DESIGNING WITH AUTONOMOUS RELATIONSHIP PROPERTIES OF COMPLEX SYSTEMS

A parametric approach to achieve building sustainability

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Tesi di Laurea Magistrale Architettura Costruzione e Città

Designing with autonomous relationship properties of complex systems: a parametric approach to achieve building sustainability

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CHAPTER ONE

complex system in Architecture

WHAT DO WE MEAN BY BUILDING?

When we think of a building, we generally think of a kind of structure with walls and roof made of certain material and that are occupied by people. However, how states Duccio Turin in his inaugural lecture at the University College of London in 1966, buildings are different form every other product, indeed they are "unique, complex, fix, bulky, costly, lasting, related to their site characteristics -climate, materials, people and availability of technical skills" (1).

The complexity intrinsic in a building can be perceived just thinking about how every product that is part of it has its own supply chain and delivery process. But also can be seen how buildings generate an impact on the environment (not only the site where is located, but also all factors related to materials supply chain), on the social perception of the space, and so promoting inclusiveness or exclusiveness and also by an economic point of view, where benefits or losses are generated. This is because buildings are a container for spatial activities, that generates impacts on the surrounding system, and also the building itself interface with the social, environmental and economic context. In this way, a building has not to be perceived as a primary need satisfaction or just a structure that contains people, but more as something that, through a strategic development, could generate social, environmental and economic benefits, by regenerating abandoned areas, giving a cultural identity to space and promoting innovation.

1. Duccio A. Turin, *What do we mean by building?*, Habitat International, Volume 5, Issues 3–4, 1980, Pages 271-288

LET'S COMPLICATE THINGS

When we talk about complexity a precise definition cannot be given, since several debates are still going on about this definition, even if, this "new" science has been the object of a lot of attention in the last years, with a steady growing output of papers. Of course, the first place to search is the dictionary or the web, where complexity in a physical system or dynamic process is defined as the degree to which components engage in organized structured interactions (2). Williams (3) state that, even is a really used word in last times, it has not a widely accepted clear definition, if not "as something that is more than a simple "big" project (3). Baccarini (4) proposes a definition by operationalizing it terms of differentiation (the number of varied elements) an interdependency (that's the degree of interrelatedness happening between these elements) and applying it to different project process dimensions. Since these different definitions are not widely recognized, most of the time, the literature talks about what complexity isn't more than what it is, often using also examples.

2. Defintion by Olaf Sporns, professor at Indiana University, Bloomington, IN
3. T. M. Williams, *The need for new paradigms for complex projects,* University of Strathclyde, Glasgow, UK, 1999
4. Baccarini D., *The concept of project complexity review,* International Journal of Project Management, 1996, Pages 201-204.

Independently from the definition of what a complex system is, it can be said that is more a way to look to a system as a whole without simplifications and observing the relations that happens between the constitutive elements. This approach allows discovering behaviours and characteristics that aren't inherent to the single elements of the system. (5)

It can be argued that the study of complex systems is something that's going on from hundreds of years, but the definition of a proper science studying them is relatively young. Of course it may depend on the subject inherent to this type of study: for instance, mathematics is one of the first fields where this theory has been started to be studied, where the discovery of chaos theory and neural networks gave a boost to the interest towards this field. In chemistry, the works of Hartree-Fockabout the molecules structures and quantum-chemistry equations opened the door to the study of complexity. However, the first signs of modern complexity theory can be found in the classical political economy of the 18th and early 19th century in Scotland (the so-called Scottish Enlightenment) developed subsequently by the Austrian school of economy.
But it's with the turn of the 20th century, with the work of Friedrich Hayek, economist and philosopher and winner of Nobel prize, where he studied the complex phenomena not only in the economic field but also by biological, psychological point of view. With the advent of the 1970's the science of complexity became explicit and in 1984 the first research institute to study it was founded in Santa Fe. Today over 50 institutes are scattered all over the world studying complex system, and every year the Complex Systems Society organize a conference about this topic.

One of the very first issues studied by this science are the characteristics owned by these types of system. Even if a lot of studies and papers have been published, the milestone work that analyzed the characters typical was published by Chris Lucas with a paper called "The philosophy of complexity" (6) where eighteen characteristics were listed.

By looking at his list is possible to notice how the major of them can be split into three different Macro groups: autonomous agents, undefined values and non-linearity.
Autonomous agents are independent elements that mainly constitute the base for a complex system.

Generally, they obey to each own rules or local laws but co-evolve to assure the survival of the system and adapt it to the surrounding environment. This means that the properties can emerge during these changes and that new relationships could be created, as old ones could die. Furthermore, complex systems are not linear meaning that the number of outputs is not equal to the inputs, indeed the sum of the properties is not equal to the properties of the whole system, because of relations between the agents are taken in account.

Finally, complex systems are non-standard since relationships between space are varying across time, allowing a change in shape and general or local behaviour. This is the way of a complex system to answer to the environment. Indeed, the system interface is not just defined but change over time and to be mapped an evaluation of the evolution of the system has to be done. This is called fitness landscape, and it is the same concept at the base of genetic algorithms. (5)

5. Bertelsen Sven, *Construction as a Complex System*, proceedings for the 11th Annual Conference of the International Group for Lean Construction, 2003
6. Lucas C., The Philosophy of Complexity, www.calresco.org/lucas/philos.htm, 2000

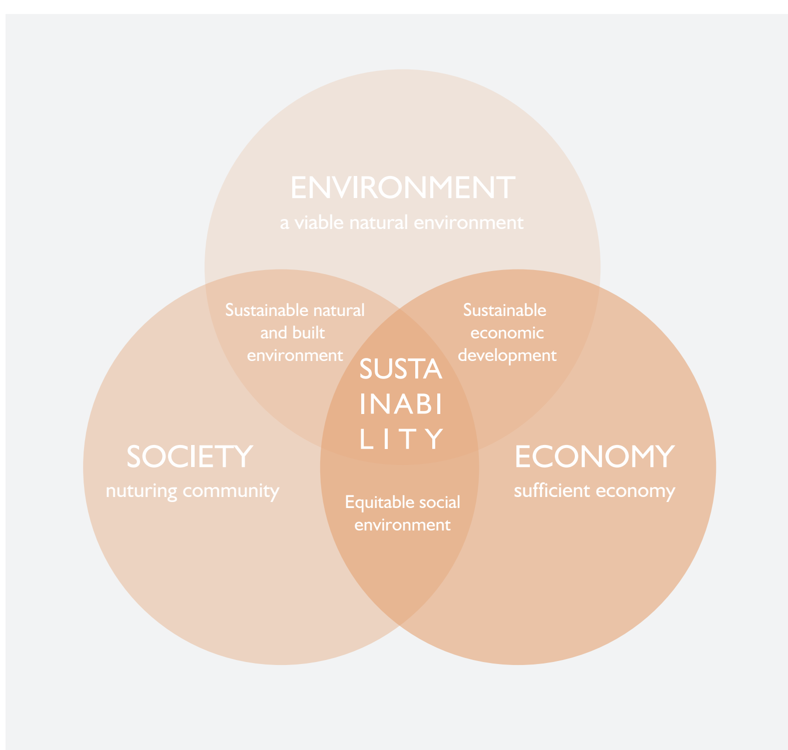
TREE SHADES OF SUSTAINABILITY

There exist several definitions of what sustainability is, but the most used is the one indicated in the Brundtland Commission report of 1987 where a sustainable development is the one "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (7). This document was the first institutional measure to focus on conscious development. It proposes a long-term strategy to achieve a sustainable development for the 2000 and beyond, to consider it as an international cooperation goal and problem and to help to define shared strategies to deal with major environmental problems.

One of the next institutional steps in this way was the "millennium development goals", where eight targets were listed and to be achieved by 2015. Between those, there was one about assure environmental sustainability. In 2005 a millennium ecosystem assessment was published by the United Nation and concludes that human actions have depleted Earth's natural capital such that the survival of future generation cannot be longer granted since the intense consumption of Earth resources.
One of the last agreements for a global effort in defending the environment was the Paris Agreement of 2016. Was promoted again by the United Nation with the target to deal with greenhouse-gas-emissions mitigation, adaptation, and finance, starting from 2020.

Even if the major institutional efforts are focused on the environmental sustainability, it's widely recognized that the concept of sustainability has three dimensions: social, economic and, as just said, environmental.

7. *United Nations General Assembly Report*, 1987, Page 4



This conception was identified by the World Summit on social development in 2005, where these three aspects were considered not exclusive one from the others, but that can be mutually reinforcing.
In this way, the concept of development become a concept with a wider significance and intend as a set of organizing principles to meet human goals but in the same time sustaining the natural system to provide resources and services upon which the society and related economy depend.

MAKING A CAKE

As cakes need ingredients to be done, sustainability, building and complex system are the main ingredients for this work. Indeed buildings can be seen as a complex system since the different phases and actors coming into play during the whole life of the building itself. A proof in this way is the fact that during the design phase a simple choice can affect social, economic and also social aspects of the whole fabric.

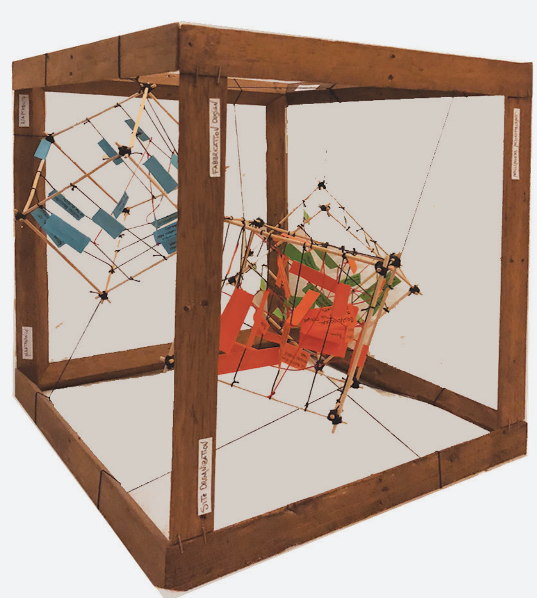
Saying that it's possible to assert how the objective of an architect is to understand the implications of design and construction decisions on social, economic and environmental fields. The main approach to evaluating how design and construction choices affect the three spheres of sustainability has been done by a downstream point of view.

This is made by mapping the characteristic elements of the building in the construction and design phase and try to understand how the choices or actors involved in these processes have influenced the results and building behaviour in these three fields. An overview of this method is shown in "Complexity theory as an epistemological approach to sustainability assessment methods definition" (8) paper. Here a methodology is proposed by mapping the constituting elements of the complex system, both in design than in construction process, and then by analyzing their impact in terms of sustainability. To do this a scale of values are introduced for an assessment of these effects and, thanks to this translation in numerical terms, effects can be visualized both in terms of which type of is more predominant than which category has mainly influenced building behaviour.

The aim of this work is trying to revert this process of evaluation by mapping typical relationships happening between elements of the building intended as a complex system and using them as a design tool to achieve sustainability in an environmental, social and economic way. The idea is to create a workflow, the most as automatic as possible to help the designer managing behaviour and aspects that are not proper of the single element itself but emerged by putting those in relation. Furthermore, the workflow should be the most linear as possible, in the sense that no complicated interaction with the definition should be taken and also should guarantee an easy translation from the concept modelling to the creation of architectural valid architectural drawings and model. Doing that should also allow enlarging the research field and the potential of this methodology. In order to achieve this target, an integrated approach is required since the need to understand how the elements influence each other and develop a strategy to satisfy multiple targets at the same time.

8. Nigra Marianna, *Complex theroy as an epistemological approach to sustainability assessment method definition*, proceedings for the 21th International Conference of engineering design, 2017


Resource assembly
Stakeholder definition
Building scope formulation
Program assembly
Space boundary assembly
Performance assembly
Building scope formulation
Specification assembly
Procurement design
Builsing system design
Operation design
Project definition and control
BUILDING DESIGN
Building production
Construction design
Project design
Fabbrication design
Manteinance design
Building functioning
Building erection
Site design
Change design
Assembly erection design
Use design
Testing design



CHAPTER TWO

competition brief

DAR AL ULOUM LIBRARY

Dar Al-Uloum library is situated in the city of Sakaka in AL Jouf region in Saudi Arabia. The library was built in 1963 and was the first in the kingdom to have a dedicated part for women. By now, it hosts a collection of 150.000 books (mainly written in Arabic) on a surface of nearly 4.500 square meters.
The competition is aimed to up to date the library in terms of programs and services and connects it with the surrounding, in order to create a holistic campus. The new building has to answer to connectivity and inclusion problems from a social point of view and at the same time, to care about energy efficiency and environmental awareness.

THE CAMPUS

The site is located in the north district of Sakaka, mainly made up of public buildings and open spaces, such as educational facilities (primary and secondary school), hotels, public plazas, Prince Abdullah Cultural Centre and civic buildings.
The design extent of the competition encompasses the parcel of land bordered by King Fahd Ibn Abdulaziz Rd, the Al Rahmaniah Mosque, and Al Rahmaniah Girls School along Al Malik Abdulaziz Rd. All the site boundaries are enclosed with a fence that's only open at the library entrance, where there are also two security checkpoints.
Dar Al-Uloum Library is situated in the centre of the site and is bordered by the Al Rahmaniah Girls School to the West, the Park Library, Workers Accommodation and Engineer's Office to the North, and the Al Rahmaniyah Mosque and Ablution Building to the East.

DESIGN GUIDELINES

The space program is not to be intended as fixed but can be adjusted and changed according to the design team. Regardless it, all spaces should answer to the need of flexibility both in short than long timescale. A special attention should be given to open and green areas, seen as an extension of the services provided by the library, as for the pedestrian connection between the different buildings of the campus.

The library spaces could be divided into four main categories:

PUBLIC SERVICES	WORK AND LOUNGE SPACES	ADMINISTRATION & STORAGE

PUBLIC SERVICES

These spaces are intended to provide and enhance the perception of the library as a cultural centre where is possible to share knowledge, consume and produce media and improve the experience of visitors with easily accessible facilities.

65 m^2

VESTIBULE

A vestibule is a small transition room before the lobby. It may contain an information desk.

140 m^2

CAFE

The café should provide both indoor and outdoor seating options and have the capability of operating outside of the library's hours. The intent of the cafe is to provide a casual area where visitors are encouraged to read or observe their children playing in the garden.

80 m^2

PRAYER ROOM

An acoustically separated space dedicated for daily prayers.

110 m^2

GALLERY

The gallery can feature both permanent and temporary exhibits, ranging in topic from archaeological finds to the work of contemporary artists, designers, and writers from the region. It should be a space that can be easily modified and equipped with modern exhibition technologies.

500 m^2

ENTRANCE HALL

The entrance hall must be wide enough to accommodate the movement of visitors. This area should serve as an informal meeting point, intended for socializing, in which visitors can have access to the Internet, read a newspaper or a magazine, and meet with friends.

500 m^2

AUDITORIUM

The ever growing area of film can be a realm that libraries choose to add to their collections to help preserve but also promote new releases. Part of that preservation might be to provide the facilities capable of screening 35 and 70 mm films, in addition to digital films. The auditoriums can become multiple purpose and also provide additional conference space, as the once that are currently held.

44 m^2

RETAIL

A retail space or bookstore, can be a space for visitors to purchase reading material but also a space for local crafts people to display and sell their work. In such a way the bookstore can support and promote local heritage and craft.

9.250 m^2

PARKING

The parking requiremnet is to be determined by the municipality. There is a possibility of consolidating library and mosque parking. The parking area should be well integrated with the design of the campus. Above or below grade parking is at the discretion of the design team.

44 m^2

PERSONAL STORAGE

Personal storage / lockers are often situated in or near the lobby to allow visitors to leave personal items, such as bisht cloaks, abayas, prams and other items in a secure location. This prevents food and beverage from entering the reading zones, as well as gives visitors more flexibility in their library use.

136 m^2

TOILET

Separate restroom facilities with individual stalls shall be provided for men and women. Accessible stalls shall be present in both, in addition to infant change stations.

9.500 m^2

GREEN AREAS

The design of green areas should encourage pedestrian traffic throughout the campus, and the landscaping should have an open and welcoming atmosphere. Entrances to the complex shall be similarly open and apparent. Increasing pedestrian traffic within the site should compliment the design of reflective and quiet spaces. Larger open areas should be considered for outdoor festivities.

WORK AND LOUNGE SPACES

The aim of the new spaces is to promote the shift to a library as an inclusive platform for sharing knowledge between visitors and the local community. In addition to this, all media collections are openly accessible, that means that work and reading areas are intertwined with bookshelves and other media storage systems. Lounge and study areas are to be both open than close in order to create a different kind of spaces that can fit all kind of need.

500 m^2

CHILDREN ZONE

It should be a safe and playful space for children to socialize and learn through play. It will contain a children's collection of books, a work station, play and reading area. Organized activities, plays or learning sessions should be expected to make use of the space, with children safe equipment available.

130 m^2

CLASSROOMS

The shared library area should have 2 classrooms of 50 sm for 24 students and 1 classroom of 30 sm for 18 students. These spaces can be used for seminars, book clubs or classes (such as TOEFL training, English classes, as an extension of the University or Primary and Secondary Schools' lectures, etc.)

120 m^2

TEEN ZONE

The teen zone is intended for use by young adults in grades 6-12. Its purpose is to centralize the information and recreation resources of youth in this age group while offering them a safe, supportive, and positive space that is uniquely their own. The teen zone features a space for gaming as well as a space for digital learning and media creation.

90 m^2

DIGITAL INNOVATION SPACE

A digital technology space is a platform not only for sharing tools and resources, but a means for community learning and engagement. These kind of spaces host workshops and seminars related to the ever prevalent customization of technology and coding. The space shall host a laser cutter, 3D printing station and other necessary tools for clubs and workshops to make use of.

90 m^2

TECH. CENTRE

The tech. centre shall contain the following equipment and services; printers, photocopy machines, 3D printer, laminating, binding, printing preparation, and laptops available for rent.

200 m^2

LOUNGES

The lounges are semi-quiet comfortable “islands” for independent or group work, relaxing and socializing. The lounges can differ in character from each other. They can be located within the collections area or the junctions between adjacent spaces, such as the main lobby. In addition to this, the fact that young people often sit on the floor and have nontraditional ways of reading should be kept in mind. Movable or transformative furniture is recommended.

236 m^2

CARRELS

Individual reading desks shall be provided in quiet zones.

120 m^2

IT STATIONS

The IT stations shall provide computers for general use, including a connection to the printers available in the tech. centre. Separate computers shall be provided for catalog and database searching.

90 m^2

PRIVATE READING ROOMS

Open reading spaces shall be provided, with workspaces able to accommodate 4, 6, 8 or more people. Acoustically, this will be classified as a quiet space.

200 m^2

RESERVABLE MEETING ROOMS

Break-out rooms are to be well equipped with the technology necessary for the arrangement of meetings. The original size of these rooms should be designed for 8 people. The partitions between the rooms will be acoustic, with a possibility to be modular and portable, making it possible to create different-sized spaces as needed. Options for screening, smart screens, air-conditioning, etc.

$120\ m^2$

RARE BOOK STORAGE

Sensitive media storage should have very specific climatic conditions and should be kept separate from the publicly accessible areas.

$180\ m^2$

PERIODICALS

Accessible shelves with periodicals. This collection would also contain the periodicals produced by the Abdulrahman Al Sudairy Cultural Centre.

$275\ m^2$

INFORMAL READING MATERIAL

Informal reading material is currently housed in the Park Library pavilion. This collection may remain in a separately accessible area or may be combined into the main library spaces. If relocated into the main library space, these reading materials shall be placed in a non quiet zone.

$1155\ m^2$

STACKS

Bookshelves for the library collections.

ADMINISTRATION AND STORAGE

Such places should be physically separated from public areas, even if a visual connection could be provided. A special focus is required for the digitalization and processing areas since that this kind of operations are intended to be done in-house, and it's expected that all the collections will be digitized over time. Also, staff areas should be provided with amenities and facilities, in order to create a pleasant working place.

80 m²

ADMINISTRATION W.C. AND CHANGE ROOMS

Dressing rooms and washrooms for the staff are often situated near a private entrance to allow for easy access coming and leaving the workplace. Staff members have their own reservable lockers, with individual shower stalls and toilets.

290 m²

ADMINISTRATION OFFICES

Individual offices shall be provided for each employee. Included in this area is allocation for an on site grounds manager and travel agent for the AACC.

160 m²

KITCHEN AND LOUNGE

The break rooms should consist of a rest area, dining area and a small kitchen for the employee to socialize in and enjoy.

106 m²

SERVICE POINTS

Service points shall be located near entrances or along main circulation routes. Their purpose is to provide information to visitors and serve as reference desks. They may also be utilized as security check points.

290 m^2

WORKER RESIDENCE

Individual apartments for 5 male workers are currently on the site.

50 m^2

SERVER ROOM

A server room is a room, usually air-conditioned, devoted to the continuous operation of computer servers.

144 m^2

AC ROOMS

The AC rooms will contain all mechanical and electrical equipment.

511 m^2

STORAGE ROOM

These rooms contain janitors storage, stage equipment storage as well as additional storage for events equipment.

90 m^2

DIGITALIZATION & PROCESSING

The digitization center on site would be a place for the conversion of analog media produced by the library to a digital format. This Programme should have the capability of expanding and developing to suit future needs. The current processing and binding procedures in the DAR Al-Uloum Library would be carried over into the future space.

CHAPTER THREE

methodology

WHY ALGORITHMIC MODELLING

One of the greatest evolutions in the field of the architectural drawing happened in the 80's when the higher informatic skills acquired and developed during the computer boom era gave birth to a shift in the conception and use of software for architectural drawing (CAD). Soon, many designers realize how the programming language could permit to highly improve the control and management of complex problems, such the building conception one, in order to achieve better results and pursuing more objectives together. This new type of modelling required to draw a process than the drawings themselves and the building would have been the result of this process. All these could be done through algorithms. But what an algorithm is? An algorithm is "a procedure used to return a solution to a question through a finite list of basic and well-defined instructions" (1). The potential of this type of working is that an algorithm splits the problem into different components, in the same way as human usually do when solving problems. An algorithm in order to generate a solution needs to have a set of unambiguous instructions and a list of input data, however not always it works, indeed sometimes the solution cannot be achieved due to a different range of errors (errors in the input data, a not well-defined routine, …).

1. Tedeschi Arturo, *AAD Algorithms-Aided Design. Parametric strategies using grasshopper*, Le Penseur, 2014

Usually, algorithms are written in code language such as C++, VB, Phyton and so on. However, is possible to notice how the existence of a different type of coding languages and the complexity in studying, understanding and finally using it could be an obstacle for designers who mainly haven't such type of knowledge, but also could be an obstacle in sharing information between two parts if different codes have been used.

To bypass these problems parametric diagrams have been introduced in order to work as a medium. Not only has a graphic interface that fit more with the way of thinking of a designer but also it doesn't require any level of knowledge in coding. Parametric design works on node diagrams, where tools called components, which each has a very specific function, are linked together to generate an output and creating, in the end, a true algorithm.

One of the most famous software used, if not the most famous one, is Grasshopper by Robert McNeel& Associates, a plugin of Rhinoceros. Grasshopper, as other visual scripting software, works with a visual editor, that is a canvas on which components are dropped and linked together, and a 3d modelling environment, where the solution, or the steps that will bring to it, are displayed. The biggest advantage of parametric modelling is the possibility to see suddenly how a propriety or behaviour changes the final configuration of the building or part of it and so permits to check different solutions and find and use the best one.

This type of approach promises to be very suitable for this kind of work since that could be possible to describe different aspects of the building and seeing how they work and bonds together and if the solution expected is useful or not.

EVOLUTIONARILY

Finding solutions, especially when facing complex problems, could be very difficult or tricky, and the trial and error method not always is usable if not helpful. In the early years of the 60's Lawrence J.Fogel published a paper called "On the organization of the intellect", where for the first time talk about evolutionary computing. These kinds of algorithms were developed then in the 70's but they start spreading in the 80's with the advent of the personal computer and nowadays are widely used as an optimization method. In Grasshopper this mechanism is implemented with Galapagos plugin, which is natively implemented in the software.

But how does evolutionary solver work? In this kind of resolution method, the problem is described such as it has to be depending upon n variables. These variables are called genes. In this way, by changing the values of the genes and so the combinations between them, we'll find different solutions, one for every possible combination for each value of each gene. The space of all these solutions is called fitness landscape. Since the fitness landscape isn't known, the first step is populating it with a random collection of individuals, named genomes.

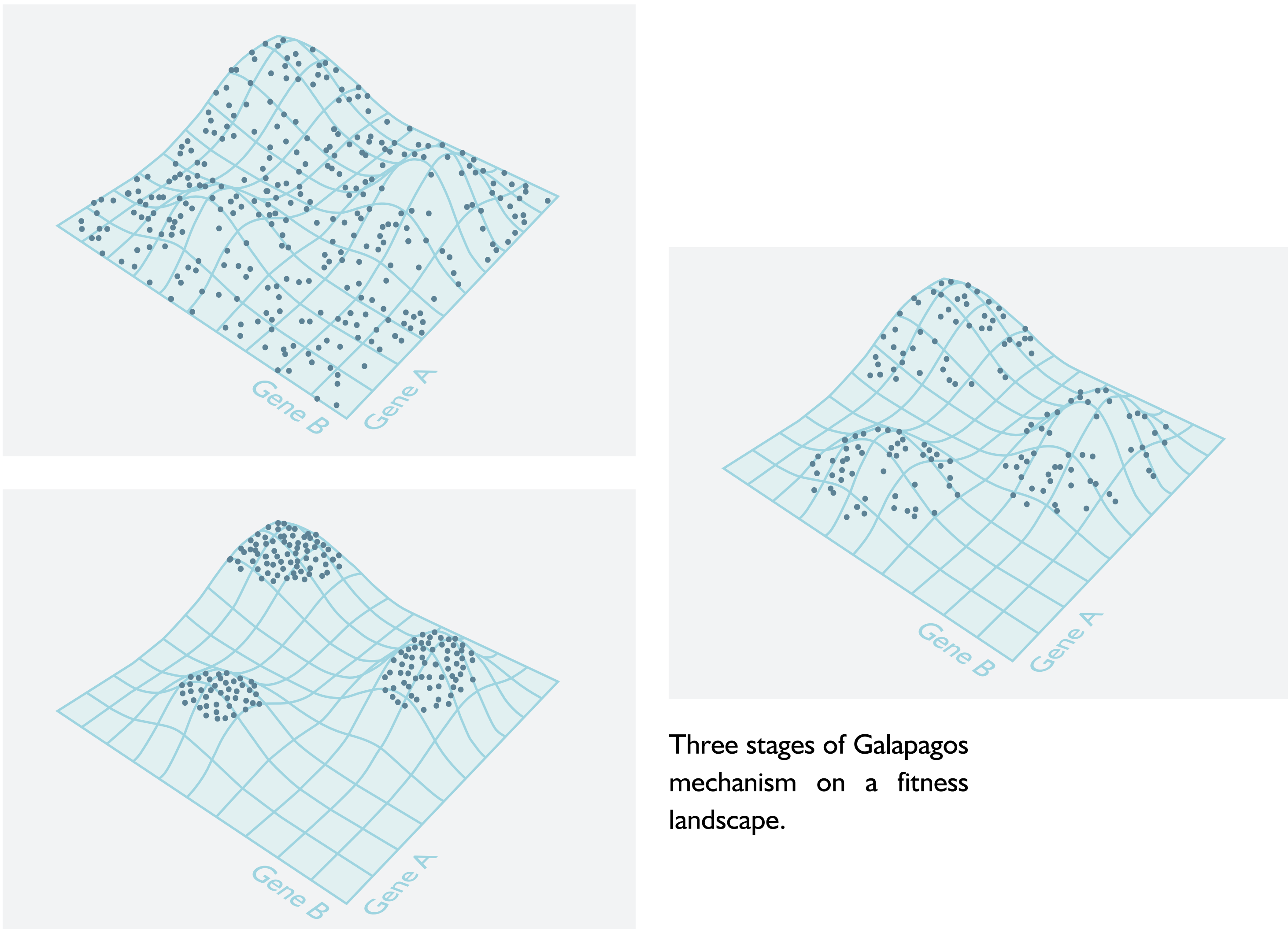
A genome is nothing more than a combination of specific value for each and every gene. Then the software applies the fitness that is the collection of instructions that transform these variables in the solution (that, in a few words, is an algorithm).

Now that the fitness model is populated we can prioritize the solutions, ranking them from the fittest to the lamest, according to what we are searching for (usually to minimize or maximize the final result). Once ranked the lamest will be killed and only the fittest will be kept. However, this population of solutions isn't still the final result we're searching for, and so at this point, a new generation, called generation one, will be created by breeding the fittest results of generation zero in order to better explore the fitness landscape where the fitness solutions better satisfy the search target. This process is repeated at different times since we have reached the solution we are looking for.

So, because all this process could work, an evolutionary solver needs of a fitness function, a selection mechanism, a coupling algorithm, a coalescence algorithm and a mutation factor.

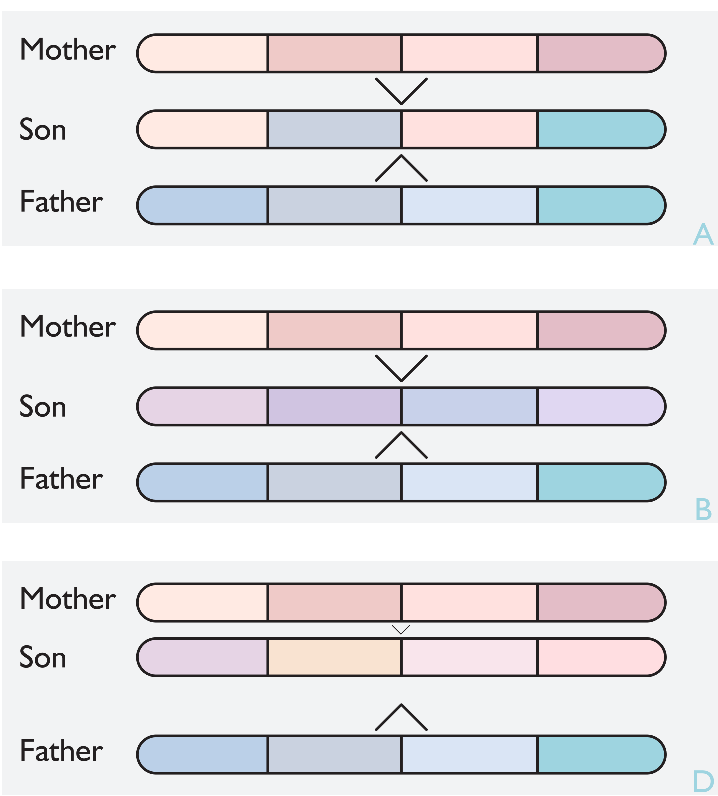
As previously said the fitness function is nothing more than what the designer is trying to solve, the function that describes the problem. Because what finally evaluated is the total fitness, the solver doesn't explore all the possible combination but try to maximize or minimize (depending on what designer is searching for) the fitness of every individual and so the field of searching of the solution is limited to the most ranked values.

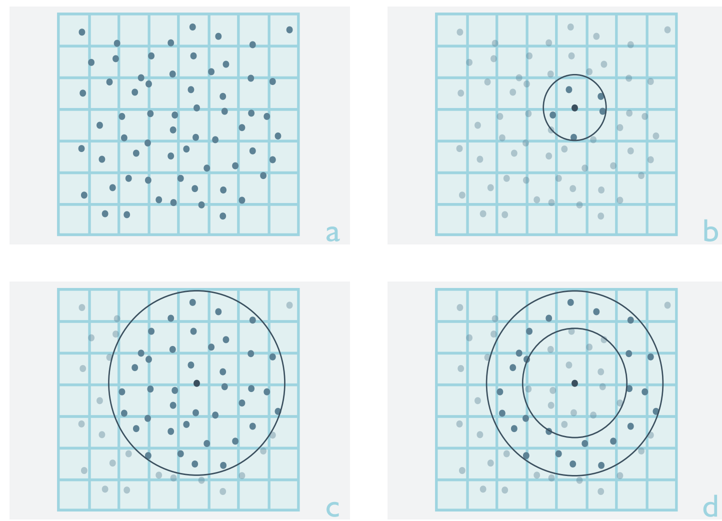
In Galapagos, there are three selection mechanism: Isotropic, exclusive and biased selection. In isotropic selection, all the individuals have the same probability to mate. That happens when all individuals have the same characteristic of success in finding the solution. With the exclusive method, only the N% of the best individuals succeed to mate, while in the biased selection, the chance of mating increase with the fitness increase.



