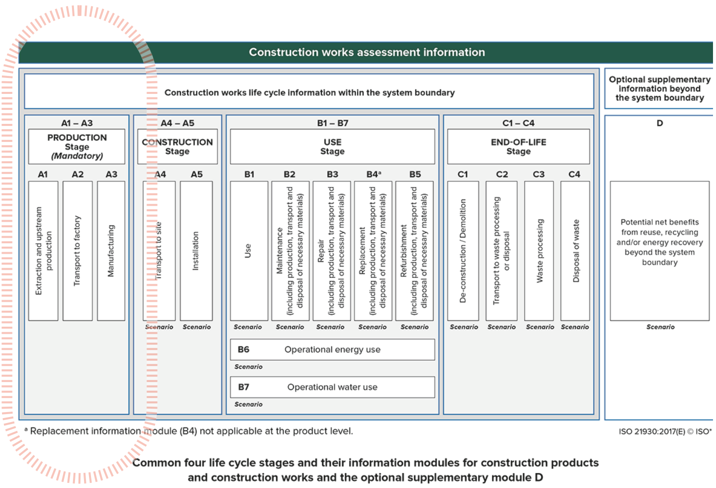


Fig.154: Constrution works life cycle system boundary

Embodied Carbon (EC) is the carbon footprint of a material. It takes into account the volume of greenhouse gases (GHGs) measured from cradle to (factory) gate, or cradle to site (of use), and cradle to grave, which is the most complete boundary condition. This LCA study has been carried out to understand the environmental performance of facade components in terms of the materials being used: steel, Aluminum, and stretched PTFE. The study covers production stage (A1-A2-A3).

The goal of the study is to evaluate the life cycle environmental performance of façade for -TRIO- a skyscraper in Milano and determine negative effects on the environment.

5•4•2 Environmental APPROACH

•Environmental Labels:

There are three types of Environmental Labels (Figure 155), Type III environmental declarations for specific aspects of products using a life-cycle approach.

Fig.155: *Environmental labels (Palumbo e Thiebat, 2019).*

Buildings are made up of various parts, each one with a wide variety of materials and specifications: the Density [kg/m3], Weight [kg/m2], Thermal conductivity [W/mK], and EC [kg CO2/kg].

There are many source data and websites for environmental labels provided by manifactures and Eco platforms like:

ECO Platform Home - Eco Platform en (eco-platform.org)

EPD EPD International (environdec.com)

ICE (Inventory of Carbon & Energy) (circularecology.com)

**** Note: The Embodied carbon energy for materials used in the LCA study in the next section is derived from these sources.***

•Design for disassembly:

It is a holistic design approach where the intention is to make any given product easy to disassemble into all its individual components. The approach is a cornerstone of the circular economy because it allows the different components to fit into a closed material cycle, where they can be reused, reassembled and recycled to new products of similar or higher quality.

Positive side effects:

The possible positive side effects from designing the building for disassembly can be summed up to (Danish Env. Protection Agency 2016, 35):

— Quicker and simpler construction process.

— Optimized operation and maintenance.

— Less waste.

— Optimized upcycling, recycling, and reuse.

— Released pressure on resource scarcity.

— Buildings as material banks.

Because products are easier to produce, repair, maintain and upcycle, less waste is produced. This waste reduction helps ease the demand for new raw materials and the resource scarcity the industries are facing.

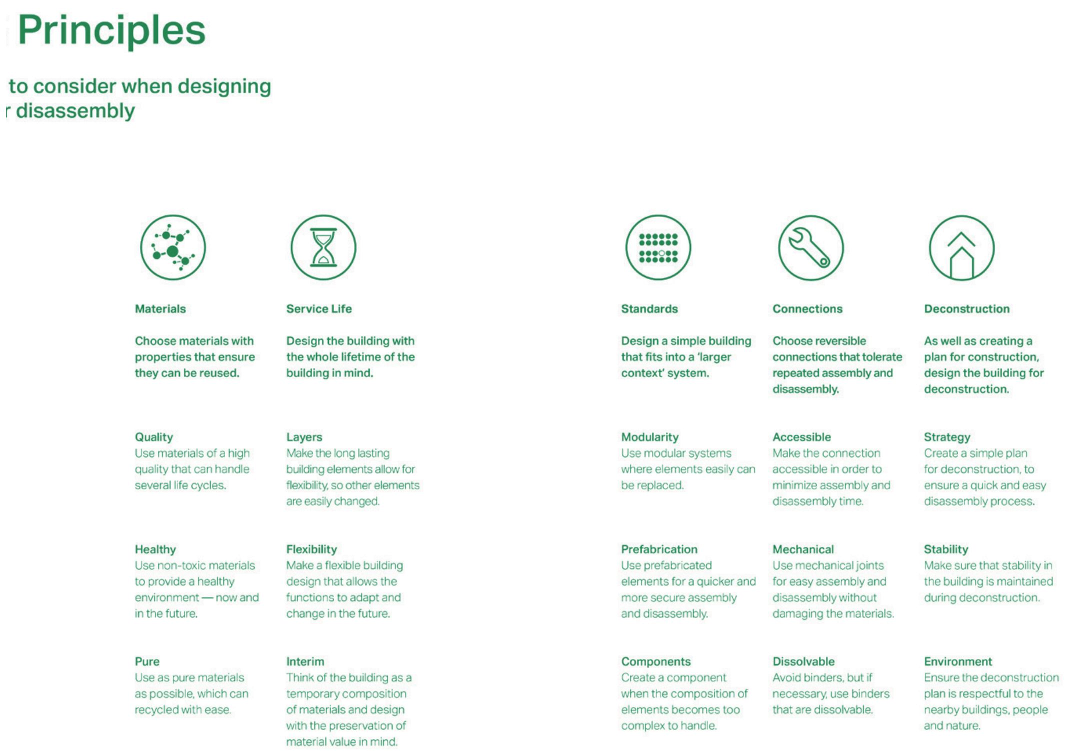


Fig.156: Principles when designing for disassembly (Danish Env. Protection Agency 2016, 39)

“Today buildings are statically welded, glued and cast together. By designing for disassembly future buildings will be flexible and function as material banks”

Kasper Guldager Jensen Architect, Senior Partner 3XN and Director GXN

Example:

KieranTimberlake Cellophane House MoMA as an example House was assembled like a car: The whole construction was broken down into integrated assemblies , called “chunks,” that were fabricated off site, then delivered via trailers to the site and stacked on top of each other with a crane. 80% of the construction was completed in six days The final experiment at MoMA was its disassembly . Virtually no waste was generated, and 100 % of the energy embodied in materials was recovered. Trio façade envelope components assembling together with a screw fixation system avoiding any adhisive method in order to have an ability to reuse all components and avoid wasting materials.

Fig.157: KieranTimberlake Cellophane House MoMA

5•4•3 Studied Features

•LCA for TRIO envelope

The feature to be explored after the features of the proposed unit in chapter 3 were studied was the LCA, which will be more relevant to the case study of TRIO presented in the last section.

•Algorithmic & Evolutionary solver technique

The Embodied carbon energy was Studied for a (TRIO) tower in Milano. Focused only on the envelope of the tower and calculated the Total embodied carbon energy per surface m2, not GFA. also (Table 10) provides the material specs used in LCA calculations for TRIO envelope.

Algorithm script (Figure 160) through the grasshopper plugin utilizing Galapagos evolutionary solver used for calculate the total embodied carbon energy per façade square meter. By implementing an excel file comprising of family materials and all specifications (Density, weight, Thermal conducivity, and Embodied Carbon).

Grasshopper allows to Extract the data from excel and link it with the quantities of all materials that derived from model to calculate the Embodied Carbon energy for each material and sum all of results then divided by the area of the facade, and through Galapagos evolutionary solver an optimum solution can be derived by minimize the total Embodied Carbon Energy..

It gives the result of

TOTAL EMBODIED CARBON ENERGY PER FAÇADE m2 = **374 KG CO^2/m^2**

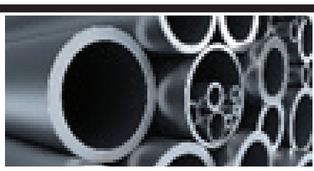
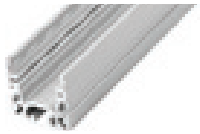
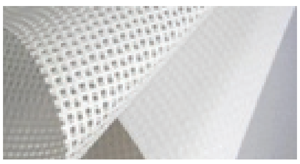
Component	*Image*	*Material.*	*Reason*	
Structure System		Stainless steel	Corrosion resistance	
Framework (Cadre)		Aluminum	Corrosion resistance	
Rails		Aluminum	Corrosion resistance	
Wires (Cables)		Steel Cable	Corrosion resistance	
Curtains		PTFE Poly-tetra- fluoro-ethylene	Weather resistance	

Fig.158: *(Table 10) Materials used on the proposed unites installed on Trio project facades*

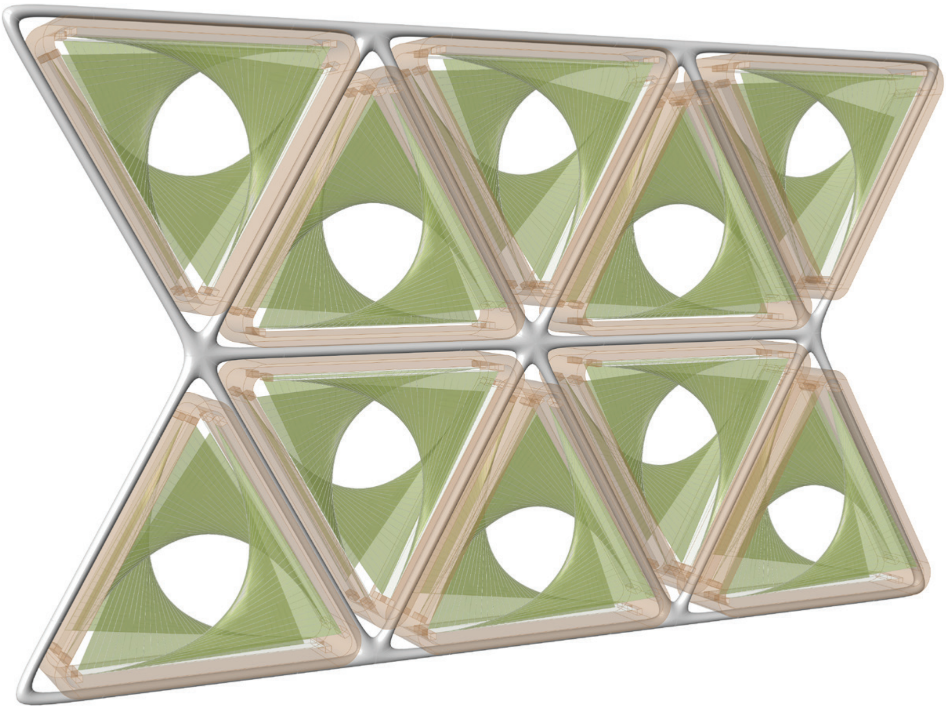


Fig.159: *Sample of Trio envelope components that used inGrasshopper calculations.*

	Assembly	*Reuse*	*Recycle*	*EC kgco2/kg*
	Screwed	Yes	Yes	**1.55**
	Screwed	Yes	Yes	**5.58**
	Screwed	Yes	Yes	**5.58**
	Screwed	Yes	Yes	**2.27**
	Stitched between wires	Yes	Yes	**2.54**

02

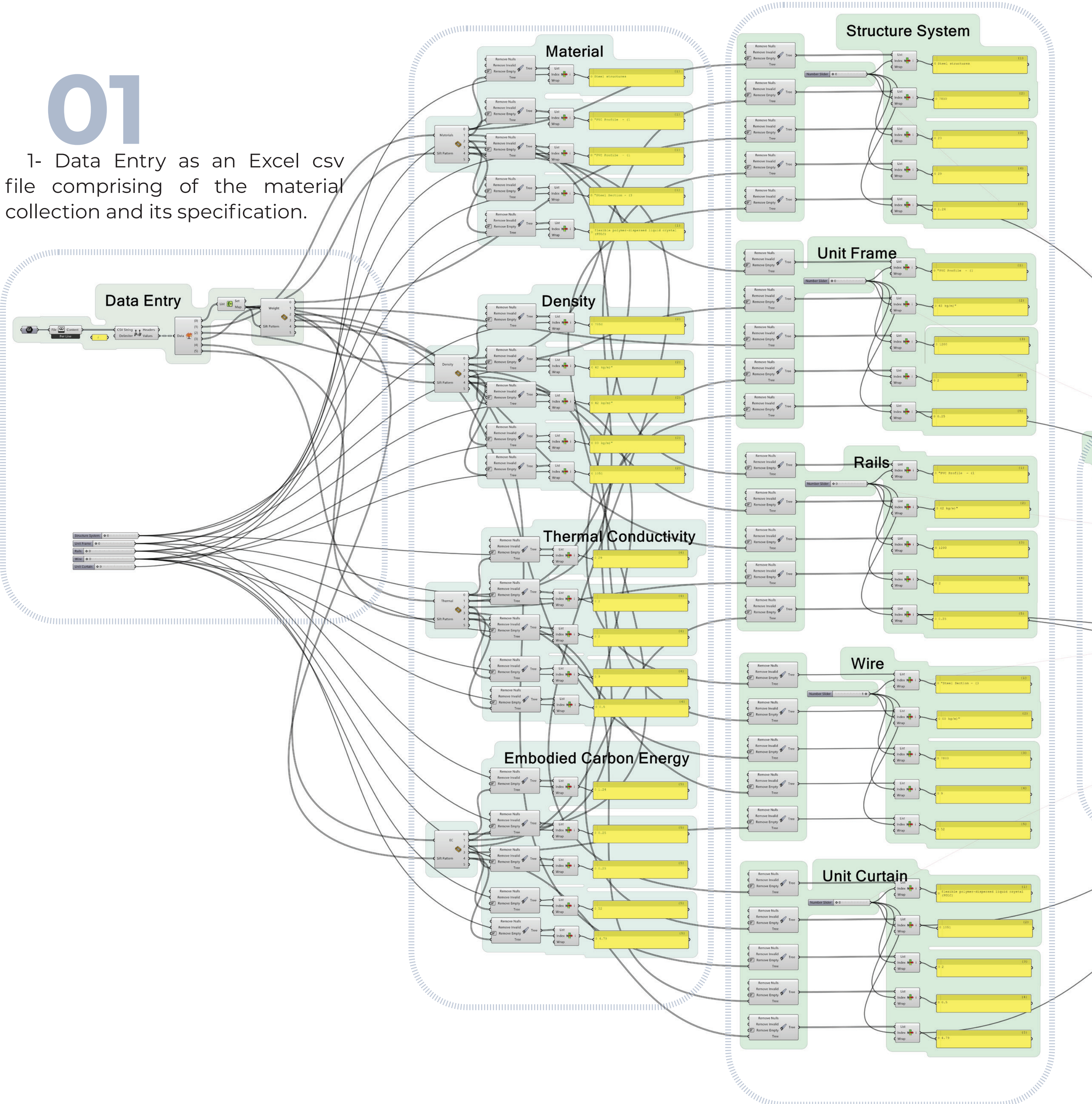
2. Extract the material specification in Data Entry into different categories

03

3. Extract the family material in Data Entry into different categories

01

1- Data Entry as an Excel csv file comprising of the material collection and its specification.



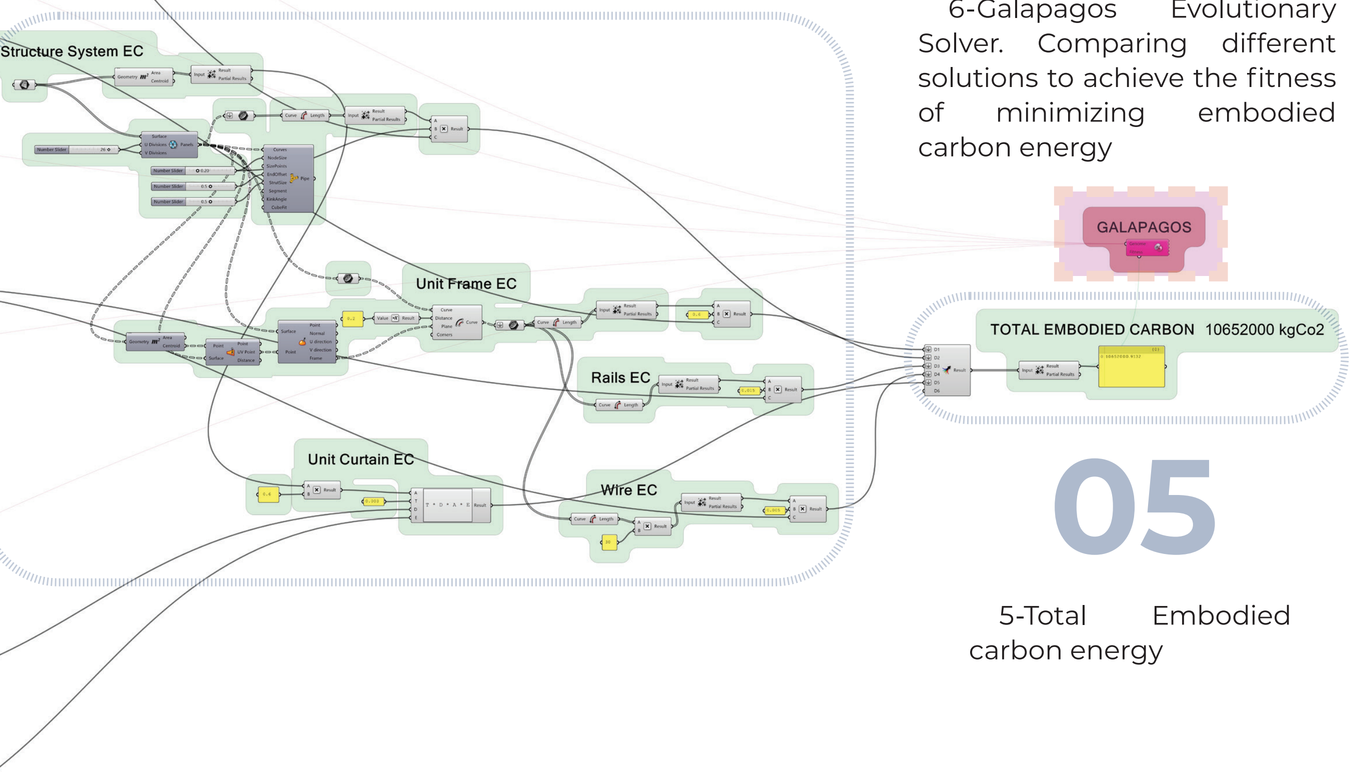
LCA

04

4-Calculate the embodied carbon energy for each material

06

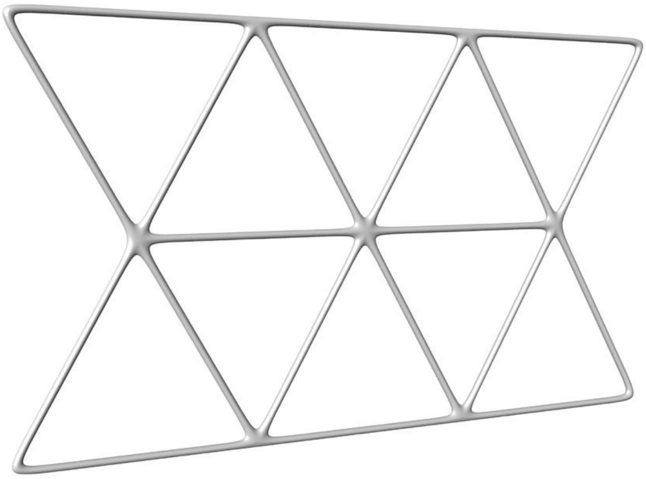
6-Galapagos Evolutionary Solver. Comparing different solutions to achieve the fitness of minimizing embodied carbon energy



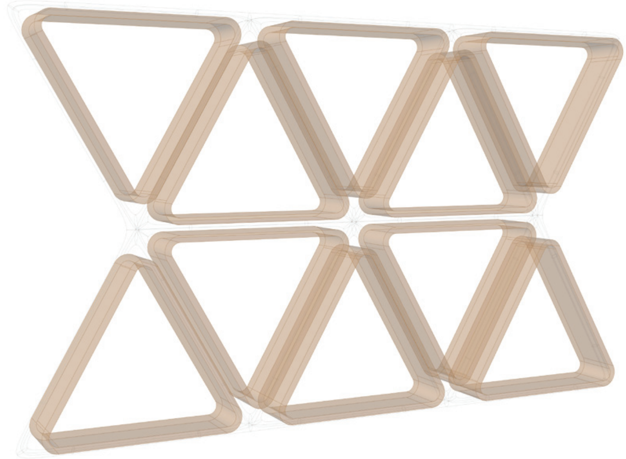
05

5-Total Embodied carbon energy

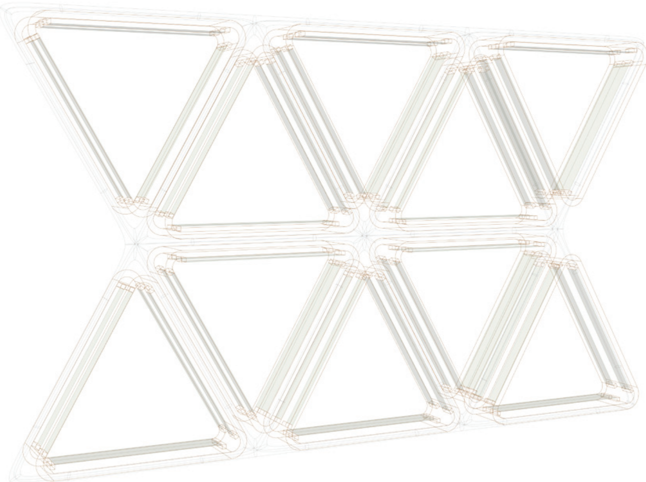
Fig.160: *Life Cycle Assessment definition on Grasshopper ecosystem.*



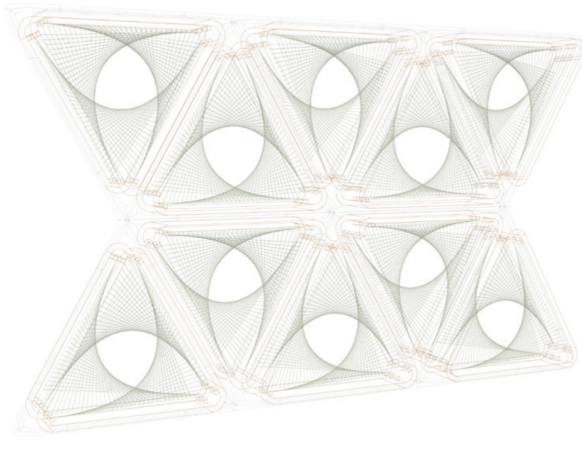
Sub- Structure: Stainless steel Section



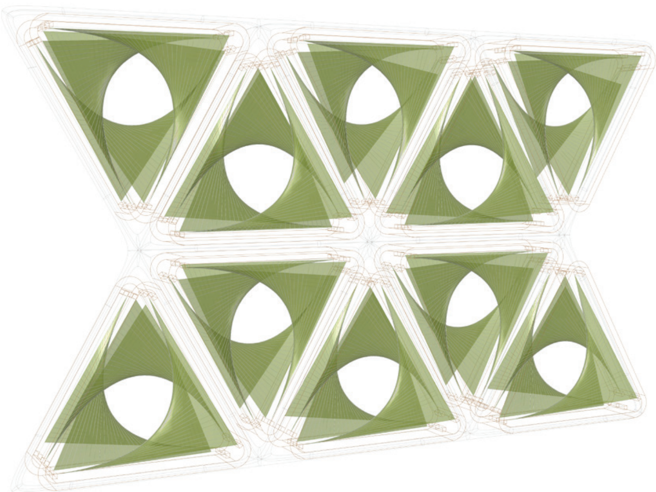
Aluminum Profile (Unit Frames): Aluminum made by connect 3 profiles together.



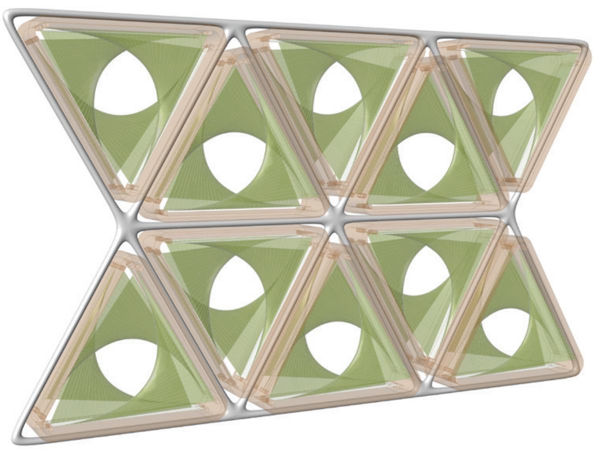
Aluminum Profile (Unit Rails): Aluminum.



Stainless Steel Wire (Unit Cables): Stainless steel.