Three stages of Galapagos mechanism on a fitness landscape.

The mating process is conducted by Galapagos by a process called genomic distances. In this process, a genomic map (a), representing all the genomes, is drawn and for each individual, a distance to all the others is computed. At this point is possible to select in the initial setting the breeding factor, which will select according to the distances compute the individual to mate with. Commonly the best mates (d) for an individual are the one that are not to close (b) (in this case an incestuous will occur and a decrease of density of the population will happen, making harder to find the solution) and no too far (c)(in this case zoophilic mating happens, bringing to the creation of different solutions, meaning that will impossible to find the best one).





Once coupling has been decided the creation of the generation occur by combining the genes of the different couples. In Galapagos this process could happen in three way: crossover (A), blend (B) and preferenced-blend (C) coalescence. In the first case, the new genome is created by selecting a random number of genes for the mom and the remaining from the dad. In the second possibility, an average between the genes is computed and used to create the new individual, while in the last one a similar operation is done but the fittest genes are weighted in order to be more prominent in the new individual.

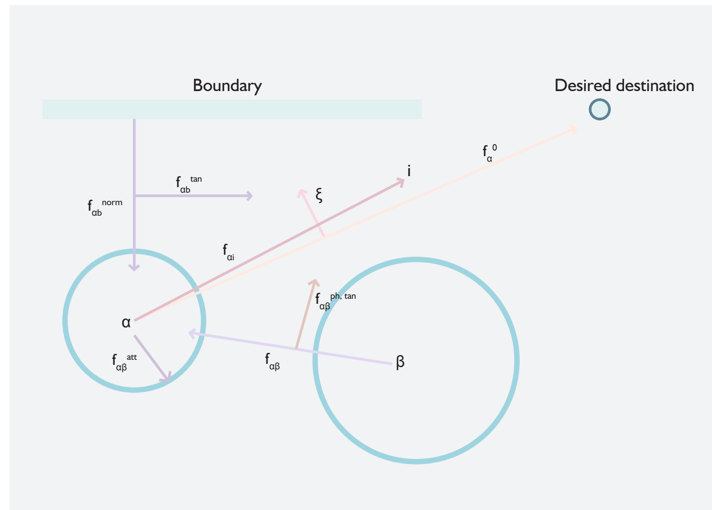
Finally, there are mutations. Because all the previous processes are done to improve the quality of the solution, by the other hand they also decrease the bio-diversity in the population and could mean in stagnant results during the solving process. Again, there are different types of mutations in Galapagos. When a single value of a gene in a genome is changed a point mutation occurs, while when two are swapped between them an inversion mutation happens.

Through this overall overview of evolutionary solvers, it's possible to define which pros and cons imply the use of them. Firstly, they are deadly slow, indeed an optimization process could last for hours if not days, depending on the dimension of the fitness landscape to search in. Secondly, they don't guarantee a solution, and if found it's one of the optimal solutions, but may not be the best one. Re-running the process it could give another solution. On the other hand, evolutionary solvers are very flexible, allowing exploring and solving a really wide range of problems. Furthermore, they forgive all the problems that have too many or too few constraints or have been poorly formulated. Lastly, they allow a high degree of interaction with the user, both in setting the problem than in the way to find the solution.

CROWD DYNAMIC

To simulate the dynamic typical of a crowd several models have been developed, and most of the time people have been treated as particles. Since the nature of this work isn't to show methods and calculations needed to build such type of simulation, I refer to other literature for insights about the history, the different models and technical explanations, but I will only cover the so-called "social force model", that is the method used in this research work.

The Social force model was developed by Helbing and Molnár (2,3,4,5,6). In this type of model each pedestrian is treated as a particle whose movement is the resultant of the forces acting on him and take in account natural phenomena occurring in pedestrian flow: the choice of the fastest route, the individual speed of each person (depending on factor such as age, sex, surrounding, etc.) and the minimal distance kept between each pedestrian.



All start with a given a pedestrian α, and we'll call driving force the force that reflects the motivation of the pedestrian to move towards its destination with a desired velocity v^0_α:

$$\vec{f}_\alpha^0 = \frac{v_\alpha^0 \cdot \vec{e}_\alpha^0(t)}{\tau_\alpha} - \frac{\vec{v}_\alpha(t)}{\tau_\alpha}$$

Where v^0_α is the instantaneous velocity, $e^0_\alpha(t)$ the desired direction of movement and τ_α the relaxation time. We can find the desired direction of movement as:

$$\vec{e}_\alpha^0(t) = \frac{\vec{p} - \overrightarrow{x_\alpha}}{\|\vec{p} - \overrightarrow{x_\alpha}\|}$$

Another type of forces are the ones that describe the interactions between pedestrians and consist in the social-psychological force and physical interactions:

$$\vec{f}_{\alpha\beta}(t) = \vec{f}_{\alpha\beta}^{soc}(t) + \vec{f}_{\alpha\beta}^{ph}(t)$$

2. Helbing D. & Molanr P., *Social force model for pedestrian dynamics*, Physical Review E, 1995
3. Helbing D, *Traffic and related self driving many-particles system*, Review of modern physics, 2001
4. Helbing D, *Verkehrsdynamik*, Springer-Verlag, 1997
5. Molnar P., *Modellierung und simulation der Dynamik von Fussgangerrstromen,* Phd thesis, University od Stuttgart, 1995
6. Schreckeenberg M.& Sharma S.D., *Pedestrian and evacuations dynamics,* Springer Verlag, 2002

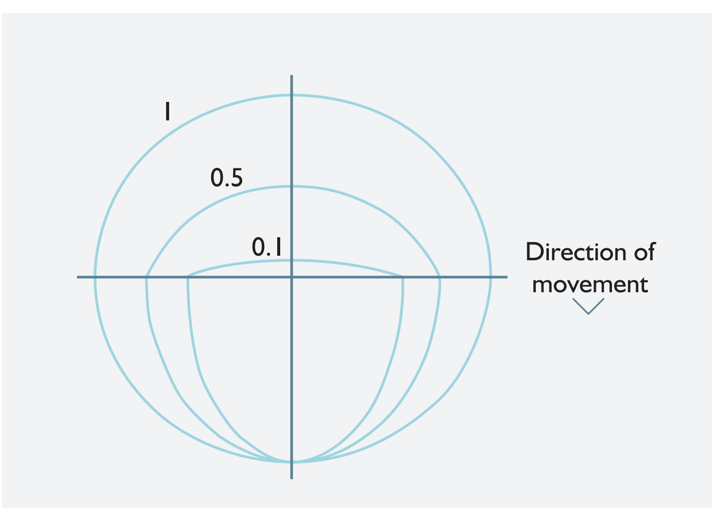
The social-psychological force describes the behaviour of people to keep a certain distance one from the others. In order to create this type of behaviour, this type of force is a repulsive one with a value that is directly proportional to the distance between the two pedestrians (higher value at the lowest distance). This can be described with an exponential function:

$$\vec{f}_{\alpha\beta}^{soc}(t) = A_\alpha e^{\frac{r_{\alpha\beta}-d_{\alpha\beta}}{B\alpha}} \overrightarrow{n_{\alpha\beta}} F_{\alpha\beta}$$

Where A_α is the interaction strength and B_α the range of the repulsive force, $r_{\alpha\beta}$ is the sum of pedestrian radii, $d_{\alpha\beta}$ the distance between the two. $n_{\alpha\beta}$ is the normalized vector from β to α and $F_{\alpha\beta}$ describe the anisotropic behavior typical of pedestrian. This type of behavior is due to the human field of view, where the actions in front of the pedestrian are more important than the ones behind him. This can be expressed as:

$$F_{\alpha\beta} = \lambda_\alpha + (1 - \lambda_\alpha) \frac{1 + \cos(\varphi_{\alpha\beta})}{2}$$

The value of λ_α can be graphically calculated:



The second component of the equation describes the repulsion force that occurs when the distance between two pedestrians become greater than the sum of their radii (that means nearly physical contact, that in ordinary situation is avoided, while it could occur in danger or panic situations). In this sense, a body force and a sliding friction force are introduced. The first one describes the tendency to avoid physical damage:

$$k\Theta(r_{\alpha\beta} - d_{\alpha\beta})\vec{n}_{\alpha\beta}$$

The second one takes into account the increase in speed of the pedestrian to avoid others:

$$\kappa\Theta(r_{\alpha\beta} - d_{\alpha\beta})\Delta v_{\beta\alpha}^{t}\vec{t}_{\alpha\beta}$$

θ(z) is a function that is equal to the argument if z>0 and 0 otherwise. $t_{\alpha\beta}$ is the tangential direction, $v^{t}_{\alpha\beta}$ the tangential component of relative velocity while k and κ are constants.
To summarize:

$$\vec{f}_{\alpha\beta}^{ph} = k\Theta(r_{\alpha\beta} - d_{\alpha\beta})\vec{n}_{\alpha\beta} + \kappa\Theta(r_{\alpha\beta} - d_{\alpha\beta})\Delta v_{\beta\alpha}^{t}\vec{t}_{\alpha\beta}$$

BOUNDARY INTERACTION

Besides the interactions with other people, the movement of a pedestrian is affected by the physical boundaries and obstacles typical of the environment. These types of interaction are threatened as for the ones between pedestrians and are described by three models, depending on the on the simulated phenomena:

- Superposition: all obstacles and boundaries affect the pedestrian movement and could be used for instance in angle passageway;

- Shortest distance: only the boundaries or obstacles within the shortest distance are considered;

- Biggest impact: only the boundaries or obstacles with the highest influence are taken into account.

In practical terms what's necessary is to calculate the distance between the pedestrian and the boundary, that's seen as an edge of a polygon, determined by its vertices p and q. The distance vector between the pedestrian position and the line is calculated through vector algebra:

$$\vec{d}_{ab} = \begin{cases} \vec{p} - \vec{x}_\alpha \; for \; \langle \vec{x}_\alpha - \vec{p}, \vec{e}_{qp} \rangle \leq 0 \\ \vec{p} - \vec{x}_\alpha - \langle \vec{e}_{qp}, \vec{p} - \vec{x}_\alpha \rangle \; for \; 0 < \langle \vec{x}_\alpha - \vec{p}, \vec{e}_{qp} \rangle \leq \| \vec{q} - \vec{p} \| \\ \vec{q} - \vec{r}_\alpha \; for \; \| \vec{q} - \vec{p} \| \leq \langle \vec{x}_\alpha - \vec{p}, \vec{e}_{qp} \rangle \end{cases}$$

Where ‹q,p› is the scalar product of p and q. Once the distance vector has been calculated, the interaction force between the pedestrians and the boundaries can be evaluated as:

$$\vec{f}_{\alpha b} = \left\{ A_\alpha e^{\frac{r_\alpha - d_{\alpha b}}{B_\alpha}} + k\theta(r_\alpha - d_{\alpha b}) \right\} \vec{n}_{\alpha b} - \kappa\theta \langle r_\alpha - d_{\alpha b} \rangle \langle v_\alpha, \vec{t}_{\alpha b} \rangle \vec{t}_{\alpha b}$$

$n_{\alpha b}$ and $t_{\alpha b}$ are respectively the direction perpendicular to the boundary and the parallel one.

OTHER FORCES

To make the model more complete we can take in consideration other attractors that can influence the behaviour of pedestrians such as shop windows, special attractions and so on. These forces are modelled as the social force between pedestrian, with a different value for the interaction range $B_{\alpha i}$ and strength parameter $A_{\alpha i}$ (it's typically smaller).

Furthermore, people often walk in group, and once separated, they tend to reform the original group. This can be simulated as a constant attraction force:

$$\vec{f}_{\alpha\beta}^{att} = -C_{\alpha\beta} \vec{n}_{\alpha b}$$

The individuality of each pedestrian can be simulated by introducing a random fluctuation force in pedestrian behaviour:

$$\xi = \langle \vec{e}_\alpha^0, \vec{f}_\alpha \rangle X \vec{e}_\alpha^\perp$$

SUMMARY

To conclude we can say that the social force model is the sum of different partial forces that represent the influences a pedestrian is subjected in the reality. Generally, not all the forces have to be computed, but only the ones that are needed to the simulation model (for instance is useless to compute the physical force if it's not the case of a panic or evacuation scenario).

$$\frac{d\vec{v}_\alpha t}{dt} = \vec{f}_\alpha^0 + \sum_\beta \vec{f}_{\alpha\beta} + \sum_b \vec{f}_{\alpha b} \sum_i \vec{f}_{\alpha i} + \sum_\beta \vec{f}_{\alpha\beta}^{att} + \xi$$

RESOLUTION METHOD

To solve all these equations and create a simulation algorithm, differential equation and numerical solvers are taken into account. More precisely a combination of the Verlet and Gear algorithms have been used. The Verlet algorithm instructs the solution as follow:

1. Insert the initial position r_i^I
2. Specify the initial velocity v_i^I
3. Calculate the position at time n+1
4. Compute the velocity at time n+1

Since the force is depending on velocity, is impossible to calculate it at n+1 timestep cause the velocity isn't known and, at the same time velocity is depending on itself and thus can't be calculated. To overcome this problem, the Gear algorithm is introduced. This is a predictor-corrector method, which first computes a predicted value that will be later corrected. To do this, first the new positions, velocities, accelerations and higher derivates are predicted:

$$r_{n+1}^{(p)} = r_n + hv_n + \frac{h^2}{2} a_n + \frac{h^3}{6} \alpha_n + \frac{h^4}{24} \beta_n$$
$$v_{n+1}^{(p)} = v_n + ha_n + \frac{h^2}{2} \alpha_n + \frac{h^3}{6} \beta_n$$
$$a_{n+1}^{(p)} = a_n + h\alpha_n + \frac{h^2}{2} \beta_n$$
$$\alpha_{n+1}^{(p)} = \alpha_n + h\beta_n$$

Then, from the predicted values a correction factor is calculated as:

$$c = a_{n+1} - a_{n+1}^{(p)}$$

And with it the corrected positions, velocities and higher derivates are finally computed:

$$r_{n+1} = r_{n+1}^{(p)} + c\frac{19h^2}{240}$$

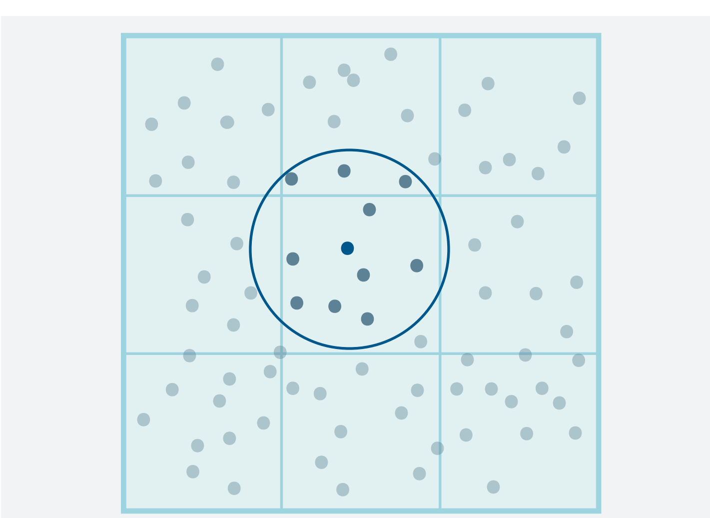
$$v_{n+1} = v_{n+1}^{(p)} + c\frac{3h}{8}$$

$$\alpha_{n+1} = \alpha_{n+1}^{(p)} + c\frac{1}{6h}$$

$$\beta_{n+1} = \beta_n + c\frac{1}{144h^2}$$

REDUCE COMPLEXITY

This type of simulation leads to an n^2 complexity dues to a double nested loop, which requires a high level of computational effort, especially if the number of simulated pedestrians is high. To improve and speed up the process, the complexity is reduced by introducing the Verlet link cell algorithm, that is a combination of the Verlet algorithm and the cell lists algorithm.
In this last one, the simulation area is divided in a grid where each cell is a square of d width. In this case, a pedestrian can interact only with the agents that are in its own cell and the neighbourhood ones.

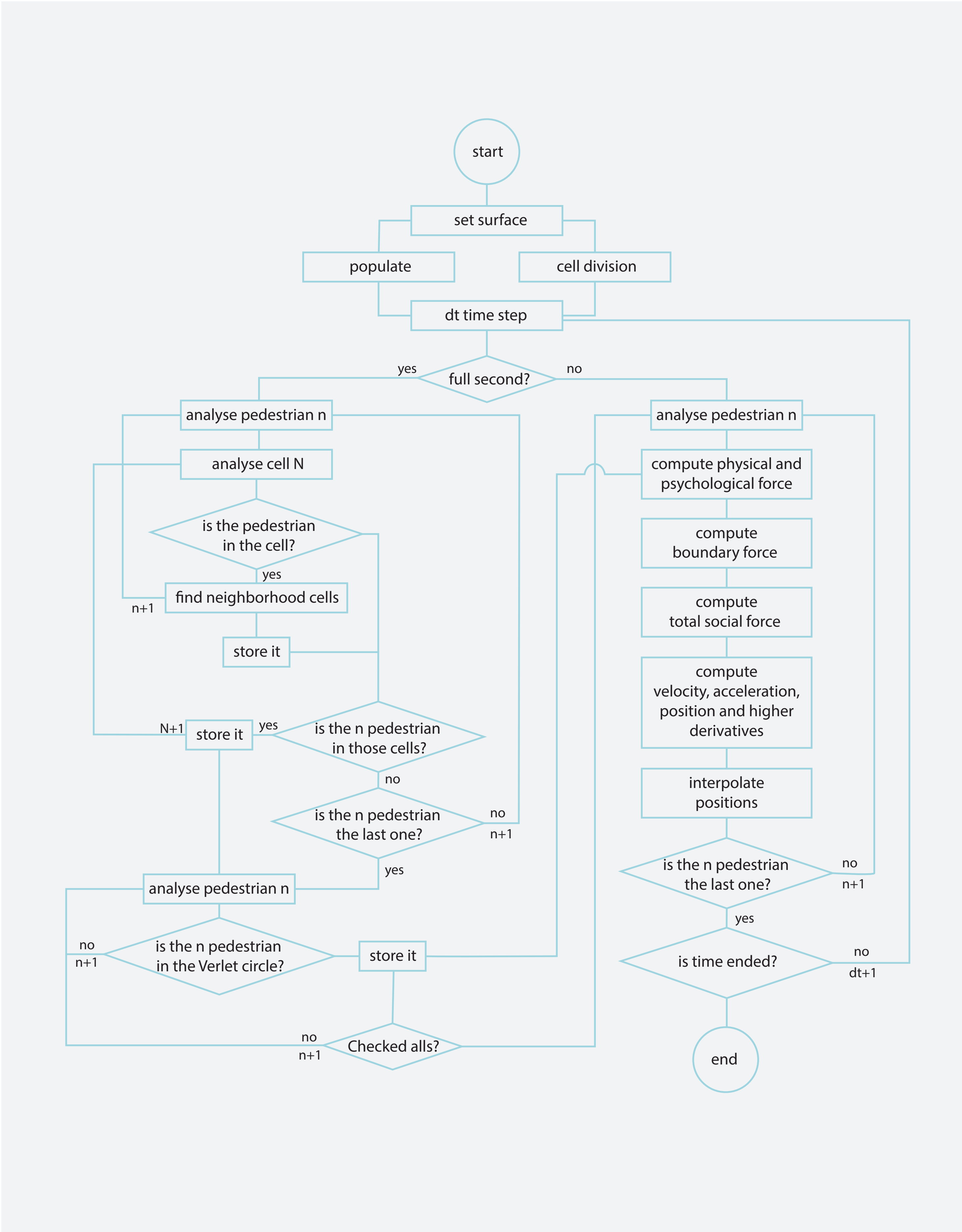


To even optimize this, a circle is introduced for each agent, where the radius r is the maximum interaction distance within the forces are calculated. Since that the agents are dynamic the number and position of other pedestrians change along time. Taken dt as a small time step, is possible to notice how the condition change only at the boundary of the circle at every dt step, where some pedestrian exit from the circle and other come in. However, these are slight changes cause the forces generated from those agents are really small cause they are at the maximum distance from the pedestrian taken into consideration. From that is clear that isn't necessary to update always the position of the agents into the circle, but it can be done every n dt steps.
If we consider a radius r of 10 m, and a dt step of 0.1 seconds we can assume that major changes occur every second, or every 10 dt steps. (7)

MOVE THE ALGORITHM IN GRASSHOPPER

This type of simulations is usually made with computer coding language (such as C++ or Visual Basic) since conditional statements and loops are well integrated and common in scripting languages. However, due to the lack of a deep scripting skill necessary to complete such routine, it's all been translated into Grasshopper components.
Natively grasshopper can't handle loop, so Anemone plugin has been used, where every cycle was considered as equal to 0.1 second and a stream gate decide if update the position of the agents or going straight in computing the new positions. An Anemone loop component has been used for each of the four values that are needed to be computed: position, speed, acceleration and its first derivate. However, all the four components are synchronized in order to compute the relative values of the same t moment.
While to create a grid of equal dimension cells, independently of the measures of the whole surface, panelling tools plugin has been introduced.

7. Apel Marko ,*Simulation of pedestrian flows based on the social force model usinge the Verlet link cell algorithm*, Master thesis, 2004


start
set surface
populate
cell division
dt time step
full second?
yes
no
analyse pedestrian n
analyse cell N
is the pedestrian in the cell?
yes
find neighborhood cells
n+1
store it
N+1
store it
yes
is the n pedestrian in those cells?
no
is the n pedestrian the last one?
no
n+1
yes
analyse pedestrian n
no
n+1
is the n pedestrian in the Verlet circle?
store it
no
n+1
Checked alls?
analyse pedestrian n
compute physical and psychological force
compute boundary force
compute total social force
compute velocity, acceleration, position and higher derivatives
interpolate positions
is the n pedestrian the last one?
no
n+1
yes
is time ended?
no
dt+1
end

SPACE SYNTAX

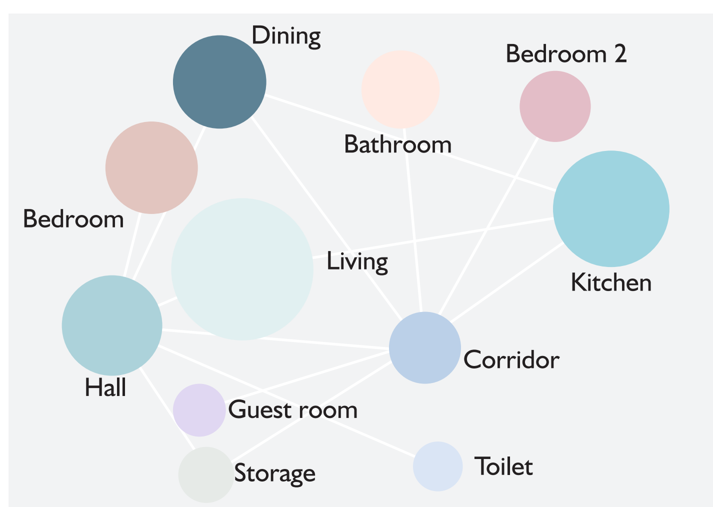
When we talk about social aspect of a building, we quite always refer to how spaces are allocated and how they influence social performances between humans. All started when we have to relate to a programmatic list of functions that a building has to have. The main challenges are how all these spaces have to be related, how should they perform in relation to the external environment and, as previously said, in which measure influence the wellbeing of the users. Space allocation can promote inclusiveness as create more private areas by isolating certain functions from the main transition ways. In this optic, space syntax theory can give a huge help in defining the spatial distribution.

Space syntax is a theory developed by Bill Hillier and Julienne Hanson, as published in "The logic of Space" in 1984. This theory takes in analysis the layout and quality of building spaces and which are the effects on human behaviour. It can be said that space syntax theory analyzes the social performance of a building (8).

This type of tools can be very effective in the case of complex building program, where starting from the designer idea of space allocation and relation, an optimization is achieved through the analysis of different ranks of spaces.

In the following paragraphs, it's conducted an overview of the "space syntax" plugin toolkit provided in Grasshopper. The aim of the toolkit is to create a bubble diagram and ranking charts of the programmatic spaces of the designer allocation idea, helping him or her in the optimizing the scheme of the relations and hence of the effects on social behaviour.This plug-in is drawn according to a see-move-see method, where designer choices are analyzed in real time to provide a feedback about that type of choice. The feedback is given in several diagrams, where everyone provides a different type of information about space consequences.

All start with a cloud of points, one for each programmatic element, and, through a panel component, a list of areas and labels are given, in the same number as for the points list. At this point, the plugin set a circle with the equivalent area for each labelled point.
Going further, the designer starts to link the labelled points as how he thinks they should be connected in reality. This type of connection could also mean as for "adjacencies", however,r it's very difficult to have a clearer idea on how to set rooms at this time of the project. Saying that it's easier to think of all this as of a connectivity graph, where the abstract designer idea takes a first form.



8. Pirouz Nourian, Samaneh Rezvani, Sevil Sariyildiz ,*Designing with Space Syntax: A configurative approach to architectural layout, proposing a computational methodology*, 2013

INTEGRATION

It measures the likeliness of a space to be private or communal, that is the measure of how integrated a certain space is when related to the global configuration. It is calculated as the total depth of a node when all the others are projected on it:

$$I = \frac{D_k(k-2)(k-1)}{2(TD-k+1)}$$

$$D_k = \frac{2\left(k\left(log_2\left(\frac{k+2}{3}\right)-1\right)+1\right)}{(k-1)(k+1)}$$

Where k is the number of nodes, TD the total depth. The D_k is called "diamond value" and indicates how much a space is individual or not.

DIFFERENCE FACTOR

It shows how differentiated (spatial articulation) is a space related to a certain configuration. It is calculated as

$$RA = \frac{2(TD-k+1)}{(k-2)(k+1)}$$

If we call a the maximum RA, b the mean, c the minimum value and t their sum; the unrelativized difference factor H is:

$$H = -\left\{\left[\frac{a}{t}\ln\left(\frac{a}{t}\right)\right]\right\} + \left\{\left[\frac{b}{t}\ln\left(\frac{b}{t}\right)\right]\right\} + \left\{\left[\frac{c}{t}\ln\left(\frac{c}{t}\right)\right]\right\}$$

And the relativized difference factor H*:

$$H^* = \frac{H - ln2}{ln3 - ln2}$$

CONTROL

It evaluates the strength between a space and other point linked in a superior manner:

$$Control = \sum_{i=1}^{n} D_i$$

Where D_i is the degree of neighborhood node and n the number of all neighbor nodes.

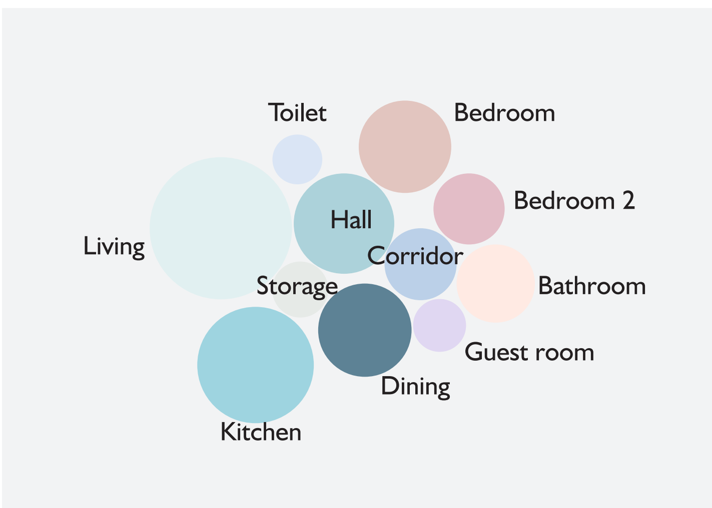
CHIOICE

It's the importance of a node in the global configuration, that is how many times a space is in the shortest paths between all other nodes. That means the probability or likeliness to be crossed by people.

$$C_g(P_i) = \sum_j \sum_k \frac{\sigma_{jk}(P_i)}{\sigma_{jk}} \quad (j<k)$$

σ_{jk} (P_i) is the number of shortest paths between node P_j and P_k, and σ_{jk} all the geodesics between P_j and P_k.

Once the analyses are provided, the toolkit is capable to provide a force-directed-connectivity graph, that is a connectivity graph redrawn according to the ordered links given by the user in order to display possible adjacencies in the physical floor plant. This component works by giving an attraction or repulsion force to every element and by relaxing the links between them.
Subsequently, it's possible to translate this diagram into a dimension-less plan pattern, where adjacencies are tried to be solved when the programmatic elements are triangulated polygons instead of circles, like a possible true floor plan.



In my study case the last two steps of the plugin aren't been used since the toolkit itself can't' graphically manage a high level of complexity, due mainly to the fact that it works in bi-dimensional space and not tri-dimensional. This problem can be translated in the lack of capability to graphically represent multi stores building program, but also the complex level of relation between the different spaces, but that are well understood and managed in the initial analysis level. Since that designer works better with image and a building is a physical element, it has been necessary to develop a way in which these complex relations could be represented, even for multi-stores building.

ADJACENCIES

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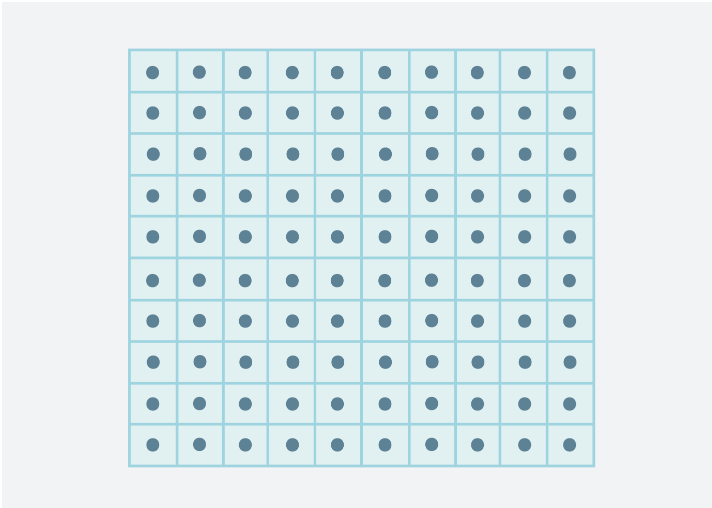
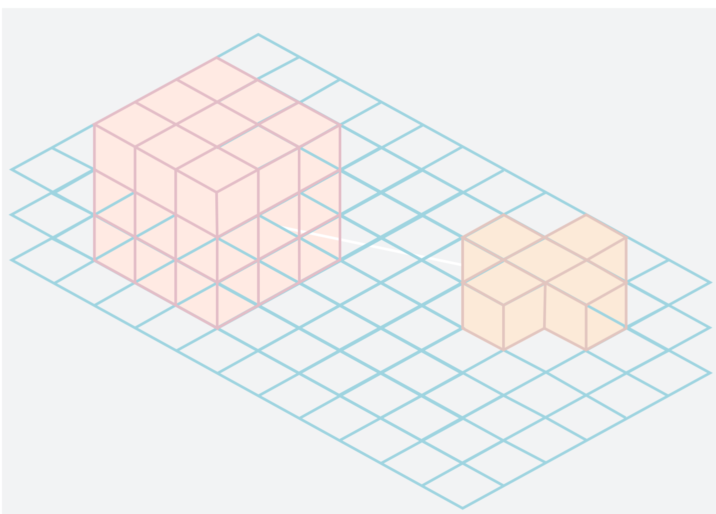
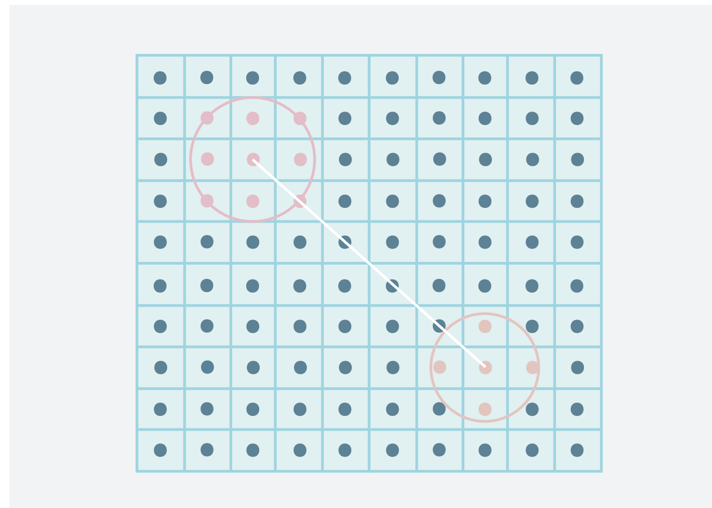
Subsequently, it's possible to translate this diagram into a dimension-less plan pattern, where adjacencies are tried to be solved when the programmatic elements are triangulated polygons instead of circles, like a possible true floor plan.