PTFE Polytetrafluoroethylene (Unit Curtains)



Full Components together (Envelope sample)

Fig.161: *Seperated envelope components used in Grasshopper calculations*

Embodied Carbon Energy Calculations Per Surface m²

Main Structure: Stainless steel Section

Diameter: 20 mm

thickness: 5 mm

weight: 1.85 kg/m

EC: 1.55 kgco2/kg

Total length = 26015 m

Total weight = 26015 *1.85 = 48128 kg

Total Main Structure Stainless steel EC = 48128 *1.55 = 74598 kgco2

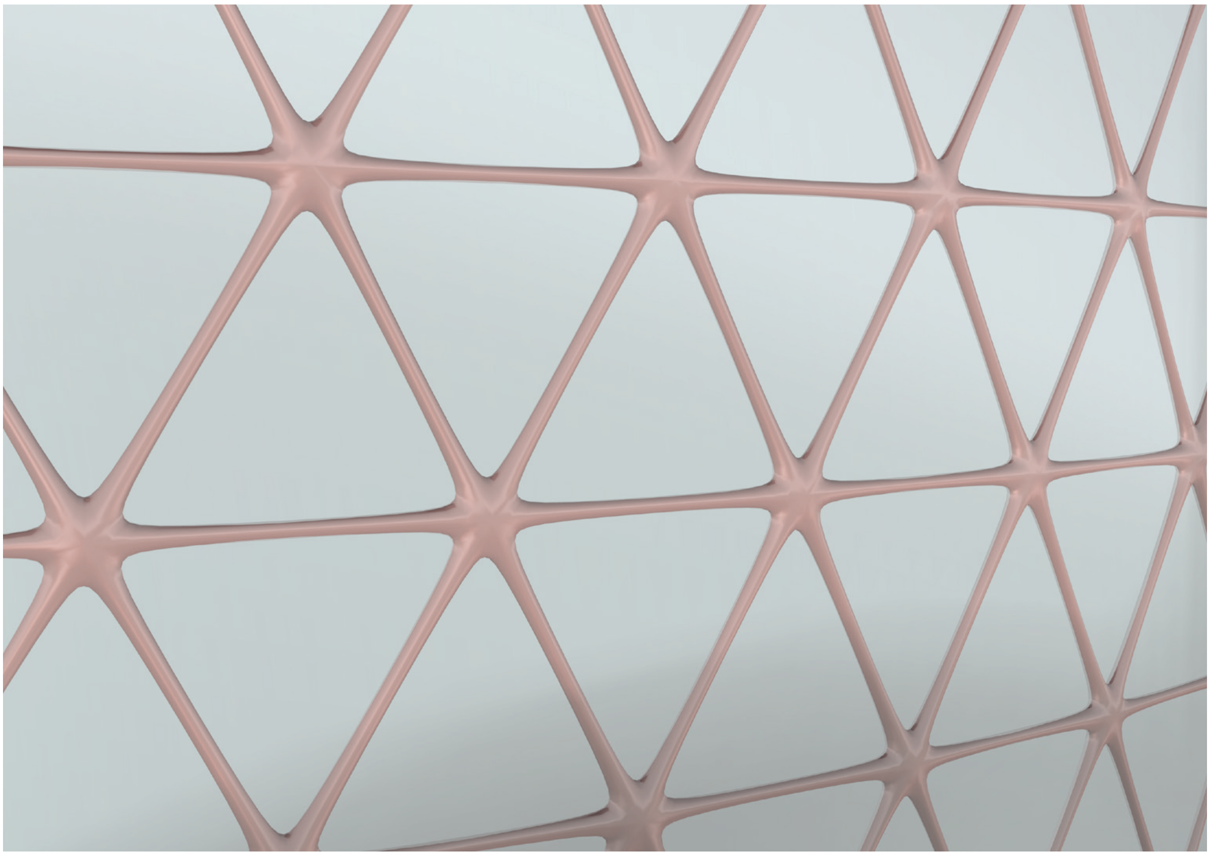


Fig.162: Stainless steel Main Structure parts installed on TRIO facade.

Connection between Structure and Sub- Structure:

Stainless steel Section

Diameter: 16 mm

thickness: 3.2 mm

weight: 1 kg/m

EC: 1.55 kgco2/kg

Total length = 2979 m

Total weight = 2979 *1 = 2979 kg

Total Connection Stainless steel EC = 2979 *1.55 = 4618 kgco2

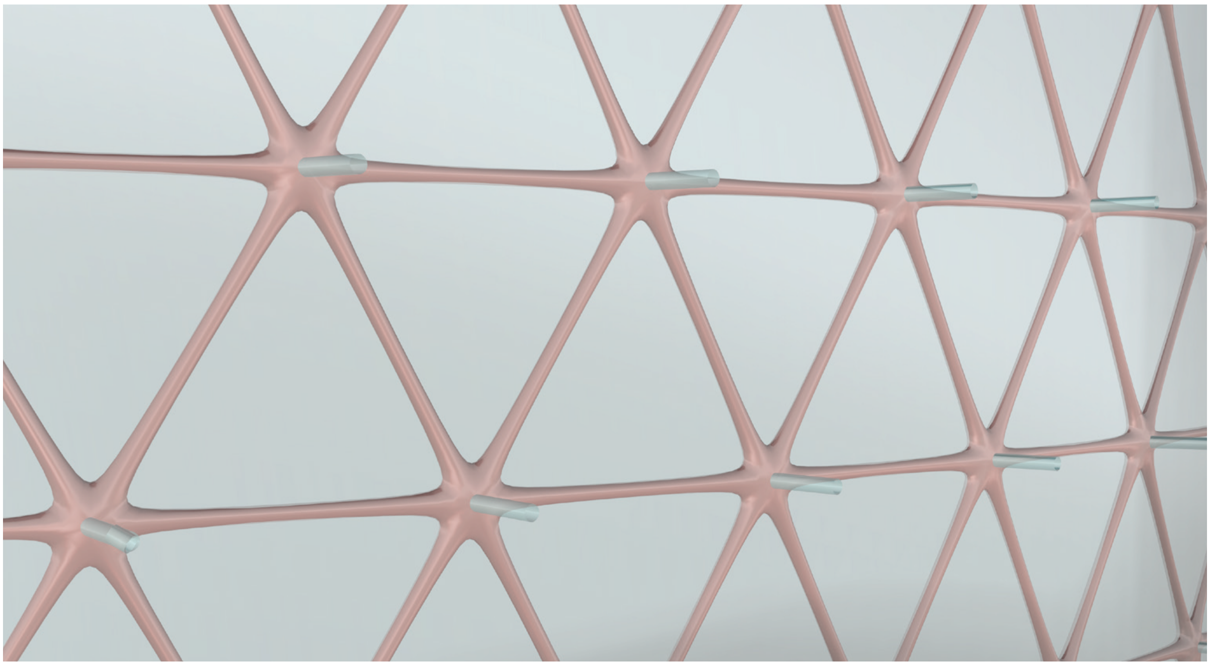


Fig.163: Connection between Structure and Sub- Structure (Stainless steel) installed on TRIO 's facade..

Sub-- Structure: Stainless steel Section

Diameter: 16 mm

thickness: 3.2 mm

weight: 1 kg/m

EC: 1.55 kgco2/kg

Total length = 26557 m

Total weight = 26557 *1 = 26557 kg

Total Sub- Structure Stainless steel EC = 26557 *1.55 = 41163 kgco2

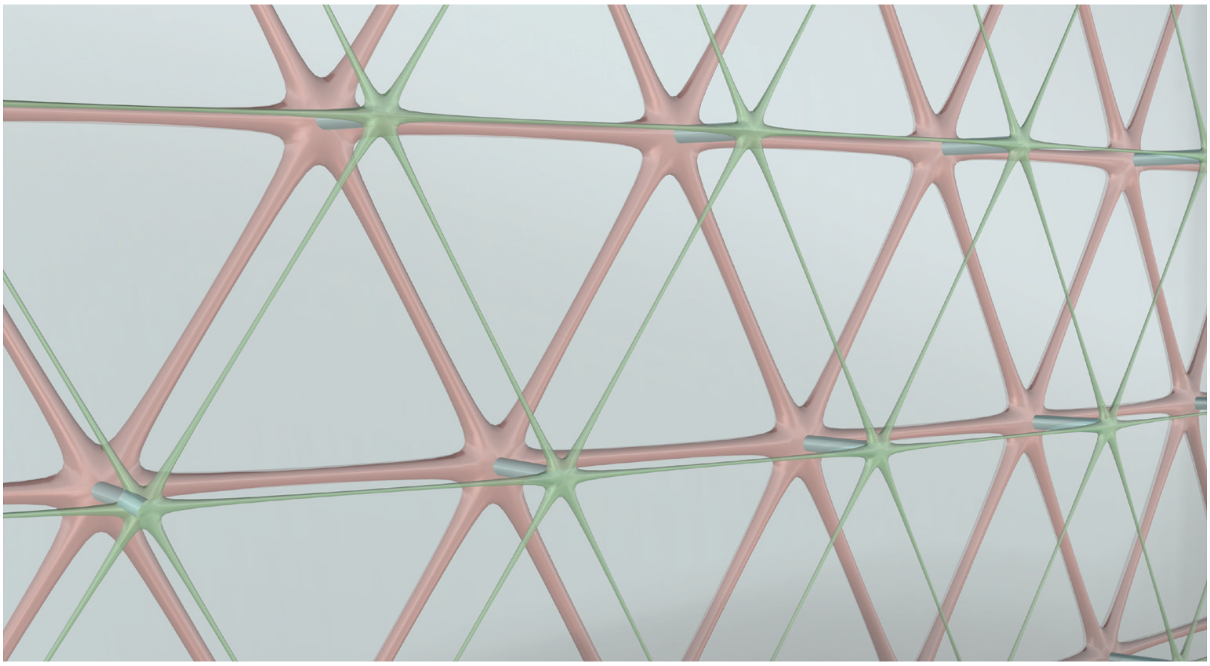


Fig.164: *Stainless steel Sub- Structure components installed on TRIO's facade.*

Aluminum Profile (Unit Frames):

Aluminum made by connect 3 profiles together.

Length: 240 mm

Width: 60 mm

weight: 12.2 kg/m

EC: 5.58 kgco2/kg

Total length = 123119 m

Total weight = 123119 *12.2 = 1502100 kg

Total Frames Aluminum Profile EC = 1502100 *5.58 = 8381500 kgco2

Aluminum Profile (Unit Rails):

Aluminum.

Length: 160 mm

Width: 20 mm

weight: 3.77 kg/m

EC: 5.58 kgco2/kg

Total length = 66991 m

Total weight = 66991 *3.77 = 252556 kg

Total Rails Aluminum Profile EC = 252556 *5.58 = 1409300 kgco2

Stainless Steel Wire (Unit Cables):

Stainless steel. Diameter: 8 mm

weight: 0.3 kg/m

EC: 2.27 kgco2/kg

Total length = 1057500 m

Total weight = 1057500 *0.3 = 317243 kg

Total Wire Stainless Steel EC = 317243 *2.27 = 720141 kgco2

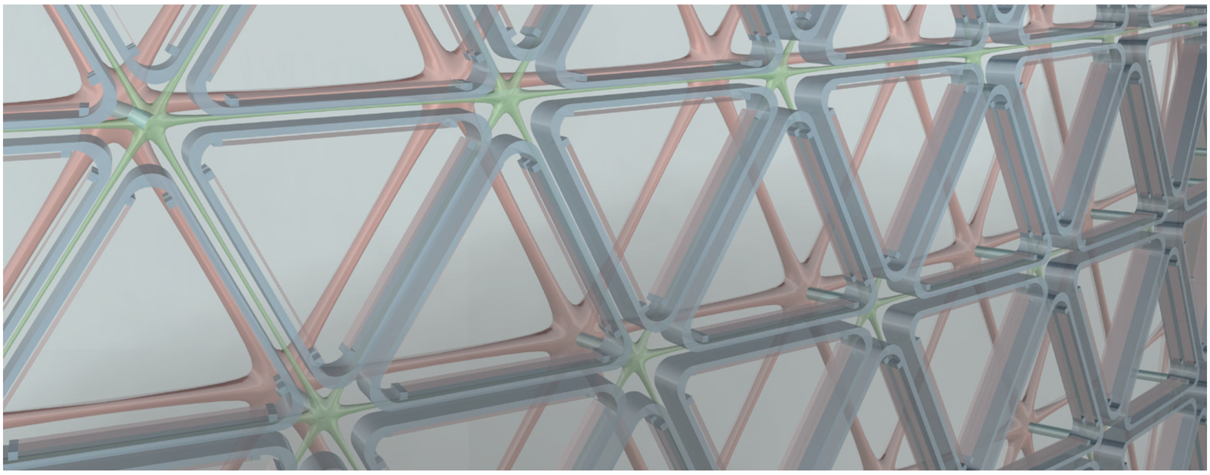


Fig.165: Aluminum Profile (Unit Frames &Rails) installed on TRIO 's facade.

PTFE Polytetrafluoroethylene (Unit Curtains):

Polytetrafluoroethylene.

Area: 8.9 m2

weight: 0.22 kg/m2

EC: 2.54 kgco2/kg

Total Area = 36683 m2

Total weight = 36683 * 0.22 = 8070 kg

Total Curtains Polytetrafluoroethylene EC = 20499 kgCo2.

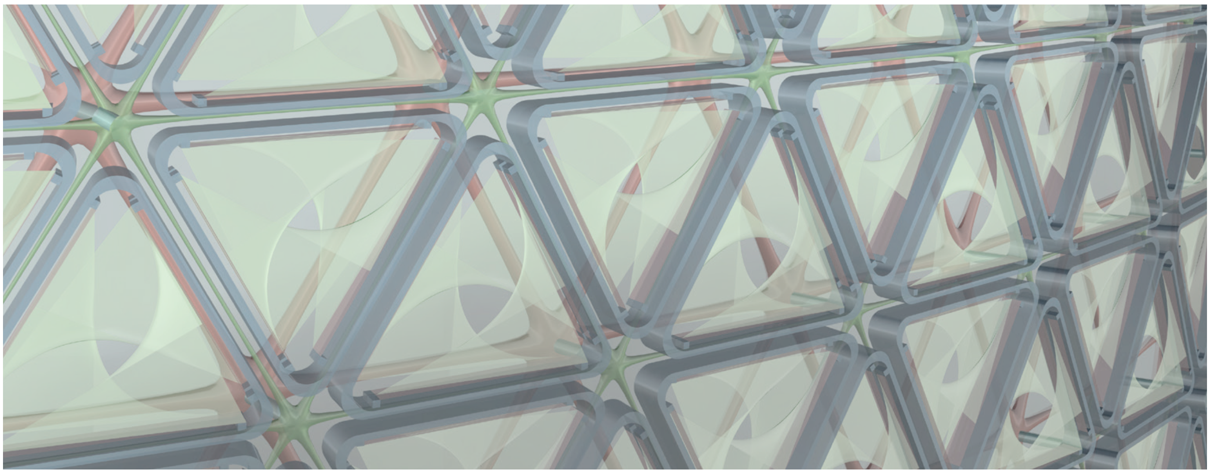


Fig.166: PTFE Polytetrafluoroethylene (Unit Curtains) with all other componennts installed on TRIO 's facade.

To achieve total embodied carbon energy for the whole envelope we must add all the previous result as follow:

TOTAL ENVELOPE EMBODIED CARBON ENERGY = 10652000 KG CO^2

TOTAL TRIO TOWER FAÇADE SURFACE AREA = 28490 m^2

EMBODIED CARBON ENERGY PER FAÇADE SQUARE METER =

10652000 /28490 = 374 KG CO2/m2.

•SHELL-influenced zones in life cycle Phases

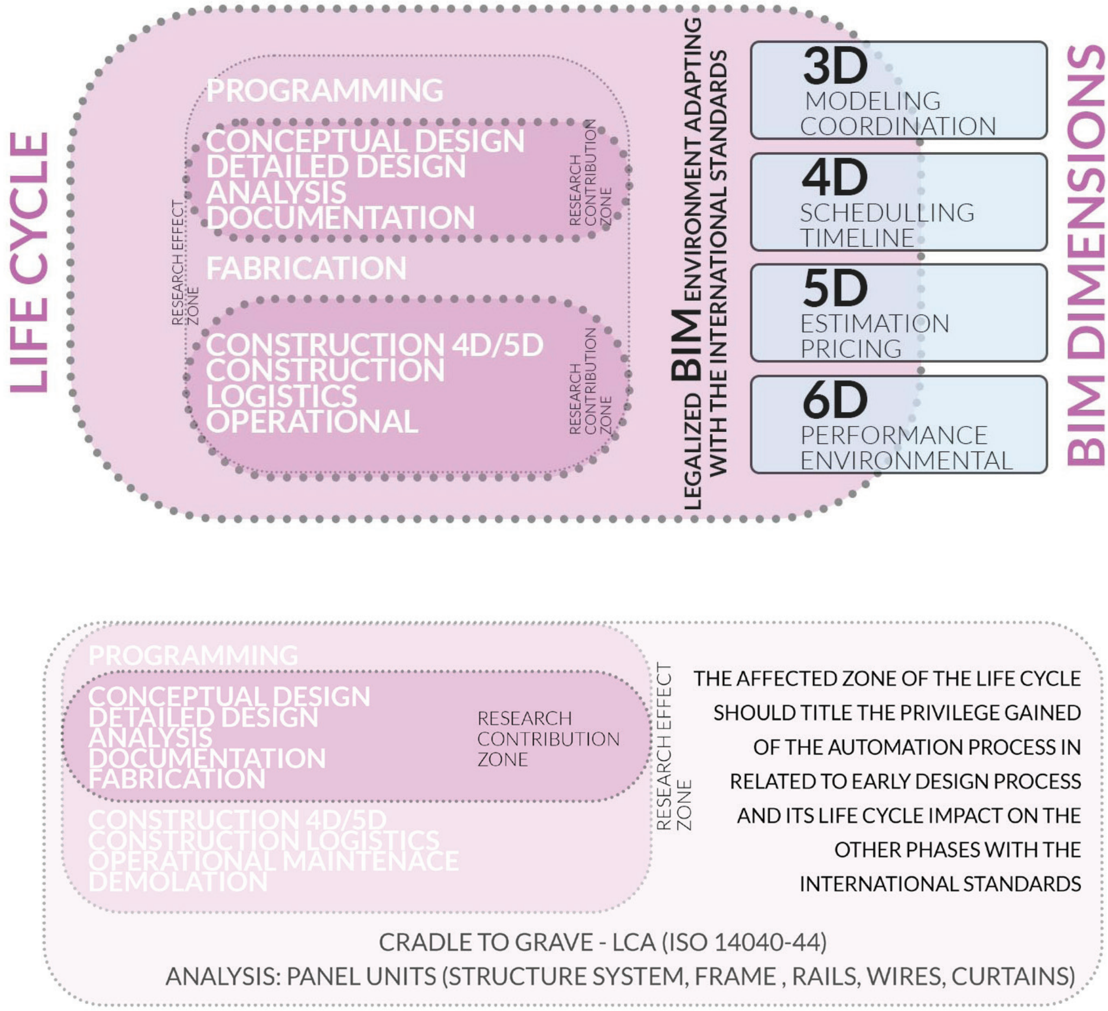


Fig.167: the diagram for the affected zones

HIGHLIGHTS : #Results
#Optimal Solution
#Discussion

RESULTS
CHAPTER VI

0 6

6. RESULTS

"The best way to predict the future is to create it"

Eleanor Roosevelt 1884 - 1962, (USA).

Based on (Figures 168) which represents the optimal solution out of the simulation cases, the following analytics describes the fitness values outputted by the evolutionary simulation. It gives an understanding of the population's fitness values. Initially, the simulation was done on the prototype without panels to obtain the indication numbers which didn't meet the optimal threshold. Panels were introduced to the prototype as a context-sensitive component.

In addition MOEA (*Multi-Objective Evolutionary Algorithm*) method was used to find the best envelope parameters to set an instantaneous movement as a response to the optimized process achieveing objectives (a specific hour (12:00 pm) on the extreme days in both winter and summer to emphasize the probable outcomes). The algorithm produced a set of solutions from the Sample Space of the problem, and the optimal solution was chosen from the Pareto Front suggestions.

The optimal solution represents the results as follow:

Equivalent Solar Area (%) (<0.04) = 0.043943,

Radiation (kwh/m2):

Façade = 1.847734,

Floor = 0.912157 (>0.02)

Day Light Factor = 0.020753.

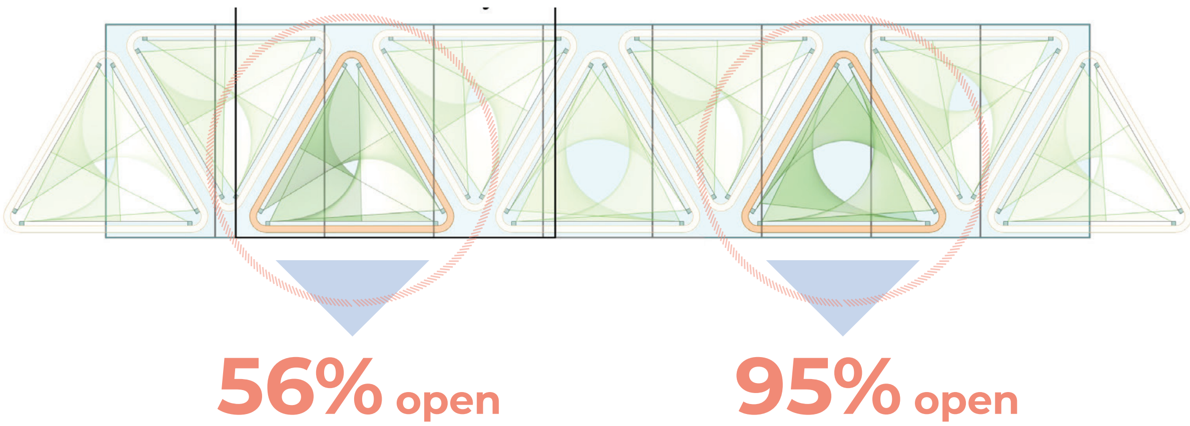


Fig.168: *Units Opening percentage in the optimal solution.*

This result is derived from opening percentage of units' curtains Opening percentage (%)

Left unit = 56 % open

right unit = 95 % open (Figure 169),

This difference between percentage openings, because the right unit was affected by 12 m heights tower (Figure 169), while the left one wasn't.

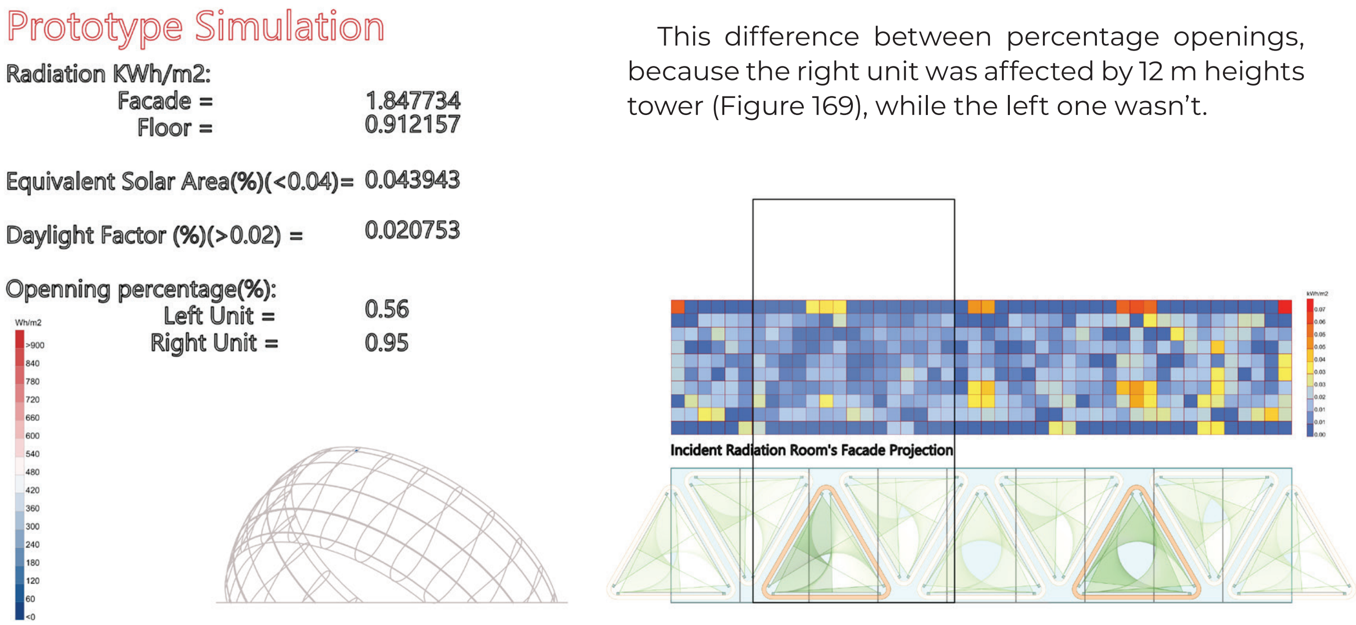


Fig.169: *Optimal Solution with the three objectives values (Front view)*

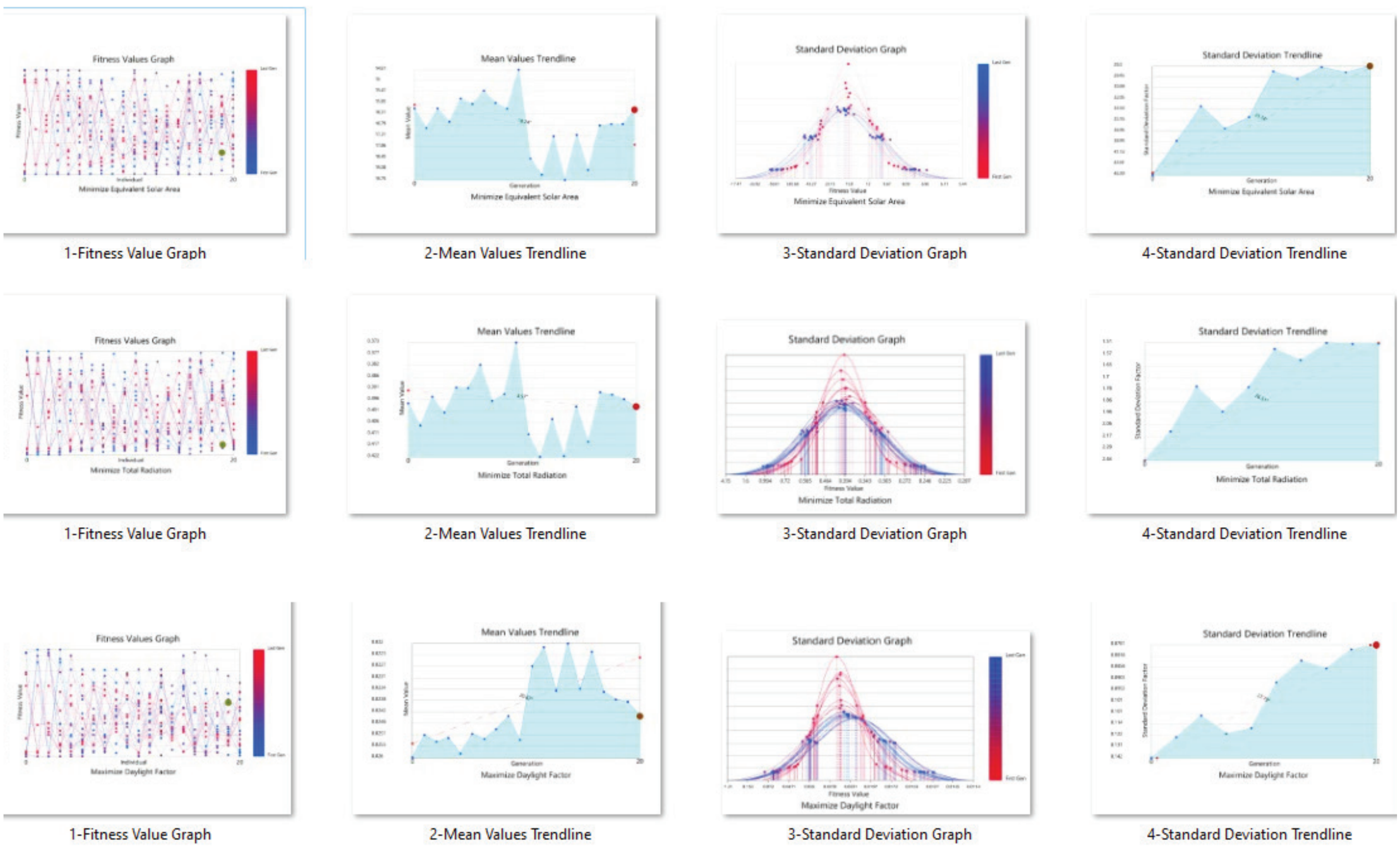


Fig.170: *Optimal solution analytics graphs.*

1-1-Minimize Equivalent Solar Area Triangle Panel, 2-Minimize Total Radiation Triangle Panel. 3-Maximize Daylight Factor Triangle Panel

However, the evaluation of the chosen optimized solution reduces the radiation impact on the façade and floor by about 80% and 85% respectively, while it minimizes the equivalent solar area and daylight factor by about 66% and 60% respectively.

The simulation results show an increase or decrease for each objective by the original set of thresholds that might be improved with larger generation sizes. For the optimal solution, it should be taken into consideration the population size of 400- and 12-hours runtime.

By raising this number, the ability to achieve better solutions increased remarkably and more accurate simulation patterns can also be determined by more powerful computers.

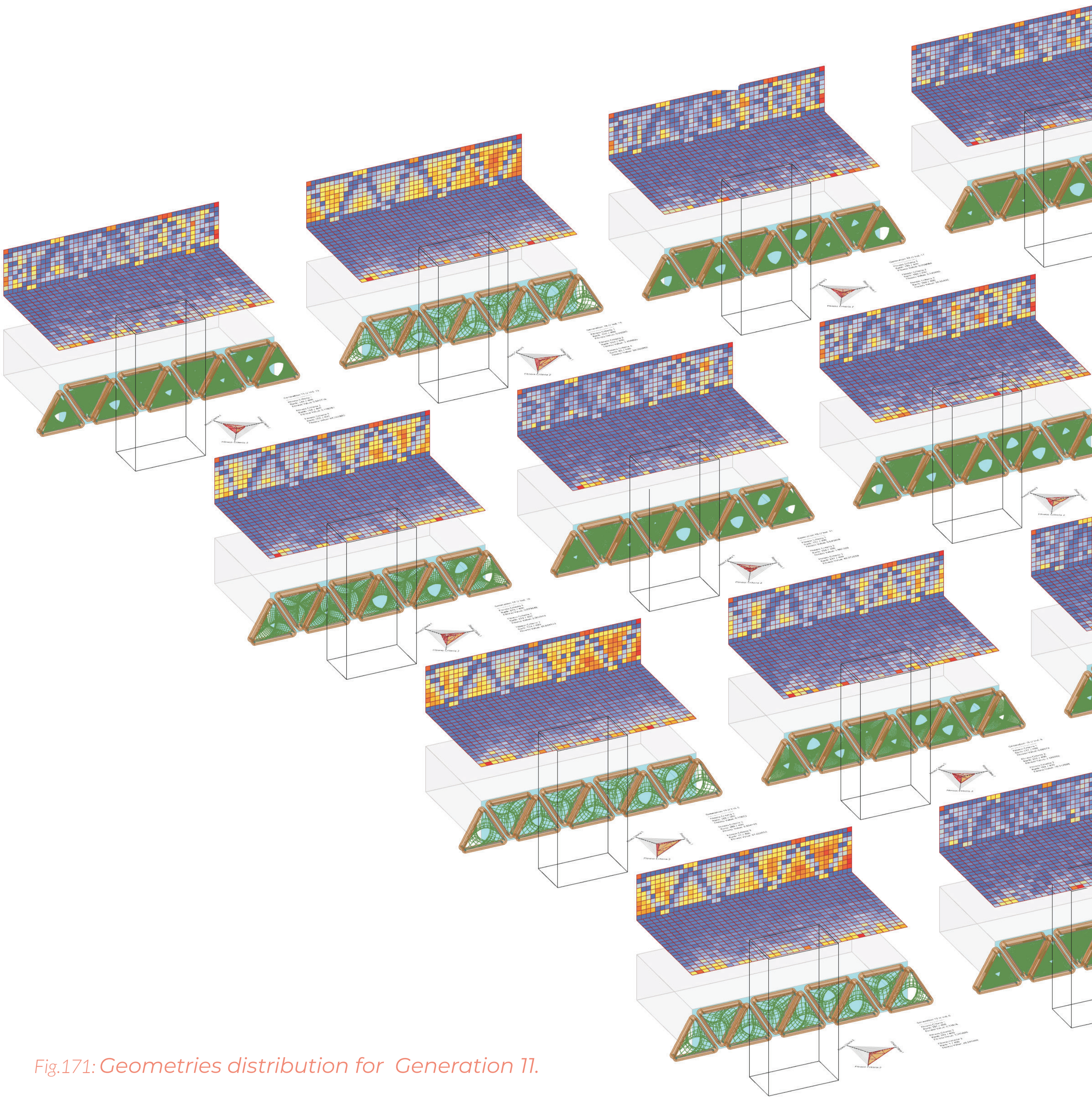
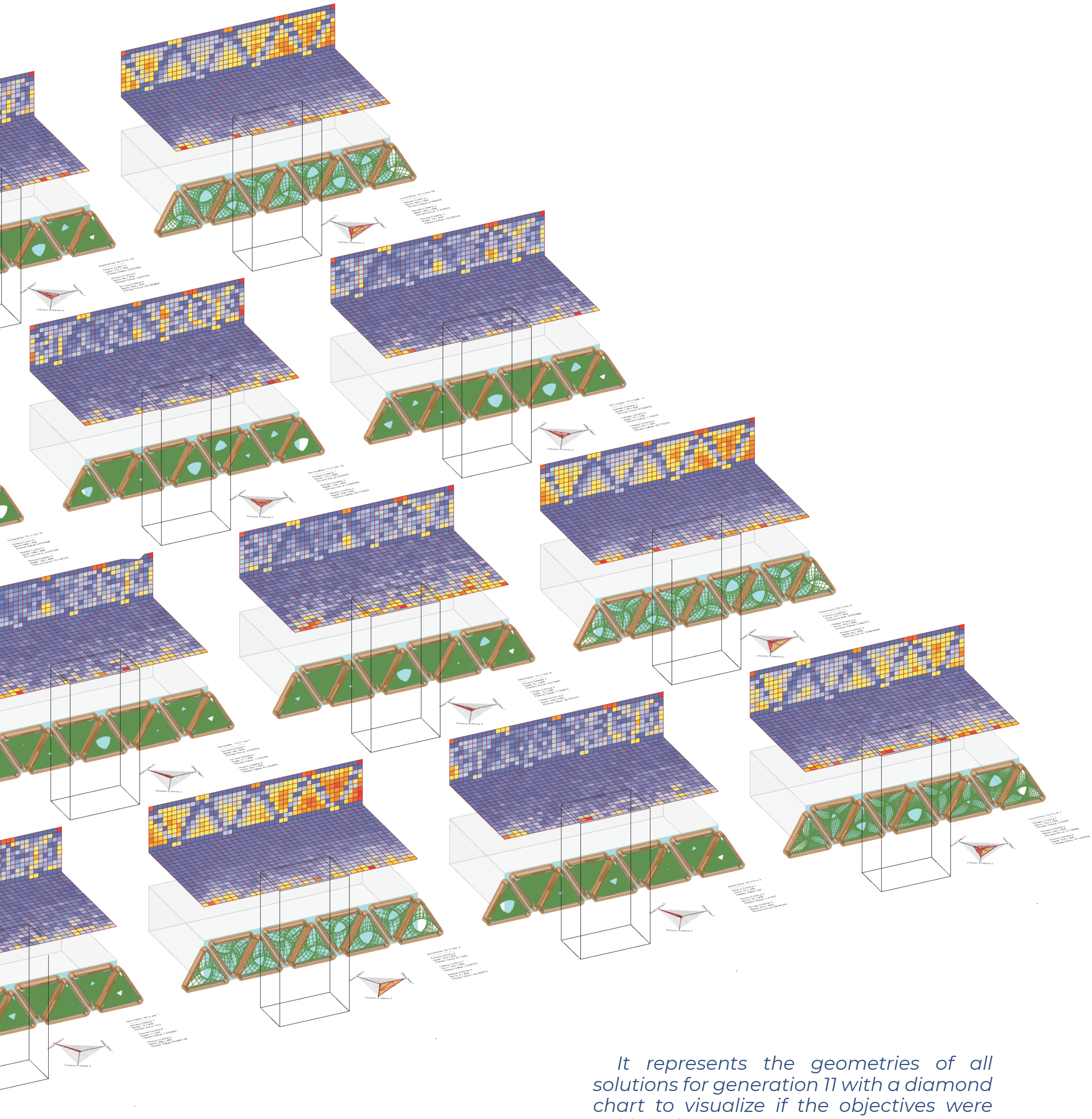


Fig.171: Geometries distribution for Generation 11.

6•1 Optimal solution

This part highlights the selection mechanism employed on the algorithm's output to choose the optimal solution.

Generally, there is a complexity associated with the multitude of design goals, it's amplified by the design goals being inherently conflicting, necessitating preference-based decisions, an approach that results in predetermined solutions driven by personal biases (Showkatbakhsh and Makki 2022).



It represents the geometries of all solutions for generation 11 with a diamond chart to visualize if the objectives were achieved or not.

	Translucency % 1 full Transparency - 100 full opaque	Framework Depth m						
Gen: 19 Ind: 0	12.5	0.46	0.52	0.52	0.51	0.48	0.52	0.51
Gen: 19 Ind: 1	75	0.56	0.48	0.7	0.66	0.74	0.48	0.64
Gen: 19 Ind: 2	12.5	0.46	0.52	0.52	0.51	0.48	0.52	0.51
Gen: 19 Ind: 3	75	0.56	0.48	0.7	0.66	0.74	0.61	0.64
Gen: 19 Ind: 4	27.5	0.55	0.74	0.65	0.71	0.66	0.63	0.61
Gen: 19 Ind: 5	12.5	0.5	0.57	0.52	0.51	0.49	0.62	0.51
Gen: 19 Ind: 6	50	0.51	0.56	0.7	0.51	0.57	0.52	0.51
Gen: 19 Ind: 7	75	0.56	0.48	0.71	0.52	0.73	0.48	0.46
Gen: 19 Ind: 8	75	0.56	0.52	0.7	0.51	0.73	0.46	0.46
Gen: 19 Ind: 9	15	0.46	0.52	0.51	0.47	0.49	0.48	0.51
Gen: 19 Ind: 10	27.5	0.55	0.48	0.7	0.7	0.7	0.52	0.45
Gen: 19 Ind: 11	70	0.58	0.48	0.7	0.66	0.49	0.48	0.45
Gen: 19 Ind: 12	72.5	0.58	0.55	0.52	0.51	0.49	0.48	0.51
Gen: 19 Ind: 13	72.5	0.58	0.55	0.52	0.51	0.48	0.62	0.5
Gen: 19 Ind: 14	75	0.56	0.52	0.7	0.52	0.73	0.46	0.46
Gen: 19 Ind: 15	75	0.58	0.55	0.52	0.51	0.48	0.48	0.5
Gen: 19 Ind: 16	12.5	0.56	0.48	0.69	0.51	0.49	0.62	0.51
Gen: 19 Ind: 17	72.5	0.58	0.55	0.52	0.51	0.48	0.61	0.5
Gen: 19 Ind: 18 (Optimal Solution)	72.5	0.58	0.48	0.7	0.51	0.7	0.52	0.46
Gen: 19 Ind: 19	15	0.46	0.52	0.7	0.47	0.49	0.48	0.51

Fig.172: *Decode Genome*

Shutter Opening %
1 = 100%

0.48	0.61	0.82	0.51	0.75	0.55	0.64	0.89	0.94	0.82	0.98
0.51	0.49	0.59	0.54	0.56	0.54	0.65	0.51	0.51	0.63	0.61
0.48	0.61	0.81	0.51	0.75	0.55	0.64	0.89	0.94	0.82	0.98
0.51	0.72	0.99	0.54	0.56	0.54	0.65	0.51	0.52	0.63	0.61
0.48	0.5	0.51	0.66	0.74	0.58	0.96	0.6	0.57	0.94	0.74
0.51	0.62	0.91	0.54	0.75	0.55	0.64	0.52	0.94	0.92	0.74
0.51	0.6	0.63	0.98	0.74	0.58	0.61	0.9	0.8	0.82	0.6
0.51	0.49	0.59	0.56	0.56	0.54	0.97	0.51	0.54	0.63	0.61
0.51	0.49	0.59	0.51	0.56	0.55	0.97	0.52	0.54	0.81	0.61
0.6	0.71	0.79	0.52	0.75	0.61	0.56	0.99	0.9	0.82	0.57
0.5	0.62	0.59	0.5	0.56	0.58	0.99	0.52	0.95	0.94	0.74
0.5	0.62	0.57	0.54	0.57	0.58	0.99	0.52	0.91	0.94	0.74
0.48	0.49	0.81	0.53	0.75	0.55	0.97	0.91	0.91	0.71	0.99
0.48	0.48	0.81	0.52	0.57	0.55	0.97	0.9	0.59	0.71	0.98
0.5	0.49	0.7	0.68	0.56	0.55	0.99	0.51	0.95	0.81	0.61
0.48	0.5	0.82	0.52	0.79	0.55	0.64	0.55	0.59	0.71	0.99
0.51	0.62	0.91	0.54	0.75	0.54	0.64	0.52	0.51	0.92	0.61
0.48	0.48	0.81	0.52	0.79	0.55	0.97	0.91	0.59	0.71	0.99
0.53	0.49	0.59	0.52	0.56	0.58	1	0.52	0.95	0.71	0.6
0.51	0.62	0.63	0.99	0.75	0.61	0.62	0.9	0.9	0.82	0.6

Closed shutter

Full Opening

Decode Genome to extract numerical values comprising each solution's genome for translucency, framework depth, and shutter opening, highlighting the genomes for the optimal solution Generation 19, solution 18

Prototype simulation Optimal Solution - Generation 19 Sol

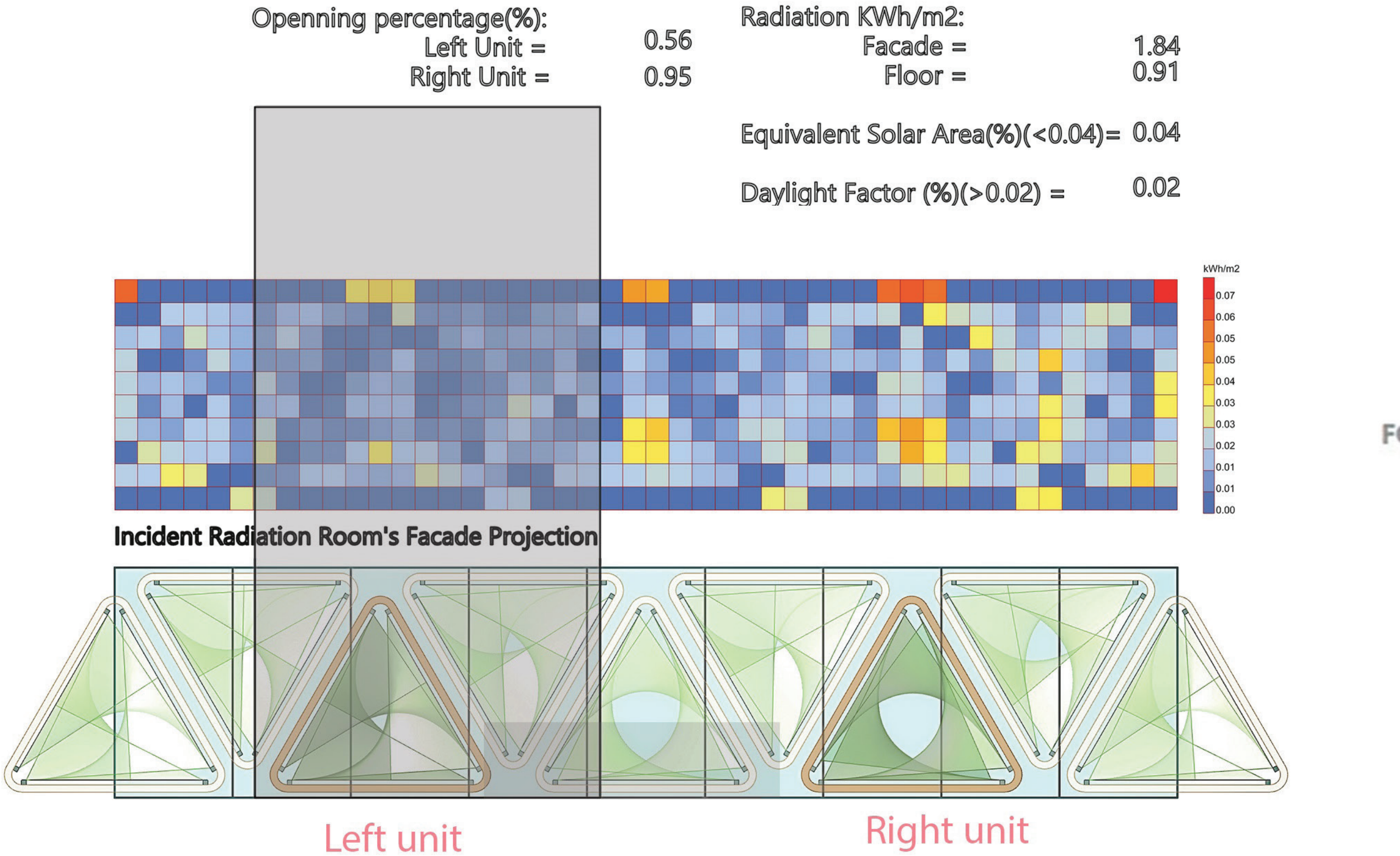


Fig.173: *Compromised (Optimal) solution (Solution closest to the (Utopia) point Gen 19-18.*

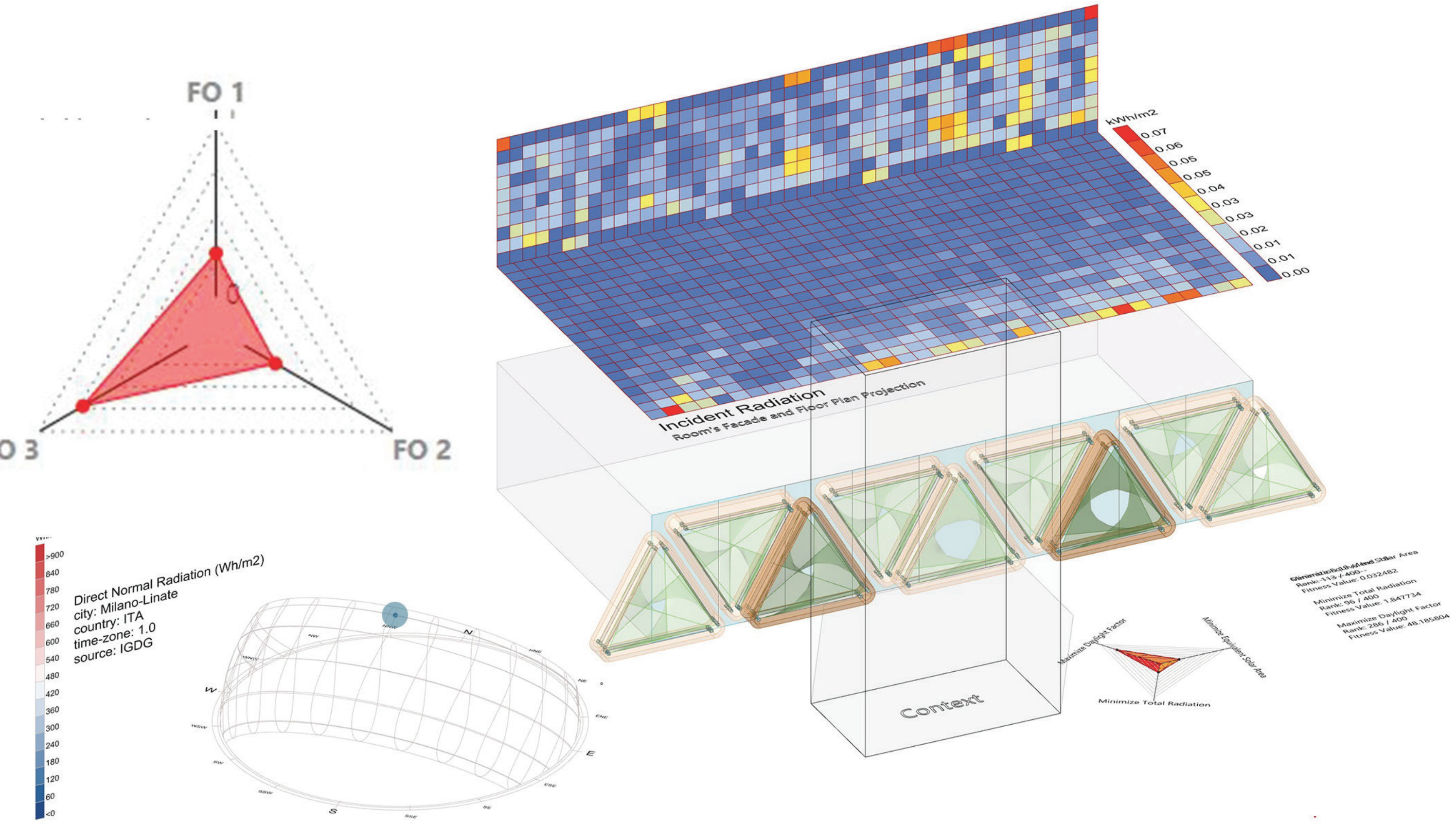
In the research case, human preferences are limited due to the automated nature of the result components. The proposed election of the solution framework includes 2 stages (Showkatbakhsh and Makki 2022):

First, it filters down the population and applies a clustering algorithm on the Pareto front of the entire population, then the phenotypes of the final cluster extracted from the last generation. Then, second step that the outliers in the Pareto front are selected; the fittest solution for each fitness function (Figure 175).

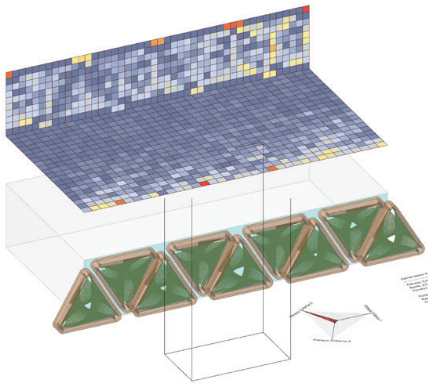
As the fitness functions in the design problem are conflicting, the fittest solution for one function usually exhibits poor fitness for other functions.

The Diamond fitness Chart 'star coordinate method' analyses the fitness values of a single solution as opposed to the population wide analyzes conducted in previous components , Comparing the fitness values and rankings for each of a single solution's fitness objectives is intended to help the user better understand how that solution performs (Figure 174).

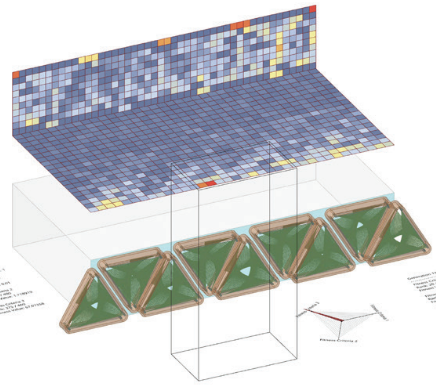
ution18 - Summer case (21 July, 12:00 pm) - Milan Case



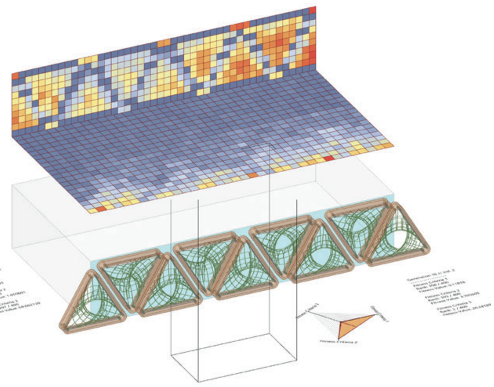
Each perspective represents the best solution for one objective and doesn't take into consideration other objectives.