By defining the site boundary, the tool will fill in the shape with a grid, with cell dimensions defined by the user. Each of these cells is marked with its own central point, and the collection of all the points is stored in a cloud. By offsetting the grid with customizable values and times is possible to define a multistory building and in the same time the three-dimensional grid representing it.
Clearly, the offset value is defined by the user, as the possibility to define multiple site boundaries, one different for each storey, if particular area constraints are present.





The cloud of all the points of all the building will work as the list of points that the definition will use as centre one, to place each programmatic element. Within the list of the building programs, a hierarchy is given. That to say that the first program of the list will be placed in one of the points of the cloud and that point will work as the mass centre of the pixilated sphere with the same volume assigned to that programmatic element. Once placed, all the points occupied by the sphere will be culled from the cloud, where the remaining points will be the only ones available for the next program, until all of them are massed out. The proximity between each program is expressed in terms of distances between the centre points. Subsequently, all these relations are weighted in order to give an importance in terms of attraction or repulsion between the different elements. Finally, all of these distances are mass summed, and this value will be the fitness of the function to try to be minimized.



First, the site area has to be defined through a boundary that will be the only geometry defined by the user. Once defined, the site is divided according to a grid, where cell size defined by the user. In case of multi stories building without particular constraints at the upper or downer levels, the grid is offset by a user input value.

Then a hierarchy of the spaces is introduced and also the central starting point for each programmatic element. The first element of the list is ranked as the most important, with the possibility to occupy whichever point in the cloud, all the others will occupy the spaces left by the previous elements. While defining the starting point for each space, also the floor area or volume is introduced to create a pixilated sphere and by removing from the cloud all the points that have been occupied.

Once defined all the elements of the program the links between them have to be explicated. These are done by the definition trough lines connecting the centre points, according to the relationship pattern given by the user. The length of linking lines is evaluated and eventually multiplied with a chosen factor to weight the distances and give them a priority. All the linking values are finally mass added.

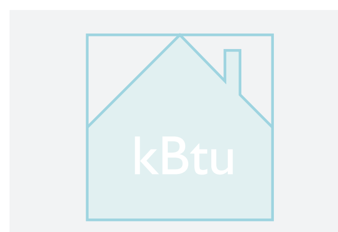
The optimization process is conducted by Galapagos plug-in. Galapagos is an evolutionary solver, where the genome (variables) is the slider which changes the position of the central point of each programmatic element, while the fitness is the mass addition. Galapagos through several iterations will try to minimize the fitness value (the overall distances between the whole elements) and give an optimal solution. It's important to notice that the solution found it's not the best one but one of the possible optimal solutions to the problem, by re-running Galapagos other solutions could be found.

NET ZERO ENERGY BUILDING

What do we mean when we talk of net-zero energy building?
In very few words we can say that net-zero energy is a measure of building's energy performance, in particular, it means that the building produces more renewable energy than how much it uses along an operational year. If we look closer to the definition, net refers to the fact that nonrenewable energy could be used, but the renewable energy produced by the building along the year has to offset or exceed the use of nonrenewable one. The concept of zero energy means the capability of the building to reach a zero-energy position for buildings that have full program demands (9). However, we have another key factor that is the operational goal, which highlights the time framework along which the zero-energy performance has to be evaluated.

This framework is one year of operation, in order to include all seasonal variations; while the use of word operation means that changes have to occur not only in the design process but also in the delivery.

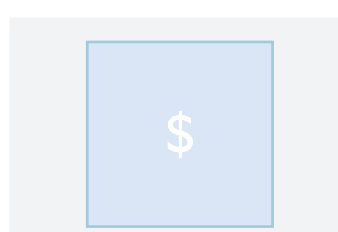
To summarize we can say that a net zero energy building is a very low-energy building with enough dedicated renewable energy generation to meet its energy generation to meet its energy requirements over the course of a year. The NREL (National renewable energy laboratory) has defined four ways to define and value net zero energy target for buildings: net zero site energy, net-zero source energy, net-zero energy emission and net zero energy cost.



Net zero site energy

Net zero source energy

Net zero energy emission



Net zero energy cost

9.Thomas Hootman ,*Net-zero energy design. a guide for commercial architecture*, John Wiley & Sons Inc., 2013

NET ZERO SITE ENERGY

With net-zero site energy, we mean that the building produces at least as much energy as it uses over the year when referred to the site. The measurement of this amount of energy is done by drawing a boundary around the site and adding up all the energy within this boundary line.

NET ZERO SOURCE ENERGY

When a building produces or purchases at least as much renewable energy as it uses on a year when accounted for the energy source. This measurement includes factor about the providing energy to a site. Indeed part of the energy is lost during the transportation because of, for instance, thermal loss. That means that the energy provided at the source is (less or more) three times bigger than the one that reaches the site.

NET ZERO ENERGY EMISSION BUILDING

A net zero energy emission building produces or purchases enough emission-free renewable energy to offset emissions due to energy consumption along the whole operational year. While the previous indexes are evaluated in terms of energy units, this value is expressed in mass of carbon-equivalent greenhouse gas emissions. To evaluate this index the energy source or fuel used is multiplied for a certain factor. This definition is quite important because is the basis for strategies to achieve the elimination of greenhouse gas emissions from building operational energy. That means that with it, is provided a way to identify a building that is carbon neutral for building energy operation.

NET ZERO ENERGY COST BUILDING

A net-zero energy building receives (at least) as much as financial credit for exported renewable energy as it's charged for energy by the provider during the course of the year. To arrive at this value, all the energy and energy service charges on the utility should be included.

BUILDING INDUSTRY PROGRAM AND RATING SYSTEM

THE 2030 CHALLENGE

The 2030 challenge defines carbon-neutral as using no fossil fuel greenhouse gas emitting energy to operate by introducing significant energy efficiency and the use of renewable energy. There aren't any limits to the amount of green energy that can be used on site to calculate the 2030 Challenge, but if it is purchased, it may be claimed for up to the 20% of the required reduction.
The proposed reductions in fossil fuel energy, starting from the current year (previous years targets are omitted as useless for this work, but can be found in the literature) are:
-2015-2019: 70% reduction
-2020-2024: 80% reduction
-2025-2029: 90% reduction
-2030: carbon neutral.
These values are to be taken into consideration for buildings of new construction, while in case of renovation, buildings have to achieve a 60% of fossil fuel energy reduction. This timeline reduction rate is referred to the expected building completion day. To define the goal, data on which make an evaluation can be taken from several databases. The most common is 2003 CBECS (commercial building energy consumption) and it's accessible through Energy STAR target finder.

ASHRAE VISION 2020

Is a strong supporter of net-zero energy buildings and it has developed many resources to move the industry in this direction. I 2008 it has published a document called "ASHRAE Vision 2020", that includes a rating system, partnership across industry organizations, target education and a certification of sustainable design.

ENERGY STAR

Is a labelling program for products, homes and commercial buildings developed by EPA and the Department of Energy. It consists of a value scale from 1 to 100, where 100 signifies a top-performing building, and to earn an ENERGY STAR label, a minimum of 75 is required (a common building is around 50). Because it's based on energy use rather than net energy use, this labelling system doesn't specifically recognize net-zero energy buildings. However, a net zero energy building would do quite well in ENERGY STAR program, with a score of 90 and beyond, since that typology of buildings is a very low source energy one.

LEED

This type of certification is one of the most diffused and known as a grading system for green buildings, that's to say that net energy zero building should achieve high levels (as Platinum) in this type of certification. LEED recognizes and prioritizes energy performance and the use of on-site renewable energy and gives designers and landowner instruments useful to the creation of green strategies. However, if it's important for a net zero energy building to earn this certification, on the other hand, it doesn't recognize all the performance and investment in on-site renewable energy of this latter type of buildings.

LIVING BUILDING CHALLENGE

This type of certification promotes the highest level of sustainability for buildings. The version 2.0 includes seven performance areas, which encompass 20 imperatives that must be met to earn the certification.

This living building challenge embraces net-zero energy buildings, since that the seventh imperative is net zero energy and no lower thresholds are possible. For what does it concern the energy on site, it allows for a photovoltaic system, wind turbines, water-powered microturbines and geothermic; but aren't allowed biomass and combustion of any type, while fuel cells could be used only if the hydrogen has been produced by renewable energy.

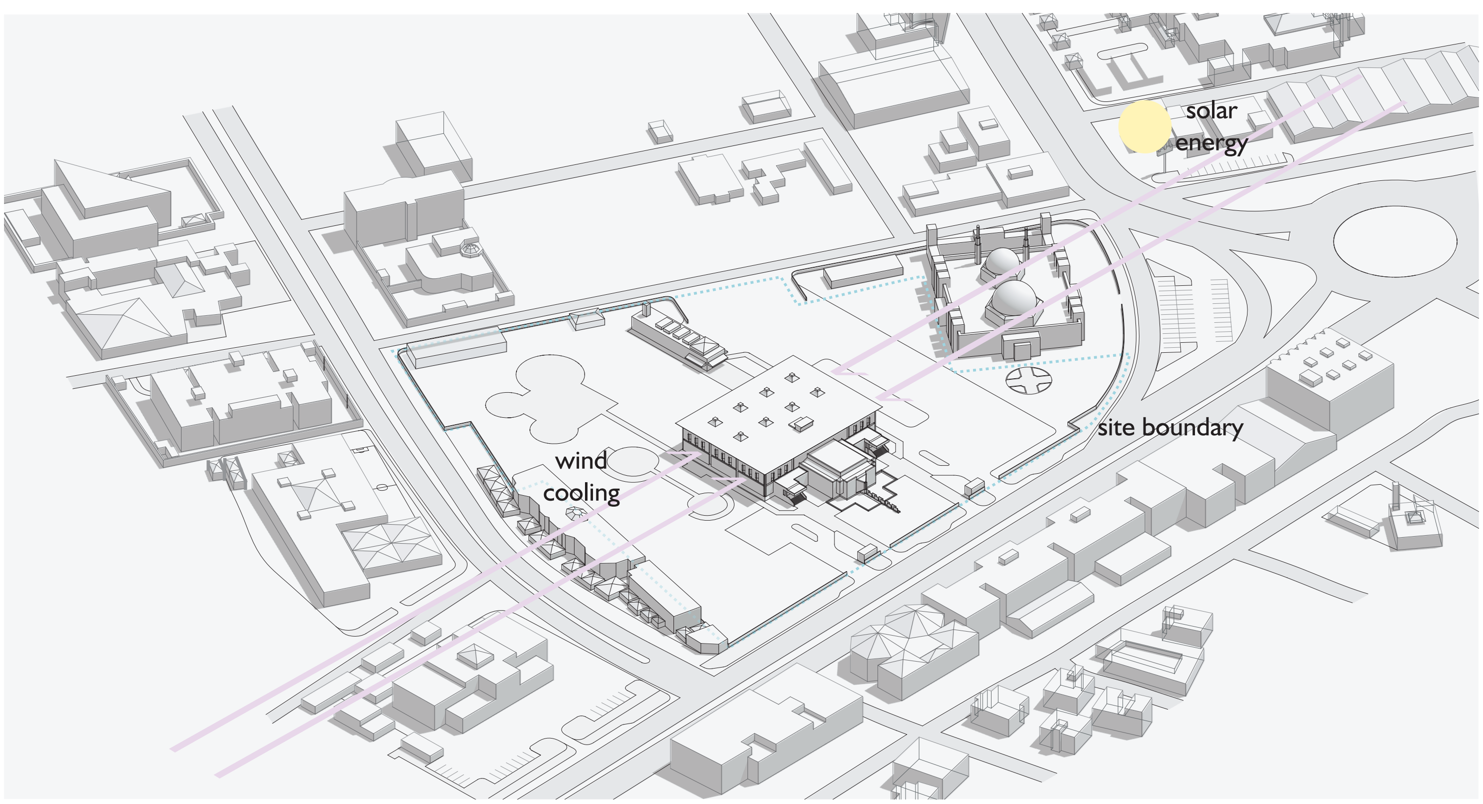
NET-ZERO ENERGY BUILDING CHARACTERISTICS AS GUIDLINES

When it comes to the conception and design process of a building, different aspects have to be taken into consideration, such that environmental quality, aesthetically beauty, costs, time and so on. We can divide all these requirements into four different categories:
-quality
-performances
-cost
-schedule
These ones reflect also the different players in the project definition of a building.

While designers are more addressed towards the aesthetical aspects, the owner will be more concerned about costs, while engineers about functionality. If quite an easy program building can be controlled by a simple design process, more complex building requires an integrated management of the objectives that are to be achieved both in environmental, social and economic spheres.
In order to achieve sustainability in these three ways, a holistic design is required, that's meaning to evaluate the impact of design choices and try to minimize, if not eliminate negative impacts and try them to strengthen each other.

When it comes to net zero energy buildings, we talk about energy, that's why it has to be the centre of all the design process. Firstly, we have to saw it as a flow system and try to conceive a flow diagram, where given a boundary (usually the same of the project area) all energy inputs, outputs and exchange between the in-site elements are highlighted in order to have a vision of the energy as a whole system. Once it's completed every source of energy is studied and analyzed in order to develop strategies capable to address the site problems and design objectives.

These strategies are needed to be developed as the design process evolve. However, due to the high standard demanding and the complexity to manage all the energy aspects, it's necessary to develop a digital model, that can be tested to see the goodness of the design choices. In order to work, a digital model has to be the more predictive possible in order to face possible changes in reality but also to answer to the most of question during the construction phase.
The first step in conceiving a net zero energy building is to set the energy target to reach. Setting a target for this type of buildings, mean establishing the lowest feasible energy use budget, where for "feasible" meaning the cost and budget, as for the current technology status should be taken in great consideration. Indeed, enhance energy efficiency is more cost effective than purchasing larger renewable energy systems.
Establishing a target is done by strongly reducing by a percentage the target founded with CBECS protocol (the reduction rate is between 65-75%) or ASHRAE 90.1 baselines (40 to 50% of reduction). However, it's usually preferable to find other net-zero energy buildings with a very similar program and use the same target (database for a peer building analysis are available online).



This living building challenge embraces net-zero energy buildings, since that the seventh imperative is net zero energy and no lower thresholds are possible. For what does it concern the energy on site, it allows for a photovoltaic system, wind turbines, water-powered microturbines and geothermic; but aren't allowed biomass and combustion of any type, while fuel cells could be used only if the hydrogen has been produced by renewable energy.

ENVIRONMENTAL ANALYSIS IN GRASSHOPPER

In Grasshopper environment there are several plugins that allow performing environmental analyses on the geometry created, however, most of them work at the end of the process and so giving a poor contribute in the exploration of the design in the very first stage of conception. Until 2015 the most known and used plugin was GECO. GECO didn't perform analysis on site but was linked to Autodesk Ecotect Analysis software, allowing a direct flow between the two software, making environmental analysis in the first stage of the project possible. In this way, geometry and climate data were imported from GECO component to Grasshopper and here the analyses performed. Once ended all the data were pushed back to Grasshopper and used to inform the geometry (10).

10. Tedeschi Arturo, *AAD Algorithms-Aided Design. Parametric strategies using grasshopper*, Le Penseur, 2014

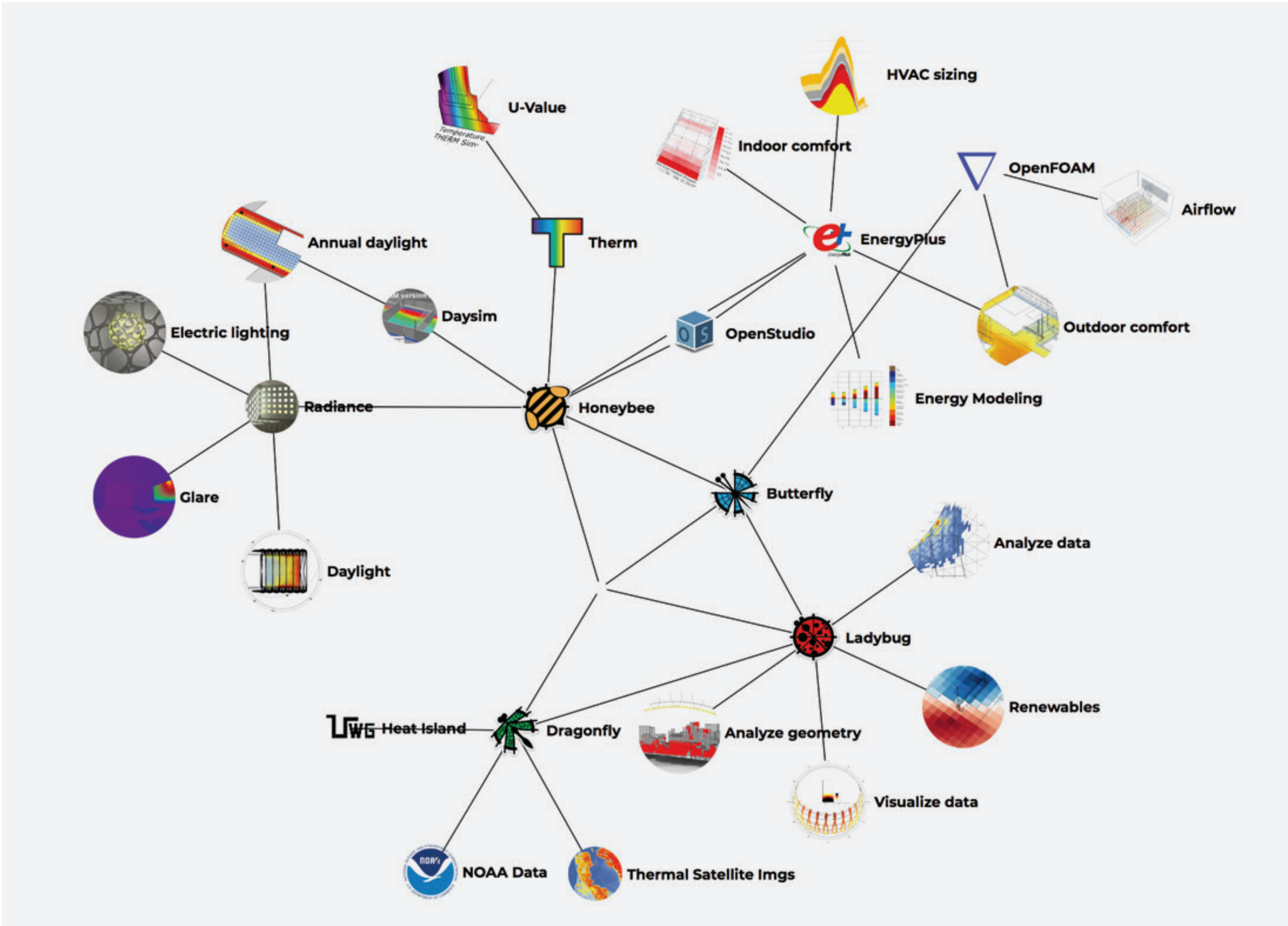
However, in 2015 Autodesk announced that the support to Ecotect Analysis software would be over by the end of the same year since that such analyses would be performed inside Autodesk Revit. Even if is still possible to download the software and the GECO plugin, the interruption of the support, and so the end of new updates, brought the necessity to find a new way to perform such analyses.

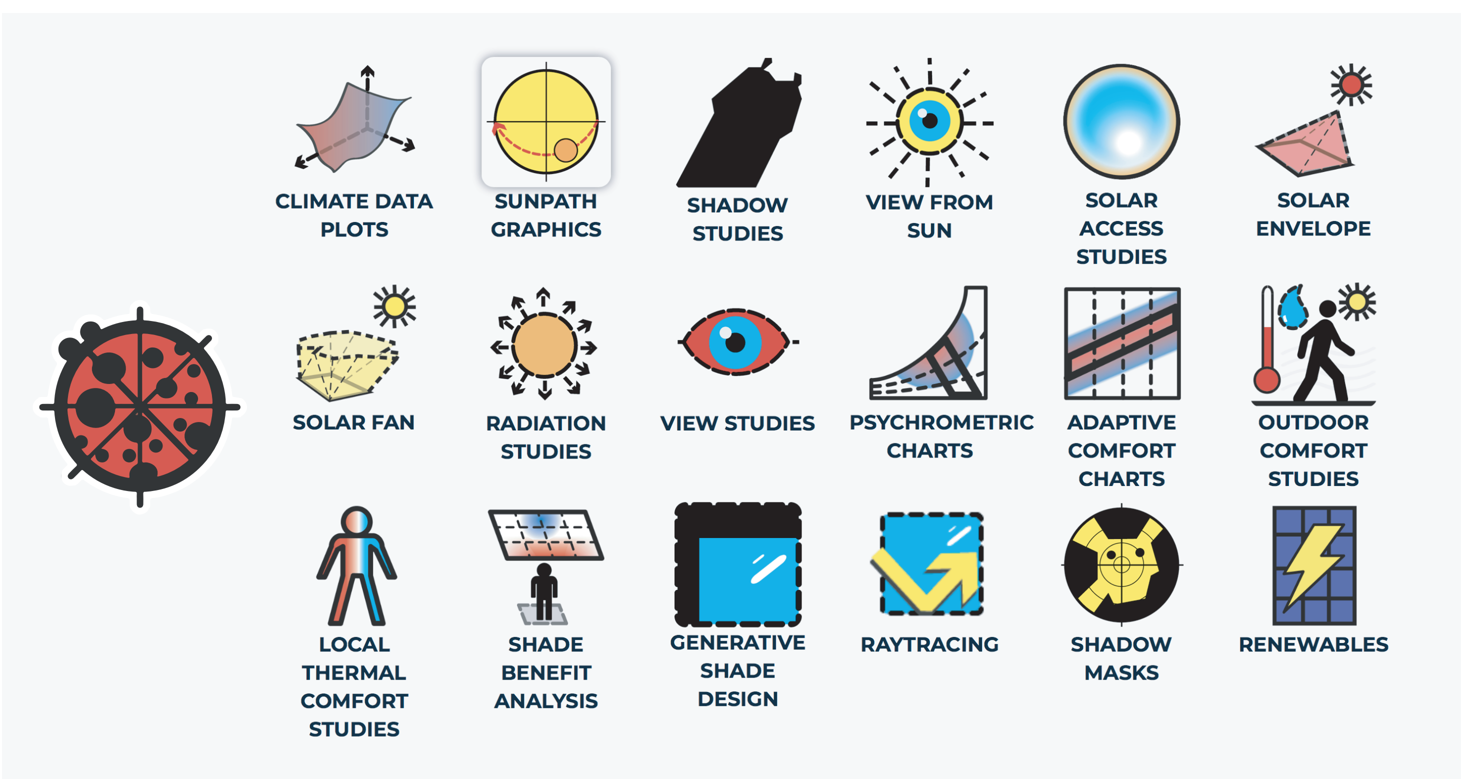
The new reference point in this field became quite immediately and easily Ladybug Tools. Ladybug Tools is a free suite of Grasshopper plugins which work (in a similar way to GECO) with free software for environmental and energy analysis.

The project was started in 2012 by Mostapha Sadeghipour Roudsari and soon after helped by Chris Makey. The idea of the two was to create a way to make accessible, free, more customizable and easier the way to perform such type of studies. The first release was delivered in 2013 and thanks to the open source library, nowadays is one if not the most known and used plugins, even from some of the most known architectural firms in the world.
Ladybug tools is composed of four different plugins: Ladybug, Honeybee, Butterfly and Dragonfly.

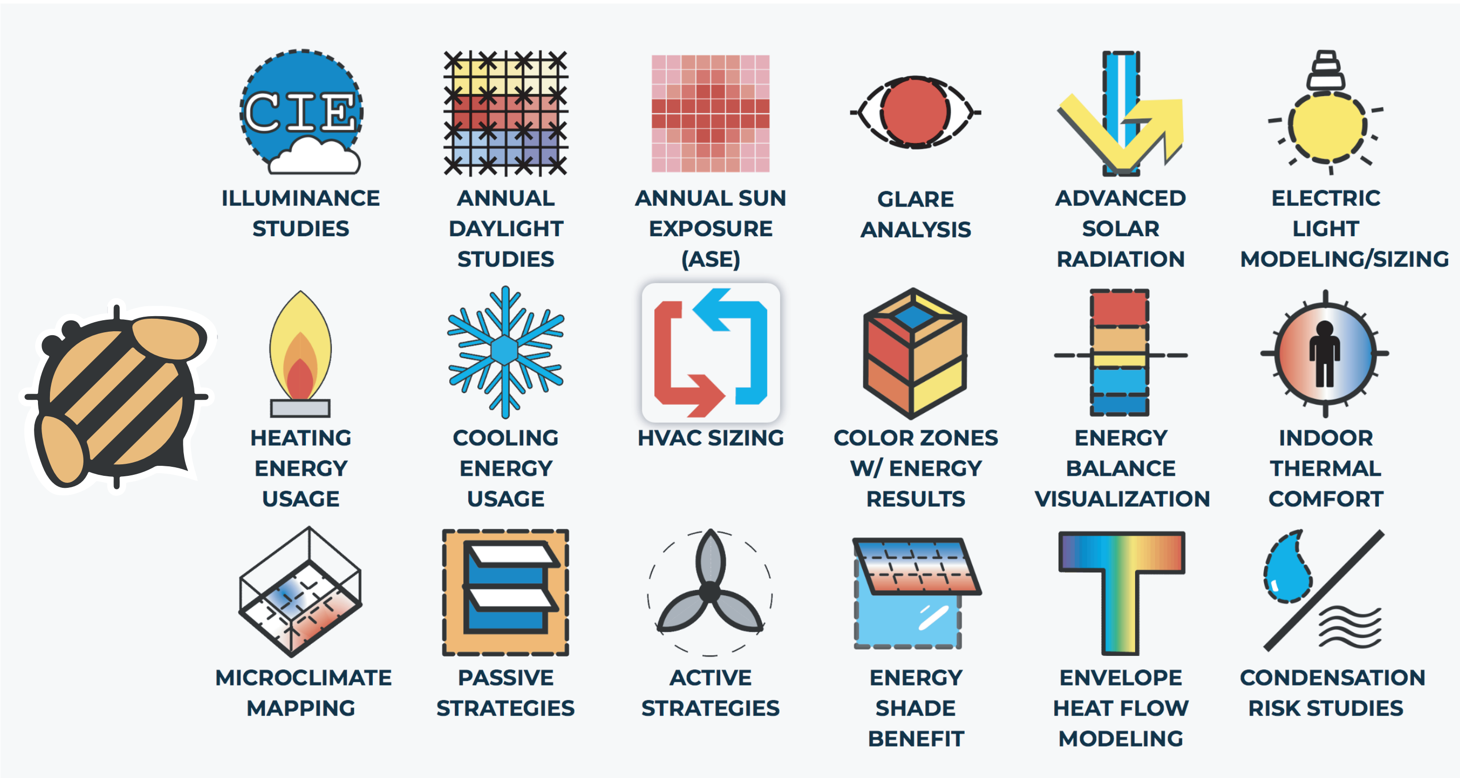
Ladybug performs climate analyses starting form Energy plus weather files (.epw). It can draw 2D and 3D interactive graphs of the data provided, and supporting the decision making during the conception stage of the project. Thanks to the modular structure (as for the others plugin of this suite) it's also possible to directly link the output of the analyses to inform geometry and optimizing it (11).

11. Mostapha Sadeghipour Roudsari, Michelle Pak, *Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design*, Adrian Smith + Gordon Gill Architecture, Chicago, U.S.A., 2013


HVAC sizing
U-Value
Indoor comfort
OpenFOAM
Airflow
Annual daylight
Therm
EnergyPlus
Daysim
Electric lighting
OpenStudio
Outdoor comfort
Radiance
Honeybee
Energy Modeling
Glare
Butterfly
Analyze data
Daylight
Ladybug
Renewables
Heat Island
Dragonfly
Analyze geometry
Visualize data
NOAA Data
Thermal Satellite Imgs

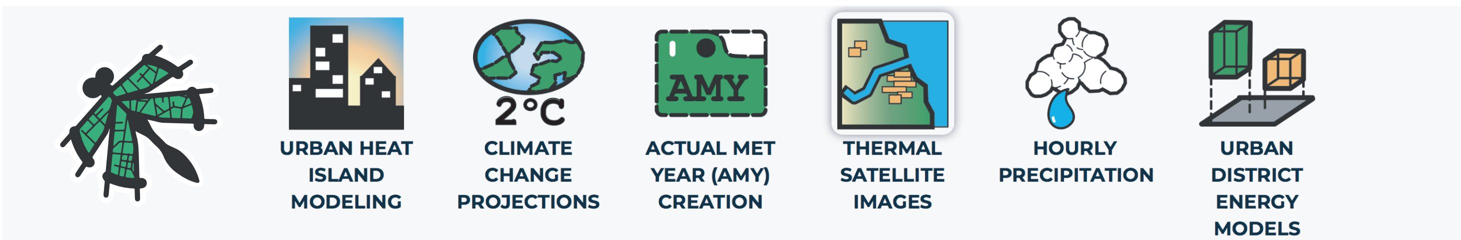

CLIMATE DATA PLOTS
SUNPATH GRAPHICS
SHADOW STUDIES
VIEW FROM SUN
SOLAR ACCESS STUDIES
SOLAR ENVELOPE
SOLAR FAN
RADIATION STUDIES
VIEW STUDIES
PSYCHROMETRIC CHARTS
ADAPTIVE COMFORT CHARTS
OUTDOOR COMFORT STUDIES
LOCAL THERMAL COMFORT STUDIES
SHADE BENEFIT ANALYSIS
GENERATIVE SHADE DESIGN
RAYTRACING
SHADOW MASKS
RENEWABLES

Honeybee creates and runs detailed daylight simulations using Radiance, energy models using OpenStudio and envelope heat flow using Therm. Usually, it's used during the mid and final design stages to check and correct the decision taken previously.



Butterfly instead performs computational fluid dynamic (CFD)simulations using OpenFOAM. By now, OpenFOAM is the most validated open source CFD engine, capable to run advanced simulations and turbulence model. Butterfly works by exporting geometry to OpenFOAM and running common types of simulations useful for building design, such as indoor and outdoor simulations and comfort, ventilation effectiveness and more. Butterfly is the one of the last plugin introduced in the suite and so, in a phase where problems (also lot of) could occur when running it.

Finally, Dragonfly is orientated towards urban (or larger) scale analyses. It's capable to estimate large-scale climate phenomena, for instance, urban heat island, climatic change and so on. The results could be used to feed the other tools of the suite as a starting point for other simulations.



The biggest advantage of these tools is that their modularity allows to merge them together and so create a strong network of information exchanging that allows defining a virtual energy model of the building as complete as possible. In this work all the tools have been used, except for Dragonfly plugin, since the scale of the project to test the theory is at an architectural scale than an urban one.

GENERATING ENERGY PLUS WEATHER FILE

As for every project, the first step in conceiving a building, by an environmental point of view, is to start studying the climate and the characteristics of the site and Ladybug is the plugin which allows, as previously said, to study and display the weather data.

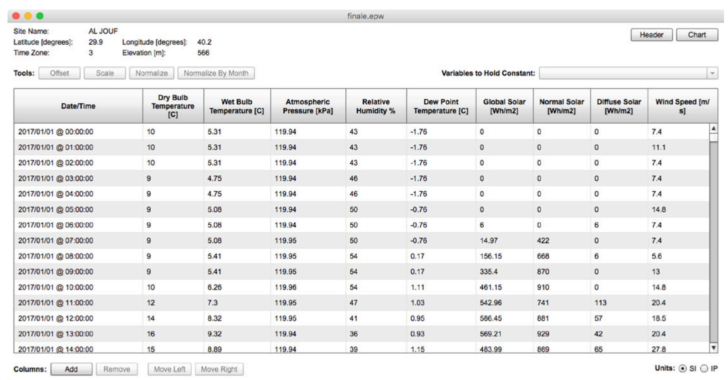
The weather files usable inside these tools are of the .epw file, an extension of Energy Plus program. Energy Plus weather files are databases which provide for every hour of the year climate data, as dry and wet bulb temperature, humidity, atmospheric pressure, speed and direction of the wind, solar radiation (both normal and diffuse than total). The amount and type of data depending on the weather station that record them, that usually are placed in the city airport. For a certain location, this data could be existing as not, as could be free or accessible after payment.
When researching for such a database it's very important to keep attention about the source of these data, since not always they are truly measured, but sometimes are created through interpolation of data of the nearest cities that feature an available. epw database. In this case, factors as the goodness of the interpolation algorithms, or the distance between the sample cities (to not mention different on-site characteristics, for instance, topography), could distort if not change these data making them pretty useless. This type of data could still be used but with a certain amount of caution and using them to drive design choices by a general point of view and not for too much specific analyses.
The most popular and commonplace where to find these files freely available is on the official energy plus website at the page https://energyplus.net/weather. Here a world map indicates all the places that feature such type of document and from here a link is provided to directly download them.

Ladybug is capable to read the epw file online without the need to download it, by only plugging a panel with the website address of the file wanted. At this point, all the data will be loaded into the software and will be possible to execute all the analyses wanted. Of course is possible to link the file after having downloaded it or created it.
Indeed when the file for the desired location isn't available and the interpolating method isn't useful to create usable data for the project, is still possible to create it, as in the project case presented in this work.

As just said, energy plus weather file contain a wide range of hourly data across a whole year, and Ladybug needs most of them in order to work and create accurate analyses. So the first problem is to find a database, possibly free, where to download historical hourly weather data of, at least, the last year. One of the best websites where to find all this range of data is Weather Underground (https://www.wunderground.com), an American weather forecast website, where not only is possible to search data for city name but also for weather station ID. In this way by searching online for the nearest weather station and its own to the project site, is possible to have access to the most reliable data possible. However, by browsing through the website is possible to access historical data only day by day, making in this way quite laborious building a database file for a whole here. Nevertheless, it's available online a shell (http://oco-carbon.com/wunderground-weather-data-downloader/) that allow by entering the ID of the weather station, the start and the end of the period that it's needed, to download a file in CSV format with all the data recorded by that station for every hour of the period requested. Since in CSV file data are divided with comas, it's necessary instead to make them be divided into columns. This is possible by editing them in an electronic paper manager software like Microsoft Excel. At this time the conversion from CSV file to an Epw one is done through ELEMENTS software. ELEMENTS is a free software available both for Mac and Windows user that allows to create, modify or generally manage Energy plus weather file.

The conversion is not directly managed by this software but it's only necessary to create a new file, entering the data about the location and which type of data the new file should contain and copying and pasting from the columns of CSV file edited previously to the corresponding columns inside ELEMENTS. Once the file is saved is ready to be used by Ladybug or any other software.

Here an exemple of the ELEMENTS interface:



Date/Time	Dry Bulb Temperature [C]	Wet Bulb Temperature [C]	Atmospheric Pressure [kPa]	Relative Humidity %	Dew Point Temperature [C]	Global Solar [Wh/m2]	Normal Solar [Wh/m2]	Diffuse Solar [Wh/m2]	Wind Speed [m/s]
2017/01/01 @ 00:00:00	10	5.31	119.94	43	-1.76	0	0	0	7.4
2017/01/01 @ 01:00:00	10	5.31	119.94	43	-1.76	0	0	0	11.1
2017/01/01 @ 02:00:00	10	5.31	119.94	43	-1.76	0	0	0	7.4
2017/01/01 @ 03:00:00	9	4.75	119.94	46	-1.76	0	0	0	7.4
2017/01/01 @ 04:00:00	9	4.75	119.94	46	-1.76	0	0	0	7.4
2017/01/01 @ 05:00:00	9	5.08	119.94	50	-0.76	0	0	0	14.8
2017/01/01 @ 06:00:00	9	5.08	119.94	50	-0.76	6	0	6	7.4
2017/01/01 @ 07:00:00	9	5.08	119.95	50	-0.76	14.97	422	0	7.4
2017/01/01 @ 08:00:00	9	5.41	119.95	54	0.17	156.15	668	6	5.6
2017/01/01 @ 09:00:00	9	5.41	119.95	54	0.17	335.4	870	0	13
2017/01/01 @ 10:00:00	10	6.26	119.96	54	1.11	461.15	910	0	14.8
2017/01/01 @ 11:00:00	12	7.3	119.95	47	1.03	542.96	741	113	20.4
2017/01/01 @ 12:00:00	14	8.32	119.95	41	0.95	586.45	881	57	18.5
2017/01/01 @ 13:00:00	16	9.32	119.94	36	0.93	569.21	929	42	20.4
2017/01/01 @ 14:00:00	15	8.89	119.94	39	1.15	483.99	869	65	27.8

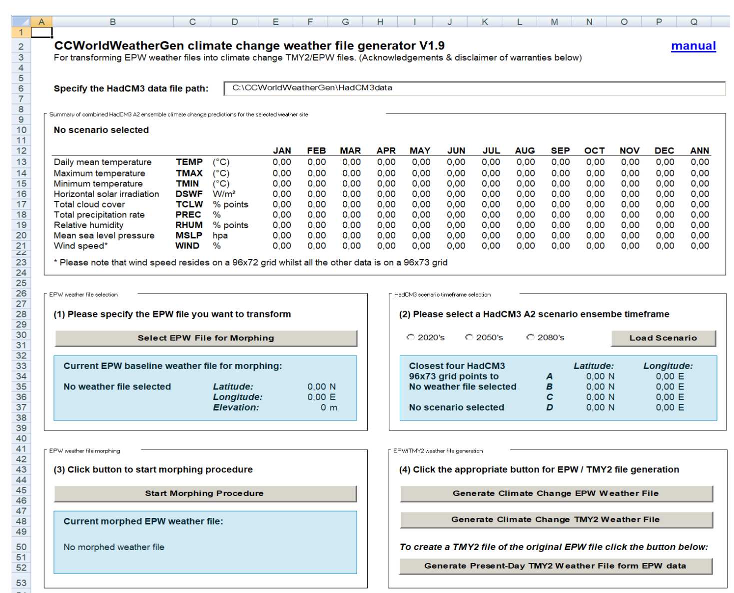
CREATING ENERGY PLUS WEATHER FILE FOR CLIMATE CHANGING

It's widely and commonly known that emissions derived from man activities are the main cause of globing warming and climate changing. According to a paper published by the Intergovernmental Panel on Climate Change (IPCC), an increase in global average temperatures is expected in a range between 1.1-2.9°C and 2.2-6.4°C by the end of the 21stcentury (12).

The built environment accounts for a percentage that goes from 30 to the 50% (13) (depending upon the country taken in consideration) in the greenhouse emission, and so an important focus it's necessary to mitigate and reduce those emissions. Indeed in the world about the 75% of people are living in urban environment and this percentage is intended to increase in the future (14). That highlights the need to specifically address strategies in designing the building environment and take in consideration the climate changes that will occur in the next decades, since that built environment usually lasts for very long times, and the capability to adapt to new operating conditions could help them to be used longer and better. To do that, a method to morph actual weather data in usable data that identify reliable future climate changes has been developed.

12. IPCC, *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York, 2007
13. Thomas Hootman, *Net-zero energy design. a guide for commercial architecture*, John Wiley & Sons Inc., 2013
14. Mark F. Jentsch , AbuBakr S. Bahaj, Patrick A.B. James, *Climate change future proofing of buildings—Generation and assessment of building simulation weather files*, University of Southampton,2017

The IPCC in its third and fourth reports used six different global emission scenarios that vary according to different possible future "economic growth, resource consumption, technology implementation and global population development" (14).
In few words, these six models represent six different development scenarios that are predicted to happen in the future and are applied on a grid spacing of 250-500 km. This spacing happens to be too much gross to be usable in building strategies development and a higher resolution is required to obtain reliable data. To increase the resolution of the grid a downscale is required and obtained through a method called morphing. This method is based on the adjustment of actual weather data by the changes to climate forecast by global circulation model and regional climate models.
This strategy has several advantages such as a reliable base of weather data based on real observations and records on the desired location but also the disadvantage that could be subject of the variability of the present-day climate. The morphing procedure is based on algorithms that shift the actual weather file to 2020, 2050 and 2080 scenarios.
The process is done through an Excel file where the actual weather data file is uploaded and then morphed using HadRM3 experiment models (15). Once morphed the file could be saved again with the same original file extension.

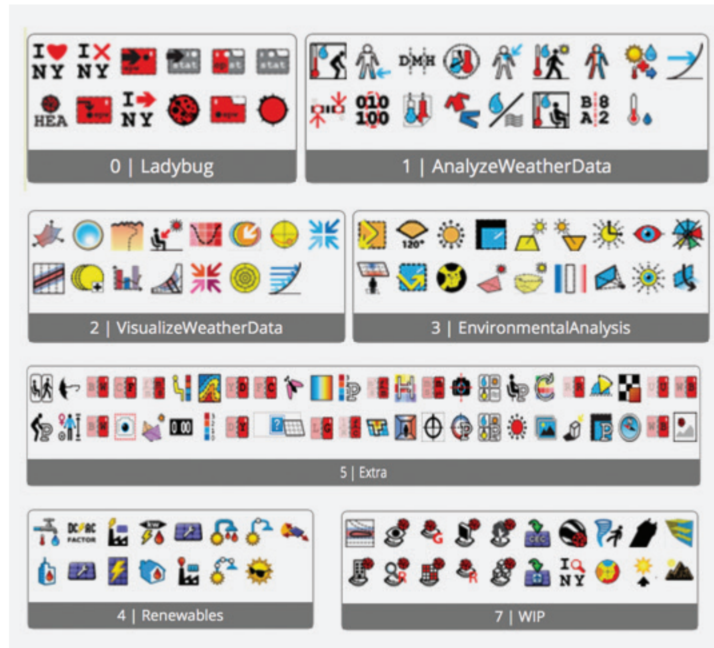


15. Belcher, Stephen E & Hacker, Jacob & Powell, *CConstructing design weather data for future climates*,Building Services Engineering Research and Technology, London, 2005

Because these files are created on a basis of forecasting models the analyses generated on these morphed files basis should weight and used to generally drive the designing thinking process in order to achieve resilience. However, should be not used to drive specific environmental strategies since the uncertainty that they may have.

SITE ANALYSIS WITH LADYBUG FOR GRASSHOPPER

To start to conceive a design idea, it's necessary to understand the characteristics and main aspects of the environment where the work is going on. So, in the very beginning, Ladybug provides a series of tools to interpret and visualize the data collected in the Energy Plus weather file. The importation of an epw file in Ladybug could be done by linking the webpage that hosts this file, it will be automatically downloaded, or by uploading a physical file. Once imported the weather data file, the Ladybug component gives a collection of data stream divided into the same categories collected by the original file (for instance: dry bulb temperature, wind speed, relative humidity, and so on). At this point the methodology under this analysis process is quite the same for every aspect taken into consideration: the output data are linked to a specific analysis component, this component will perform calculations, the interpreted data are displayed through a graph component and a panel if numerical values are requested. Analyses could be performed along a whole year or a specified period that could be even a single day or last for different months.
There are several analysis components in Ladybug that can work alone or linked between them to create more complex analysis.



RADIATION ANALYSIS

The main source of energy on our planet is obviously the sun. Across the year the sun follows a specific moving pattern along the day and the season and depending on the latitude of the studied location. That means that, from an architectural point of view, a different degree of radiation and perception is perceived along the year. It's a very important data to analyze since it tells how much heat is gained by the building along the year and so, is possible to develop a strategy that helps prevent overheating during summer and use the heat gained during the winter. The solar radiation is divided into two main components: the direct one, which is the radiation that directly hits the ground, and the diffuse one, which happens especially in case of cloudiness, where the radiation is diffused through the particles that are present in the atmosphere before it hits the ground.

Because the cloudiness is a factor that varies across the year and it could be different in different years, is unpredictable by the theoretical model, and so only approximations of absolute values can be referred as valid (16).

Ladybug radiation analysis is composed of different steps. Firstly it uses Radiance's Gendaymtx function to calculate the radiation value for each hour of the year. The Gendaymtx is an algorithm based on the Perez all-weather model, which is capable to produce a sky matrix form a weather tape(17). The matrix is a numerical representation of the sky patch, which means that is possible to increase or decrease the resolution of the net, according to the accuracy of the analyses required.
The second step involves the selection of the whole or part of this matrix according to the period taken into consideration. Interesting periods could be the seasons, indeed understanding seasonal variations could address specific strategies. Once the sky matrix is selected is possible to run the radiation simulation. To perform this, not only is necessary to link the sky matrix just selected but also the geometry on which to perform the analyses and the shape of the context, that could affect the result. Once the analysis is conducted the result could be displayed as a grid mesh on the studied geometry but also as a radiation rose, a simple chart to visualize variations or even a projection of useful or harmful radiations on the skydome. In this last case, of course, is necessary to provide a threshold of division between what is considered helpful and what is not.

To make it works I used as discriminator value the temperature. A split component is introduced to divide the list of all the hour temperatures that are above the 20 °C and using these hours as the period to extrapolate the sky matrix from the whole one.
Once separated, the patches of the matrix have been coloured with a gradient depending on the temperature: greener the better, red the worst.

16. Alexis Aguila, Carlos Alonso, Helena Coch, Rafael Serra, *Solar radiation and architectural design in Barcelona Reconciling protection in summer and gain in winter*, Contribution for the 27th Conference on Passive and Low Energy Architecture, Belgium, 2011
17. http://www.radiance-online.org/learning/documentation/manual-pages/pdfs/gendaymtx.pdf

Once coloured, all the data have been fused again together and used with the skydome component that allows visualizing the sky mesh coming from the sky matrix. This dome has been overlapped with a stereographic sun chart with drawn the position of the sun along the whole year and the obstruction due to the context.

Solar radiation not only influences the heat gained by the buildings but also the temperature of the ground. Thanks to the high thermal mass of the soil the temperature decrease at a deeper level with respect to air temperature, and that's because in hot countries a useful strategy is to build into the earth. Of course, temperatures vary along the hours of the day and the year. Again Ladybug helps in visualizing these data with a component that is directly fed by the epw file. This component works by interpolating the soil temperature registered by the weather file at the three standard depth (0.5, 2 and 4 meters under the level of the ground) and calculating the temperature at the depth requested. Of course by linking the results to a graph component is possible to display the variation across the time period chosen.
Another aspect linked to solar analyses conducted by the plugin is the study related to sun position. Through the sun path component, Ladybug can compute the position of the sun of every single hour of a year and so calculate the direction and inclination of sun vectors. Once the simulation is conducted, not only is possible to preview the path of the sun along a certain period, but also conducts deeper analysis such as a shadow study that can be helpful to develop strategies in a hot climate or understanding the relationship with the context and develop also a solar fan. For instance, shadows analysis could be very useful to be displayed during solstices and equinoxes.

WIND ANALYSIS

Wind can play an important role in achieving the desired thermal comfort and reducing energy consumption due to cooling during hot season or quite the entire year in arid countries, thanks to passive strategies, that will be discussed later, while in this part of the chapter the focus is on the management and display analysis

of the weather data.Ladybug allows the user to display the information about the wind in the form of wind rose in a plane view and as a profile in a front one.
The wind rose is very helpful in understanding how often the wind blows in a certain direction and with which intensity during the year or for a certain period. In this way is possible to develop strategies to use wind as cooling strategy during the hot season or defending the outer areas if it creates a discomfort situation. If it is the first case the wind profile component could be very useful in finding the orientation of the building in order to maximize the amount of wind caught and, in this way, improving the natural ventilation. Both the component could be used to feed the Butterfly component and perform a CFD analysis to test the goodness of the strategy adopted.

PSYCHROMETRIC CHART

The study of the thermodynamic characteristics of the air is called psychrometry, and in architecture is used to understanding how the variations in the moisture of the air affect the thermal comfort of human, but also how a strategy could affect the people wellbeing. This study is conducted through a tool called psychrometric chart. The chart includes different variables such as dry and wet bulb temperature, relative and absolute humidity, dew point, enthalpy, specific volume and so on (18).
The very first step in using it, is defining the thermal comfort zone in which the building can operate, and then draw the characteristics of the site. In this way is possible to notice how much is necessary to develop environmental strategies to achieve the comfort target. Again, a Ladybug component to perform such study is given. Starting from the data extrapolated from the energy plus weather file the plugin draws a psychrometric chart were polygons highlight the comfort zone but also the effect of passive strategies on it.

The comfort model implemented in this tool is the Predicted mean vote (PMV) that is a seven-point scale from cold (-3) to hot (+3) that is used in comfort surveys. Middle values are: -2: Cool, -1: Slightly Cool, 0:Neutral, +1:Slightly Warm, +2:Warm. With the range of comfort is situated in a PMV range between -1 and +1. Accordingly, this component will also output the PMV of the occupant for the input conditions as well as an estimated percentage of people dissatisfied (PPD) in the given conditions (19).

MASSING OPTIMIZATION

When conceiving a building the very first steps are all about concept and playing with shapes. In this stage introducing environmental strategies could bring benefits to the project just from the beginning. When playing with conceptual shapes to understand the juxtaposition with the context a key role in environmental strategies is orientating the building in order to maximize the exposure when thermal gain is required and minimize it when became harmful.

The idea behind this process is to evaluate on the four walls of a sample box representing the building the incoming radiation (the roof is excluded since here the radiation doesn't depend on the orientation) both helpful that harmful depending on the angle of orientation with respect to geographic north.

18.Thomas Hootman ,*Net-zero energy design. a guide for commercial architecture*, John Wiley & Sons Inc., 2013
19.https://code.google.com/p/cbe-comfort-tool/wiki/Comfort-Models

As for the algorithm to display the radiation on the sky-dome, the radiation is divided by a threshold temperature set at 20°C. At this point, the sky matrix is created for each case and then the radiation analysis conducted for both. Once computed, the values coming from the set of useful radiation are subtracted from the harmful and then mass addicted.
This final value became the fitness to be maximized by Galapagos by changing the angle of orientation of the building. Further optimization can be introduced by parametrizing the dimension of the building box.
However, these values have to be searched within a range since if no limits are given the result will be a box with a very dominant direction of development with respect to the other.
To display the result of the massing orientation a grading colour is introduced, by highlighting on the façade which faces receiving helpful radiation and which not.

In urban areas or site where buildings are lot constricted by the context, and so the amount of radiation varies according to the highness of the building, a good improvement could be to perform this searching analysis on each floor rather than on the whole building. In this way, every floor will receive the best ratio possible.

This methodology can also be used to search for the best orientation to maximize the amount of wind caught, so can be used for natural ventilation. In this case, the optimization algorithm will try to tilt the geometry in order that the biggest surface of the building will be perpendicular to the direction of the highest wind blowing frequencies computed by the wind rose component. In this case, the genome is the frequency coming from a certain wind direction and hitting the biggest surface available, while the genome is again the angle of orientation. Because also, in this case, the fitness has to be maximized (in the case that should be minimized, multi-objective plugin, such as Octopus, could be used), it's possible to sum the two fitness (the one from radiation and the one from the wind) and search for the best orientation that can satisfy both the requirement.

Of course, is possible to make one value predominant on the other one by multiplying for a weight factor one of the two. In this way, the most weighted value will be the one that mainly drove the search for the solution.

DAYLIGHT ANALYSIS

The sun is not only responsible to provide heat by radiation, but it plays a central role in defining the luminance in the building. Natural light is a form of electromagnetic radiation in the visible-light spectrum, and it's directly involved in human physiological process and wellbeing, for instance, it's at the base of the circadian system, UV allows the production of D vitamin and a direct view on the outdoor help decreasing stress. Natural light not always is more performative than the artificial one, but it has the big advantage of being available in great amount and it assures a high colour rendering. Natural daylight for an ambient depends upon:
-direct luminous flux, deriving from sun and sky
-reflected luminous flux, due to obstructions and external surfaces
-undirected luminous flux, a consequence of several reflections that happen inside the room.

So it's possible to understand how the main external light sources, context, opening and environment characteristics are determinants for daylight performance in a building. Sun and sky are the two main external sources that provide natural light. While the former is characterized by a strong directionality, high contrast and very high luminance that produce glare, the latter produces no glare thanks to a diffuse distribution that also means low contrast in the object perception.

While the light produced by the sun is quite constant if not during the first and last hours of a day (indeed is described by only 1 theoretical model), skylight intensity and distribution depends lots of the weather conditions, and, because of this, different theoretical models are required to describe it: clear sky, partially cloud-covered sky, cloud covered with uniform luminance and cloud covered with variable luminance.(20)

In Ladybug tools this aspect it's addressed by using the value of cloudiness recorded in the epw file, in this way reliable values of daylight will be given according to the period analyzed. Daylight simulation could be done through Ladybug and the radiation components, but values are to be taken with a certain caution since it doesn't take care of reflection of the environment and can't manage complex shapes. That's why these analyses are computed through Honeybee, which starting from the epw file and a database of material to be assigned at the geometry, uses Radiance software to run the computation and give reliable results.

20.G. Forcolini, *Schede di fisica tecnica ambientale* , Hoepli, 2004

RUNNING AND OPTIMIZING DAYLIGHTING WITH HONEYBEE

As for the wind simulation in Butterfly, also in Honeybee is necessary some preparation steps run the analysis. Here the main step is to convert Grasshopper or Rhino geometries to Honeybee geometries and apply materials for opaque and glass elements. A library of common material is implemented, but it's always possible to create custom ones. All this process is done thanks to a set of components that is possible to find in the very first tab of the plugin. Once all the geometry and materials have been set, it's necessary to create a grid of test points on the floor surface or whichever surface that the user wants to be analyzed. As always higher the resolution of the grid, longer the time that will be required to finish the calculation. The third step is to create a recipe for the simulation. A recipe is nothing more than a component which collects all the parameters and field where to find and compute the solution. Her the type of analysis (luminance, energetic, …) has to be set as for the model of the sky to be used, and the period of the year to test. Once do that, is possible to run the simulation by linking Honeybee zone and recipe to the daylight test component. The results calculated will be numerical and so, a post-processing on the data is necessary in order to graphically display them on the test grid, this is easily be done by recolouring the initial surface mesh according to a grading associated to the solution values.

This algorithm is the basis for the development of optimization process for daylight target, indeed by varying some geometry parameters is possible to vary intensity and distribution of the daylight. In this work, the optimization process is conducted by working on the dimension and position of openings and shading elements.

For what concerns the openings, dimensions and position have been made dependent according to two factors: inclination of sun rays with respect to the building surface and the level of daylight on a test surface. The inclination of sun rays to shape the dimension of openings has been a very common approach since the development of parametric environmental design. The idea behind this process is to use the inclination angle between sun rays and the normal vector of the surfaces as a scale factor for openings. Because this angle varies for every hour of the day of the year, a selection of which days to use is necessary, and solstices and equinoxes having respectively highest or lowest and average inclinations represent the extremes of the research field.

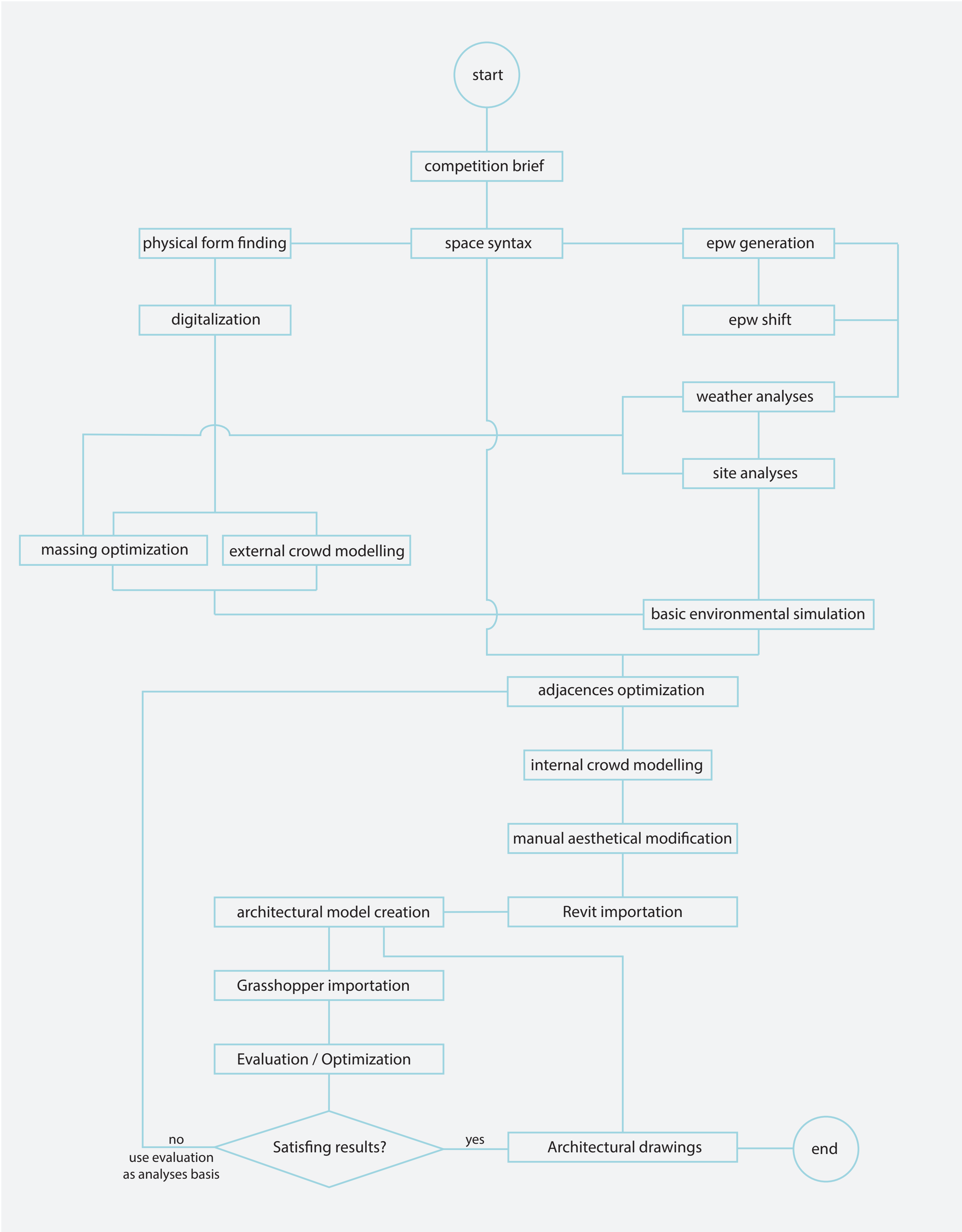
However, to better fit the optimization process to the characteristics of the local weather, a selection mask is created to filter the sun rays, based on the positive and negative radiation projection on the skydome algorithm explained before. By searching for which rays a helpful solar gain is also achieved a positive scale factor is associated, while, when harmful heat gain occurs, a negative value is introduced. In this way, the openings will be larger in correspondence of portion of the sky dome where a heat gain for colder month is accomplished, while smaller when the gain due to solar radiation has to be avoided. Once the angles are computed, a remap process of them in a scale factors scale is conducted and associated with the rays provenience from the Skydome. The extension of the scale factor scale is decided by the designer, but it's necessary to keep in mind that too much big or small values could bring to unwanted results as windows too small for meeting daylight target. Besides the choice of the extremes for the factor values, a correction method of the algorithm is by trying to maximize the percentage of surface where an illuminance target is achieved by changing the dimensions of the window, but of course setting a limit to where the algorithm can work, otherwise large openings where heat gain is negative could be created and vice versa. The process of optimization is done by simply running a daylight analysis, compute the percentage of the tested surface that happens to have a illuminance value equal or higher than the wanted target (could be 100, 300 or 500 lux depending on the destination of use) and then trying to maximize this value by changing windows dimensions (and also position if wanted) in the range set.

A final correction is done for trying to avoid direct sunlight (and so thermal radiation) in unwanted spaces by working on shading. The shading is designed through the component shading designer of Ladybug. It works by cutting or extending an initial shading surface by calculating the number of sun vectors entering through the window surface. In order to make it work, the component has to be fed with the sunray vectors coming from the sun path calculation, the geometry of the window and of the shading surface and the geometry of the context that could help in blocking sun vectors. Once that component has run, an output mesh will be given, where a contour of the ideal shading surface is provided.

MAKING ALL WORK TOGETHER

The aim of this work is trying to manage the complex interactions that are established during the building design and realization process by creating a process where different aspects are merged and integrated together in order to face problems that could emerge when different target has to be achieved at the same time. As just said in the introduction, this work is not intended to be explicative for all the aspects in project design and realization since the extreme wideness of this field, but it focuses on some areas and creates a basis for a model that could be developed and integrated subsequently.
Once all the single algorithms have been created, the problem that has been faced was finding a way to making some of them work together and at the same time, meaning that a way to manage and weight the relations that happen in the design process needs to be found.
To do that, it's all started by arranging the different algorithms according to a typical design timeline, constructing a relationship where the first algorithms feed those after and then flatten to the same level those ones that have to interact and doesn't need data from following algorithms.
The first step has been the translation of the physical finding form model in a digital one, this has been achieved with translating photos of the model in a grey scale and then using it with the image sampler component that allows using an image as a generation of numerical data (from 0 to 1) according to the intensity of the colour of each image pixel. As explained later modification and adjustments are introduced according to an aesthetical point of view. At the same time, the space program has been converted in a conceptual graph and analyzed with space syntax algorithm, defining the relationship patterns that should be created in order to achieve targeted inclusion or exclusion depending by the functions.
Once the raw shape has been defined the next step includes two different parallel algorithms: the massing orientation optimization and crowd modelling for the external area. While optimizing the orientation of the surface with respect to wind and solar radiation, a pedestrian simulation has run to find main access points to the new building. The surface is updated with the intersection of the interpolated paths point with the surface itself, and intersection points are extracted to be used in indoor crowd simulation.