Generation 6 - Solution 1
Obj1: Solar equivalent area < 0.04



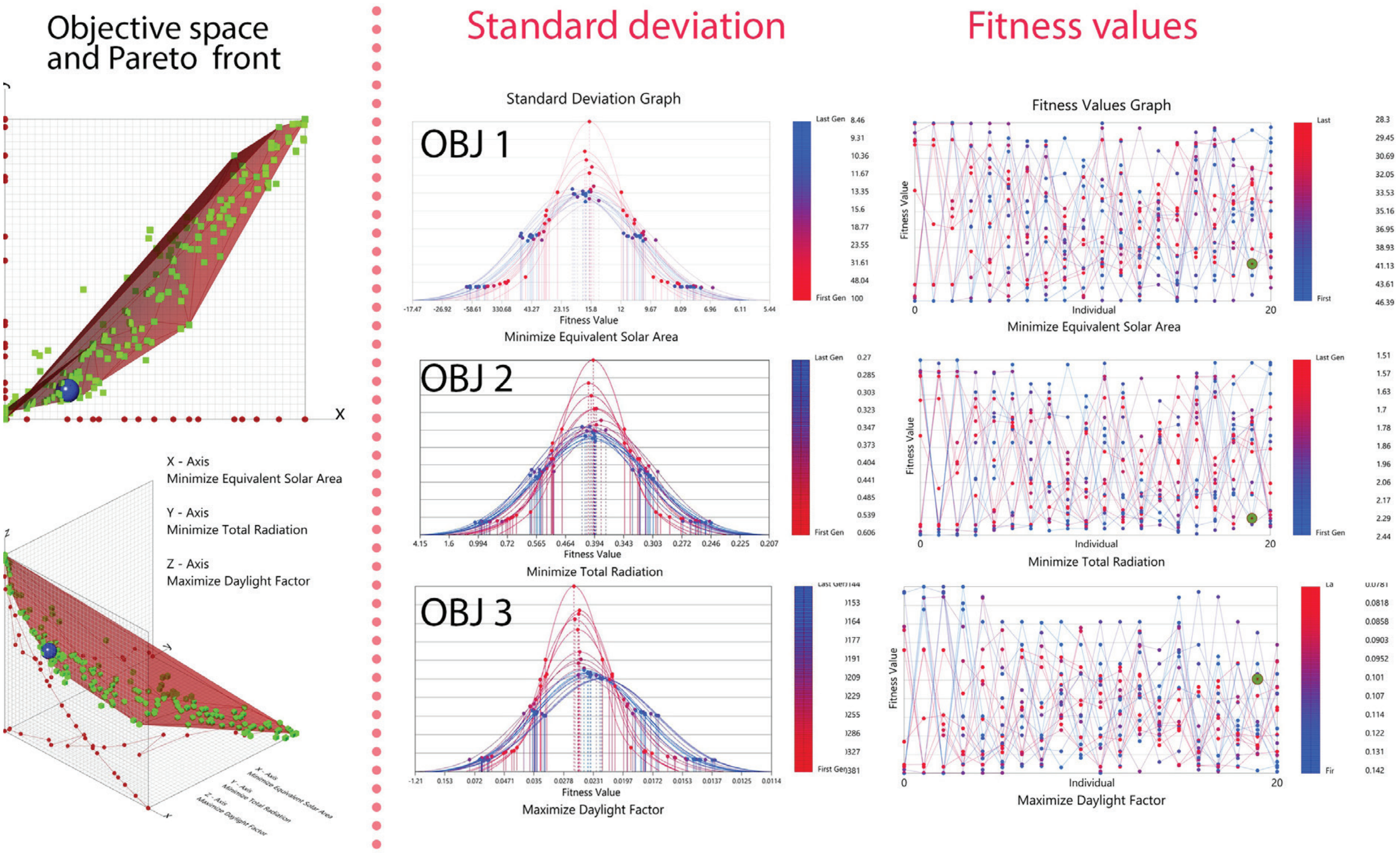
Generation 13 - Solution 2
Obj2: Minimizing Radiation = 1.65 kwh/m2



Generation 16 - Solution 2
Obj3: Daylight Factor >0.02

Fig.174: The fittest solution for each fitness function with respective diamond chart

Fig.175: The graph results from Wallacei analytics for the optimal solution, across four key metrics and the Pareto front (Standard deviation, Fitness values, Standard deviation trendline, and Mean values Trend line.



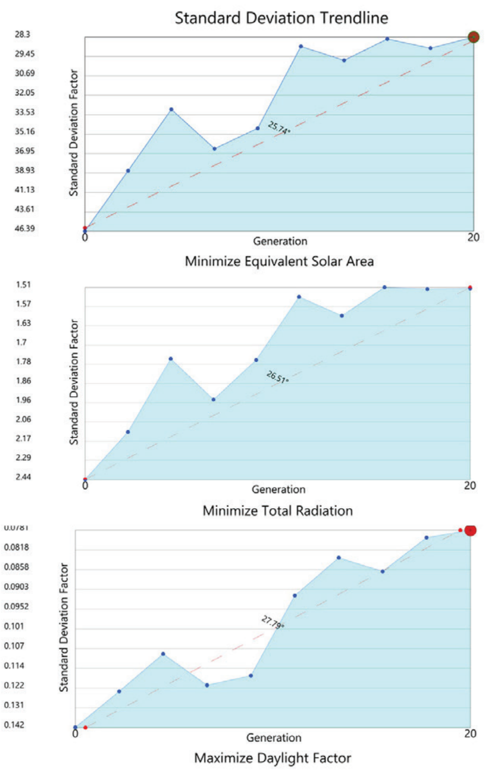
1- The standard deviation for the optimal solution in all objectives shows a concave curve compared to the others which are convex curves. The more concave curve the closer to the objective and the center of the diamond chart. A shift in the curve to the left indicates better mean performance.

2- Fitness values shows how the solutions are performing in relation to one another, both within each generation and across the population.

The phenotypes recognized for Generation 6 Solution 1 represent the best fitness objective value for the Solar equivalent area < 0.04, Generation 13 Solution 2 represents the best fitness objective value for the minimizing Radiation 1.65 kwh/m2, Generation 16 Solution 2 represents the best fitness objective value for the daylight Factor >0.02.

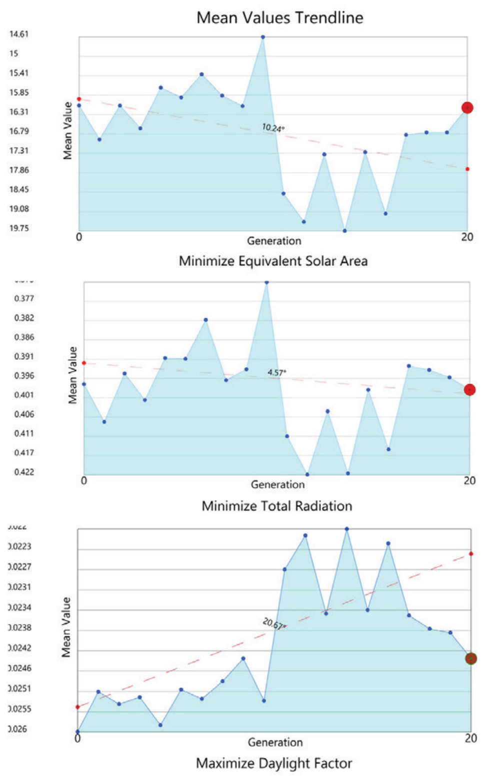
Analyzing the simulation's results and cross-referencing the different fitness objectives to one another. after exporting the optimal solution that meets the objectives the user can visualize each objective separately.

S.Deviation Trendline



3- Standard deviation trend line shows almost 26 degrees for all objectives minimizing the solar equivalent area and radiation and the same degrees for maximizing the daylight factor for all objectives between the first and optimal solution.

Mean Values Trendline



4- Mean value trend line shows 10, and 4.5 degrees for minimizing equivalent solar area and total radiation respectively while 20 degrees for the maximizing daylight factor between the first and optimal solution.

6•2 Optimal solution Interpretation

The Standard deviation charts (Figure 175) represent the increasing variation between generations and the distribution set of values from the mean indicates the level of variation

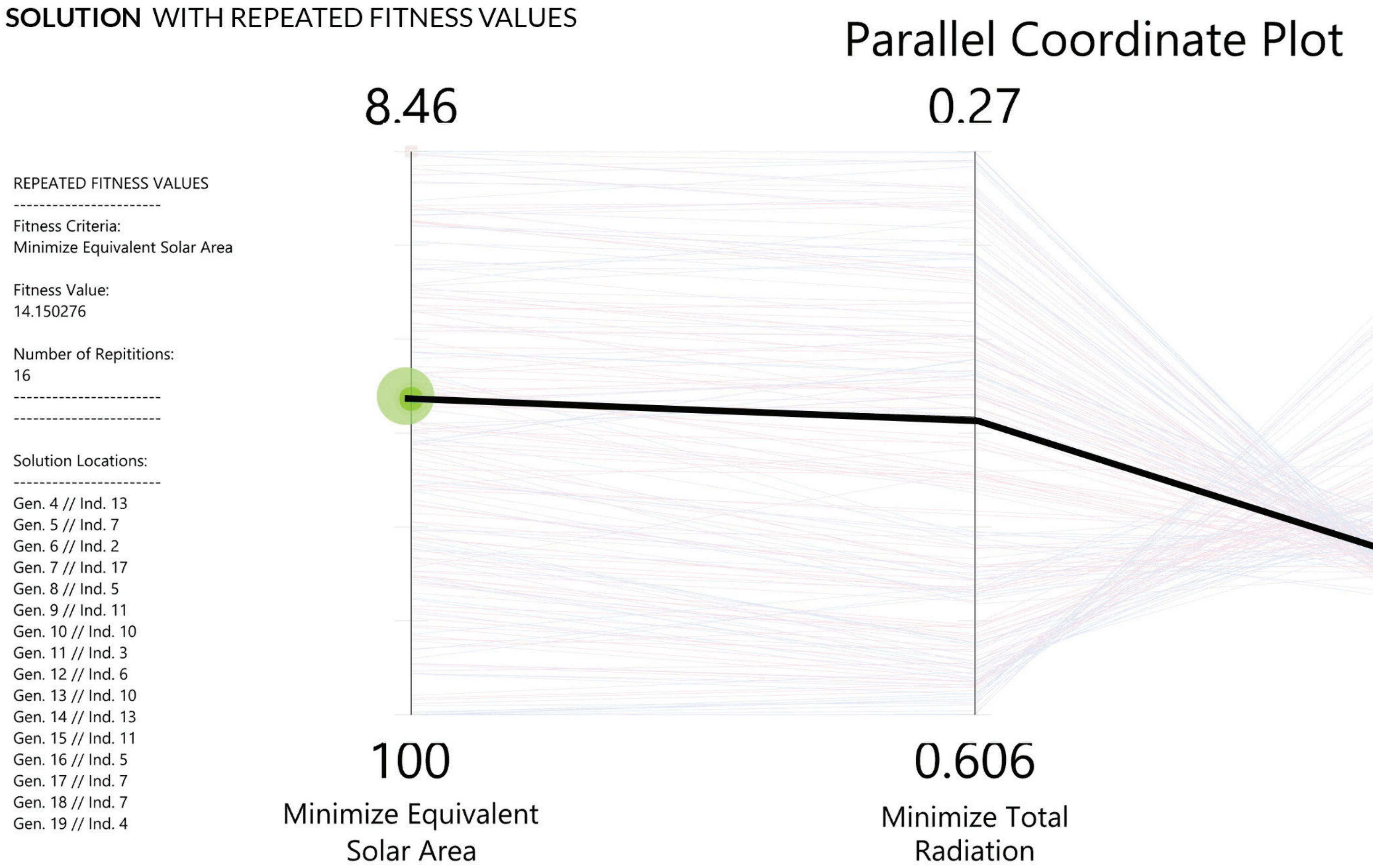


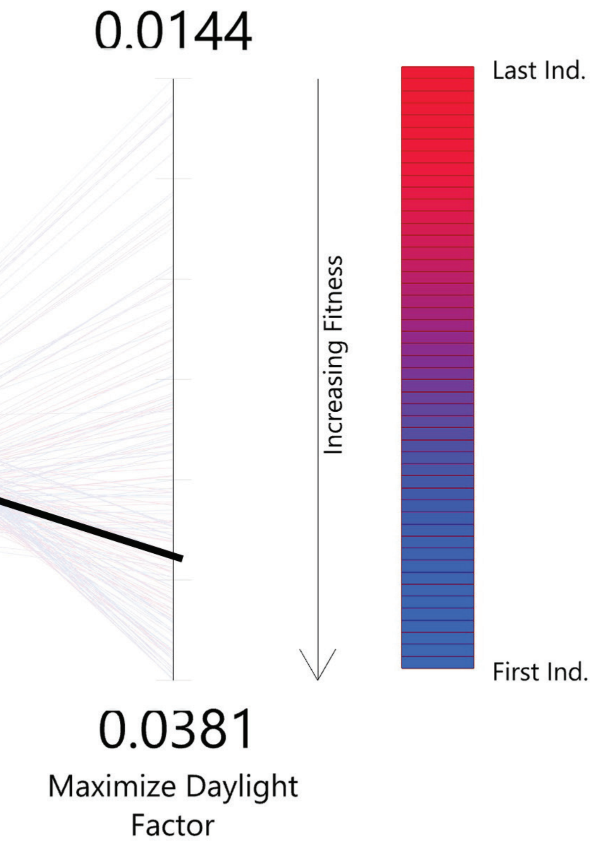
Fig.176: Parallel Coordinate Plot for the solutions with repeated fitness values

The aim is to extract emergent behavior exhibited by the simulation and better understand how the solutions are optimizing throughout the simulation

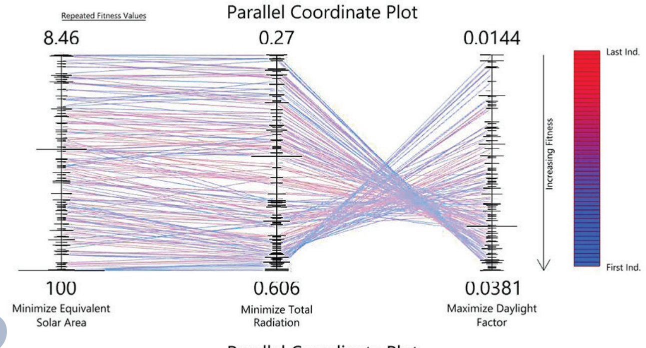
convergence for each generation. Better average performance is indicated by a shift in the curve to the left.

The Fitness Value charts analyzes the fitness values for each fitness objective independently and represents how the solutions are performing in relation to each other. The Standard deviation Trendline chart presents the deviation value for each fitness objective independently from start to finish highlighting specific trends in the variation. While Mean Values Trendline presents the mean fitness value. The 'Objective Space' (OS) and 'Pareto Front' (PF) components combined for all the objectives which displays the objective space for all the solutions in the population (as opposed to only one generation in the population).

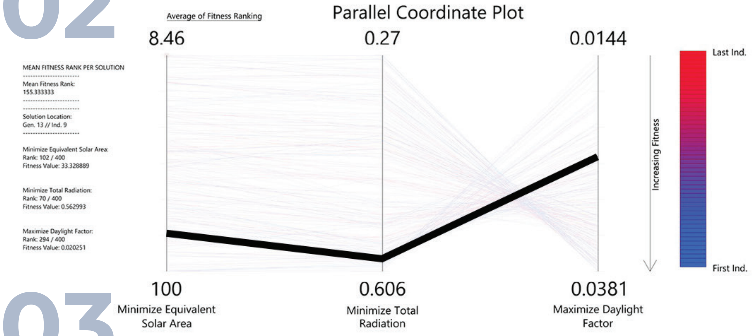
REPEATED FITNESS VALUES



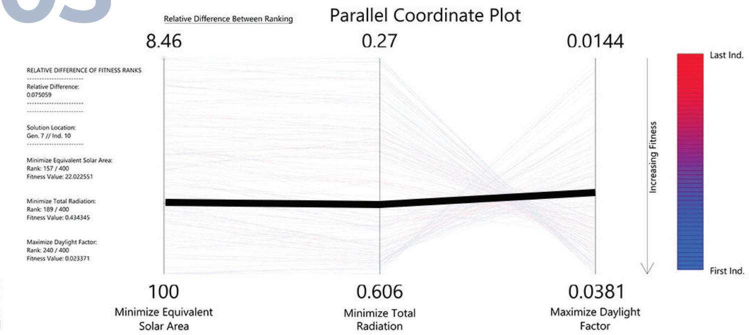
01



02



03



AVERAGE OF FITNESS RANKING

RELATIVE DIFFERENCE BETWEEN RANKING

01 PCP for the solutions with repeated fitness values

his presents the most repeated fitness values in the population (from most repeated to least repeated)

02 PCP for the solutions with Average of fitness ranking

This method orders the solutions according to their mean fitness by calculating the mean fitness rank of each solution's fitness objectives (the 'fittest' solution is the one with the lowest mean rank).

03 PCP for the solutions with relative difference between ranking

This method orders the solutions according to the relative difference between the fitness ranks of the different objectives. In this method, the 'fittest' solution is the one that has the same rank for all fitness objectives.

Wallacei Analytics

Wallacei Analytics used to analyze the fitness values outputted by an evolutionary simulation. It gives an understanding of the population's fitness values

1- Fitness Value Graph, 2- Mean Values Trendline, 3-Standard Deviation Graph, 4- Standard Deviation Trendline, 5- Objective Space and Pareto Front, 6- Diamond Fitness Chart , 7- Parallel Coordinate Plot.

In the Parallel Coordinate Plot PCP, each fitness objective is attributed a y-axis, in which the first objective is the left most y-axis, and the last objective is the right most y-axis. However, users can manually control which axis displays which objective through the 'order fitness criteria' input. The methods of analysis provided in the PCP-A are the following:

1. Most repeated fitness values: This presents the most repeated fitness values in the population (from most repeated to least repeated) and outputs the corresponding data.

2. Solutions with most repeated fitness values: This extracts and highlights the solutions associated with the most repeated fitness values calculated in the method '1'. Through this, the user can highlight the frequency of repeated fitness values across the simulation.

3. Relative difference between ranks: This method orders the solutions according to the relative difference between the fitness ranks of the different objectives. In this method, the 'fittest' solution is the one that has the same rank for all fitness objectives.

4. Average Fitness Rank: This method orders the solutions according to their mean fitness by calculating the mean fitness rank of each solution's fitness objectives (the 'fittest' solution is the one with the lowest mean rank).

The Parallel Coordinate Plot (PCP) (Figure 176) compares the fitness values for each solution across all fitness objectives to analyze all solutions in the population. It indicates a deeper understanding of how the solutions are optimizing through 4 graphs.

The Solutions with the most repeated fitness values graph extract and highlight the frequency of repeated fitness values across the simulation, while the most repeated fitness values graph presents them from most repeated to least repeated and outputs the corresponding data. The relative difference between ranking graph give a method orders the solutions according to the relative difference between the fitness ranks of the different objectives. And the Average Fitness Rank gives method orders the solutions according to their mean fitness.

6•3 Summary

The research introduces a mediator as a controlled envelope between the indoor environment and the momentary outdoor changes that put computing in the face of the instantaneous changes from the external environment of the targeted building to maintain an indoor quality and comfort levels style according to numerical rates. This mediator could be created automatically with a new software plugin called SHELL works with Grasshopper program ecosystems.

SHELL focuses on the solar and visual factors while using MOEA -*Multi-Objective Optimization Algorithms*- to achieve the desired comfortable levels while using unity adaptable envelope (devices) have the potential to maximize the needed quantitative objectives and redefine them to reach preferred calculated numerical results to ensure the occupants' needs.

These envelope units (devices) could come in three geometrical typologies (Trinary, Quaternary, and Senaty) with different algorithmic definitions and had the potential of eight features (*Thermal, Visual, Solar, Acoustical, Form, LCA -Life Cycle Assessment-, CFD -Computational Fluid Dynamics-, and energy*), five of these features studied separately on the units while it introduces only the first three aspects to the optimization process with a set of objectives to target.

During the methodology and after building a Grasshopper definition of three main steps (***01 Constructive Algorithms for the units, 02 Environmental processing, and 03 Optimization predication***), The research conducted a prototype simulation run for nine different scenarios to cover all possible conditions. the empirical simulations run in northern Italy climate zone.

Three of the empirical simulations pertain to annual cumulative fixed solutions and six for Kinetic instantaneous or daily solutions in summer and winter to represent the units' abilities that introduced the objectives. Other objectives could be added to the evolutionary optimization such as acoustic, aerial, and material means while it needs a high computing capability. Prototype simulation aimed to better understand the revolutionary runs and to make more informed decisions in all the different typologies.

SHELL as an innovative software intoduce a process of two phases for the users (01 **Initial model** (Prototype), 02 **Real project** (user's model)), the first phase is to use a Prototype components to let the software recommend the prefered unit. the second phase is to use the recommended unit's component and apply it to the real project. Finally the software give the user an optimized and adaptable envelope solution.

The previous process applied by authors, first on a prototype when recommended the trinary unit as an optimal solution, and then applied on a case study of a Skyscraper in Milan CityLife district as a dense context site to test the effect of surronding towers. the Skyscraper project called TRIO and it was shortlisted in Skyhive International competition for skyscraper, 2022 edition.

6•4 Conclusion

This research provides a full framework of performance-driven architectural design for an adaptive façade utilizing MOEA. To develop a dynamic system that responds to outdoor climate conditions to improve the indoor environmental quality by controlling solar and visual factors and targets minimizing the energy demand to be achieved through a detailed workflow of three stages. The main arguments and conclusions are summarized as follows:

Currently, the Sustainable Development Goals (SDGs) remain one of the most important determinants for the architect's role which highlights their responsibility to provide more green urban patterns with less impact on the environment. Thus, reduce energy demand and minimize the carbon footprint by extension.

- Evolutionary architecture is one of the most important manifestations to introduce more coherent architecture which faces difficulties and solves complicated issues.

- The task is to create an active, protective, and adaptive building envelope between the indoor and outdoor to respond to the environment changes.

- The hypothesis is that the computer can face and solve complicated tasks that occur from instantaneous weather changes or the surrounding urban pattern to meet the building physics regulations and enhance the indoor environmental quality.

- Simulation and optimization softwares (mainly Ladybug and Wallacei) were integrated with building physics regulated formulas into Rhinoceros and grasshopper to establish the workflow.

- The most efficient model in terms of morphology and environmental performance that results in thermal comfort within the space was determined through the application of special tests to a prototype. The best solution is chosen in the summer based on the (Solar Equivalent Area, Daylight factor, and incident radiation) factors.

- The last solution in recent generations is not necessarily the best solution, it can be chosen based on personal preferences.

- A case study was conducted on a conceptual model of a skyscraper project in a central area of high-rise buildings in Milan city to test the surrounded buildings effect.

6•5 Limitations and Future works.

Although the methodology and techniques developed in the paper are valuable, they have some limitations that warrant future research work. First, the workflows were set up using customer computers, which is inappropriate for an evolutionary process of this nature. The time and the outcomes will both improve with more processing power. Specifications of the hardware used to run the simulation: (CPUs: AMD Ryzen 7 2700x 3.7GHz, Core i7 7820HQ 2.9 GH & Corei7-10750H 2.60GHz, Ram 32 Gb, GPU GeForce GTX 1070 Ti Duke 8Gb, Quadro B3000 6 Gb and GTX 2060 6 Gb).

Although SHELL software integrates with the Grasshopper environment, a great computational platform, it still need improvement in the interoperability workflow to be able to manage the practises currently used in the construction sector (check part 5.1.4).

Also, the process needs an API development to have an architect-friendly interface, so that no coding capability is required. Moreover, the optimizations showed a requirement for value extraction which is not practical, an automated process needed to indicate the appropriate values and to be directly applied on the targeted envelope, both need development, and which will be the natural next step.