Once this step is concluded daylight and thermal analysis and optimization are conducted to create a field according to which internal spaces will be allocated. Starting from this analysis the centre of auditorium mass has been placed in the place with lowest illumination values, that's been the only volume that can't be changed by the adjacency algorithm that meanwhile collected the relation pattern from space syntax algorithm. At this point, the optimization process for programmatic spaces has been turned on and a configuration for interior spaces emerged. After this, central points of each mass spaces have been collected and merged with access points found during the crowd simulation in an exterior environment, with the latter working as starting propagation points. Now the crowd dynamics simulation has been switched on again but to create a path between the different spaces.
Since there is no hierarchy in how particles moved from one space to another, they will create a network linking all the points among them. To select only those paths that reflect the links found by the space syntax analysis, a selection mask is introduced by computing the distance between the paths themselves and lines representing the links. The ones with the shortest distance are so picked.
Once the space distribution has been cleared further corrections and optimizations are made to enhance the performance in main spaces.
After all these analyses the final conceptual volume is linked to Grevit plugin to be translated in a true architectural form.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epw generation
digitalization
epw shift
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site analyses
massing optimization
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basic environmental simulation
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internal crowd modelling
manual aesthetical modification
architectural model creation
Revit importation
Grasshopper importation
Evaluation / Optimization
no
use evaluation
as analyses basis
Satisfing results?
yes
Architectural drawings
end

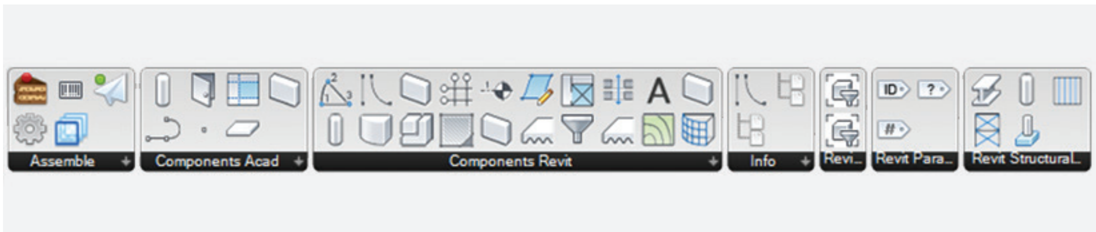
ARCHITECTURALLY SPEAKING

In the end, what comes out has just been only a geometry, that tries to satisfy all the set targets. The next step is making it readable and usable by an architectural point of view. That simply means to draw it. Of course, there exists different ways to create architectural drawings but since the core of this work is trying to automate and manage in a more fluent way the workflow that occurs during the building creation, also in this stage a similar approach has been taken. Instead of simply shifting a 3D model in 2D reality, the geometry has been imported in a BIM software in order to have the possibility to continue to manage the complexity also during the practical definition of the architecture and extend the possibility to develop in the future an optimization process also during the final part of the design. I

n particular, the aim has not been to bake the Grasshopper geometry, converting it in a static 3D model file and using it as the base of drawings, but creating a connection between Grasshopper and BIM software so that changes made in the parametric world could be suddenly translated in the BIM one. Autodesk Revit has been chosen as BIM software since the easier compatibility with Autodesk AutoCAD for finishing the 2D drawing processing and the wide usage in Europe architectural reality.

Unlike Graphisoft Archicad which has a plugin that allows a live connection between Grasshopper and Archicad interface, Revit doesn't have it. However several plugins have been developed to try to fill this gap, even a true live connection at this time still doesn't exist. Generally, plugins for porting Grasshopper geometry to Revit work by defining each element as a Revit family, saving the file as .rfa file (Revit family file extension) and then opening this family in Revit. As it's possible to understand this methodology doesn't create an easy and quick workflow to move data between the two software, neither an automated one. However exists a plugin that working in the same way, it creates a better workflow even if still a bit intricate, this is Grevit. How described before, Grevit works by defining each architectural element or surface as a Revit family (such as pillars, walls, roof and so on) but instead of saving a physical file to open later in Revit, it sends data across the network and then download them into the BIM software, in this way by changing parameters into Grasshopper, the changes will be updated in the Revit model as soon as the data will be sent. This relying on network connection bring both advantages then disadvantages, indeed if by a hand it allows accessing remotely to the file (is possible to work on Grasshopper on a computer and importing it in Revit on another one), by the other hand if no connection is available is impossible to work.

Once imported the model, is possible to start drawing and modelling the final building and produce what it needs for the delivery.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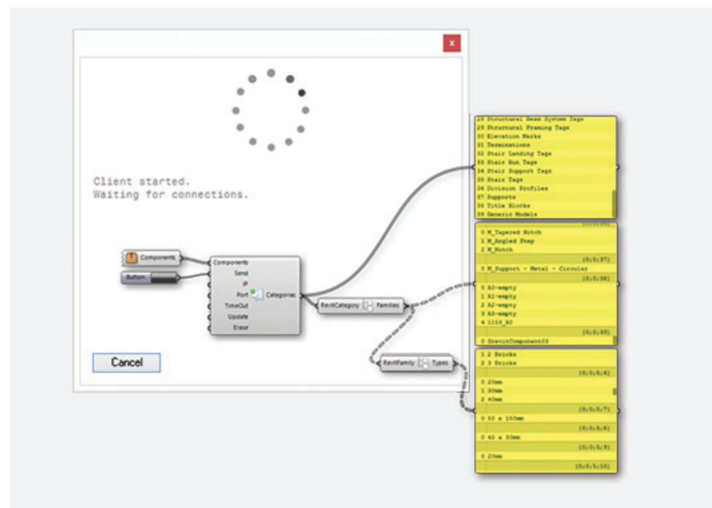
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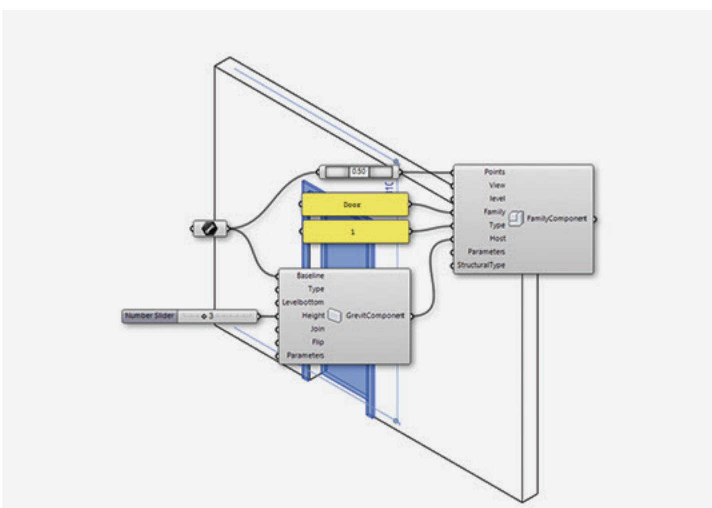
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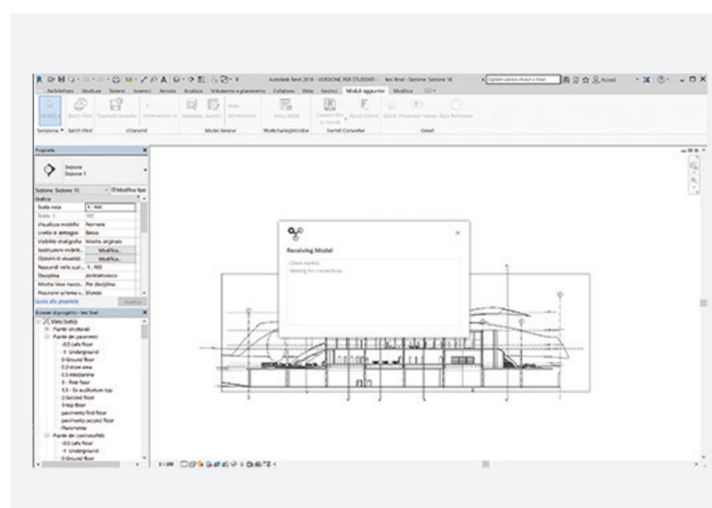


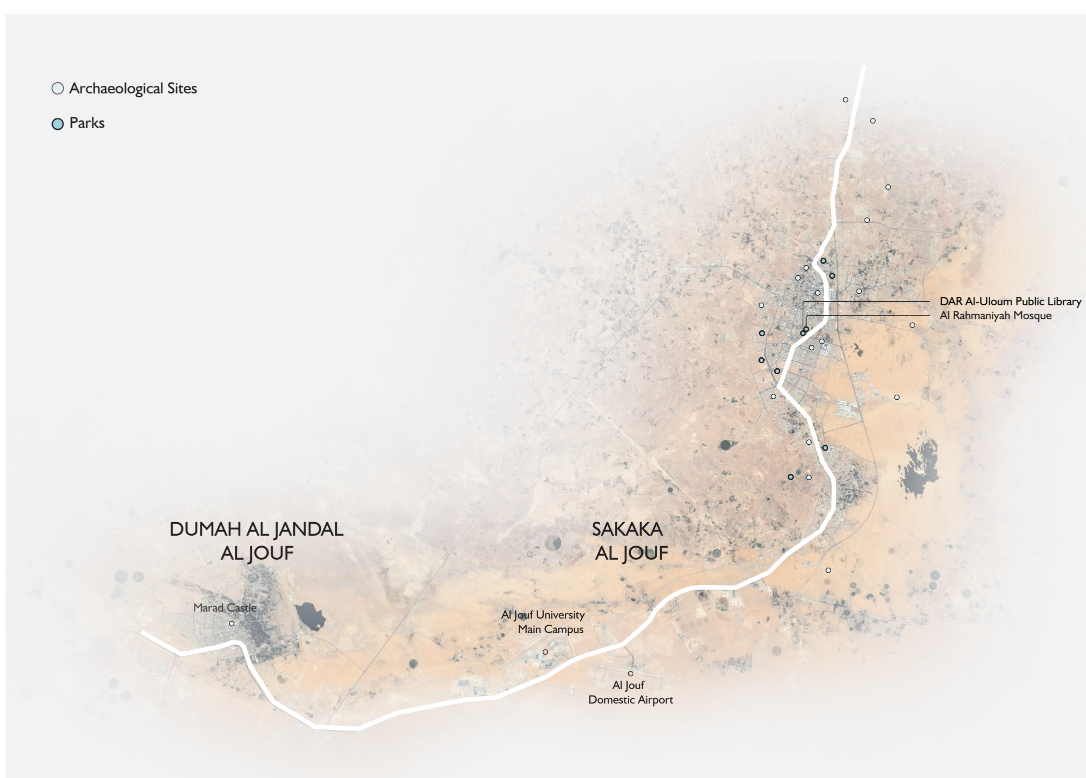
CHAPTER FOUR

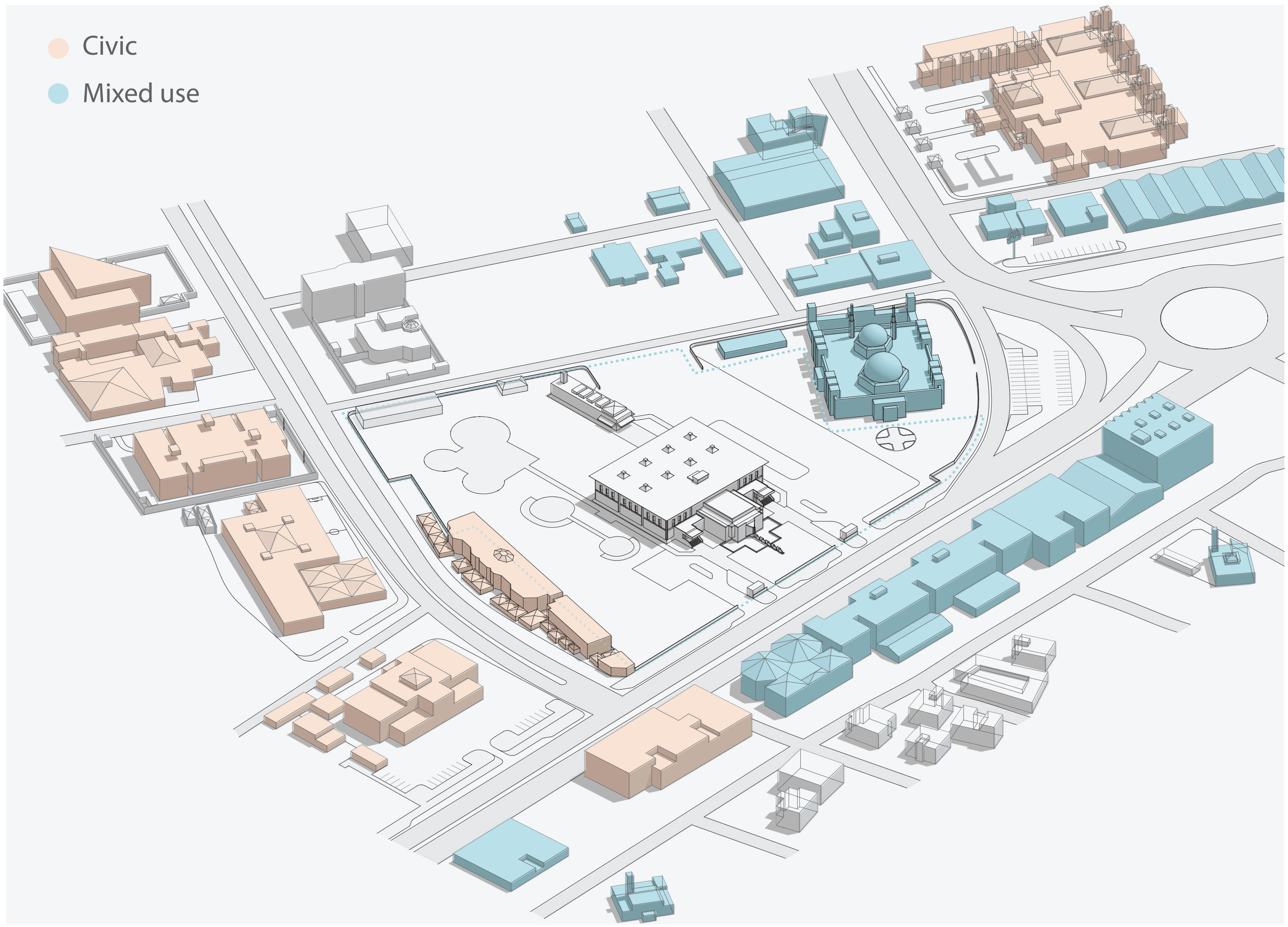
project

WHERE ARE WE?

The project site is situated in Saudi Arabia state, particularly in Sakaka, the capital of Al-Jouf region, in the north of the state, and that's located on the border with Jordan.

Precisely it is located in the north district, near the highway which runs for the entire length of the city and linking it to the other municipalities. This district is characterized by mainly public buildings and spaces, where we can find also the General Court and several Ministries of Public Works. In the last fifty years, new additions have been made, including a new university department, two hospitals and the Dar Al-Uloum library which is the subject of this design challenge.





In particular the library is set in a block that is mainly divided into two parts: the left one is characterized by the presence of the library, its park and several pavilions as the worker residence and the engineer's workshop, while in the other half there is the Al Rahmaniyah Mosque and Ablution which is surrounded by a big parking lot.

THE CLIMATE

By a general point of view the climate in Al Jouf region is of desertic type with very low rainfall, indeed the average precipitation is of about 3 mm per month. Also, cloudiness is not very common, with December as the cloudiest month (31% of being covered), while the rest of the year, especially in summer, the sky is quite always clear. Summer usually starts from May and end in September, with temperatures ranging from 27° to 41°C, whilst the coolest months are from November to February with temperatures included between 5° to 16°C.
If this is the situation nowadays, mathematical and weather models predict an increase of the dry bulb temperature in the next 30 years because of the climate change. According to these models, the 95th percentile temperatures for the months going from July to September will replace the averages for those months. That means that average temperatures in summer will fluctuate from 40° to 45°C. While predicting an increase of the dry bulb temperature is quite simple, the changes for the wet bulb temperature, that is more similar to the perceived temperature, is more difficult since different factors come to play. These factors are mainly related to the mitigation and influences exercised by the Red Sea and Gulf. An increase in air motion due to lower atmospheric pressure at east will mean an even clearer sky while the low albedo of the Red Sea and Gulf will be translated in a higher heat flux (1).

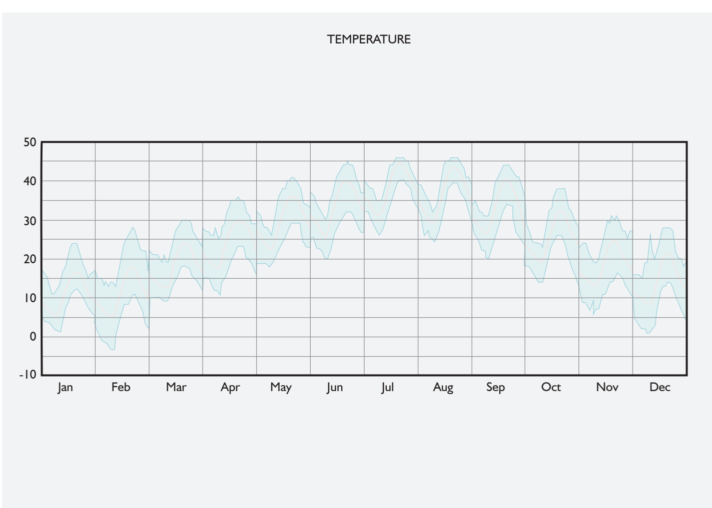
While these information can provide a general overview and idea of the climate in which the building will operate, they also aren't sufficient to give and drive a designing process aimed to achieve optimal environmental results. As said in the previous chapter, the analysis has been made with Ladybug for Grasshopper, which works using Energy plus Weather file, easily accessible through the Energy Plus official website. However the .epw file for Sakaka is not provided by this database, neither by others, sources searched by googling the requested information. A possible solution could be buying the searched data, since available on different websites specialized in selling this type of information. However the highest percentage of this sites, construct the weather file by analyzing satellite images of the region and extracting them by interpolating the data acquired through those images (is the same process used by Dragonfly, one of the other Ladybug tools plugin suite) with data obtained by the nearest common weather station available in the zone. These means purchasing a file that, as far as it could be precise, it could be not really is, since the reliability depends not so much from the satellite images but from the weather station used to interpolate the acquired data. To check how interpolated data could be reliable, one way could verify where the main weather stations are located and decide how acceptably far they could be with respect to the city site. In this case, the nearest weather station used for weather forecast is placed in Riyad, that is quite 900 km away from Sakaka, while one other is in Amman, but it's too near to the Mediterranean Sea, that mitigates the climate, to be trusted.

Because even this way is not possible, the EnergyPlus weather file has been created by downloading raw data from a less known weather station nearer to the city. Thankfully Sakaka is provided by an airport that means that a weather station is available in the city since local weather data are necessary for flights procedure to be

1.Jeremy S.Pal and Elfatih A.B. Eltahir, *Future temperature in southwest Asia projected to exceed a threshold for human adaptability*, Nature Climate Change volume 6, 2016, pages 197-200 done correctly. To find the ID and name of this station a simple internet research has been used since all the weather stations have to been registered on world or country database. The one of Sakaka airport is named OESK, with 40361 as ID. Once downloaded as described in the methodology chapter, the analyses have been done.

TEMPERATURE

The temperature in Sakaka city follows the country trend, with very high temperature in summer, reaching the 45°C, and a mild winter low. Average temperatures are inside the comfort range (20.3°-26.7°C) for the months of March, April, October and November. During the year average nocturnal temperatures fall into the comfort zone or quite below, making possible the use of night purging. strategy to cool down inside temperature during the period going from March to June and September to November. Furthermore, a deep swing happens between diurnal and nocturnal temperatures, implying the possibility to use the thermal mass to protect the building from heat overload.



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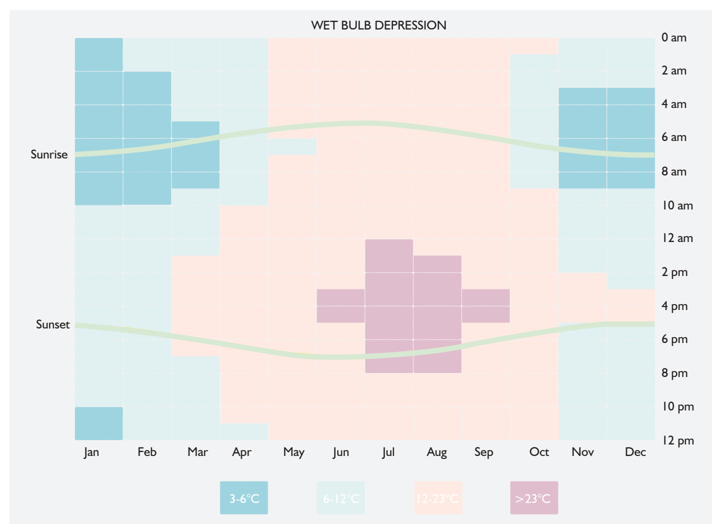
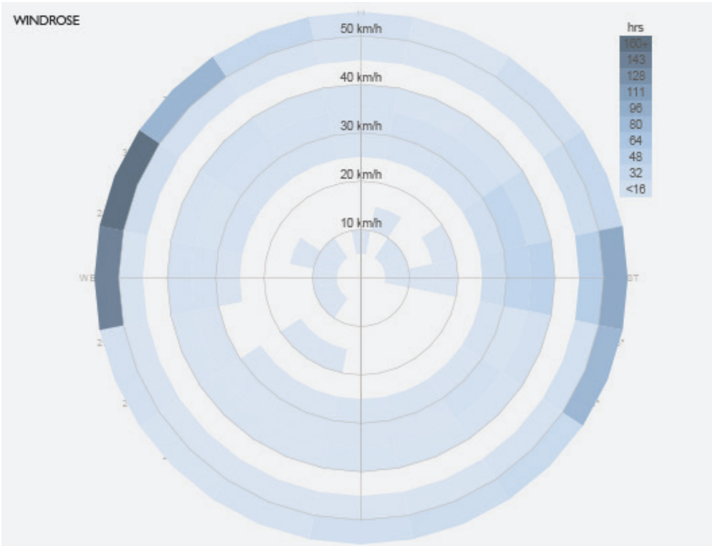
HUMIDITY

What easily pop up form this graph is that a wide humidity depression happens during the hot season and also beyond. This suggests the use of evaporative cooling technology to cool down temperatures, that by looking at the graph could be useful if not determinant in ten months out of twelve.



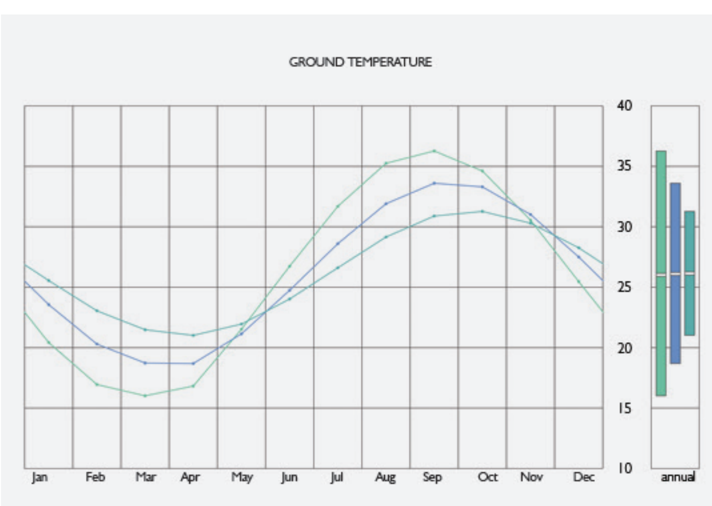
WINDROSE

These graphs show the frequency of prevailing winds by direction along the year. They come mainly from West-North-West and East-South-east directions. Evening and morning winds come from the same direction meaning that these parts of the day have the higher concentration of prevailing winds.



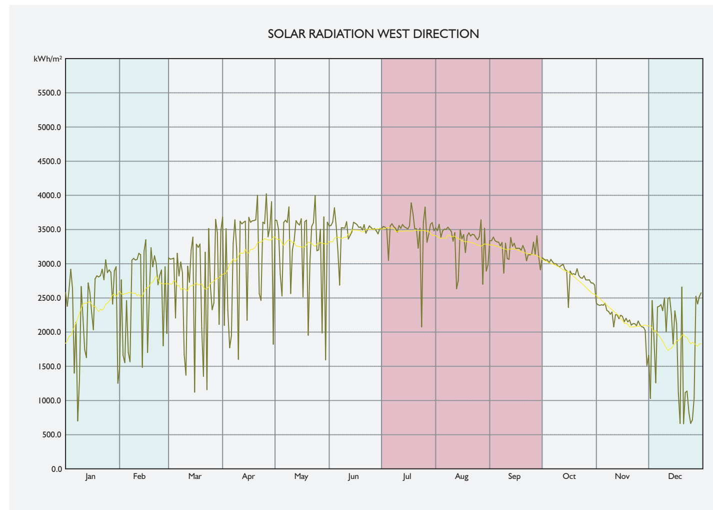
GROUND TEMPERATURE

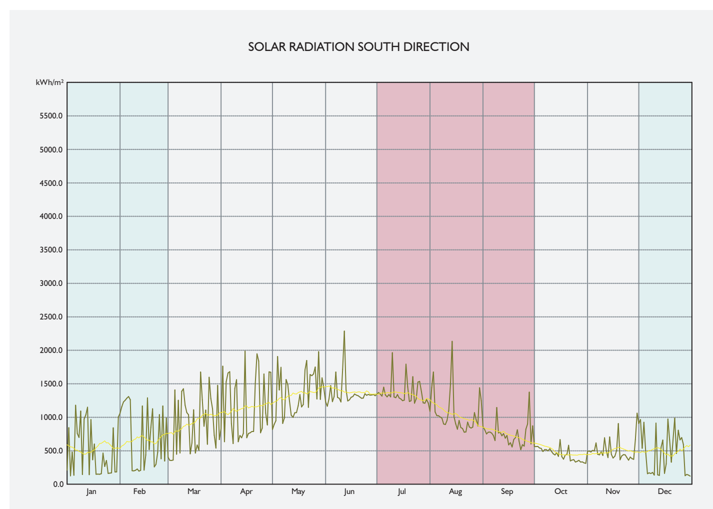
This graph records the shift in soil temperature as far as depth is increased. The temperature starts to become stable at 22°-23°C at 4 meters under the level of the ground and deeper. Furthermore, important differences between air and ground temperatures can be noticed, suggesting the use of earth coupling as a possible strategy to mitigate hot summer climate.

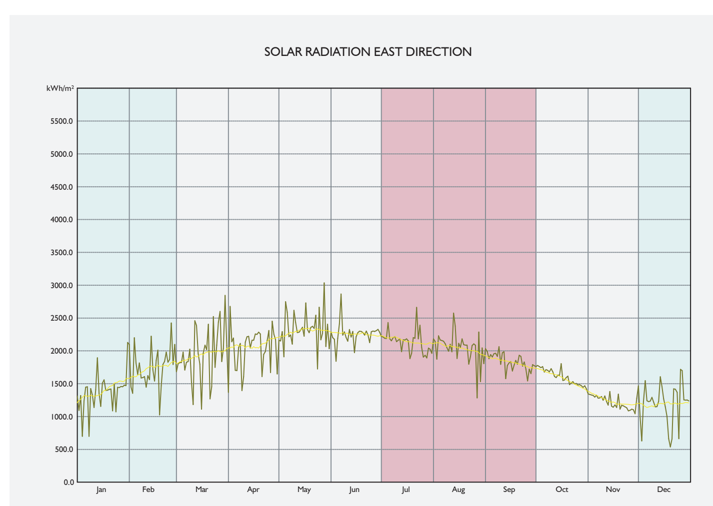


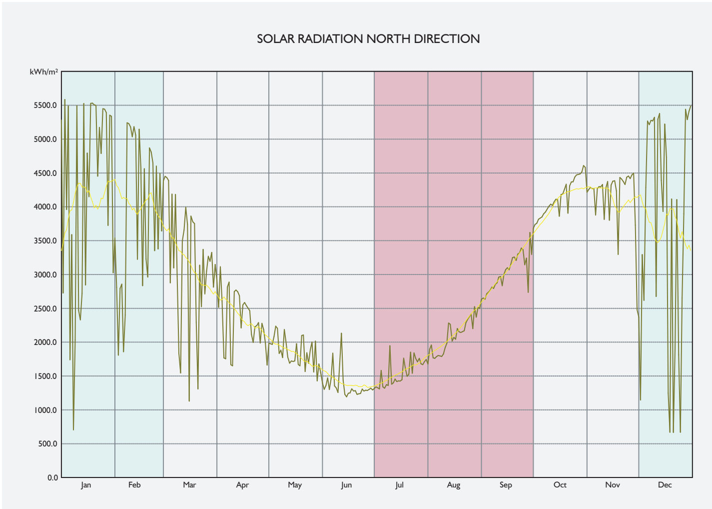
SOLAR RADIATION

Solar radiation graph divide for each main direction helps to address mass orientation optimization, by noticing from where higher or lower values are registered, and so exposing less or more building surface respectively.



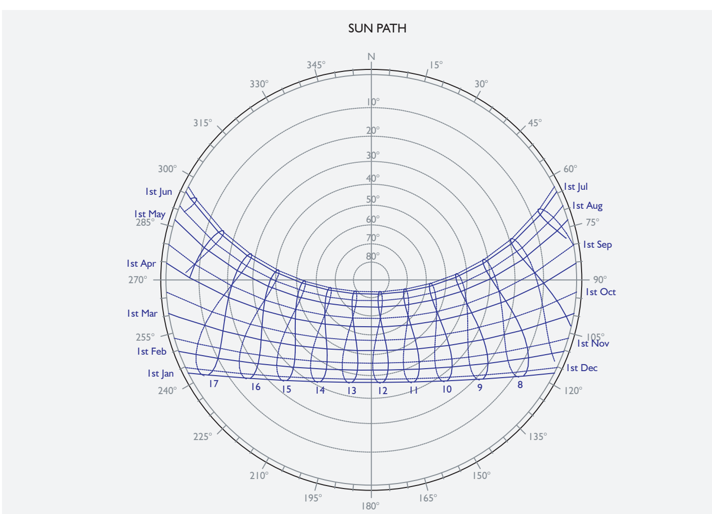






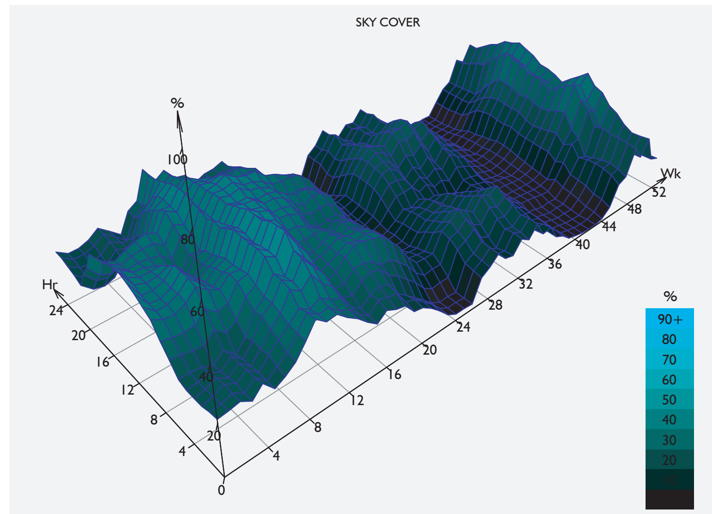
SUN PATH

Sun path is characterized by high altitude angle values, meaning that shading the roof could bring a big advantage in decreasing the heat gain in the building.



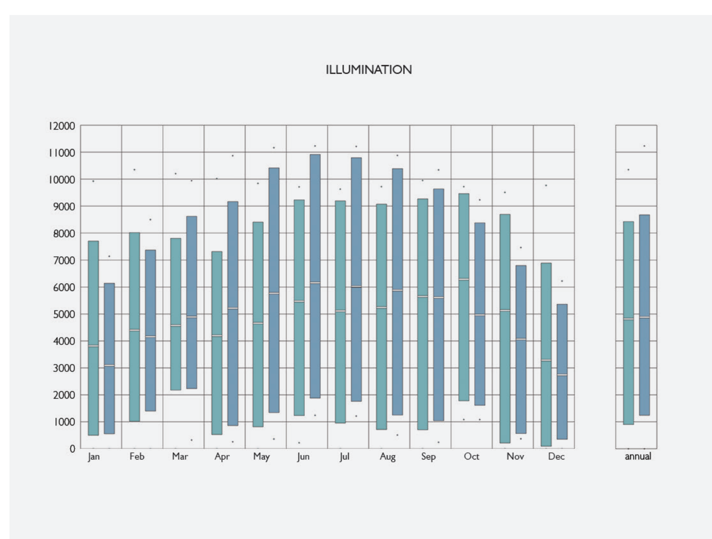
SKY COVER

The sky is speckled of some clouds at the morning of the very first months but being never overcast.



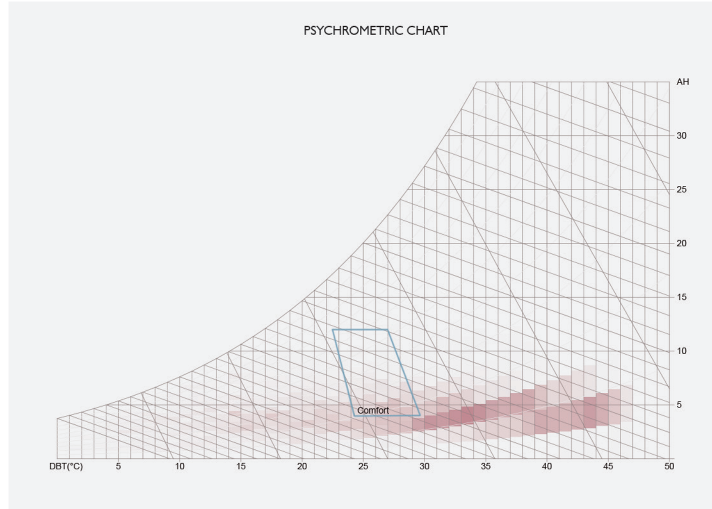
ILLUMINATION

igh values of natural illumination are achieved on the ground, giving a very good basis for developing strategies addressed to decrease the electricity cost due to artificial lighting. The annual average fluctuates around 5.000 lux (10 times the daily factor required) with the worst case in December, when a value of 2.700 lux is achieved.



PSYCHROMETRIC CHART

The graph highlight that the comfort is achieved without any interventions for the 19% of the year, while an evaporative cooling strategy could be determinant in achieving the comfort target in the 41% of days. Sun shading of windows helps for the 18% in achieving the comfort, while heat gain during winter is useful for 23% of the annual time. Using thermal mass is useful only for the 10% of the year, while for the remaining hours no passive strategies could be helpful, and an active intervention is required.



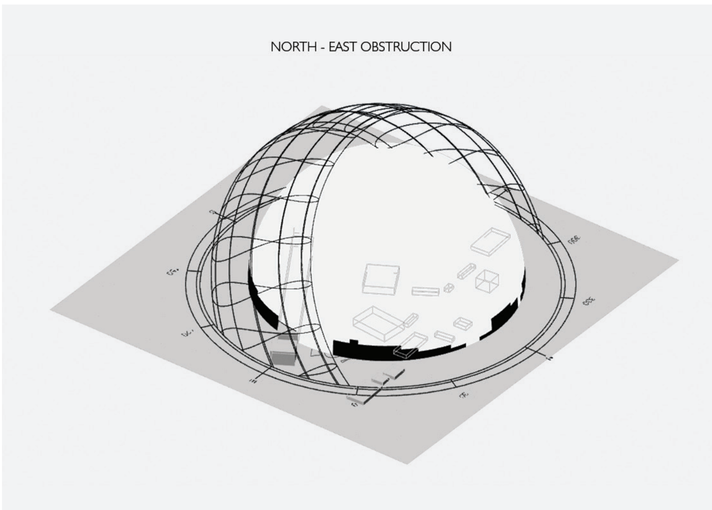
DESIGNING FOR CLIMATE CHANGE

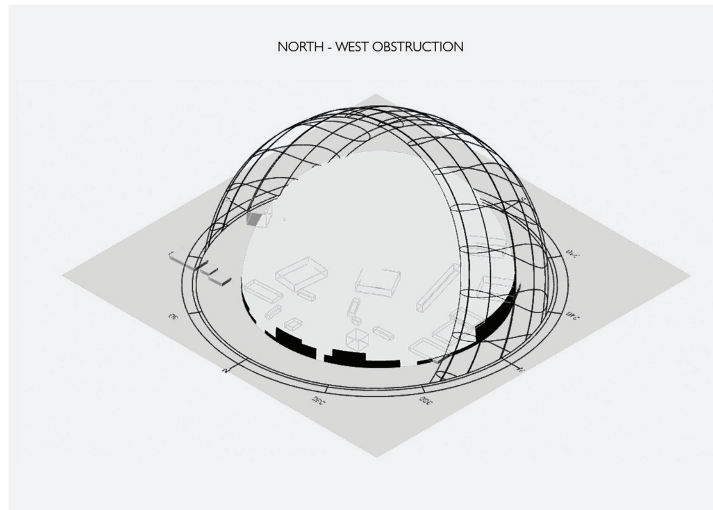
As said in the methodology chapter, climate change is one of today great issue since it could affect how the building will work and, designing keeping in mind this aspect, could help to achieve resiliency in the new building. After morphing the EnergyPlus file with the described process, the same type of analyses has been done and differences annotated to see how far climate change could impact actual strategies.

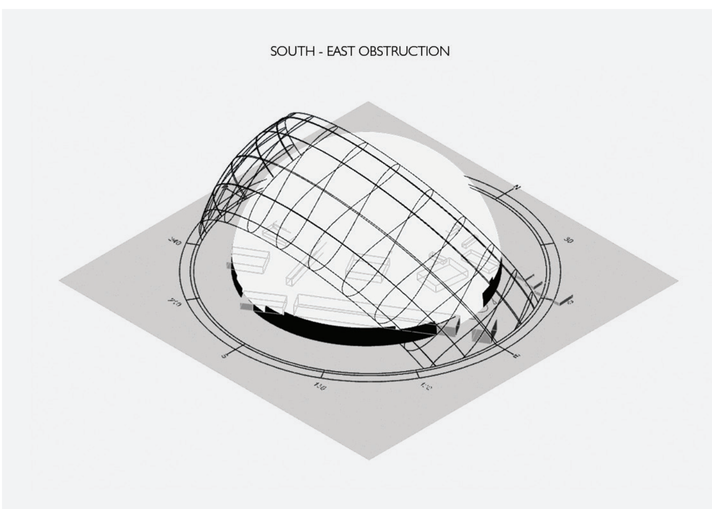
DATA	TODAY	2050	2080
Solar radiation at North and south direction	Range values: 400-1500 kWh/m^2 Peak from May to July	Range values: 600-1500 kWh/m^2 Peak from May to July	Range values: 600-1500 kWh/m^2 Peak from April to July
Average temperature increase	-	+2.5°C	+5°C
Highest temperature	45°C	51-52°C	55°C
Underheated stress	50.8 hours	0.8 hours	O hours
Overheated stress	1944,7 hours	2520,3 hours	2885,7 hours
Wind speed increase (average)	-	+ 1 m/s	+ 2m/s
Ground temperature at 4 m underground (average)	22-23°C	24°C	25°C
Illumination (average)	5.000 lux	5.200 lux	5.200 lux
Wet bulb depression increase	-	Quite the double hours	Unchanged situation with respect 2050 scenario
Percentage of comfort hours without any intervention	19%	17,9%	17,7%
Percentage of hours requiring sun shading	18%	23,2%	24,7%
Percentage of hours in which evaporative cooling is useful to achieve comfort	41,5%	49,6%	52,9%

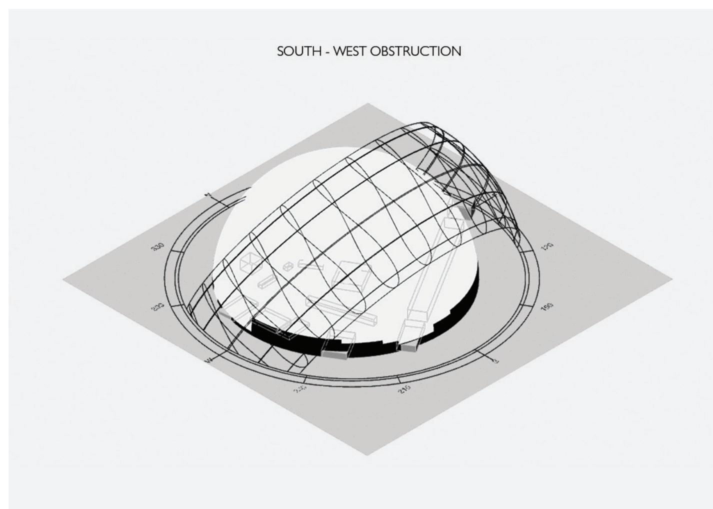
SITE ANALYSES

Besides climate analyses about the general climate in the city, a study of the project site should be conducted in order to understand the dynamic and relationship with the surrounding environment.

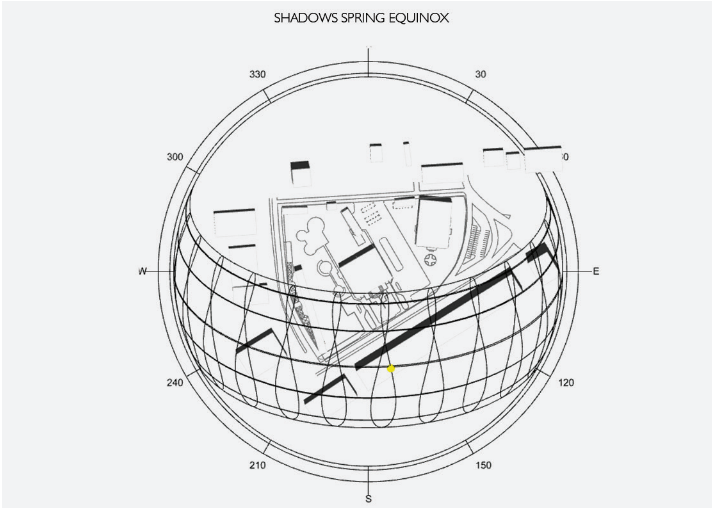


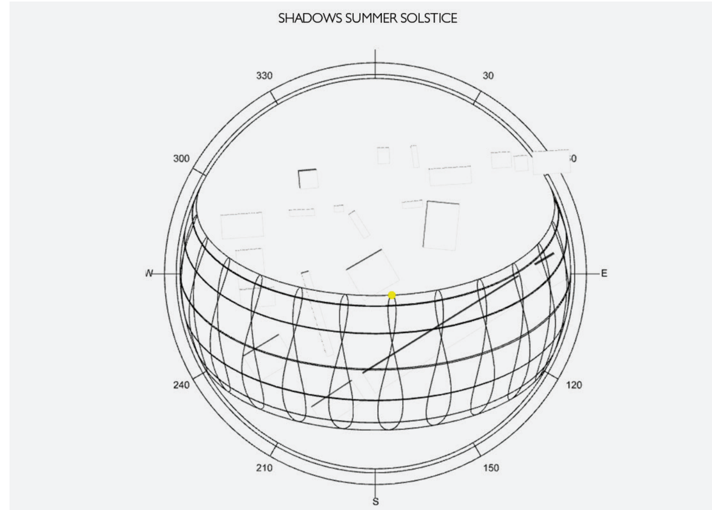


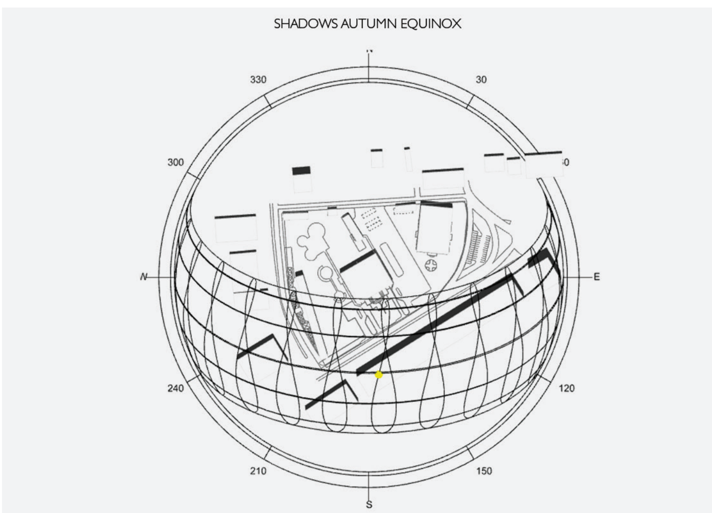


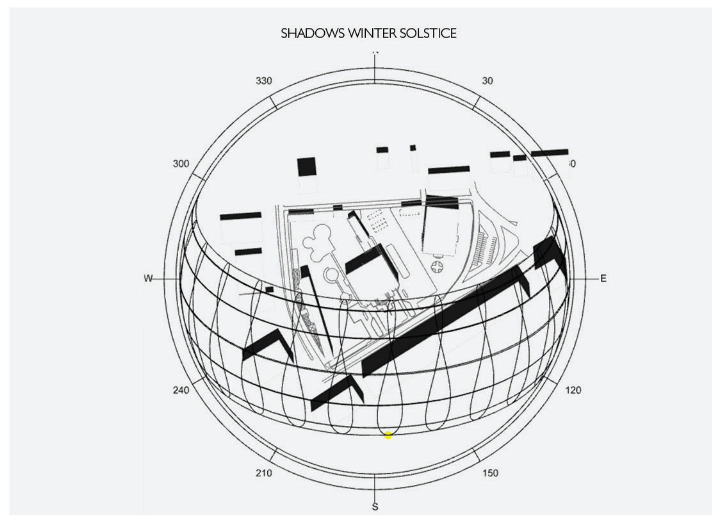


Since casting a shadow on the building surface could be a useful strategy in decreasing the radiation amount hitting the building, but also prevent overheating of the surfaces, an obstruction analysis could highlight benefits provided by avoiding direct access to the sun thanks to the surrounding structures. Furthermore, this analysis is accompanied by a shadow study for the two solstices and equinoxes. However, since the central position of the main building with respect to the campus, and high angles of sun altitude, no protection is achieved, especially during hot seasons where shadowing strategy could result determinant.

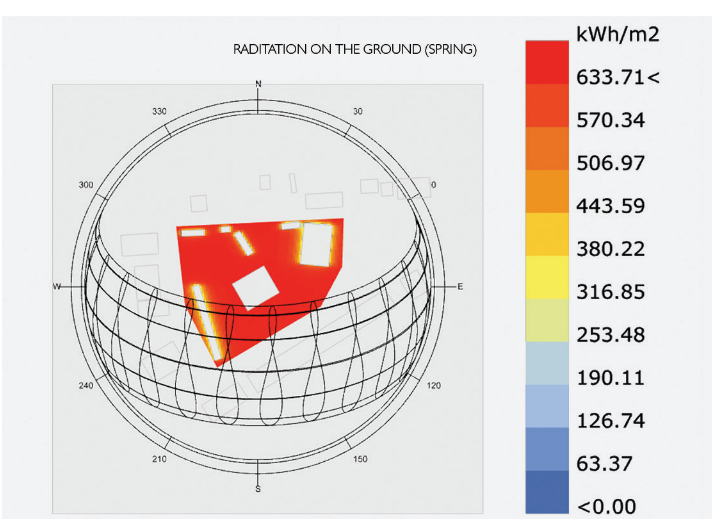


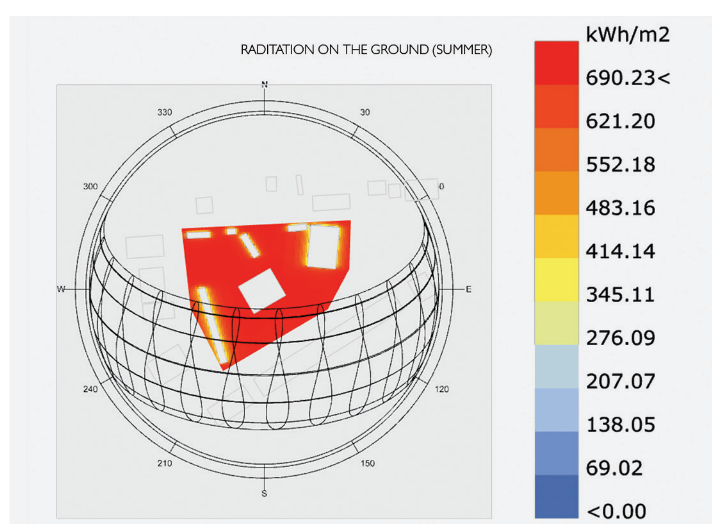


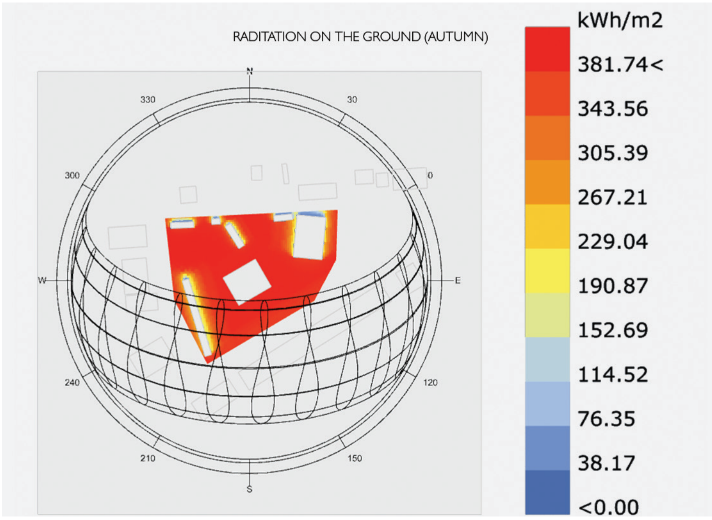


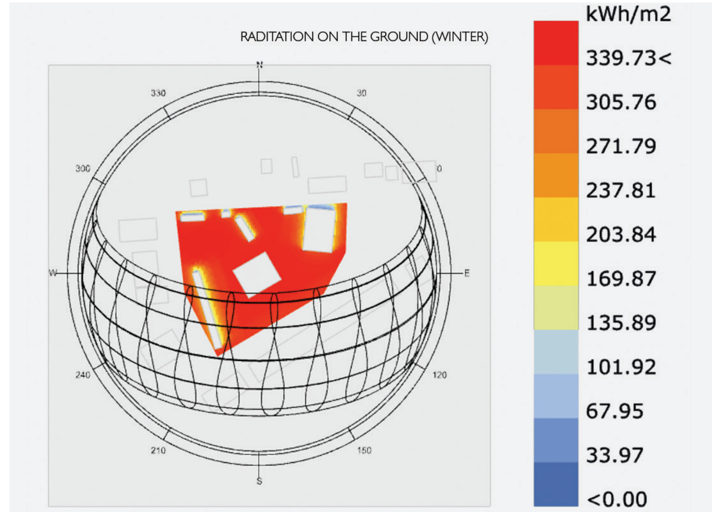


Looking at radiation analyses at ground level for the same four days of the year, it's noticeable how radiation value reaches very high value for square meter in the area around the actual building from all the directions. This is mainly due to the lack of protection from context buildings or by other natural or architectonical elements. All this could suggest the creation of a transition area around the building in order to mitigate the effect of heat gain due to reflected solar radiation.

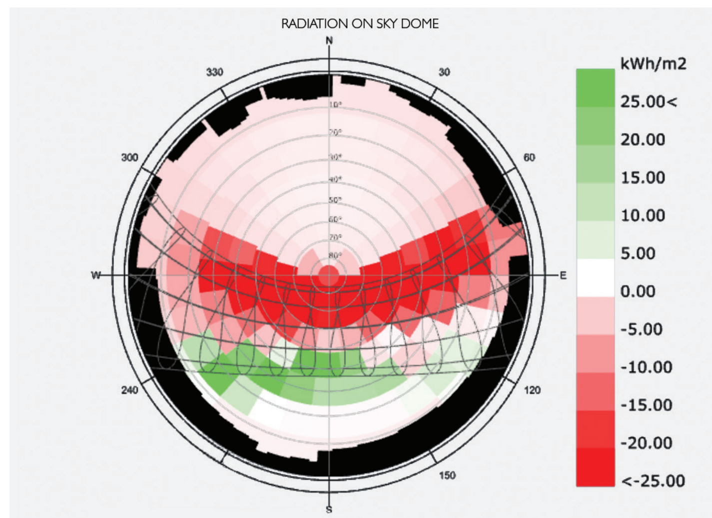




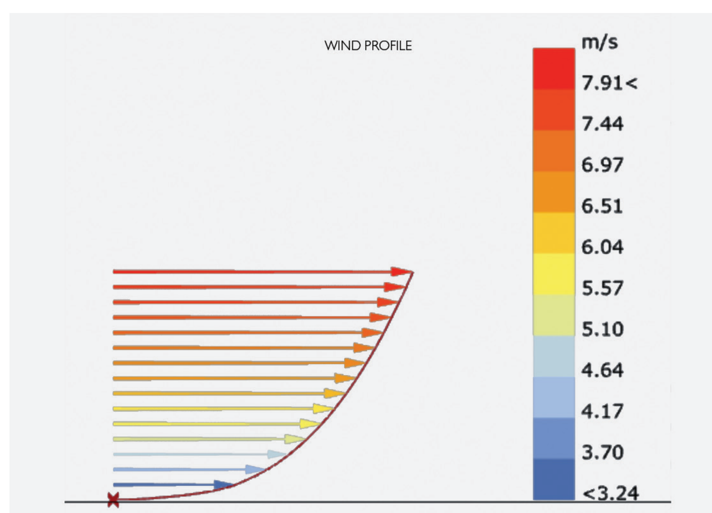


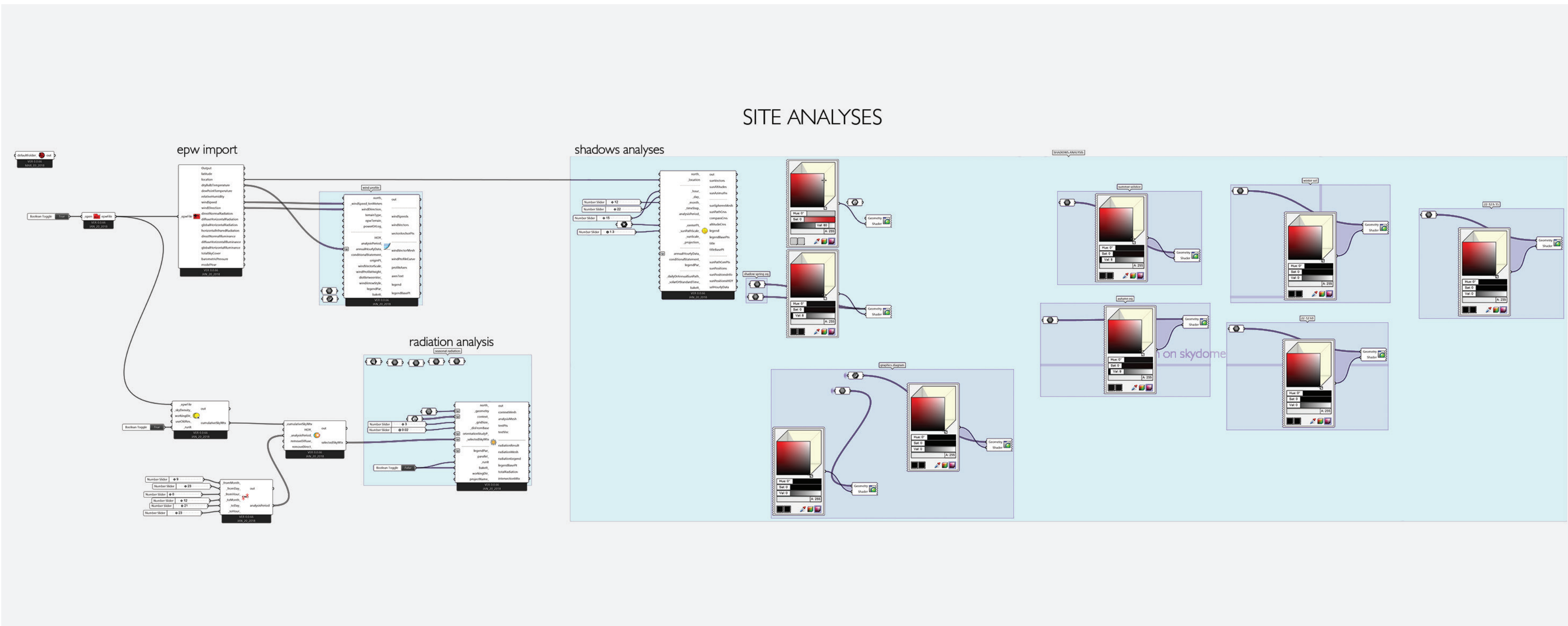


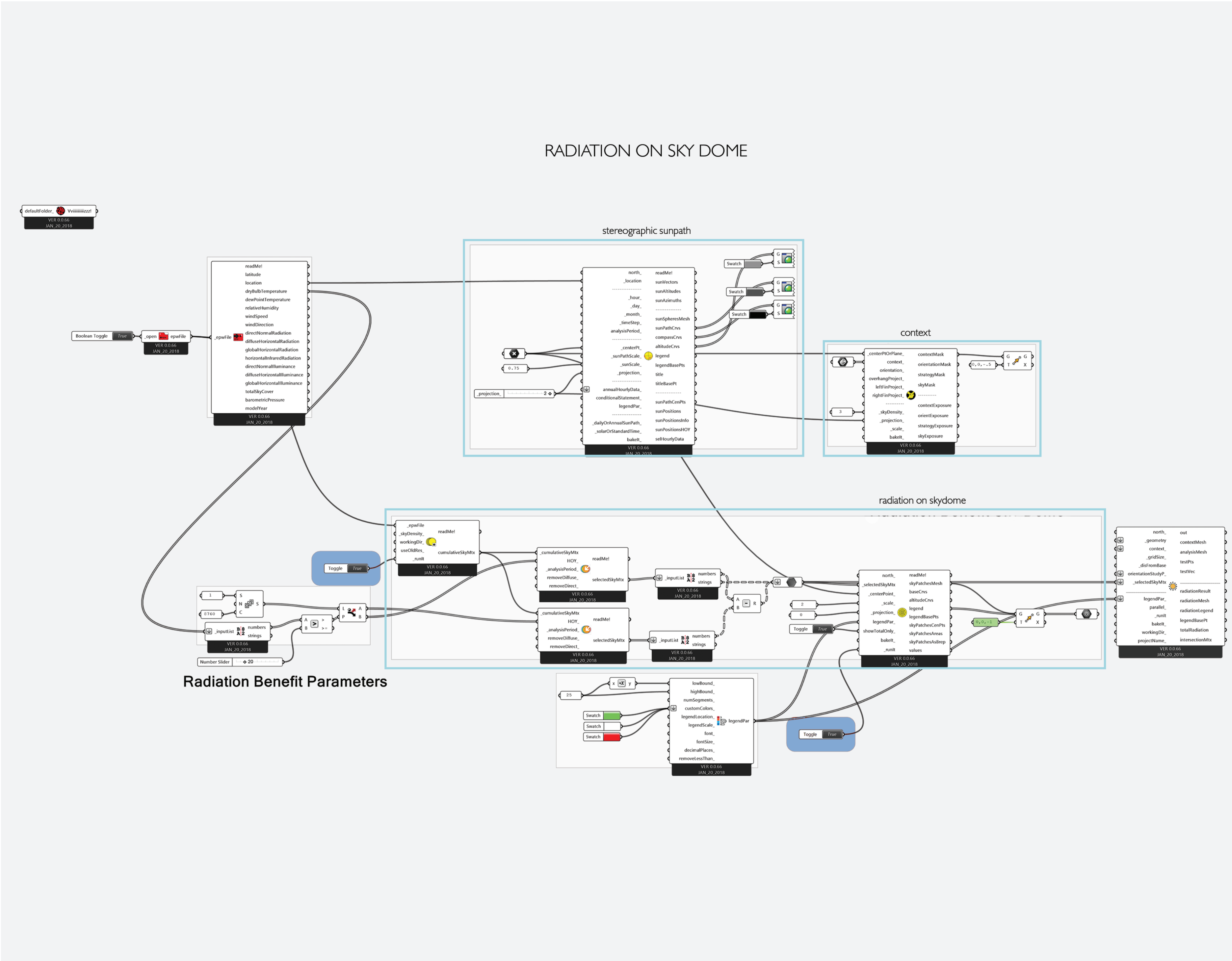
Radiation graph on sky dome algorithm gives an idea and bring important information about solar radiation accessibility direction. How it's easy to image, helpful solar gain comes only at very low values of altitude, and with a linear distribution. Furthermore, values are quite steady at low levels or sometimes being null. On the other hand, harmful radiation gain characterizes quite all the graph with several intensive peaks at zenith highness. What is interesting is that, even if low, harmful values are also recorded in the south part of the sky dome, where usually a neutral behaviour is expected.



Regarding wind influences on site area beside the information about speed and frequent directions collected through wind rose analysis, a wind profile study and CFD simulation are conducted, in order to understand the overall behaviour of this element with respect the site context. As it possible to see, wind reaches a speed of 7.91 m/s at 10-meter highness, while the site area conformation allows to the wind to overtake the surrounding buildings and affects also the lower part of the district. Linking this site wind morphology with previous climate analyses, it's possible to conclude that passive cooling with evaporative methodology is not only possible but very recommended.




SITE ANALYSES
epw import
shadows analyses
radiation analysis
on skydome



RADIATION ON SKY DOME
stereographic sunpath
context
radiation on skydome
Radiation Benefit Parameters

EVAPORATIVE COOLING WIND TOWERS

Wind catchers are a passive cooling strategy traditionally used in buildings in the Persian Gulf area. They are made of a squared plan tower with openings on the top to collect wind. A partition could be present in order to collect wind from different directions, while at the end nozzles introduce the wind stream in the building. Originally, this strategy was aimed to perform as a natural ventilator, but following improving where introduced in order to cool down the temperature inside the building. In particular, to enhance this effect, water elements, such as a fountain or pool were introduced for moistening inlet air. (2) Today nozzles are introduced at the top of the tower in order to enhance the cooling power due to humidification process helping in decreasing room temperature up to 10°C. Fans can also be introduced in order to improve wind speed in case of slow velocity values, as a drum at the top inlet grid to close the system in case of sandstorm, for those countries affected by this phenomenon (3).

2.Kassir Radwan, *Passive downdraught evaporative cooling wind-towers: A case study using simulation with field- corroborated results*, Building Services Engineering Research and Technology, 2015

3.Chiesa Giacomo & Grosso Mario & Bogni Alessio & Garavaglia Giacomo, *Passive downdraught evaporative cooling system integration in existing residential building typologies: a case study*, Energy Procedia, 2017

In particular, sandstorm is a problem to take into consideration for this project, since they are rising in frequency in the region due to natural and anthropogenic activities. The main causes of dust production in Al-Jouf region are upstream water control in Iraq, farmland in Syria and the increased erosion in Jordan river. The effectiveness of this technology is confirmed also in "Summer discomfort reduction by direct evaporative cooling in Southern Mediterranean areas" (3) paper where sample cities in southern Mediterranean areas are taken in analyses to verify the goodness of direct evaporative cooling strategy and if night ventilation can improve or compromise its performances. The paper concludes how night ventilation introduction abreast direct evaporative cooling improve the overall performances in quite all the case studies, with the exception of cities locate in hot and dry location, where the performance of only evaporative cooling technology performs better than the combination of the two, since the extreme climate condition of operation (low relative humidity and high dry bulb temperature). Since Sakaka city shares a similar climate, particularly during the summer, the night ventilation strategy has been set aside, integrating only the direct cooling evaporative method.