P O L I T E C N I C O

HIGHLIGHTS : #References
#Appendices
#Code

APPENDICES
CHAPTER VII

0 7

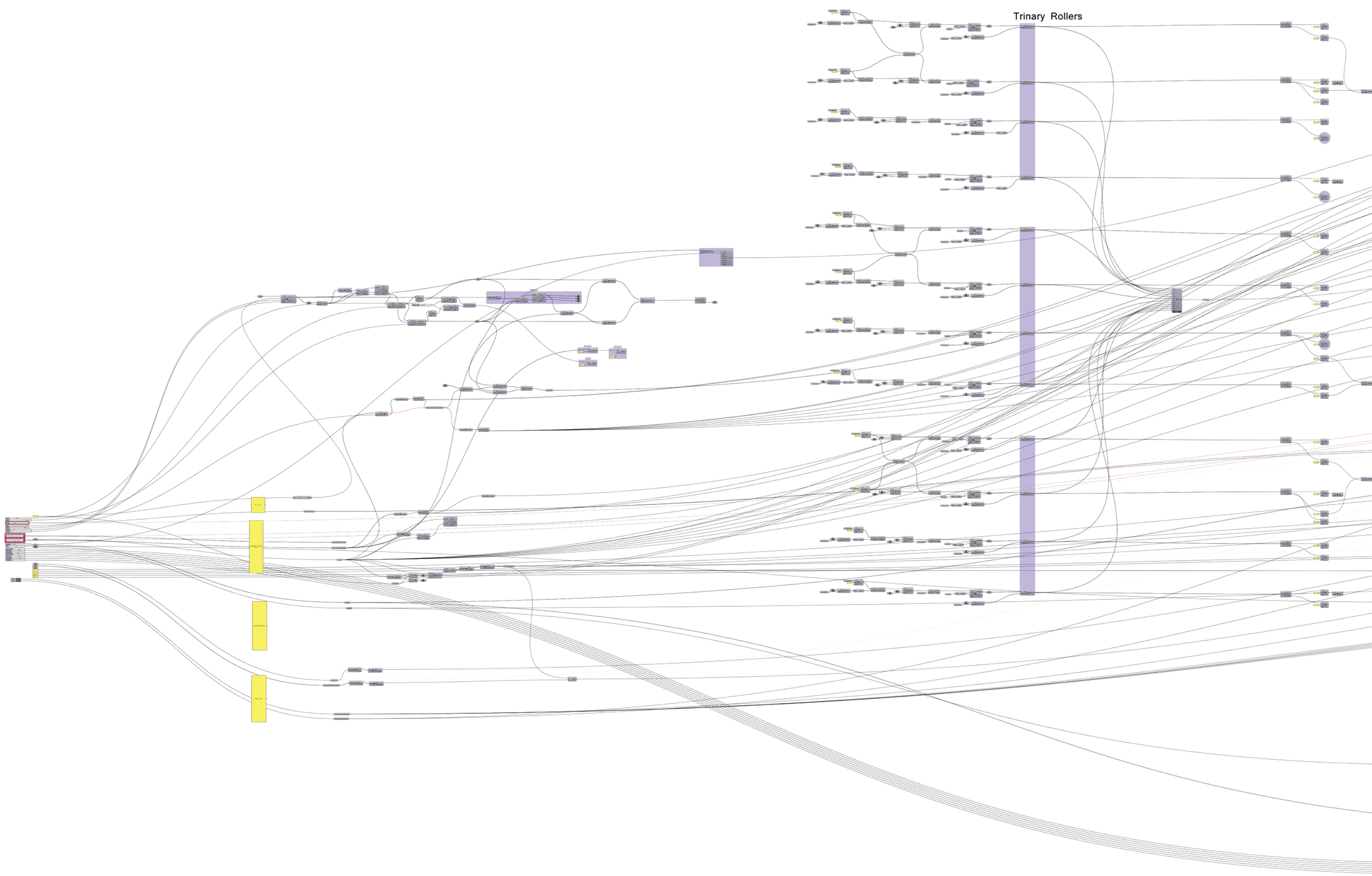
MSC THESIS

ARCHITECTURAL
COMPUTATIONAL
SUSTAINABILITY

7. APPENDICES

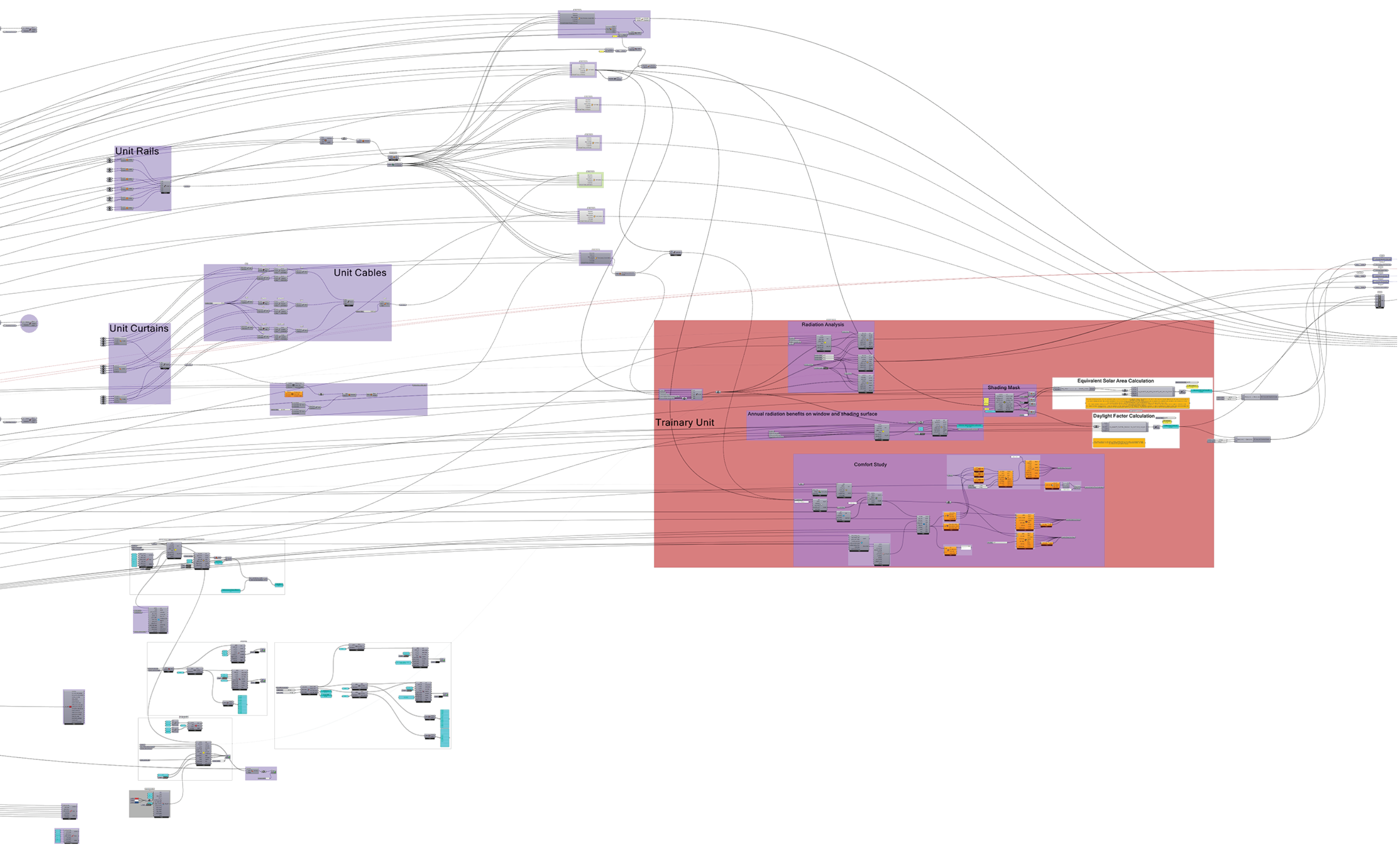
“Our endeavors do not have to end in defeat, as long as we have resolved not to die before trying to live.”

Radwa ashur 1946-2014 , (Egypt).



7•1 Appendix 01

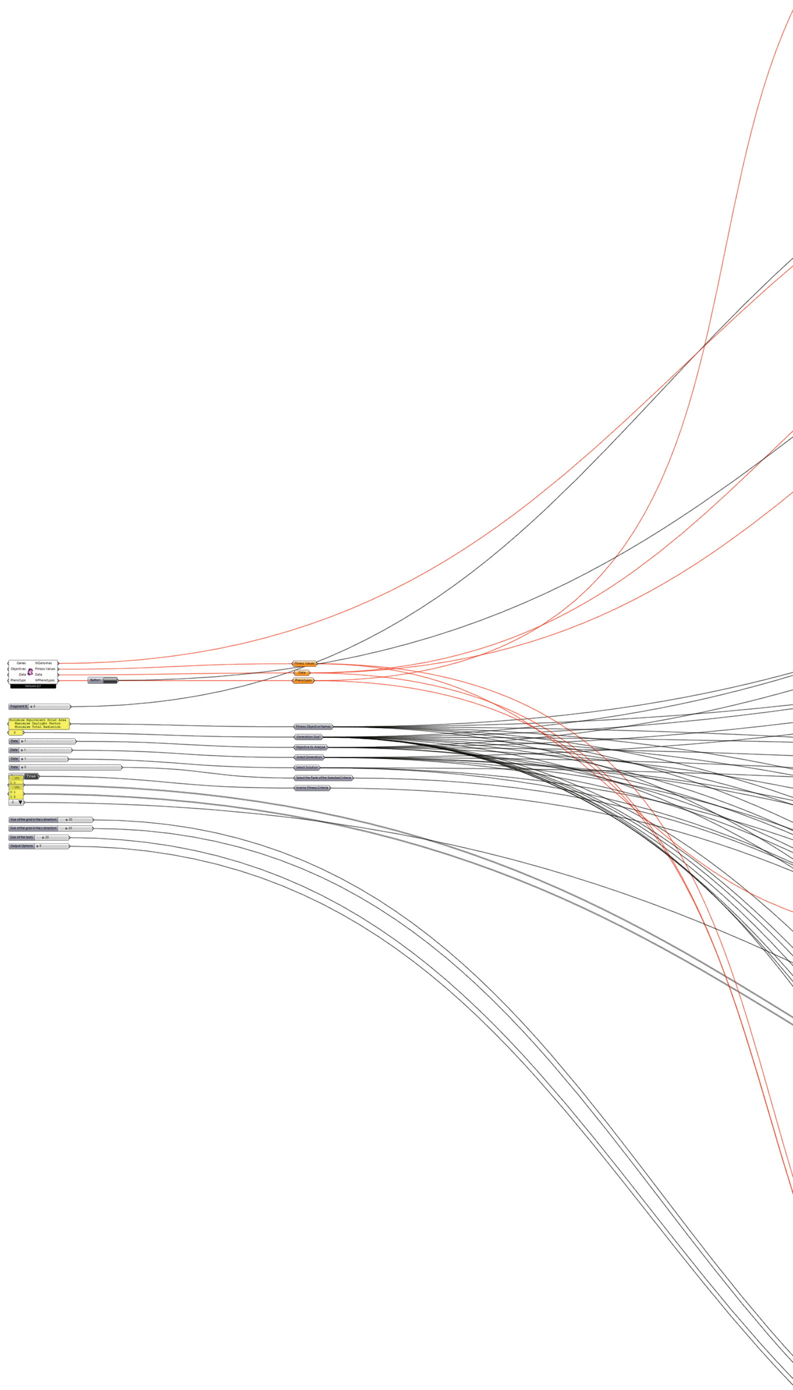
In this appendix, the visual programming script used to create the Trinary unit cluster (Applications Chapter).



Detailed Trinary unit component script

7•2 Appendix 02

In this appendix, the visual programming script used to create the Outcomes clusters (Applications Chapter)

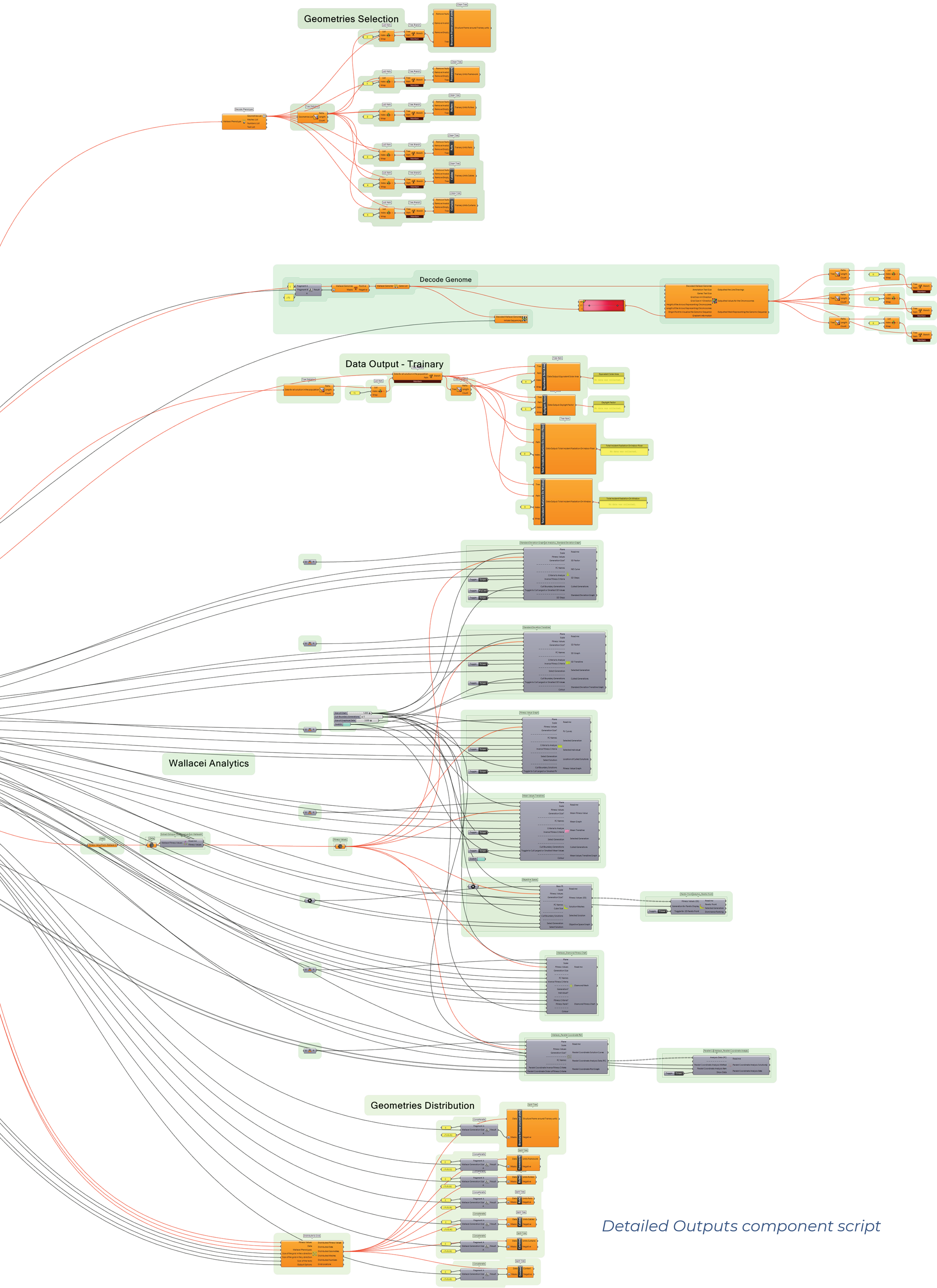


7•3 Appendix 03

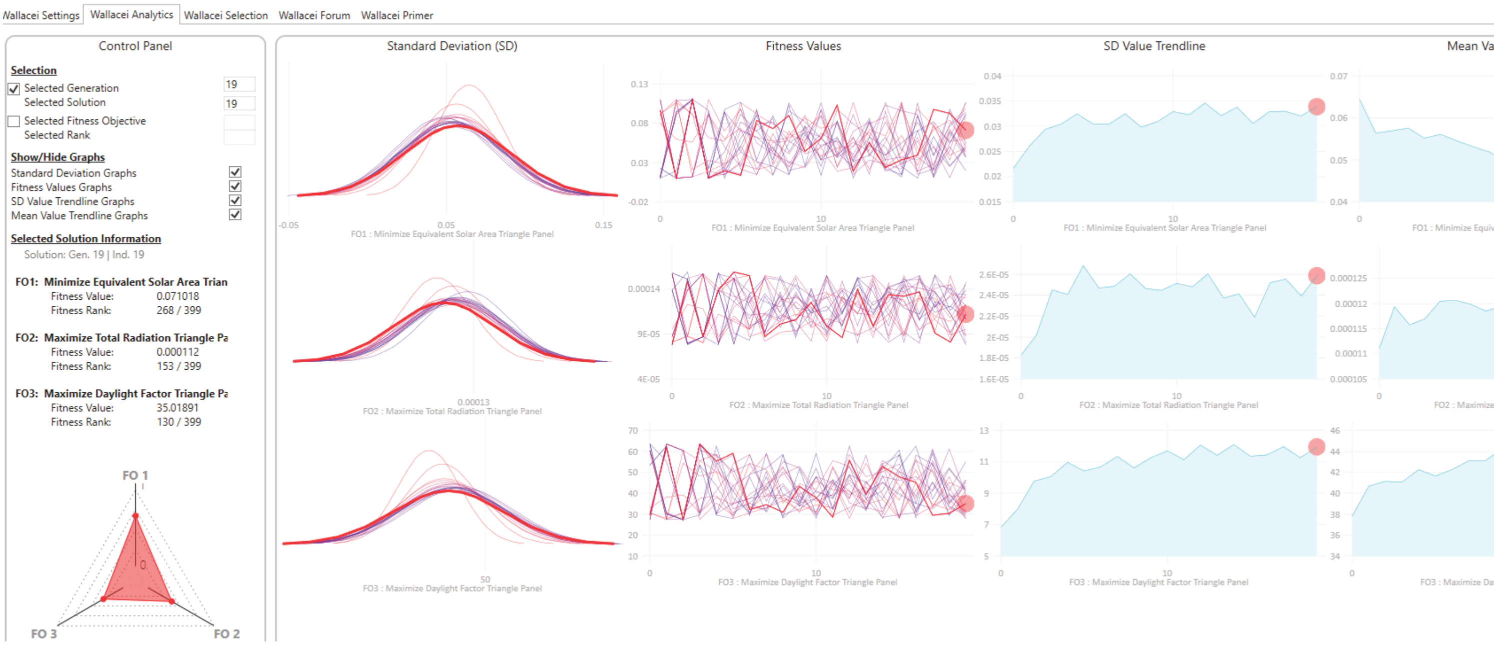
The following appendix is the evolutionary engine analytics (Wallacei) of the Empirical studies (Chapter 04 Method) and the the parallel coordinate plot (PCP) which analyses all the solutions in the population through comparing the fitness values for each solution across all fitness objectives.

The aim is to extract emergent behavior exhibited by the simulation and better understand how the solutions are optimizing throughout the simulation.

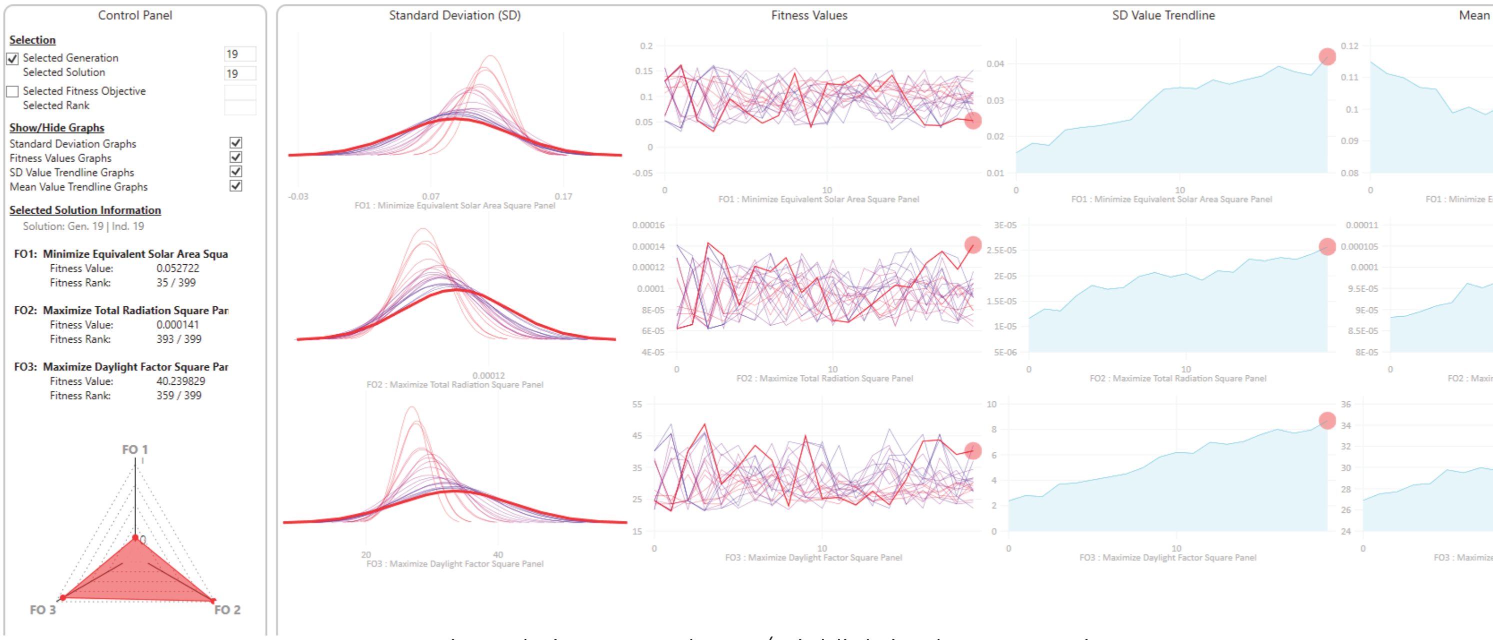
The Parallel coordinate plot analysis component (PCP-A) provides the user with 4 methods of analysis of all solutions in the population.



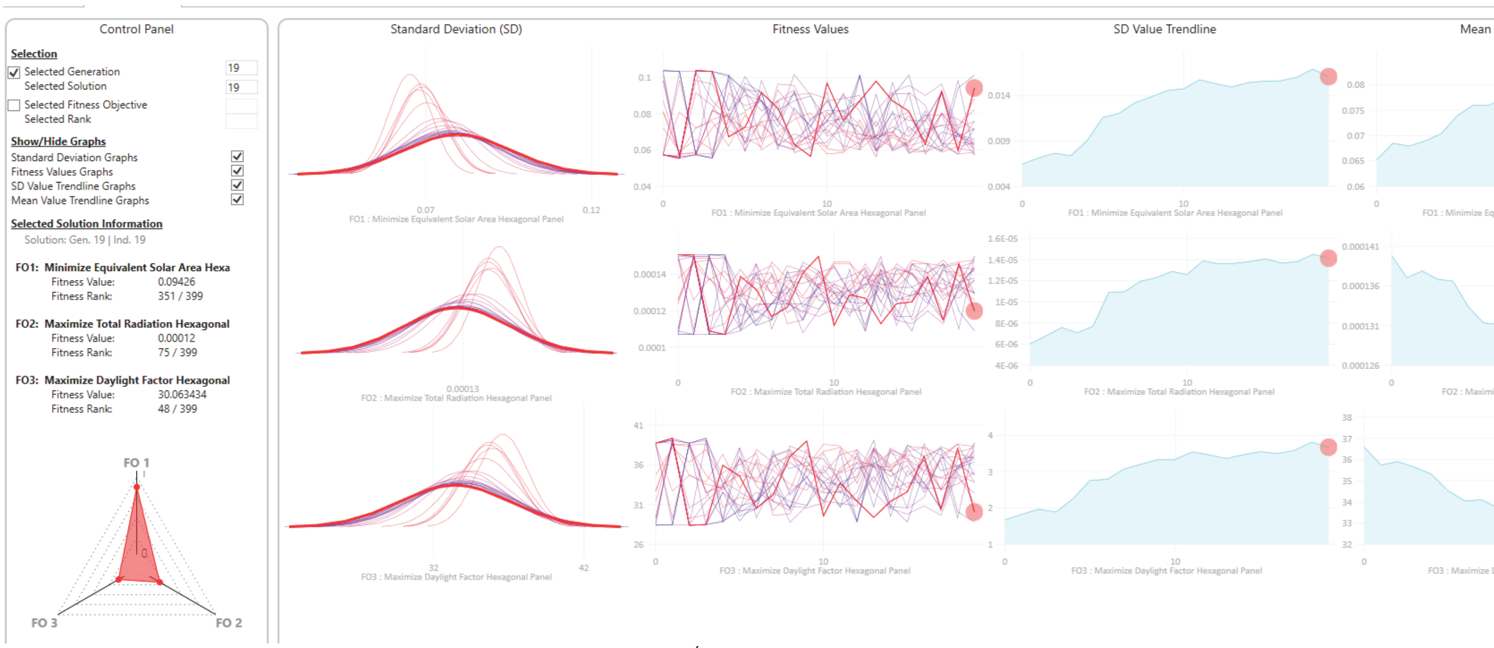
Detailed Outputs component script



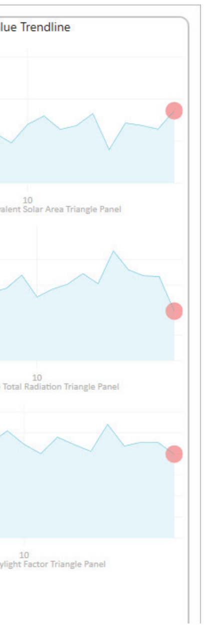
Trinary unit Analytics - Annual case - Highlighting last generation 19-19