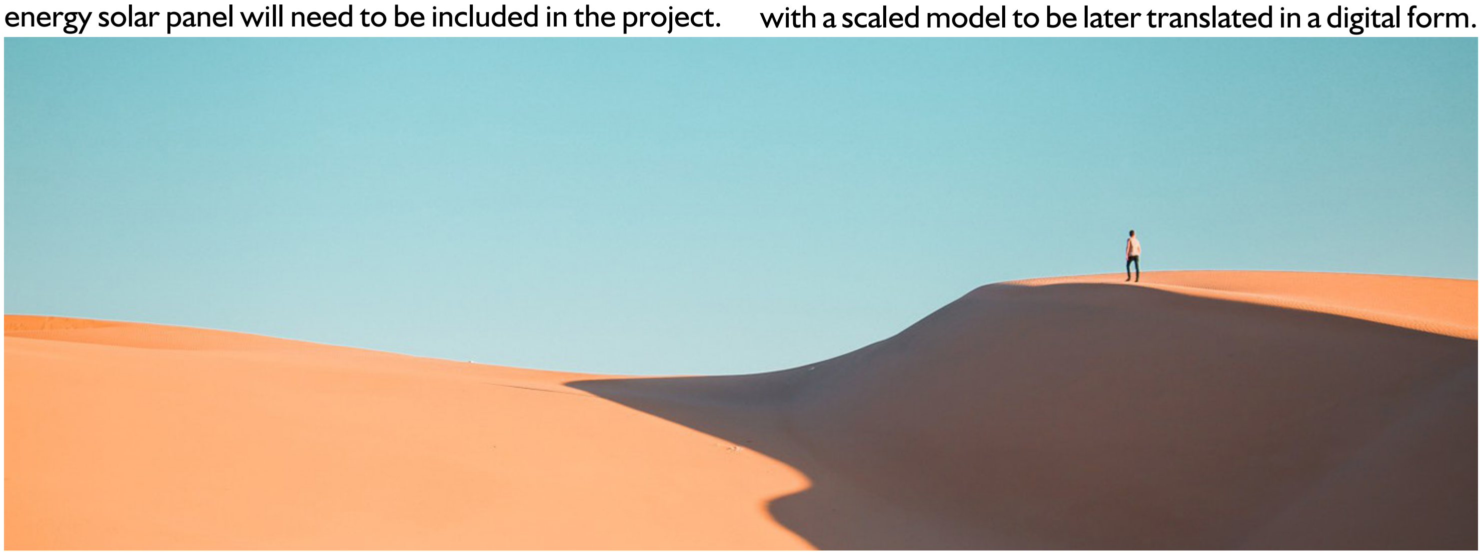
4.Giacomo Chiesa, Nora Huberman, David Pearlmutter, Mario Grosso, *Summer discomfort reduction by direct evaporative cooling in Southern Mediterranean areas*, Energy Procedia, 2017

ENERGY SOURCE IN SAUDI ARABIA

When designing environmental strategies to enhance building quality and comfort is always useful to keep in mind that sometimes the costs for introducing certain environmental technologies area higher than buying electricity from the grid. Of course, in this case, it's necessary that the building produces as much as renewable energy to put back in the grid as much as not renewable energy has used. To quantify how much energy the building has to produce with respect the energy bought it's necessary to understand how much of that energy was coming from renewable sources and how much not. In Saudi Arabia, the production of energy relies mainly on the combustion of natural gas (51,16%) and oil (48,84%) for a total of 53,62 Gigawatts of energy produced. Renewable energy account for only the 0,00032% with 0,036 Gigawatts produced. However, it has been approved a plan for the construction of a 200 Gigawatts solar farm. Emissions related to the actual energy procurement produce annually 413.231 thousand metric tons (kT) of CO_2, 49.514 kT of CO_2equivalent of Methane and 1.003 kT of CO_2equivalent of Nitrous Oxide. This general overview of energy sources in the state, clearly stands out how the building will need to produce as much energy as the one that uses, at least until 2030 when the solar farm will be completed. In order to produce such energy solar panel will need to be included in the project.

LET'S START DESIGNING

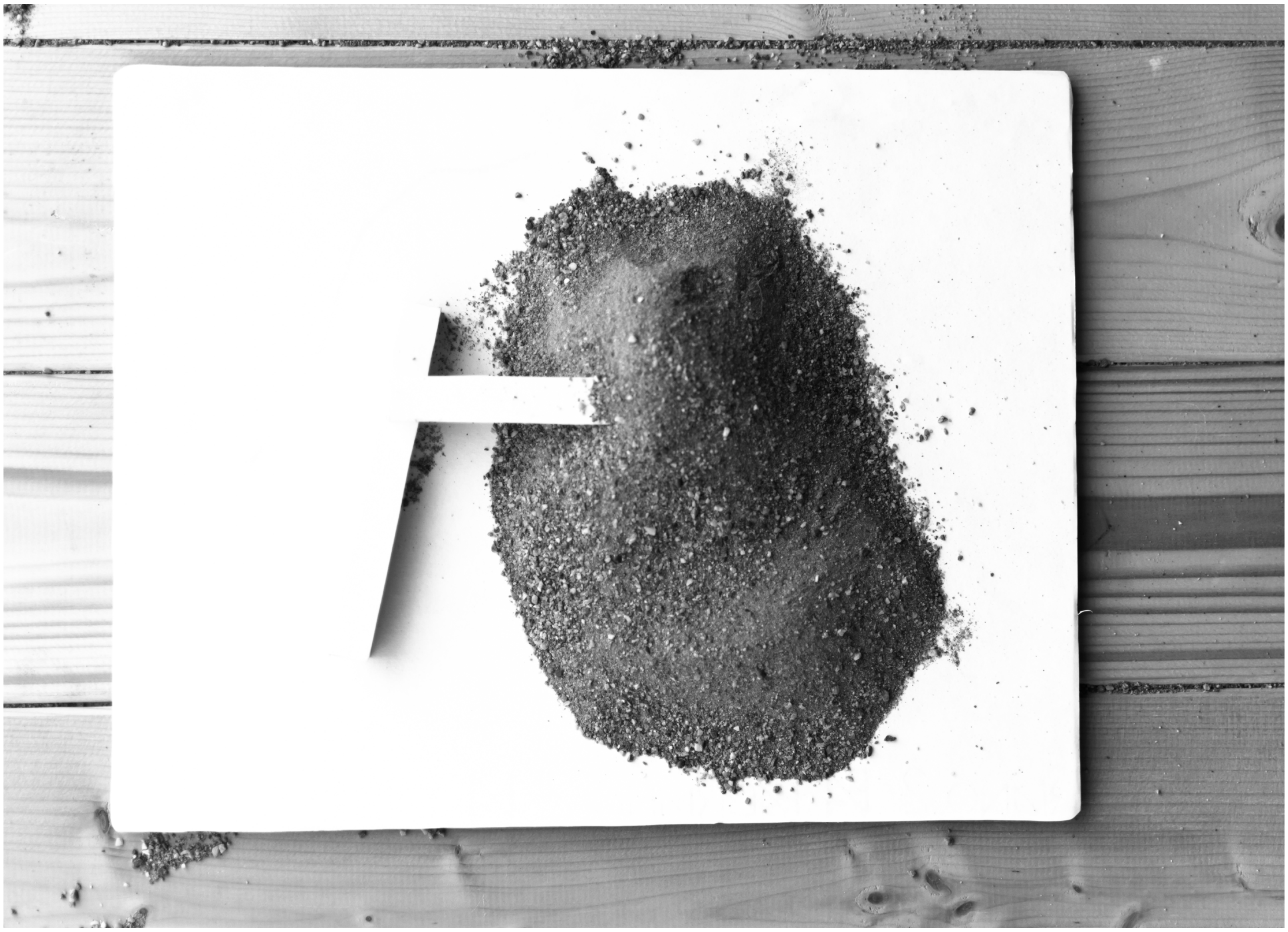
Besides all theoretical and technical aspects, architecture required (of course) a creative conceptual component to drive all the design process. The idea is to create a surface that will cover the existing building, which will be filled with the most of functions, in order to introduce a level of shadowing. Furthermore, a transition space under this surface will be created with the remaining functions and that will help in mediating the outer with the inner environment. For this project, several concepts and from founding techniques have been used and explored. Starting from digital form finding using Frei Otto theory to developable surfaces with origami techniques, the chosen idea has been the use of physical exploration with a scaled model to be later translated in a digital form.




FINDING FORM
EXPERIMENTS




THE CHOOSEN
SHAPE

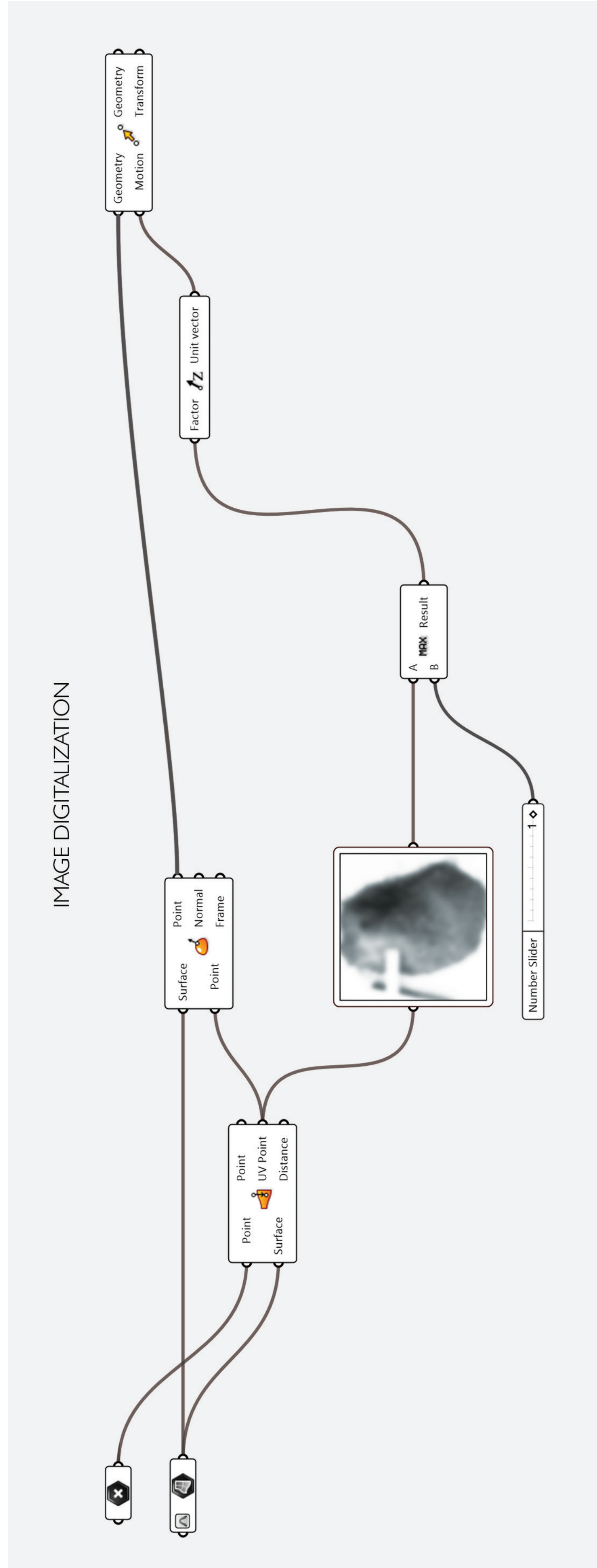


Since the project is located in an arid region where the main common element to be found is sand, the concept for form finding is the use of it to create an architectural form. Particularly to find it, the process used is the same that is possible to see in action in nature through the dune formation: sand carried by the wind and moved from one place to another.

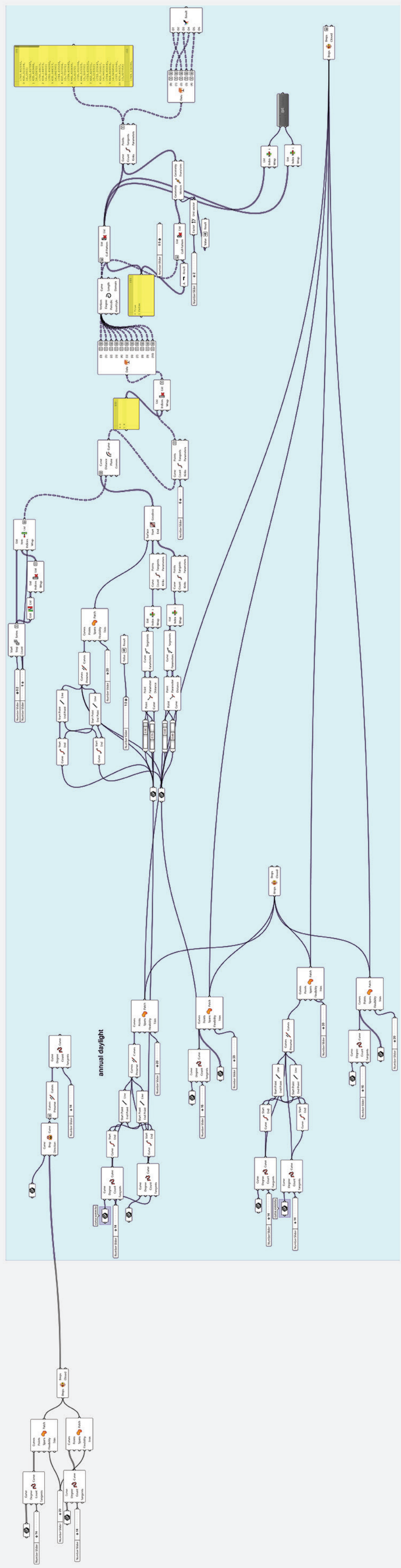
The start basis has been the creation of a physical conceptual model of the possible massing of the new building. Then different experiments have been brought on. The first consists of arranging sand next to the model and then start to move it according to the wind direction typical of the project site thanks to a hairdryer.

A second experiment has been done with the same methodology but instead, the sand was used to cover the building and the sculpted with air. While in this case the sand was under only its own weight, another attempt has been done by pressing the mound of sand and the sculpted in the same way. In the last experiment, a sandstorm was recreated by making the sand falling like rain while the hairdryer was switched on, making the sand moving while still in the air.

Once all the experiments were concluded, they were photographed and the nicer one selected. At this point, the problem to face was to translate a physical 3D object in a digital one that best approximated the geometry of the real one without using special scanners or stuff like that. To achieve this objective the photos have been converted in grey scale colour scale and worked with contrast and luminance to highlights the main characteristic of the founded form. Once post-produced the images are upload on grasshopper and used as gradient map for a system of attractors relative to a surface: darker the colour, higher the offset in the Z direction. This surface is then been treated as a raw one.



SURFACE CREATION

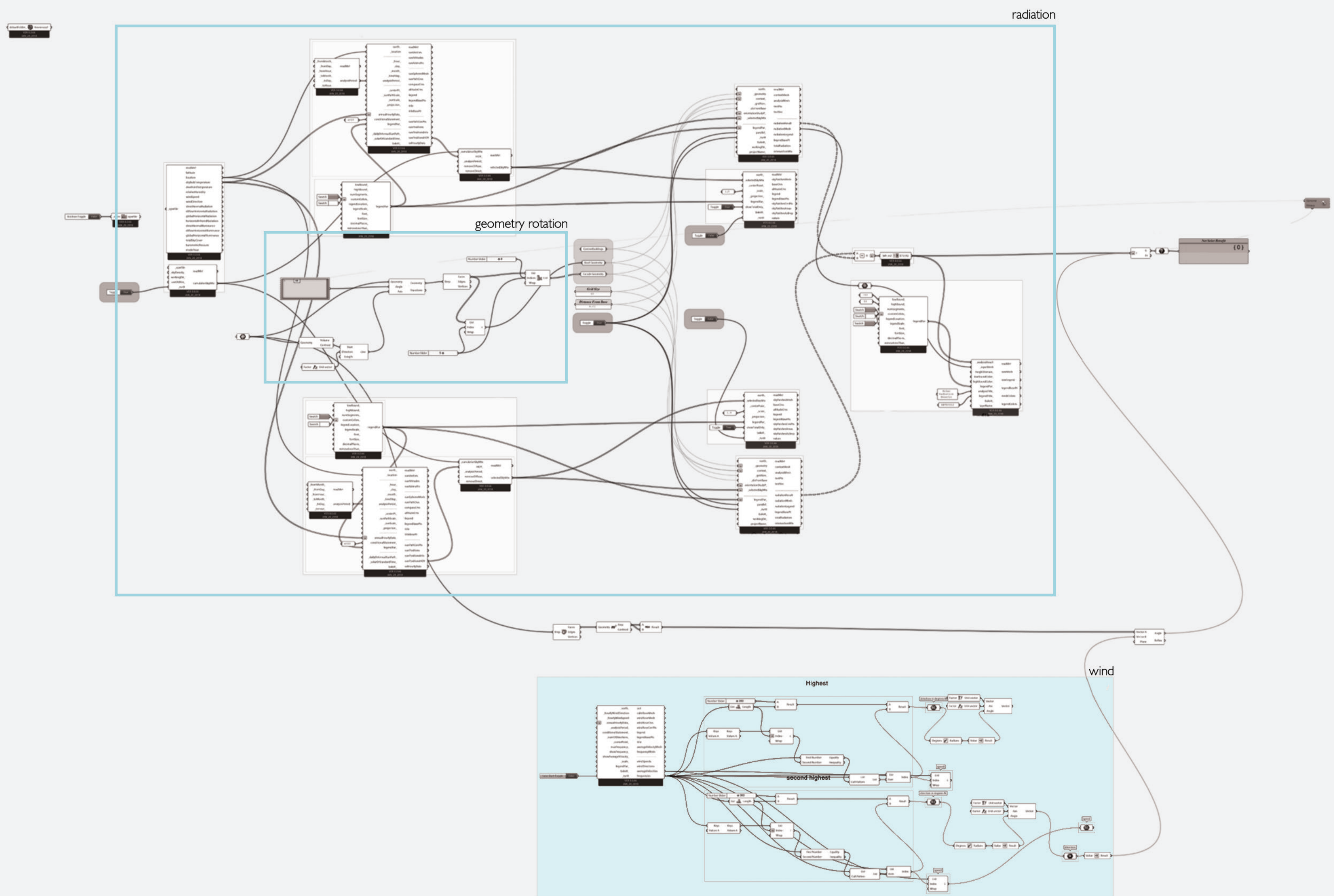


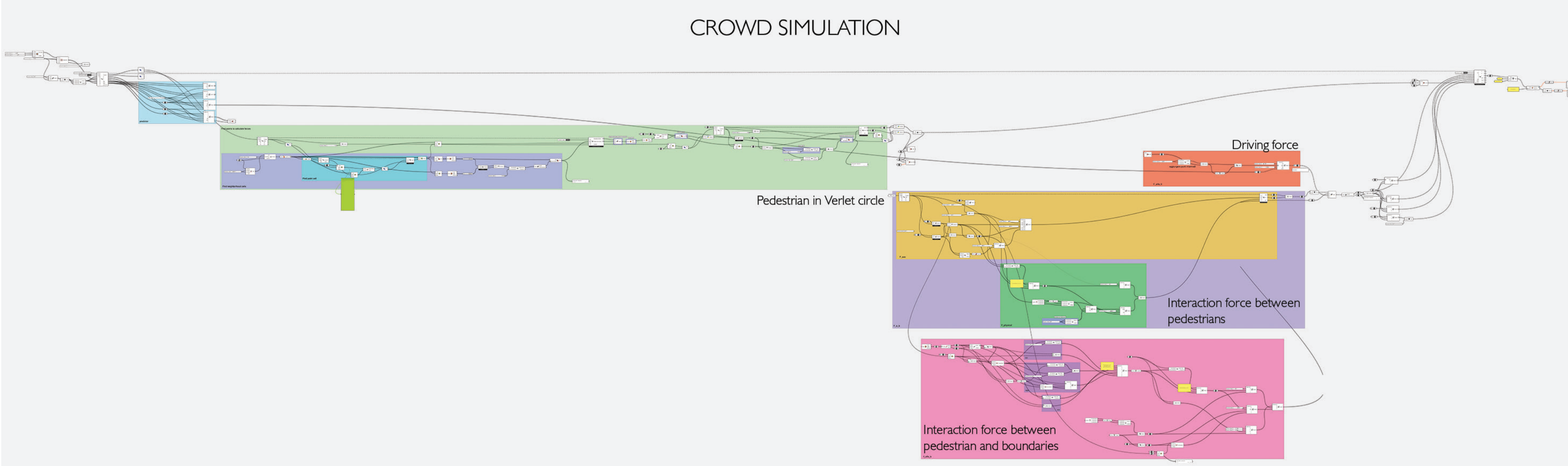
Correction and modifications have been introduced to eliminate errors, but also to aesthetically enhance the result. Particularly to highlight salient characteristics, an approach as the one adopted by Bruno Fioretti Marquez for the re-construction of Bauhaus Master Houses. The photos of the physical form have been blurred with an increasing strength in order to bring out the characteristics that make this form recognizable. At this point, the surface becomes the object on which run all the optimization algorithms.

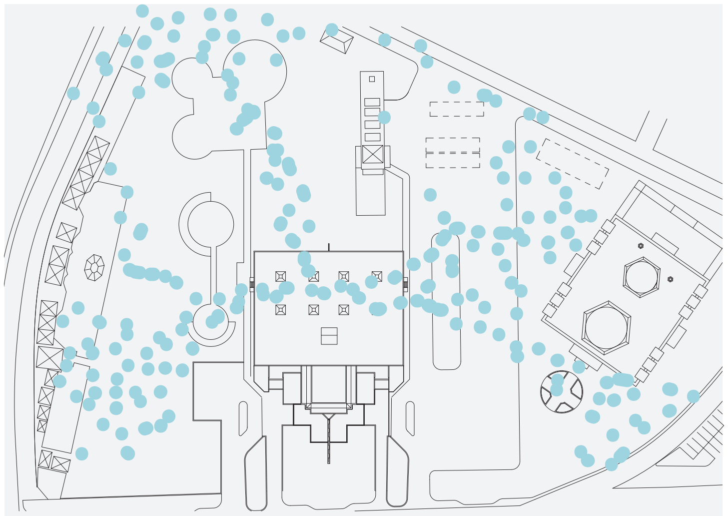
The first interaction with the newly born surface has been to optimize it with respect to solar radiation and wind direction. The optimization algorithm has been linked to the surface and has been started. The surface has been rotated around its own centre, which was located in correspondence of the existing building centre.

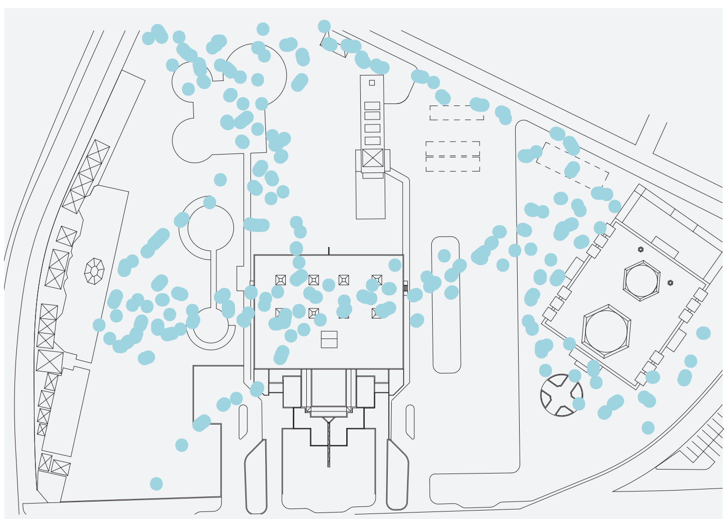
After having optimized the orientation of the mass and shape according to wind aerodynamics, a parallel stage has been brought on in order to open the shell to people by running the crowd simulation algorithm in the whole site area. Starting surfaces populated with points representing pedestrians have been introduced at the main attraction area and important places in the campus site (for instance the mosque and school). Then a point in the middle of the existing building has been placed as arrival target, in order to make pedestrians moving forward it. The simulation then has been run several times to record variation and find the most common paths used and point of pedestrian paths collected. At this point, the simulation that better summarize all has been chosen and the point of path interpolated. The new lines intersections with the surface have been computed and became the starting point of generation for interior simulation, as explained later.

MASS OPTIMIZATION

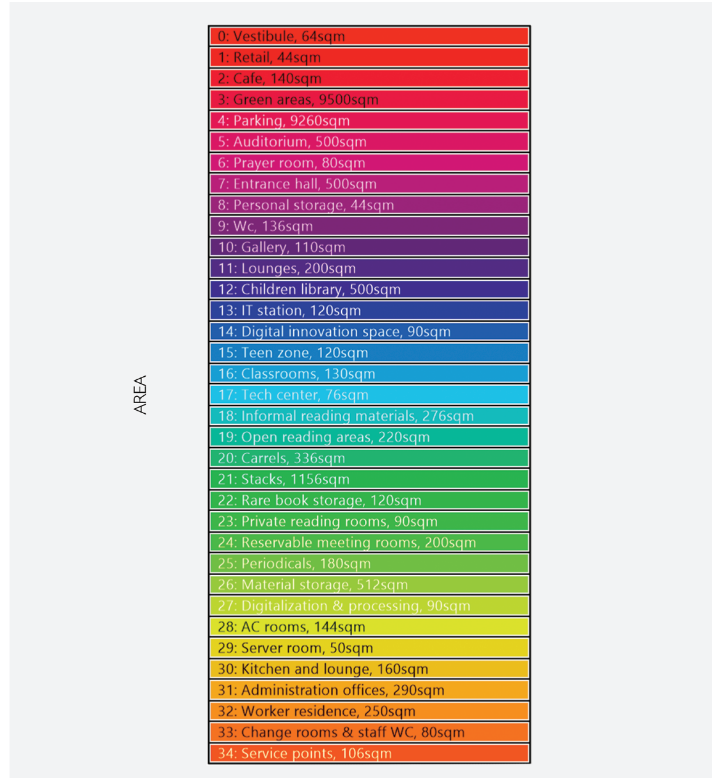


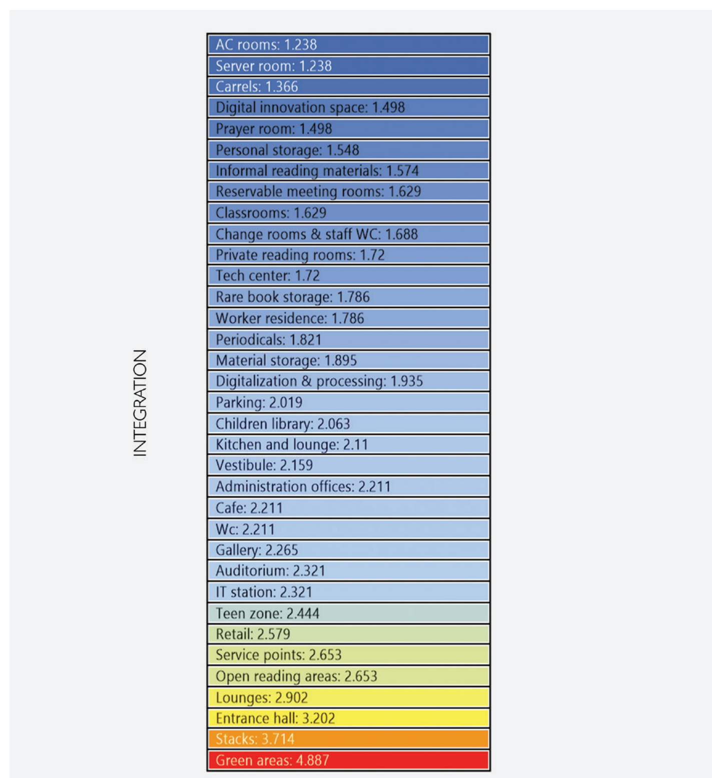

CROWD SIMULATION
Driving force
Pedestrian in Verlet circle
Interaction force between
pedestrians
Interaction force between
pedestrian and boundaries



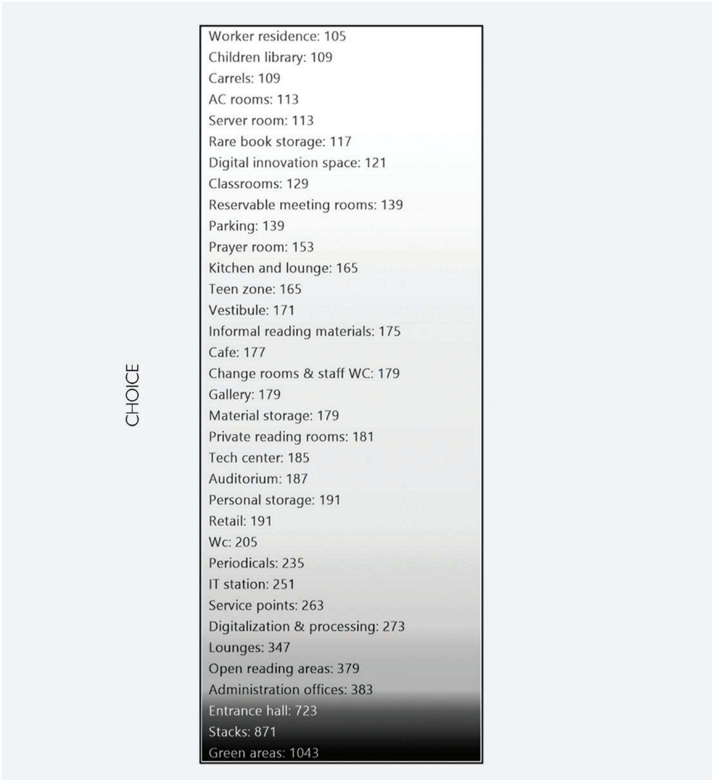


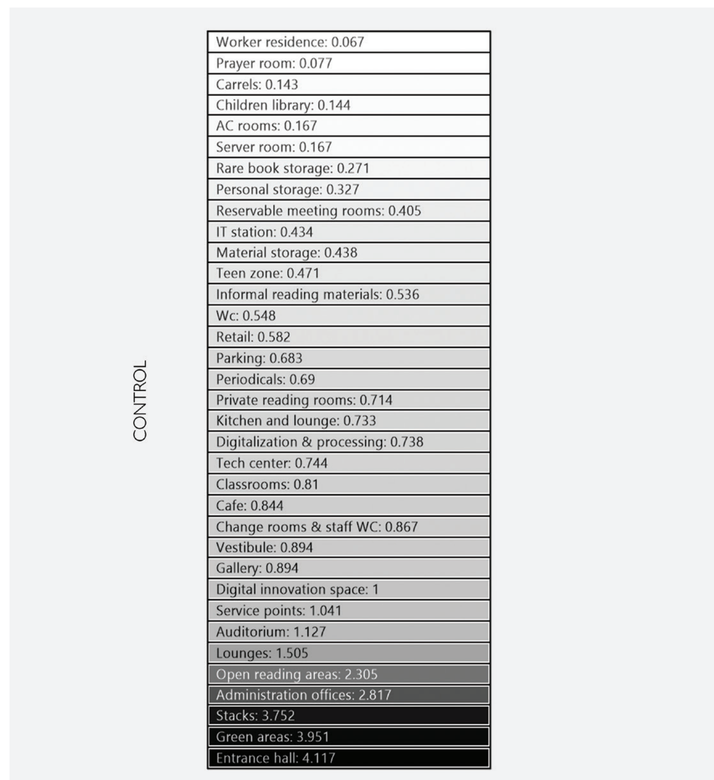
In the meanwhile, another algorithm performs an analysis on programmatic spaces according to what has been explained in the methodology chapter. During the application of space syntax algorithm, a certain amount of interaction with the designer is required since links between each space have to be manually provided according to the concept idea of the designer itself. What's useful in this process is the possibility to see the consequences at social level of the links created, allowing the designer to follow a project idea about inclusion or exclusion that can be later translated in a physical space.