Quaternary unit Analytics - Annual case / Highlighting last generation 19-19



Hexa-unit Analytics - Annual case / Highlighting last generation 19-19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Total Radiation Triangle Panel
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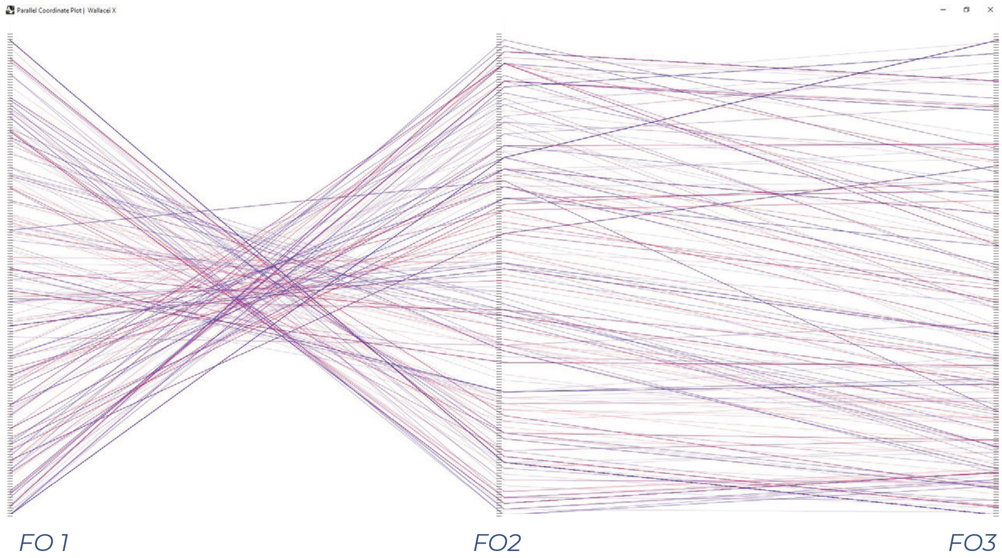
Parallel Coordinate Plot | Wallacei X
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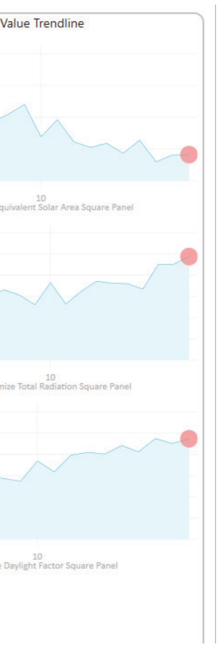
FO2
FO3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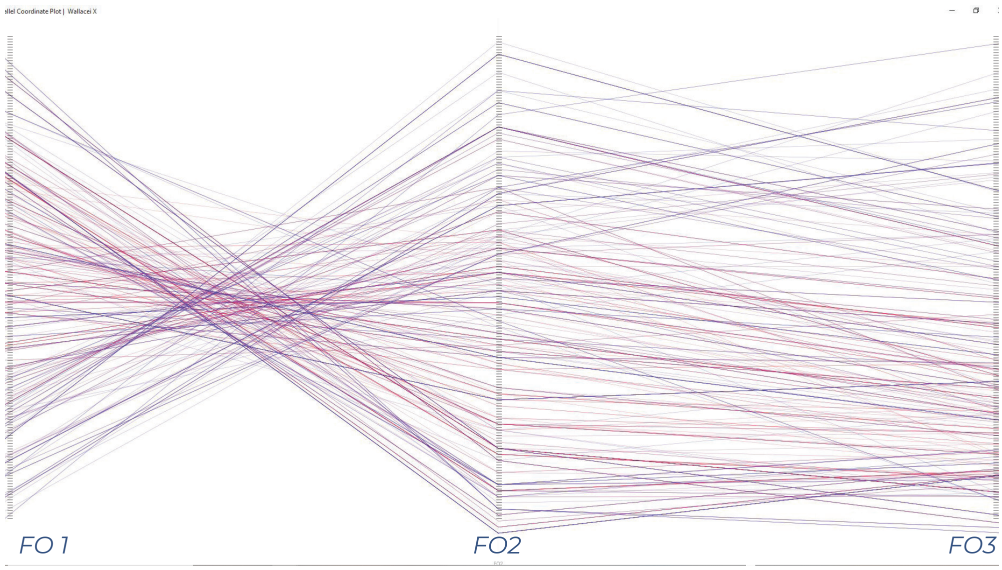
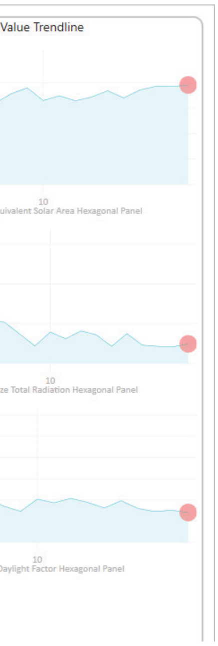
Daylight Factor Square Panel


llel Coordinate Plot | Wallacei X
FO 1
FO2
FO3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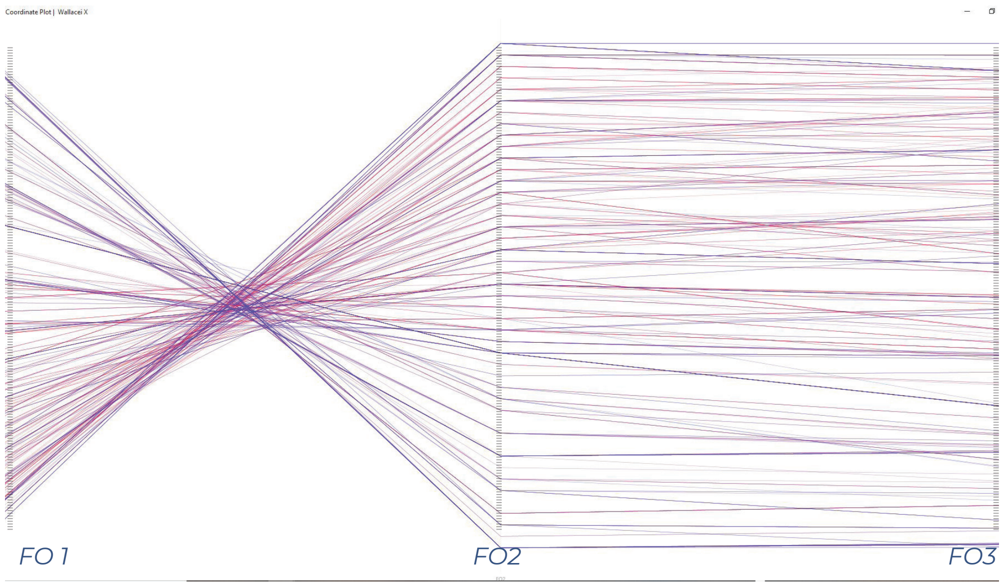
Coordinate Plot | Wallacei X
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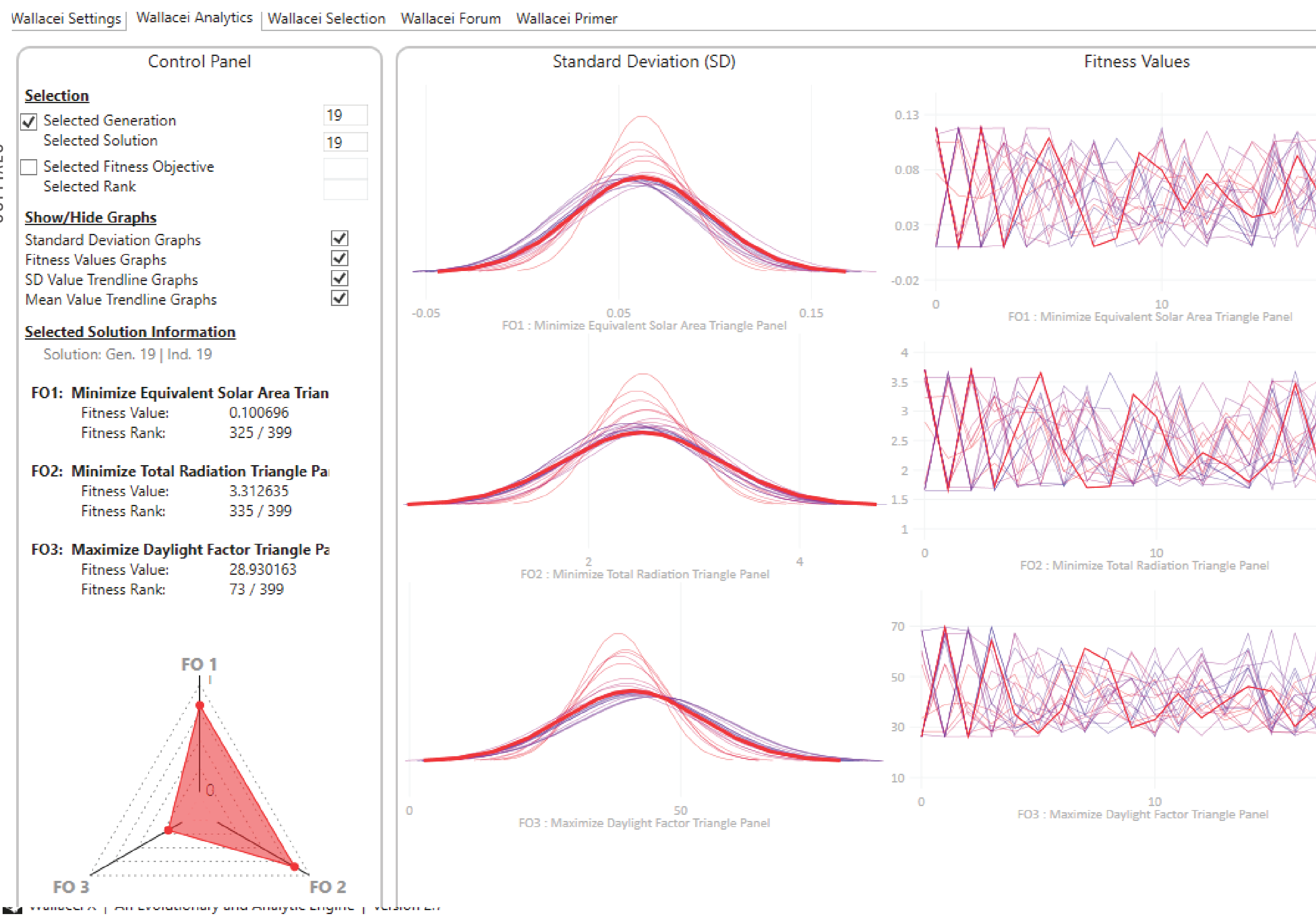
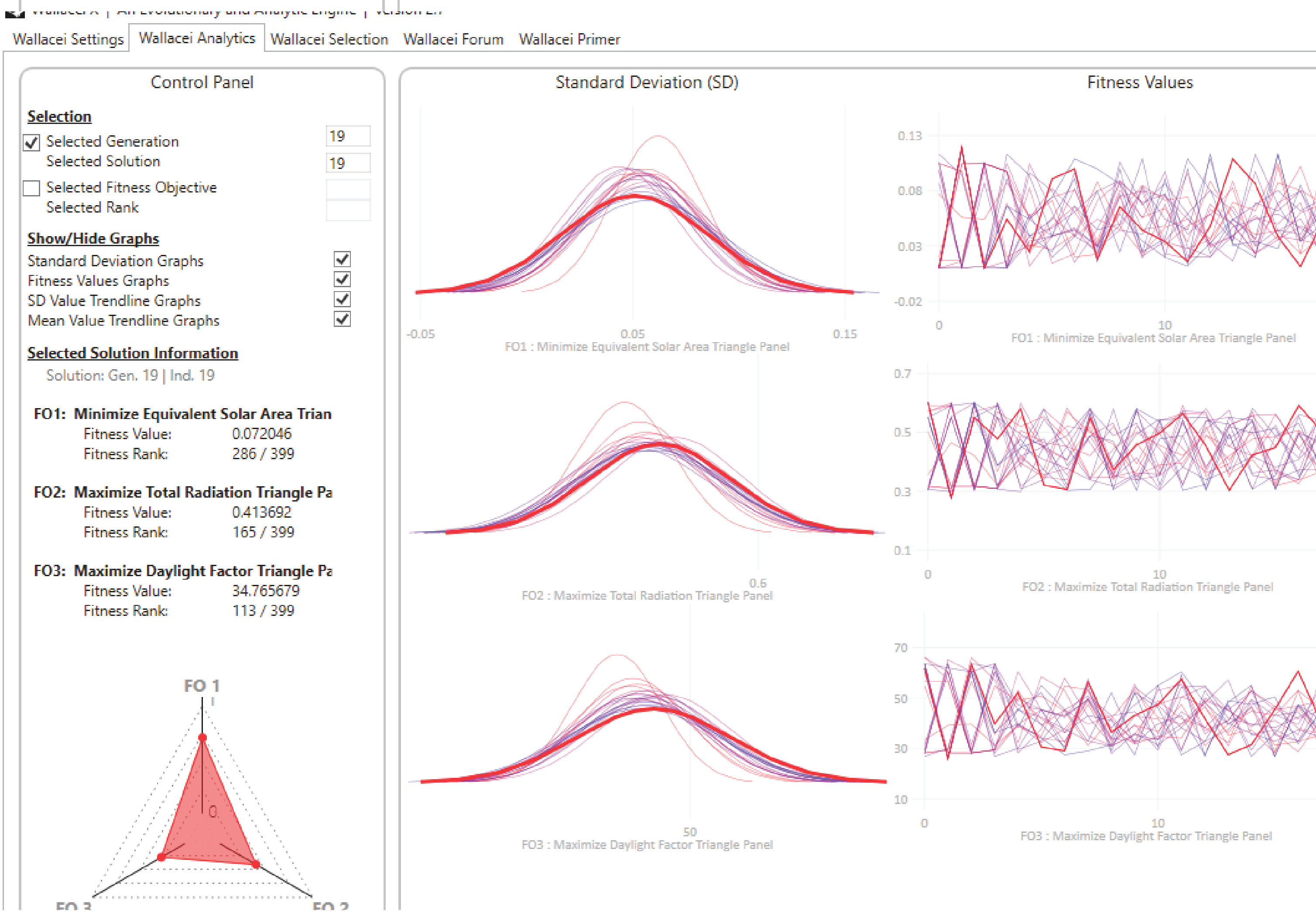
FO2
FO3


Wallacei Settings
Wallacei Analytics
Wallacei Selection
Wallacei Forum
Wallacei Primer
Control Panel
Selection
Selected Generation 19
Selected Solution 19
Selected Fitness Objective
Selected Rank
Show/Hide Graphs
Standard Deviation Graphs
Fitness Values Graphs
SD Value Trendline Graphs
Mean Value Trendline Graphs
Selected Solution Information
Solution: Gen. 19 | Ind. 19
FO1: Minimize Equivalent Solar Area Trian
Fitness Value: 0.100696
Fitness Rank: 325 / 399
FO2: Minimize Total Radiation Triangle Pa
Fitness Value: 3.312635
Fitness Rank: 335 / 399
FO3: Maximize Daylight Factor Triangle Pa
Fitness Value: 28.930163
Fitness Rank: 73 / 399
FO 1
FO 3
FO 2
Standard Deviation (SD)
FO1 : Minimize Equivalent Solar Area Triangle Panel
FO2 : Minimize Total Radiation Triangle Panel
FO3 : Maximize Daylight Factor Triangle Panel
Fitness Values
FO1 : Minimize Equivalent Solar Area Triangle Panel
FO2 : Minimize Total Radiation Triangle Panel
FO3 : Maximize Daylight Factor Triangle Panel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Wallacei Forum
Wallacei Primer
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Standard Deviation Graphs
Fitness Values Graphs
SD Value Trendline Graphs
Mean Value Trendline Graphs
Selected Solution Information
Solution: Gen. 19 | Ind. 19
FO1: Minimize Equivalent Solar Area Trian
Fitness Value: 0.072046
Fitness Rank: 286 / 399
FO2: Maximize Total Radiation Triangle Pa
Fitness Value: 0.413692
Fitness Rank: 165 / 399
FO3: Maximize Daylight Factor Triangle Pa
Fitness Value: 34.765679
Fitness Rank: 113 / 399
FO 1
Standard Deviation (SD)
FO1 : Minimize Equivalent Solar Area Triangle Panel
FO2 : Maximize Total Radiation Triangle Panel
FO3 : Maximize Daylight Factor Triangle Panel
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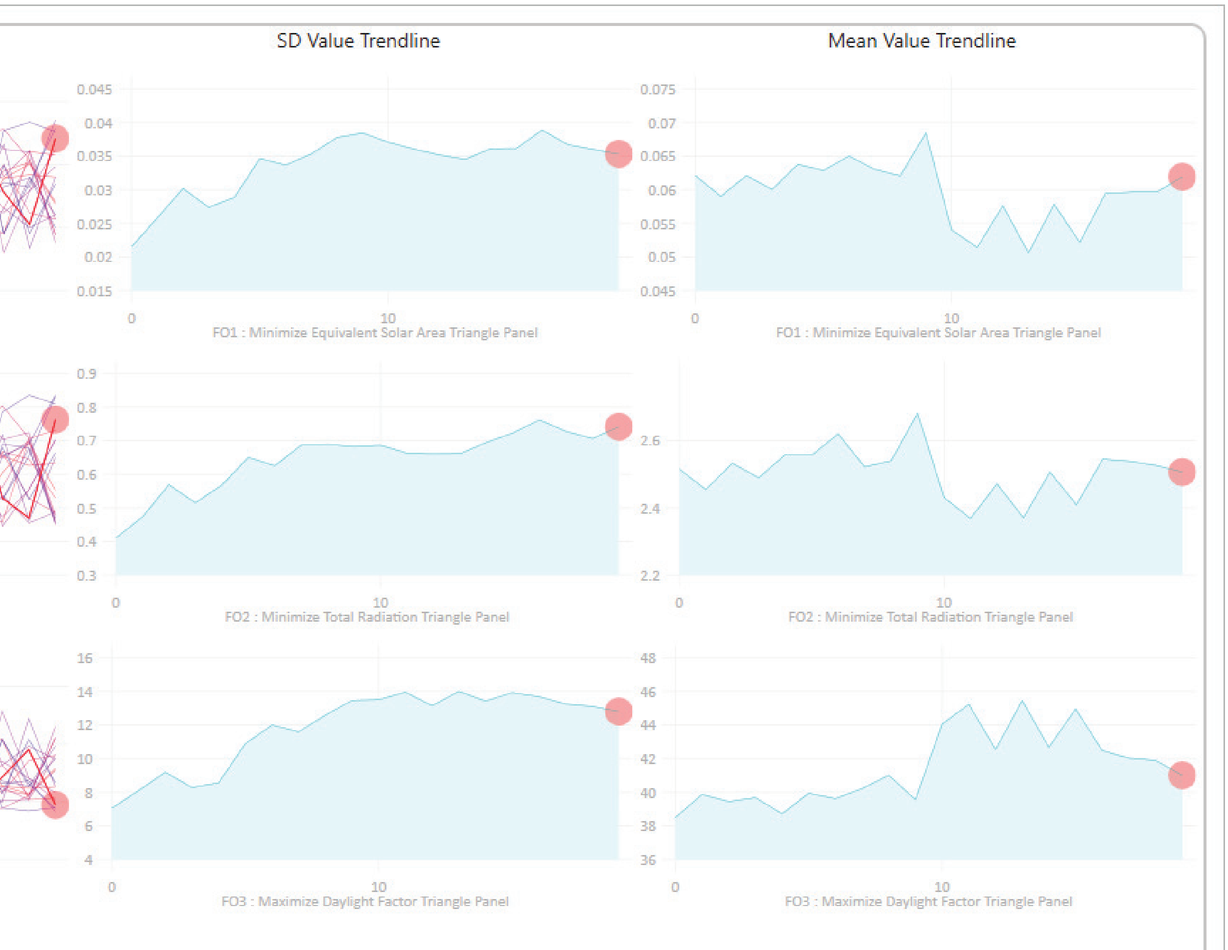
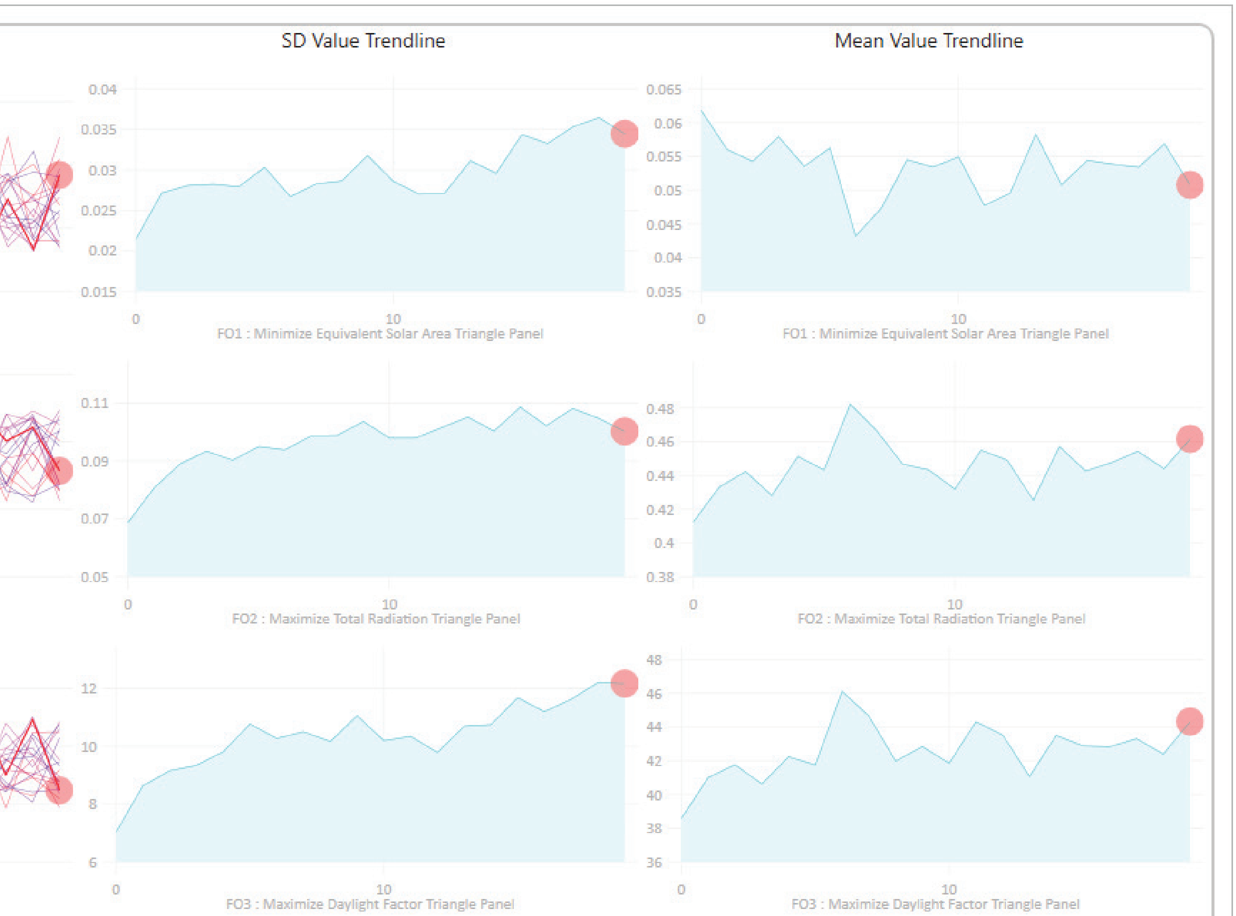
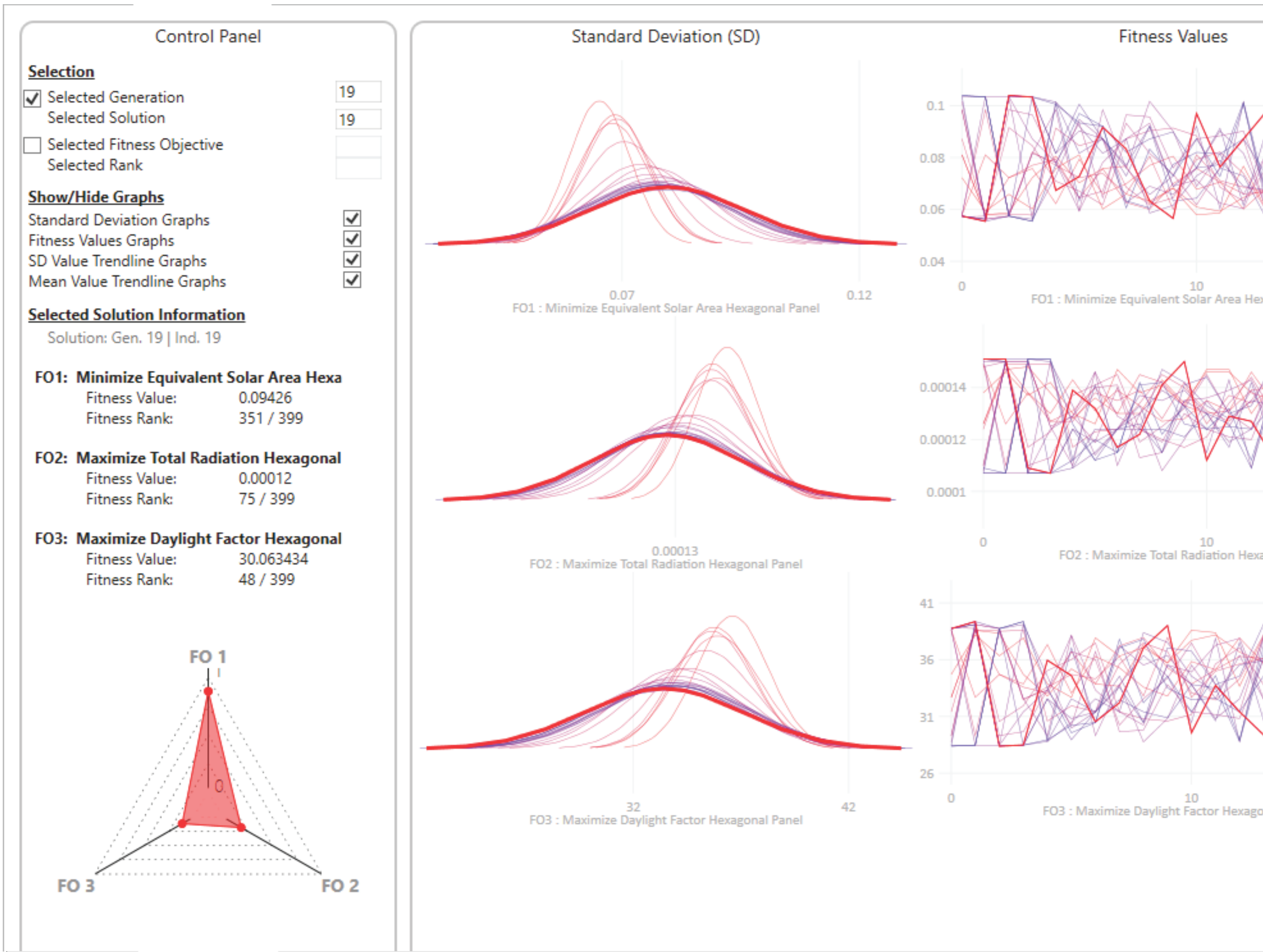
FO1 : Minimize Equivalent Solar Area Triangle Panel
FO2 : Maximize Total Radiation Triangle Panel
FO3 : Maximize Daylight Factor Triangle Panel



Trinary unit Analytics - Summer / Highlighting last generation 19-19



Trinary unit Analytics - Winter / Highlighting last generation 19-19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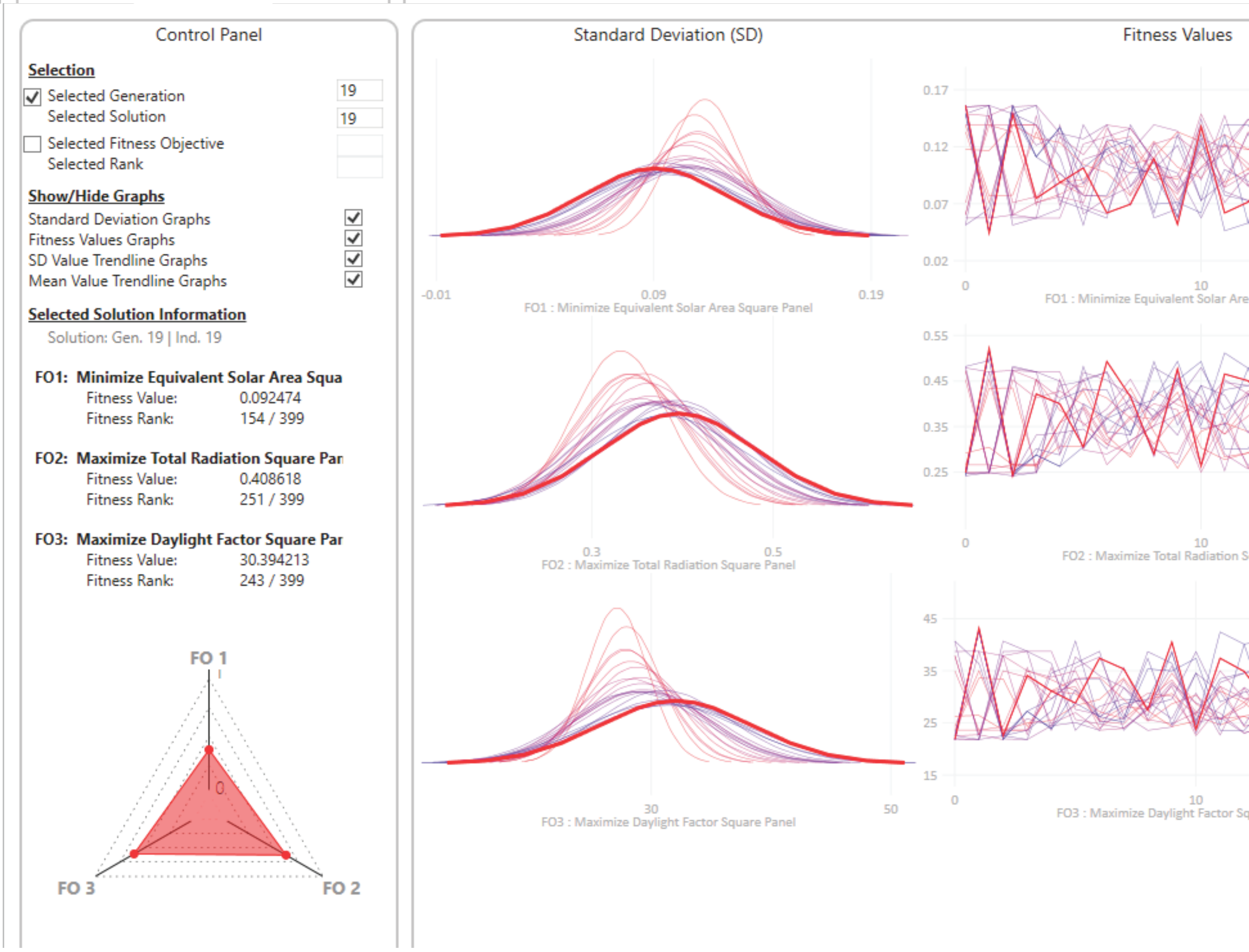
Standard Deviation Graphs
Fitness Values Graphs
SD Value Trendline Graphs
Mean Value Trendline Graphs
Selected Solution Information
Solution: Gen. 19 | Ind. 19
FO1: Minimize Equivalent Solar Area Hexa
Fitness Value: 0.09426
Fitness Rank: 351 / 399
FO2: Maximize Total Radiation Hexagonal
Fitness Value: 0.00012
Fitness Rank: 75 / 399
FO3: Maximize Daylight Factor Hexagonal
Fitness Value: 30.063434
Fitness Rank: 48 / 399
FO 1
FO 2
FO 3
Standard Deviation (SD)
0.07
0.12
FO1 : Minimize Equivalent Solar Area Hexagonal Panel
0.00013
FO2 : Maximize Total Radiation Hexagonal Panel
32
42
FO3 : Maximize Daylight Factor Hexagonal Panel
Fitness Values
0.1
0.08
0.06
0.04
0
10
FO1 : Minimize Equivalent Solar Area Hex
0.00014
0.00012
0.0001
FO2 : Maximize Total Radiation Hexa
41
36
31
26
FO3 : Maximize Daylight Factor Hexago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SD Value Trendline Graphs
Mean Value Trendline Graphs
Selected Solution Information
Solution: Gen. 19 | Ind. 19
FO1: Minimize Equivalent Solar Area Squa
Fitness Value: 0.092474
Fitness Rank: 154 / 399
FO2: Maximize Total Radiation Square Par
Fitness Value: 0.408618
Fitness Rank: 251 / 399
FO3: Maximize Daylight Factor Square Par
Fitness Value: 30.394213
Fitness Rank: 243 / 399
FO 1
FO 2
FO 3
Standard Deviation (SD)
-0.01
0.09
0.19
FO1 : Minimize Equivalent Solar Area Square Panel
0.3
0.5
FO2 : Maximize Total Radiation Square Panel
30
50
FO3 : Maximize Daylight Factor Square Panel
Fitness Values
0.17
0.12
0.07
0.02
0
10
FO1 : Minimize Equivalent Solar Are
0.55
0.45
0.35
0.25
FO2 : Maximize Total Radiation S
45
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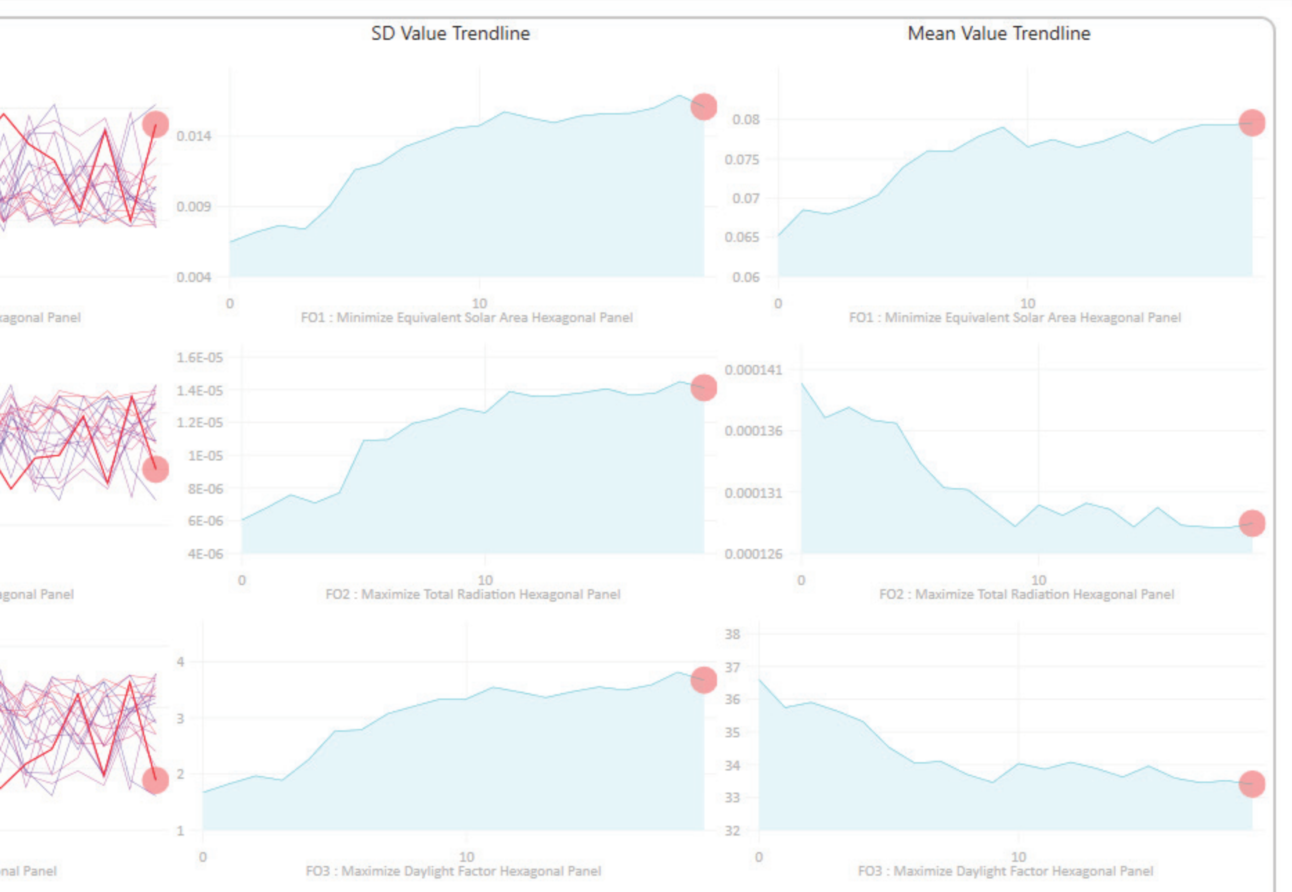
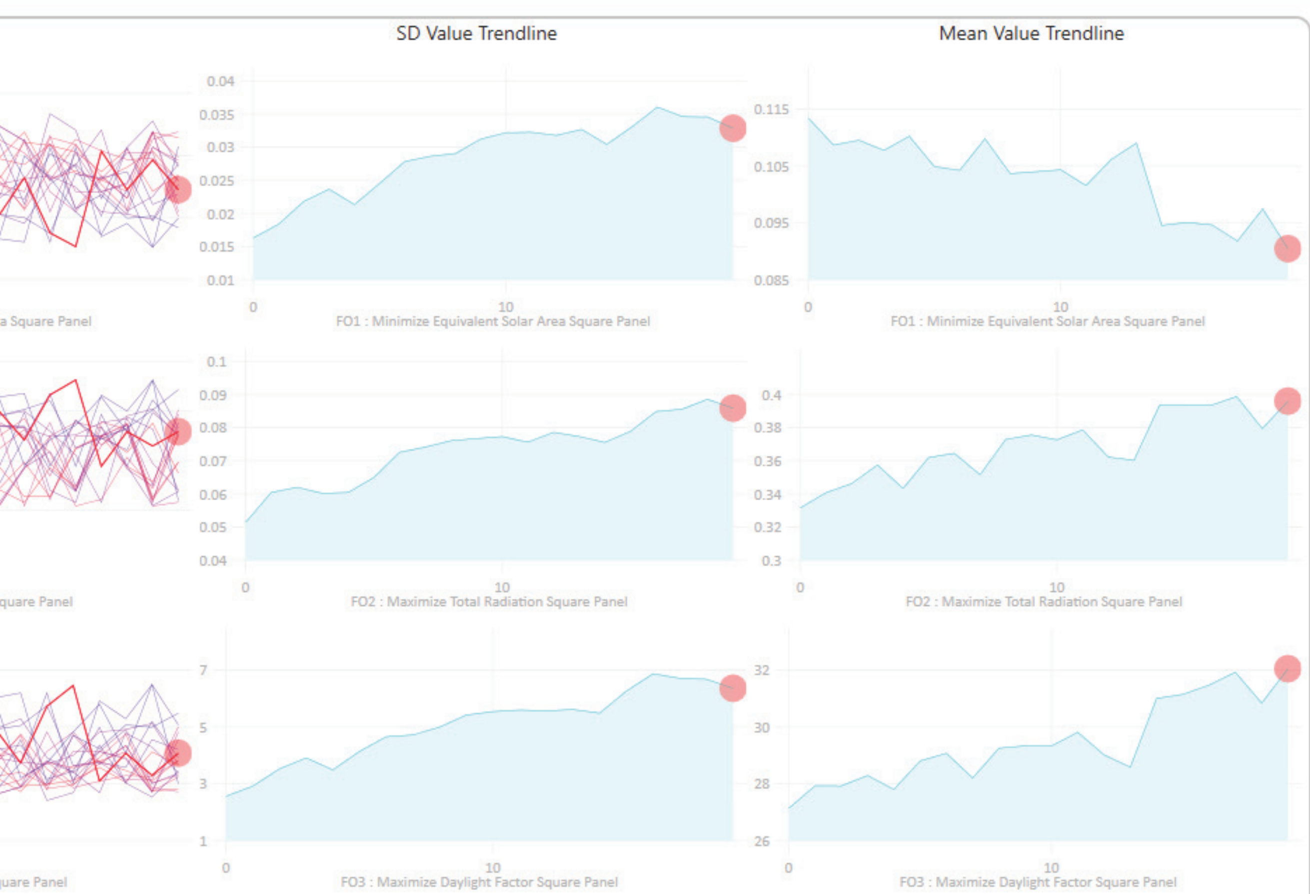
25
15
FO3 : Maximize Daylight Factor Sq



Quaternary unit Analytics - Summer / Highlighting last generation 19-19



Quaternary unit Analytics - Winter / Highlighting last generation 19-19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Standard Deviation Graphs
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Mean Value Trendline Graphs
Selected Solution Information
Solution: Gen. 19 | Ind. 19
FO1: Minimize Equivalent Solar Area Hexa
Fitness Value: 0.058364
Fitness Rank: 52 / 399
FO2: Minimize Total Radiation Hexagonal
Fitness Value: 1.897138
Fitness Rank: 103 / 399
FO3: Maximize Daylight Factor Hexagonal
Fitness Value: 38.470416
Fitness Rank: 347 / 399
FO 1
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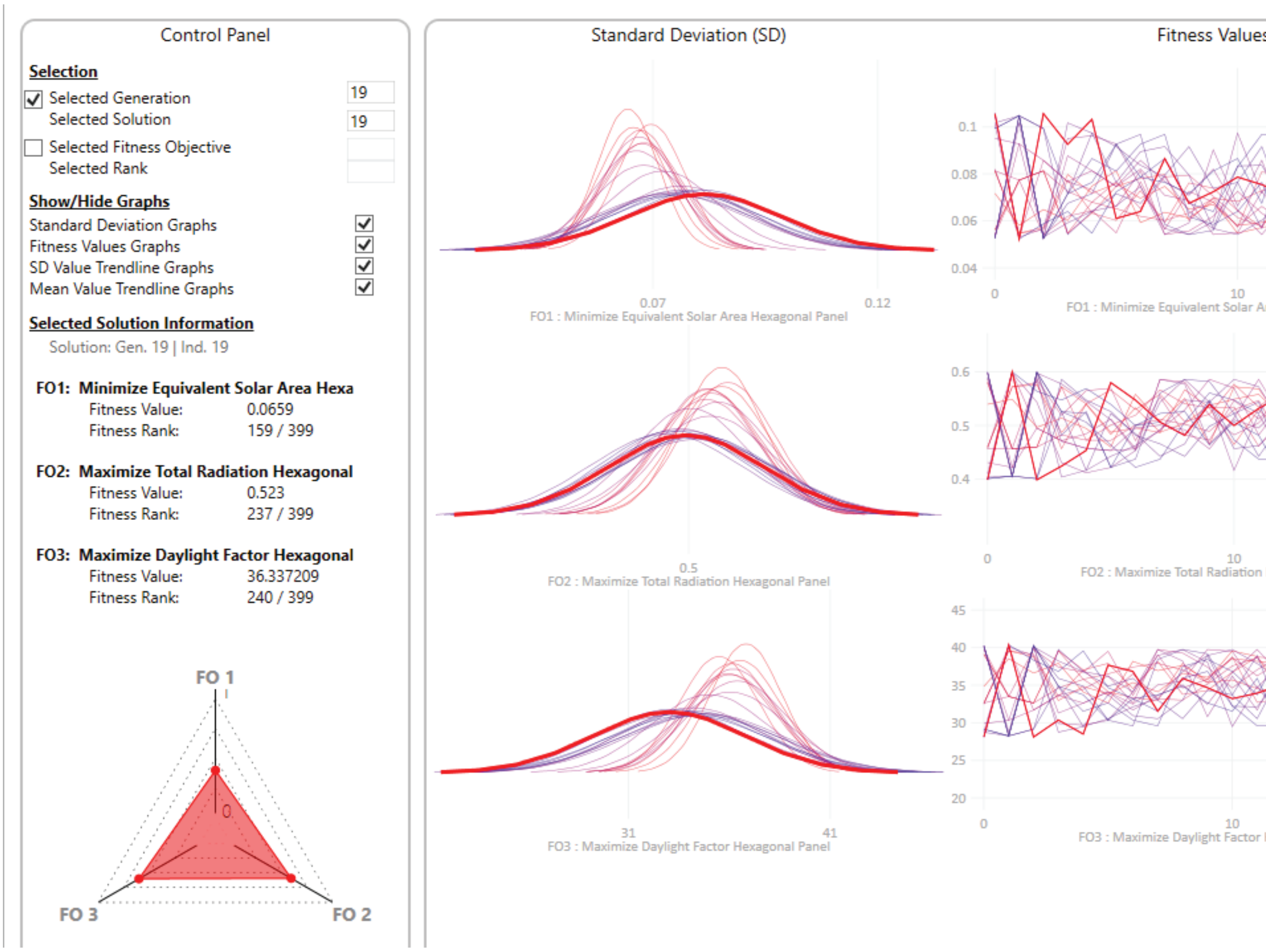
FO3 : Maximize Daylight Facto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Show/Hide Graphs
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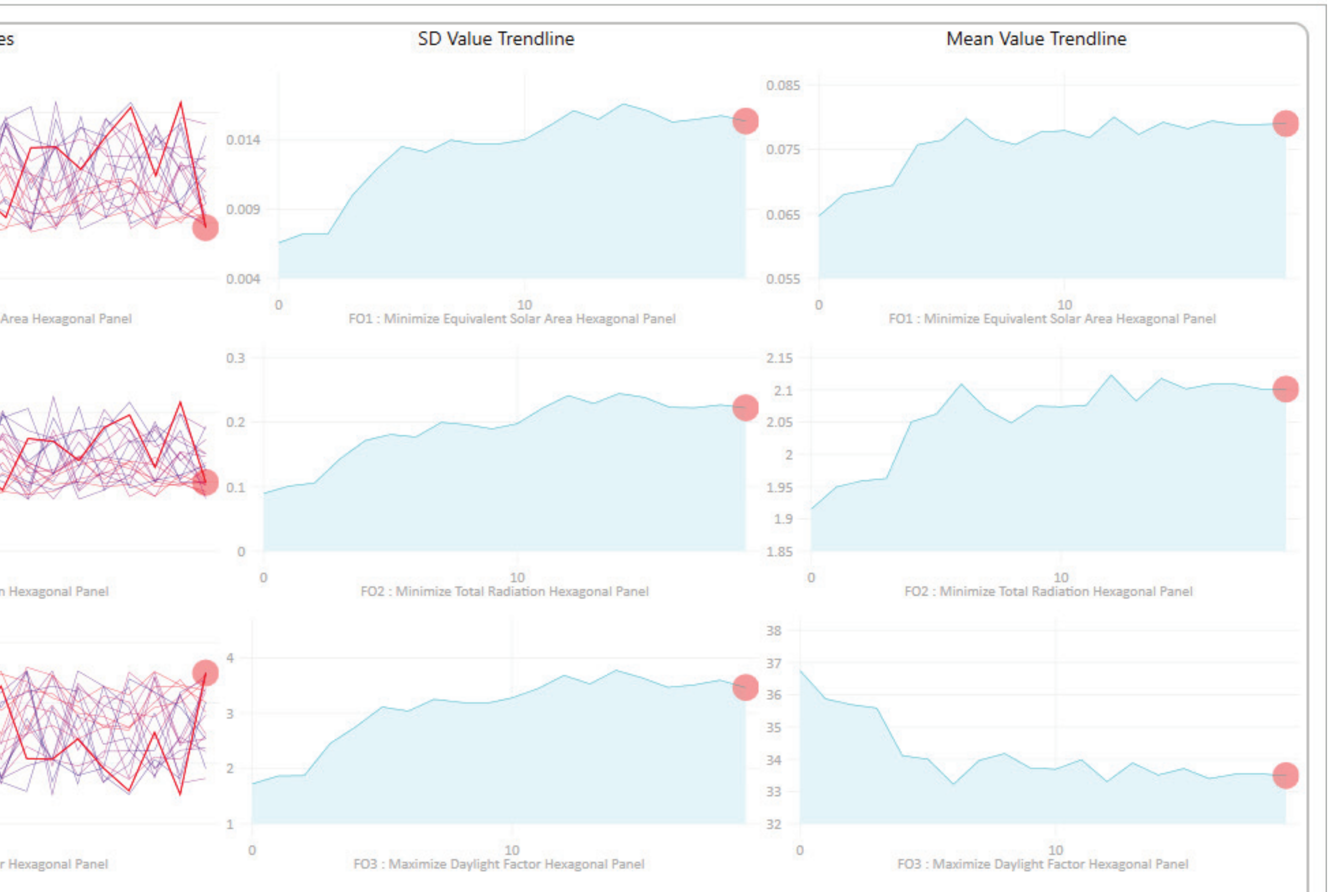
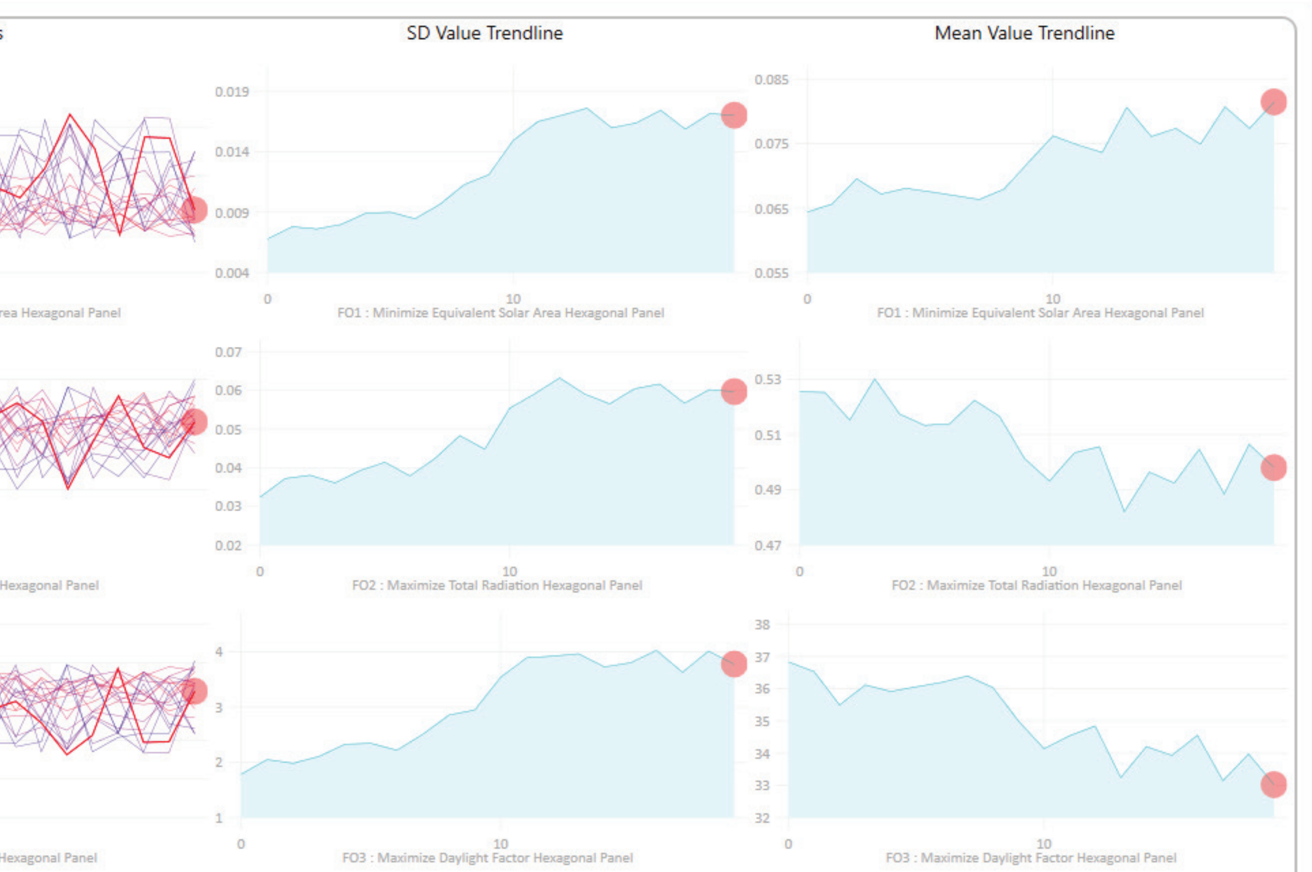
Mean Value Trendline Graphs
Selected Solution Information
Solution: Gen. 19 | Ind. 19
FO1: Minimize Equivalent Solar Area Hexa
Fitness Value: 0.0659
Fitness Rank: 159 / 399
FO2: Maximize Total Radiation Hexagonal
Fitness Value: 0.523
Fitness Rank: 237 / 399
FO3: Maximize Daylight Factor Hexagonal
Fitness Value: 36.337209
Fitness Rank: 240 / 399
FO 1
FO 2
FO 3
Standard Deviation (SD)
Fitness Values
FO1 : Minimize Equivalent Solar Area Hexagonal Panel
FO2 : Maximize Total Radiation Hexagonal Panel
FO3 : Maximize Daylight Factor Hexagonal Panel
FO1 : Minimize Equivalent Solar A
FO2 : Maximize Total Radiation
FO3 : Maximize Daylight Factor

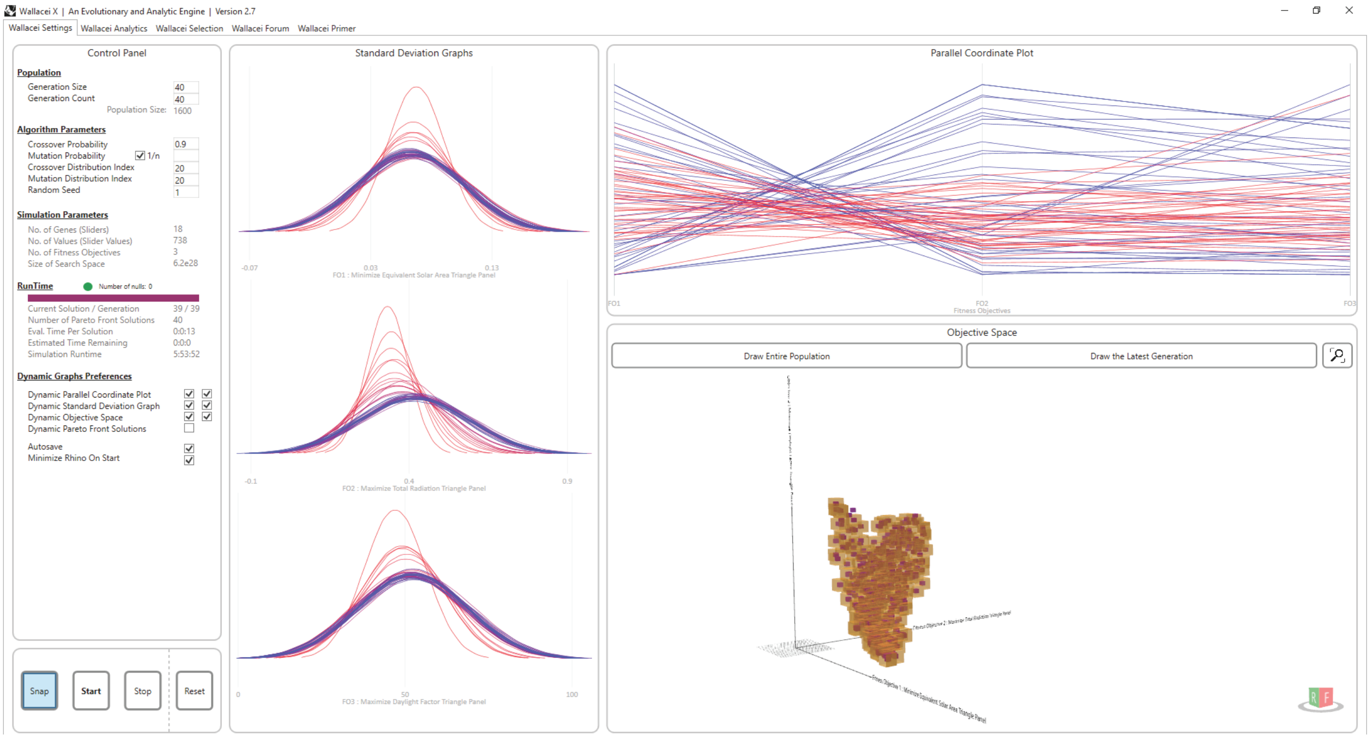


Hexa- unit Analytics - Summer / Highlighting last generation 19-19

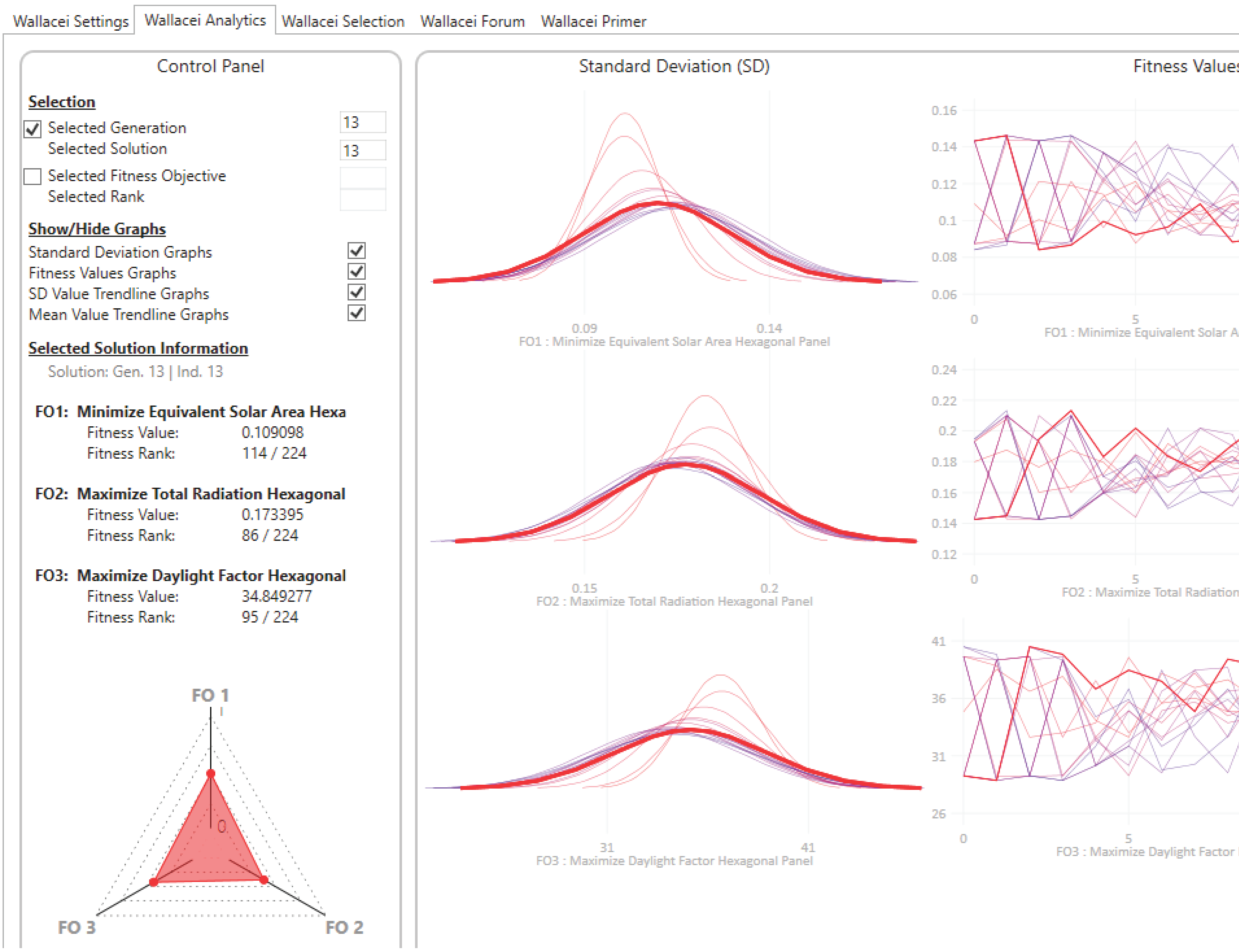


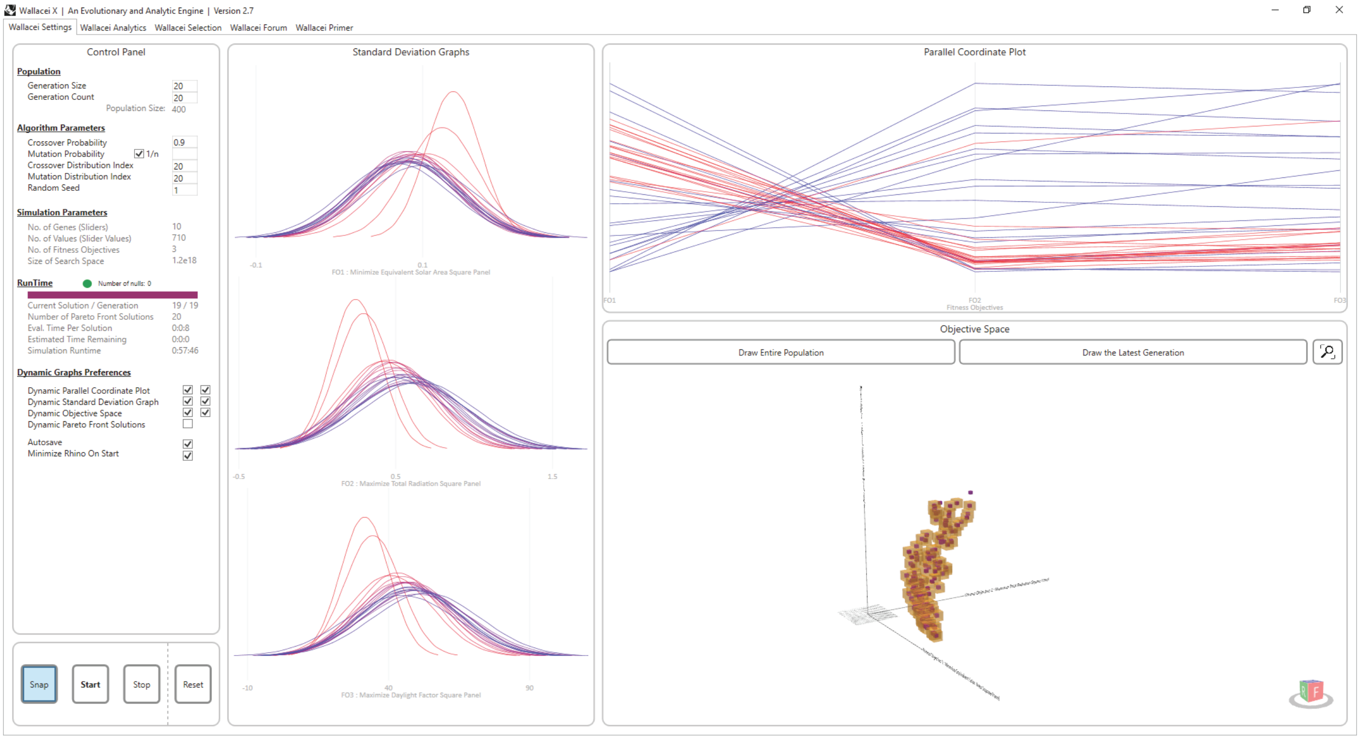
Hexa - unit Analytics - Winter / Highlighting last generation 19-19

OPAQUE curtains analytics samples (Failed results P. 146)



Winter coldest day - Trinary (Generation 40-40)





Winter coldest day - Quaternary (Generation 20-20)

Winter coldest day -Hexa unit (Generation 13-1.3)

7•4 Appendix 04

The following appendix works as a part of Revir API usage code helps to get information in BIM environment (Revit) Which helps the interoperability of different softwares, as is also a step towards automating the entire workflow mentioned in Chapter Five (Applications)

The manifst file

```
<?xml version="1.0" encoding="utf-8" standalone="no"?>
<RevitAddIns>
	<AddIn Type="Command">
		<Name>MyRevitCommand</Name>
		<Assembly>LAB1.dll</Assembly>
		<AddInId>6DB9FD48-6106-416D-B131-082A44EB7AA5</AddInId>
		<FullClassName>LAB1.Class1</FullClassName>
		<Text>MN GET ID </Text>
		<Description> GET ID</Description>
		<VendorId>MNAGY</VendorId>
		<VendorDescription> Mahmoud N. Elsayed</VendorDescription>
		<VisibilityMode>NotVisibleWhenNoActiveDocument</VisibilityMode>
	</AddIn>
</RevitAddIns>
```

The CALSS file in c#

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using Autodesk.Revit.UI;
using Autodesk.Revit.DB;
using Autodesk.Revit.Attributes;
using Autodesk.Revit.UI.Selection;

namespace LAB1
{
  [TransactionAttribute(TransactionMode.Manual) ]
  public class Class1 : IExternalCommand
  {
```

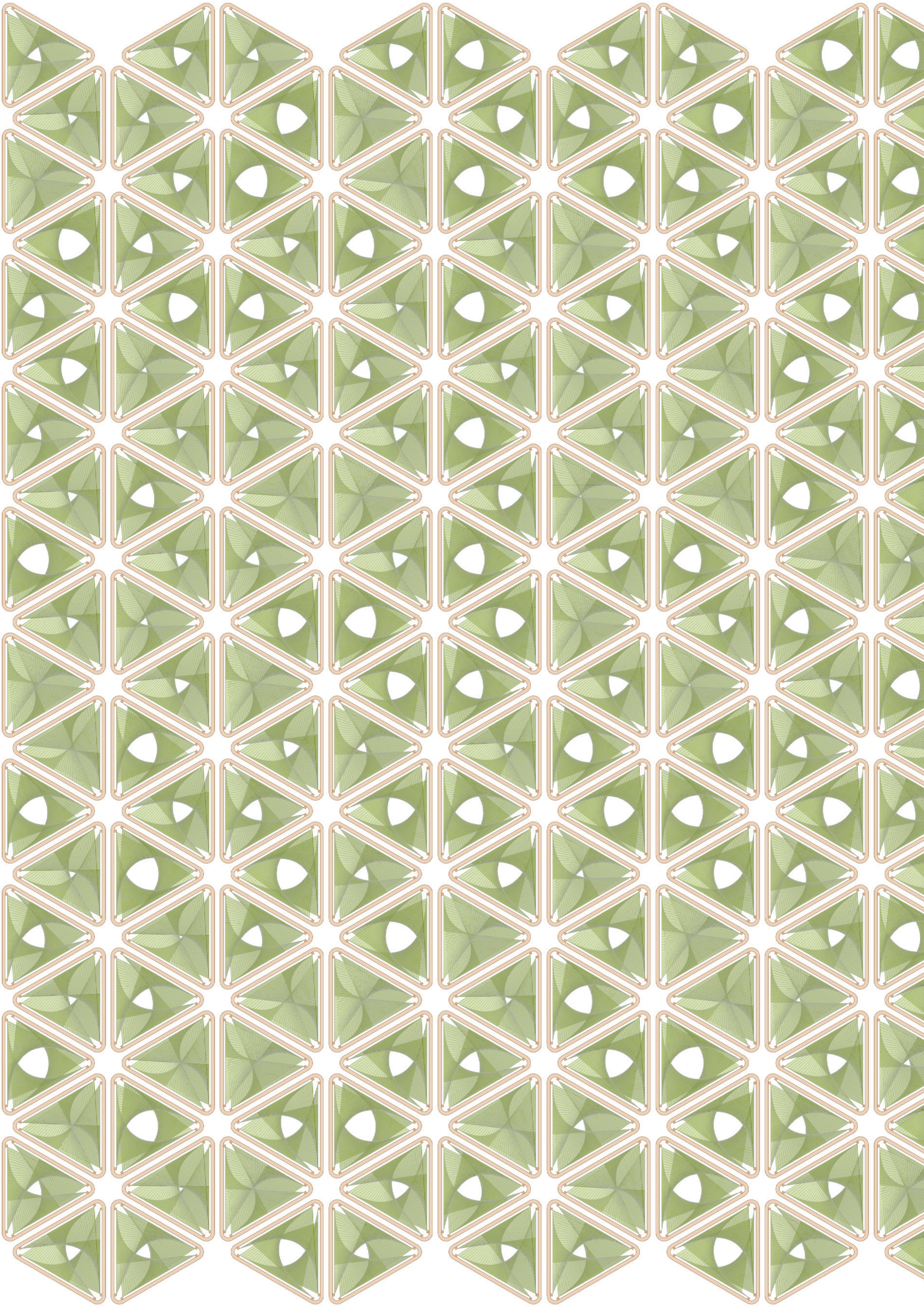
```
            public Result Execute(ExternalCommandData commanData, ref string message,
ElementSet elements)
        {
            // TO get the active document
            UIDocument uidoc = commanData.Application.ActiveUIDocument;
            Document doc = uidoc.Document;

            // selection to pick object
               Reference reference = uidoc.Selection.PickObject(ObjectType.Element, “pick an
object - iti”);
            //ElementId eID = reference.ElementId;

            //Get Element
            //Element element = doc.GetElement(reference.ElementId);
            Element element = doc.GetElement(reference.ElementId);

            // Get Element type
            ElementId eTypeId = element.GetTypeId();
            //Element eType = doc.GetElement(eTypeId);
            ElementType eType = doc.GetElement(eTypeId) as ElementType;

            TaskDialog.Show(“Element Information”,
               “ElementID  : “ + reference.ElementId.ToString() + Environment.NewLine +
               “Category   : “ + element.Category.Name + Environment.NewLine +
               “Instance   : “ + element.Name + Environment.NewLine +
               “Symbol     : “ + eType.Name + Environment.NewLine +
               “family     : “ + eType.FamilyName);

            return Result.Succeeded;
        }
    }
}
```

The path needed to setup the plugin

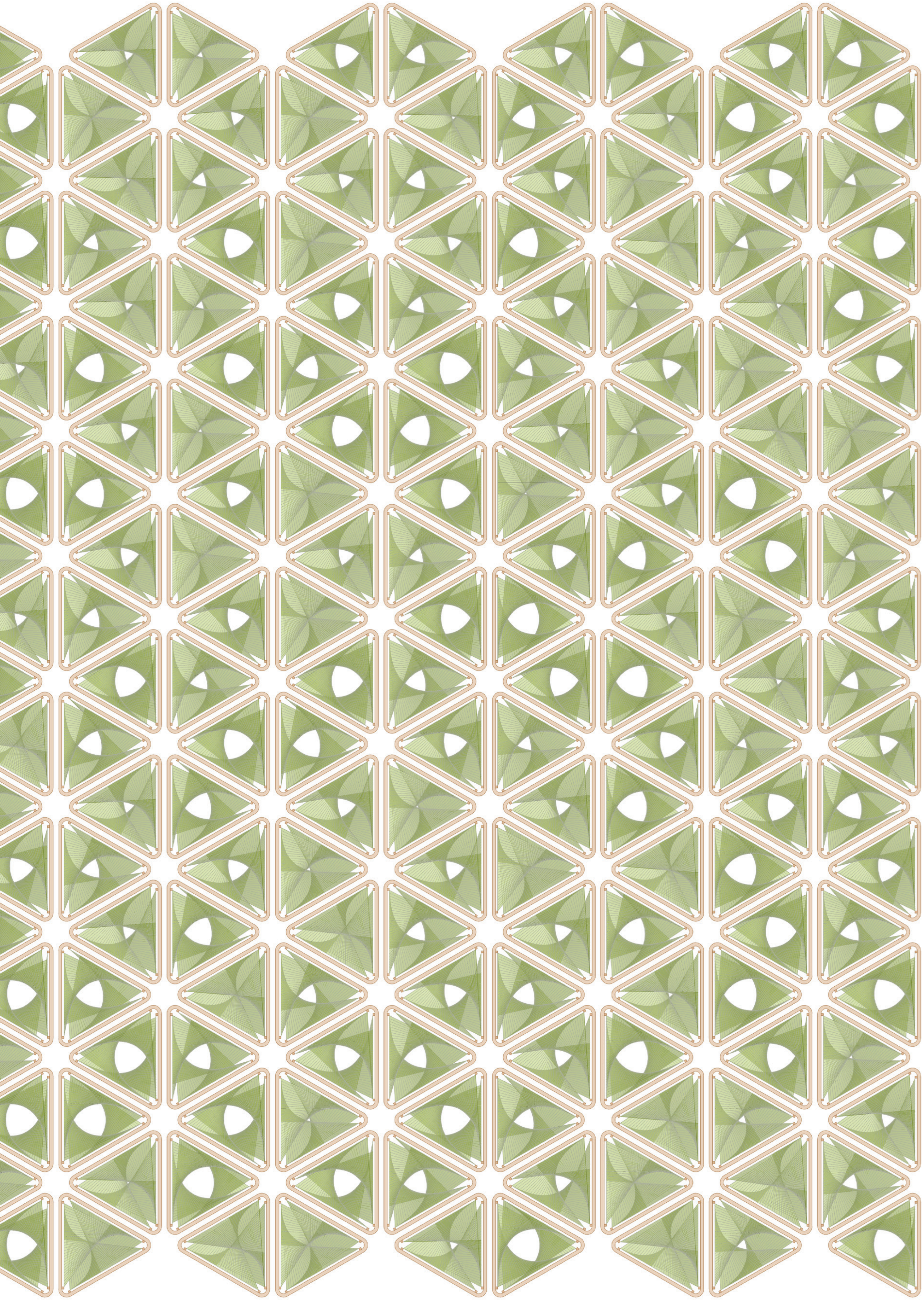
C:\Users\ma7mo\AppData\Roaming\Autodesk\Revit\Addins\2022

7•5 Appendix 05

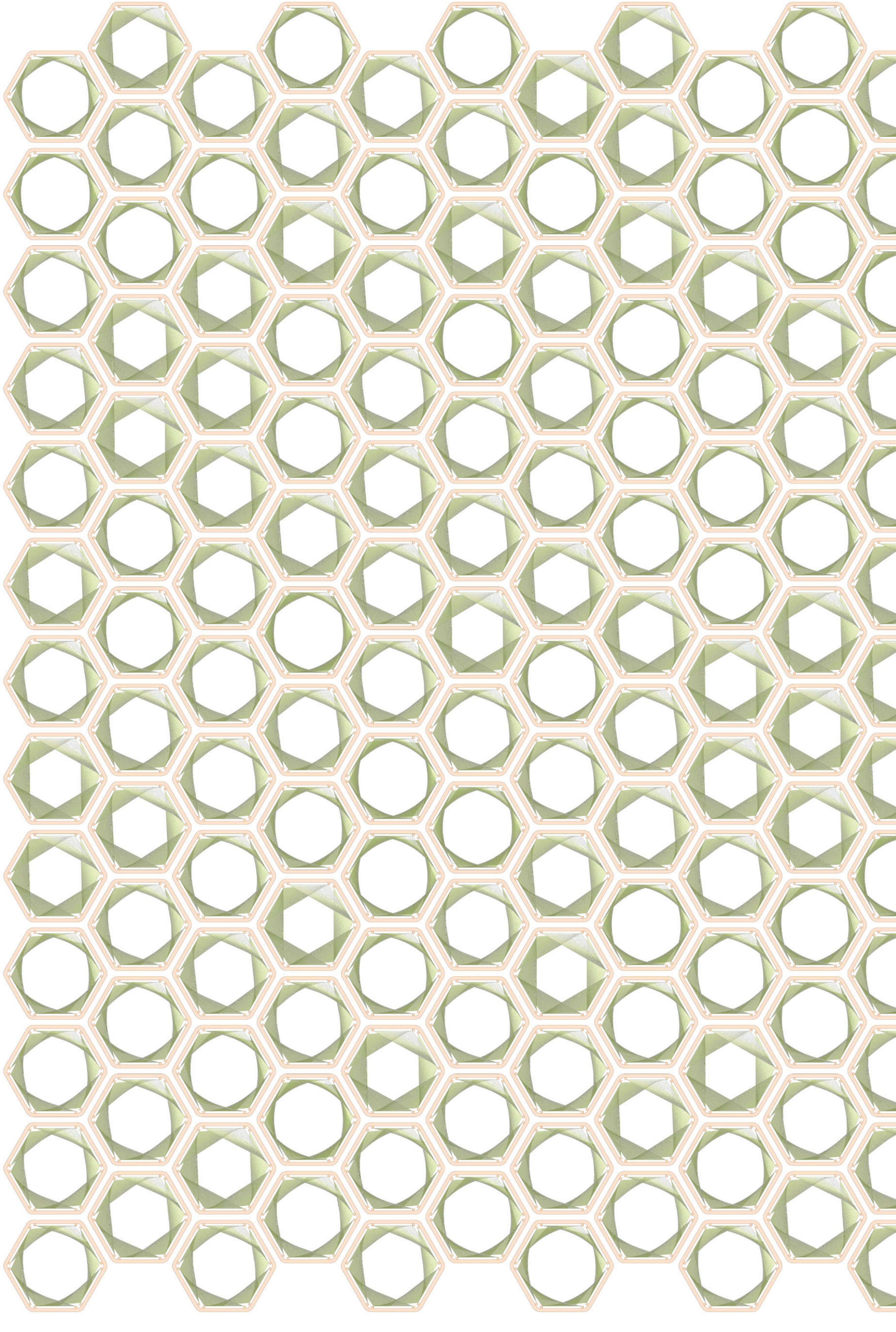
The following appendix shows a graphical representation of an array for a random optimized units



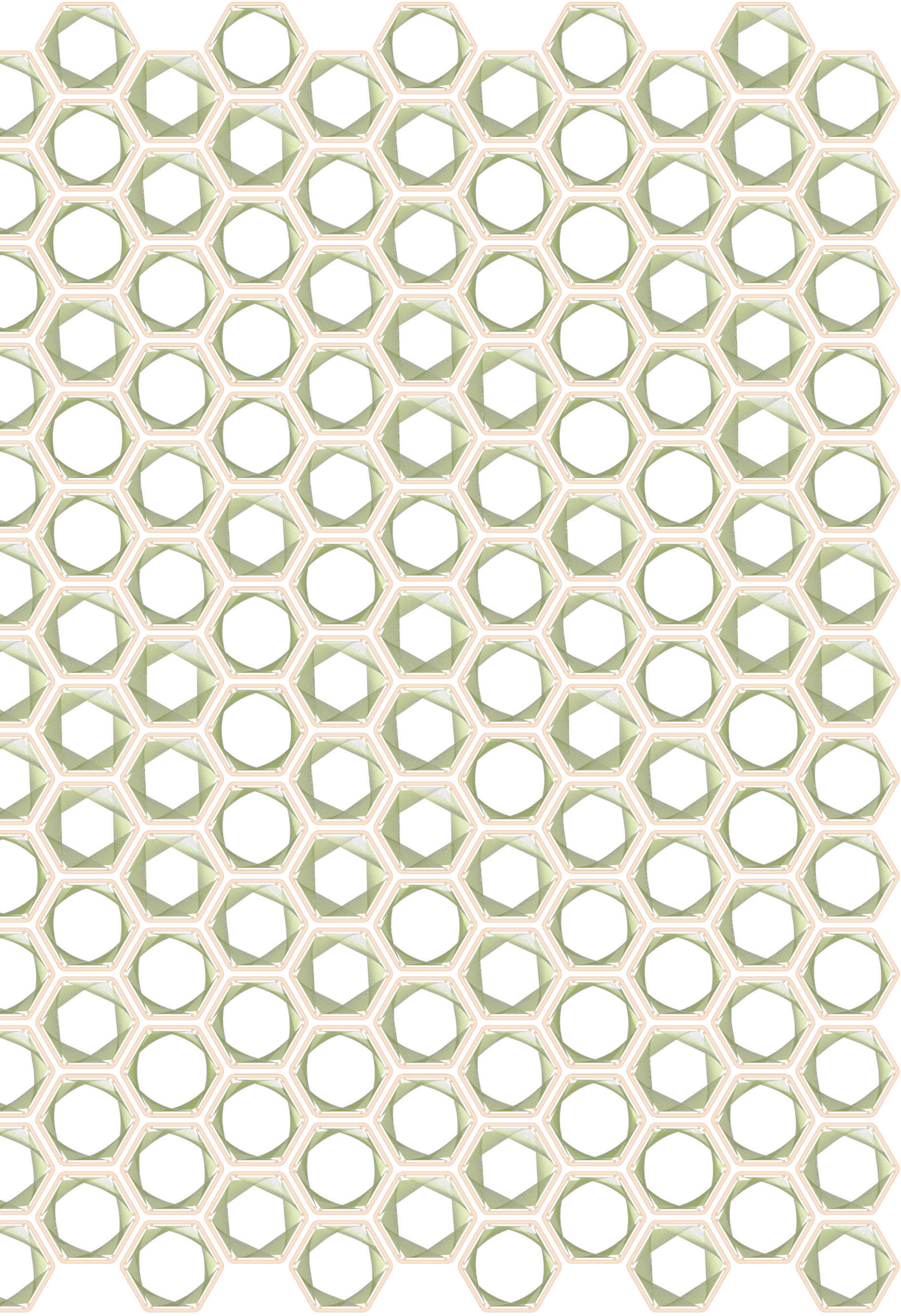
Figure, Trinary unit array with various optimized ranges.



Figure, Quaternary unit array with various optimized ranges.



Figure, Hexa - unit array with various optimized ranges.



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