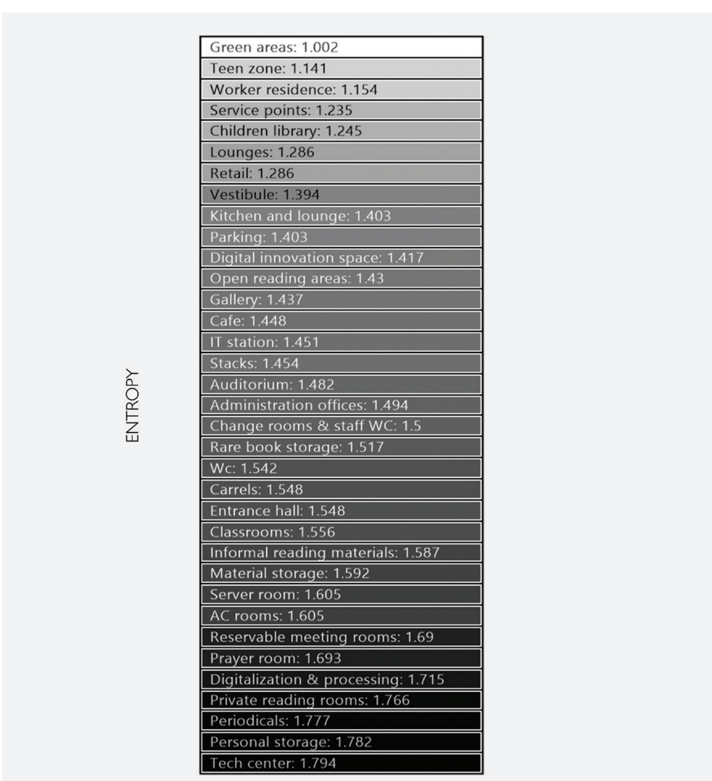




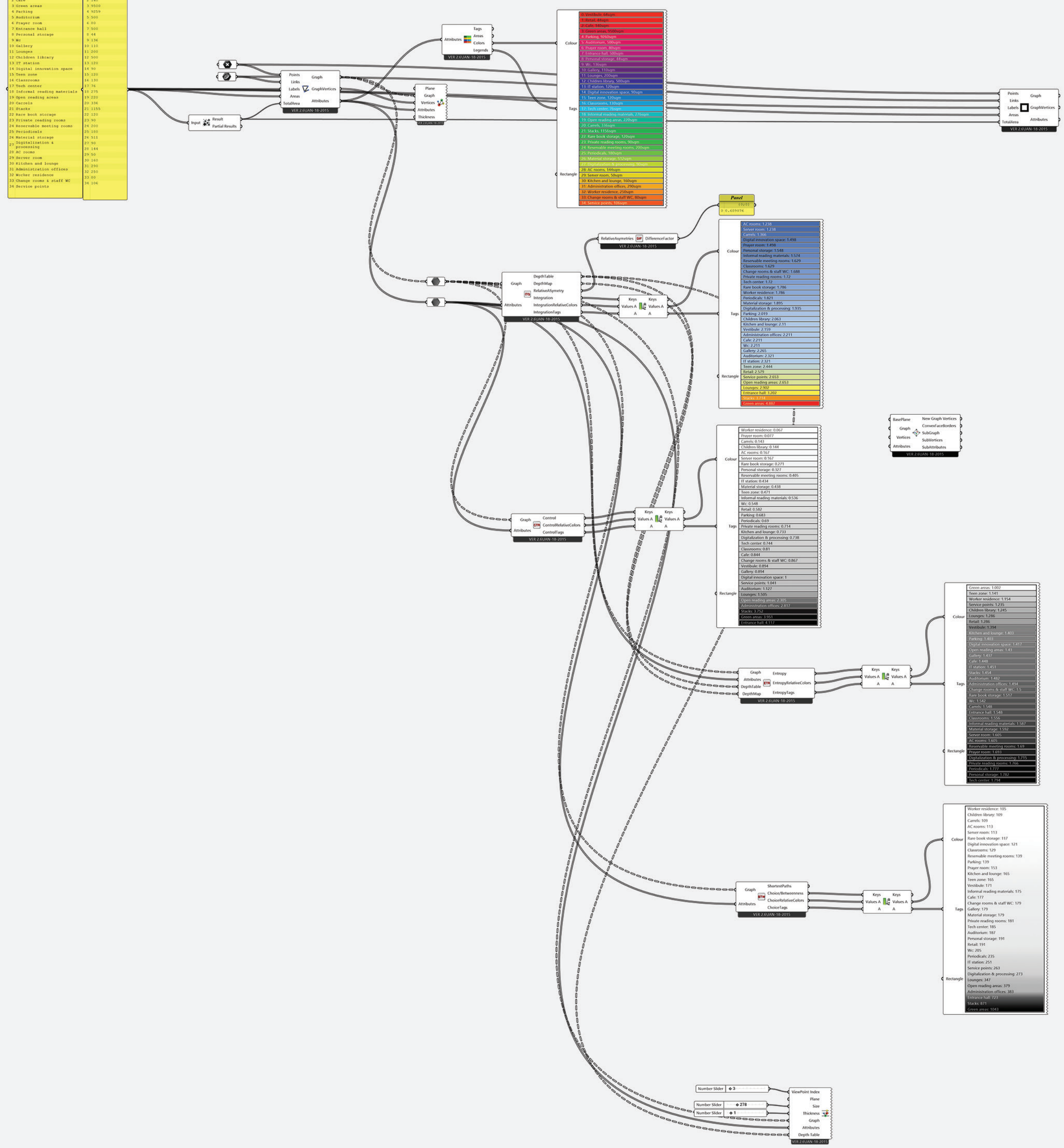
DIFFERENCE FACTOR: 0.68907

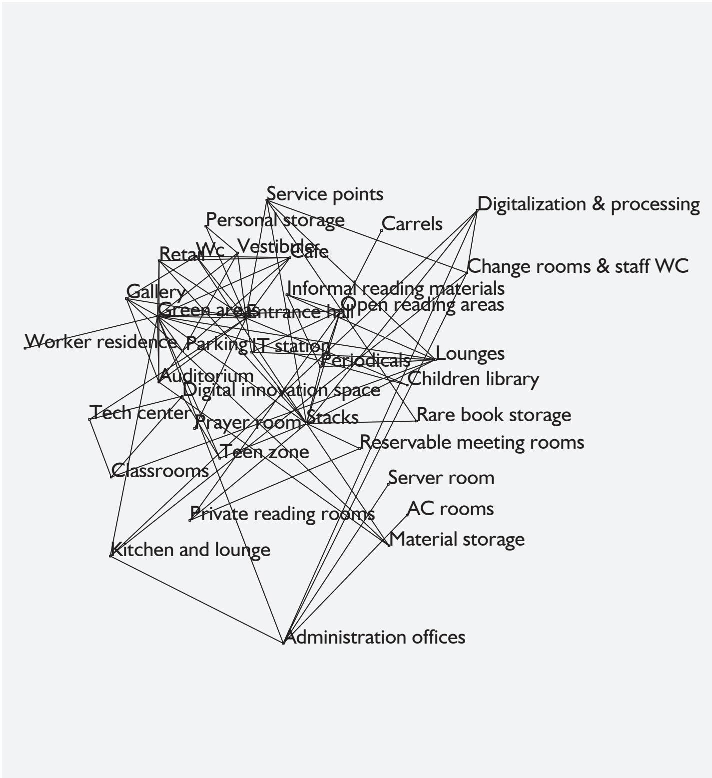

CHOICE
Worker residence: 105
Children library: 109
Carrels: 109
AC rooms: 113
Server room: 113
Rare book storage: 117
Digital innovation space: 121
Classrooms: 129
Reservable meeting rooms: 139
Parking: 139
Prayer room: 153
Kitchen and lounge: 165
Teen zone: 165
Vestibule: 171
Informal reading materials: 175
Cafe: 177
Change rooms & staff WC: 179
Gallery: 179
Material storage: 179
Private reading rooms: 181
Tech center: 185
Auditorium: 187
Personal storage: 191
Retail: 191
Wc: 205
Periodicals: 235
IT station: 251
Service points: 263
Digitalization & processing: 273
Lounges: 347
Open reading areas: 379
Administration offices: 383
Entrance hall: 723
Stacks: 871
Green areas: 1043

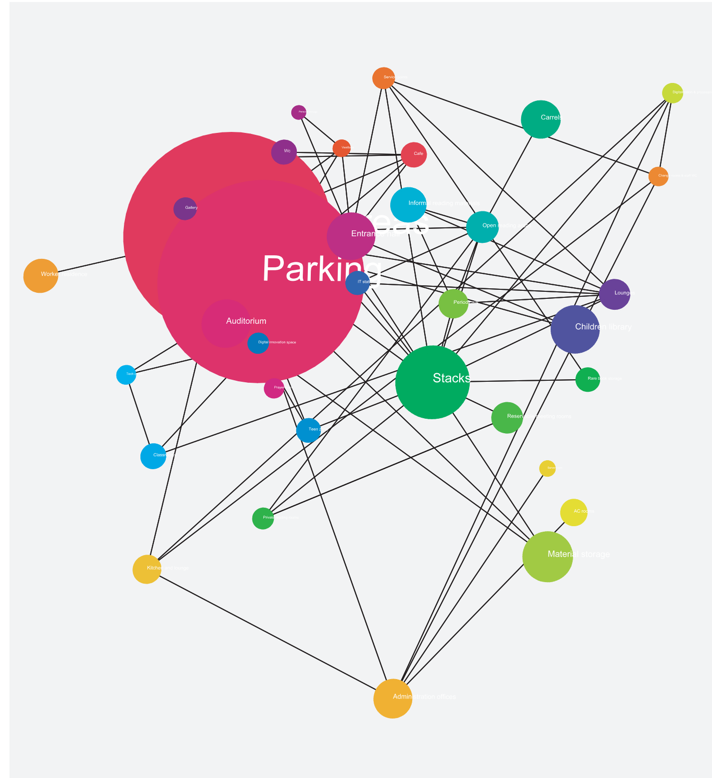

CONTROL
Worker residence: 0.067
Prayer room: 0.077
Carrels: 0.143
Children library: 0.144
AC rooms: 0.167
Server room: 0.167
Rare book storage: 0.271
Personal storage: 0.327
Reservable meeting rooms: 0.405
IT station: 0.434
Material storage: 0.438
Teen zone: 0.471
Informal reading materials: 0.536
Wc: 0.548
Retail: 0.582
Parking: 0.683
Periodicals: 0.69
Private reading rooms: 0.714
Kitchen and lounge: 0.733
Digitalization & processing: 0.738
Tech center: 0.744
Classrooms: 0.81
Cafe: 0.844
Change rooms & staff WC: 0.867
Vestibule: 0.894
Gallery: 0.894
Digital innovation space: 1
Service points: 1.041
Auditorium: 1.127
Lounges: 1.505
Open reading areas: 2.305
Administration offices: 2.817
Stacks: 3.752
Green areas: 3.951
Entrance hall: 4.117

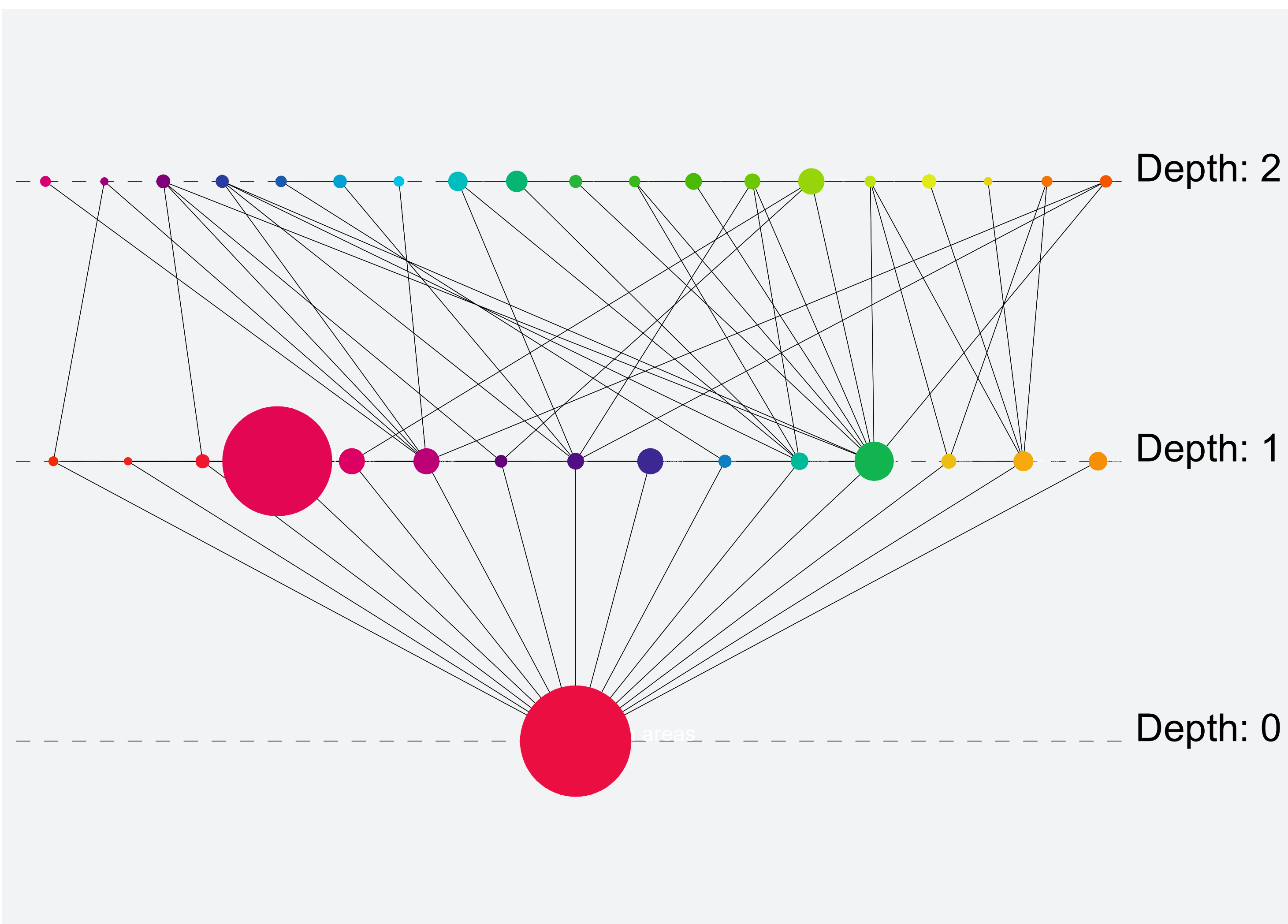

ENTROPY
Green areas: 1.002
Teen zone: 1.141
Worker residence: 1.154
Service points: 1.235
Children library: 1.245
Lounges: 1.286
Retail: 1.286
Vestibule: 1.394
Kitchen and lounge: 1.403
Parking: 1.403
Digital innovation space: 1.417
Open reading areas: 1.43
Gallery: 1.437
Cafe: 1.448
IT station: 1.451
Stacks: 1.454
Auditorium: 1.482
Administration offices: 1.494
Change rooms & staff WC: 1.5
Rare book storage: 1.517
Wc: 1.542
Carrels: 1.548
Entrance hall: 1.548
Classrooms: 1.556
Informal reading materials: 1.587
Material storage: 1.592
Server room: 1.605
AC rooms: 1.605
Reservable meeting rooms: 1.69
Prayer room: 1.693
Digitalization & processing: 1.715
Private reading rooms: 1.766
Periodicals: 1.777
Personal storage: 1.782
Tech center: 1.794

SPACE SYNTAX




Service points
Digitalization & processing
Personal storage
Carrels
Retail
Wc
Vestibules
Cafe
Change rooms & staff WC
Gallery
Informal reading materials
Open reading areas
Green area
Entrance hall
Worker residence
Parking
IT station
Lounges
Periodicals
Auditorium
Children library
Digital innovation space
Tech center
Prayer room
Stacks
Rare book storage
Reservable meeting rooms
Teen zone
Classrooms
Server room
AC rooms
Private reading rooms
Material storage
Kitchen and lounge
Administration offices

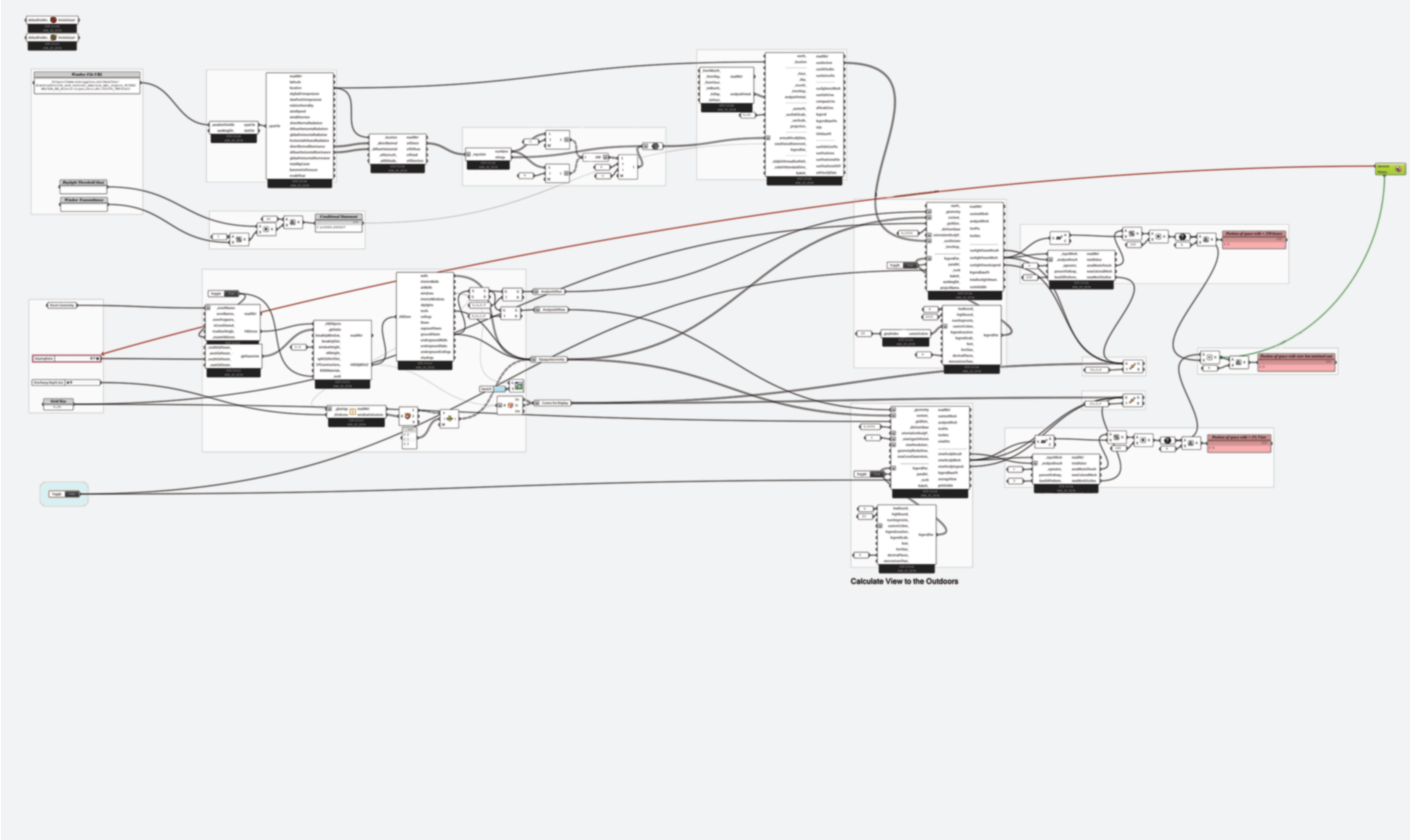

Parking
Stacks
Auditorium


Depth: 2
Depth: 1
Depth: 0

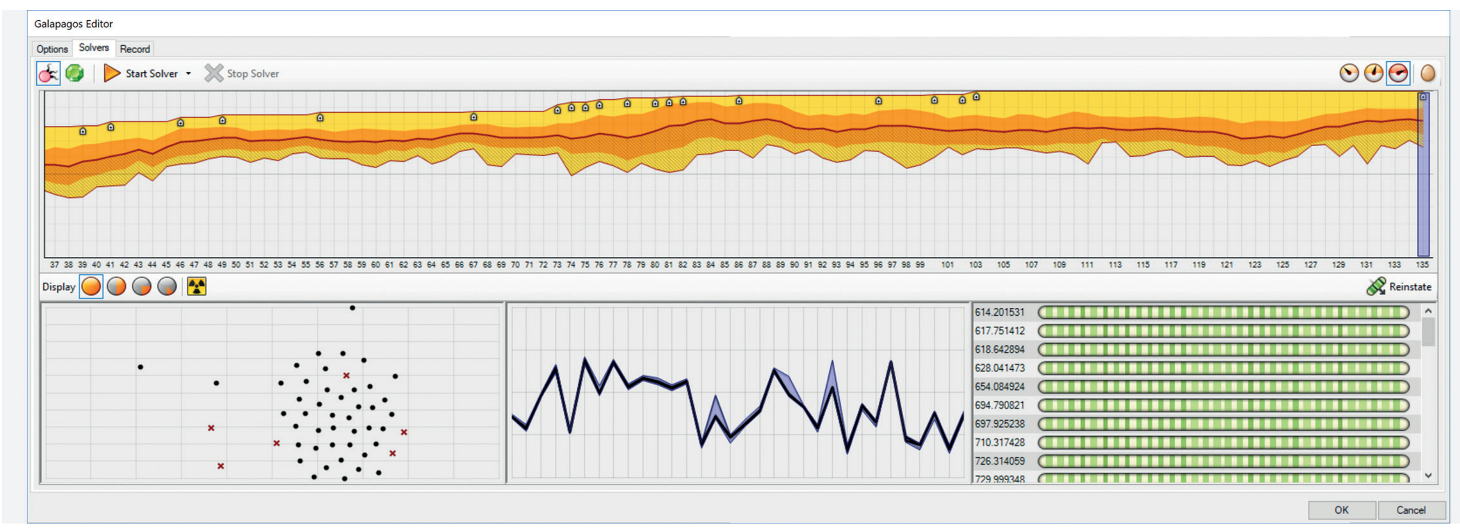
Now the optimization process for daylight and thermal is used in order to enhance the amount of daylight entering the building while minimizing heat gain. However, when running the part of algorithm related to solar radiation unexpected results come out preventing the part of opening creation to work correctly. Indeed solar radiation reaches very high values all over the surface and so it is impossible for the window algorithm to search for areas on the shell where to place openings. Because of this, some modifications have been introduced in order to create accesses for daylight. They have been designed manually and the algorithm used to find their optimal dimensions by using them to scale the created shapes. The shadowing algorithm also fails to provide usable surfaces for shading the opening since the high values of solar rays altitude but also due to the shape of the shell. However, it isn't been all an unsuccessful since it helps to introduce the idea of trying to decrease the solar radiation hitting the whole surface by introducing irregularity in the surface of the shell itself. Thinking about it, it's the same strategies using in nature by cacti and desert plants. Indeed the presence of ribs creates a shadowing pattern on the plant itself (5) but also helps in enhancing heat radiation. Different studies have shown how the presence of ribs on cacti surface helps the plant in losing heating for convection up to 2.5 times more than a smooth surface (6). In this way type of ribs are introduced on the surface of the building, but since the main concept is the one of forms created by sand and dunes, the pattern used is the one typical to see on dunes in the desert. Instead to mediate the heat entering from the new openings elements to diffuse the direct light are introduced just under the glass level.

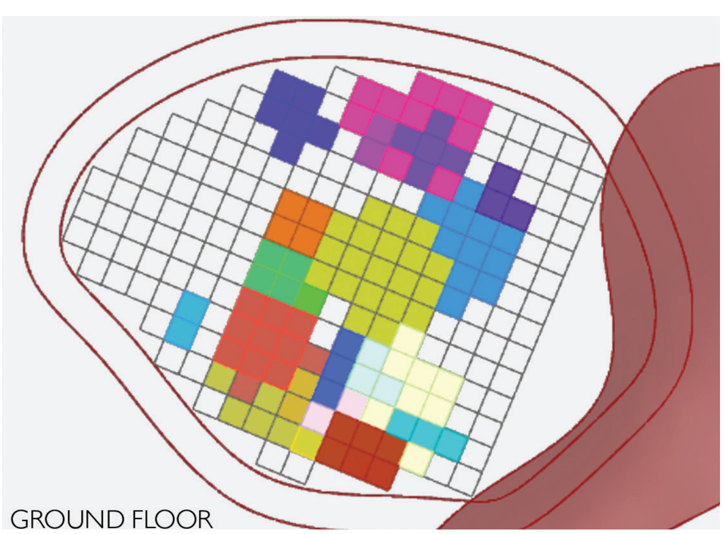
4.Helmut Tributsch, *How Life Learned to Live: Adaptation in Nature*, 1983
5.D. A. Lewis, P. S. Nobel, *Thermal Energy Exchange Model and Water Loss of a Barrel Cactus*, Ferocactusacanthodes Plant Physiology, 2008

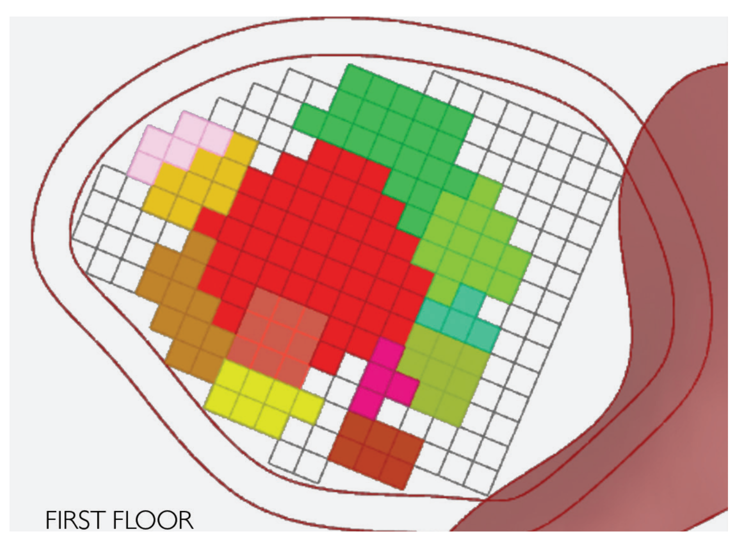
OPENINGS OPTIMIZATION



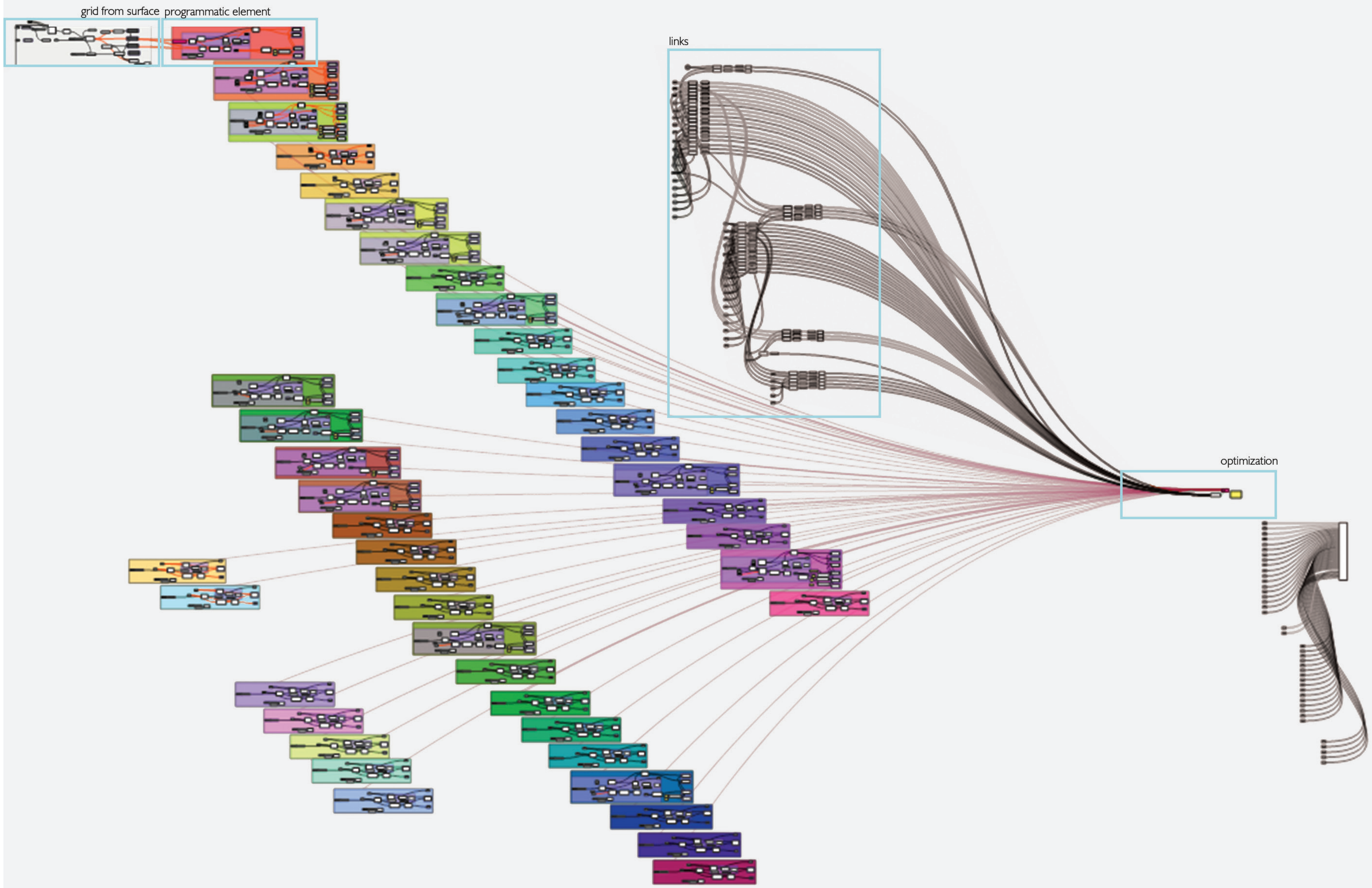
Now the optimization process for daylight and thermal is used in order to enhance the amount of daylight entering the building while minimizing heat gain. However, when running the part of algorithm related to solar radiation unexpected results come out preventing the part of opening creation to work correctly. Indeed solar radiation reaches very high values all over the surface and so it is impossible for the window algorithm to search for areas on the shell where to place openings. Because of this, some modifications have been introduced in order to create accesses for daylight. They have been designed manually and the algorithm used to find their optimal dimensions by using them to scale the created shapes. The shadowing algorithm also fails to provide usable surfaces for shading the opening since the high values of solar rays altitude but also due to the shape of the shell. However, it isn't been all an unsuccessful since it helps to introduce the idea of trying to decrease the solar radiation hitting the whole surface by introducing irregularity in the surface of the shell itself. Thinking about it, it's the same strategies using in nature by cacti and desert plants. Indeed the presence of ribs creates a shadowing pattern on the plant itself (5) but also helps in enhancing heat radiation. Different studies have shown how the presence of ribs on cacti surface helps the plant in losing heating for convection up to 2.5 times more than a smooth surface (6). In this way type of ribs are introduced on the surface of the building, but since the main concept is the one of forms created by sand and dunes, the pattern used is the one typical to see on dunes in the desert. Instead to mediate the heat entering from the new openings elements to diffuse the direct light are introduced just under the glass level.




GROUND FLOOR


FIRST FLOOR

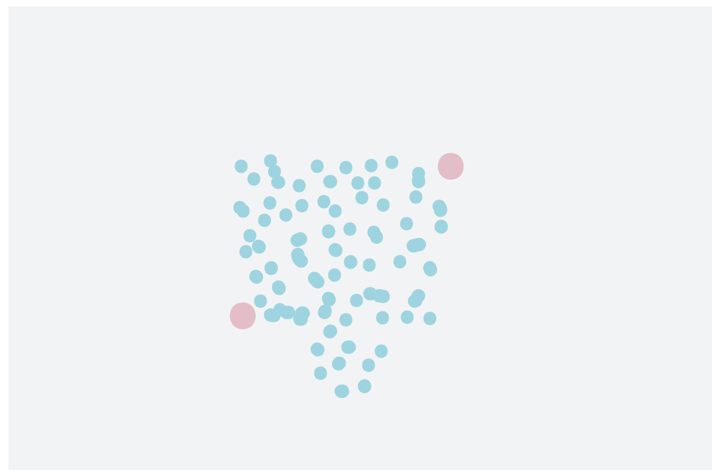
ADJACENCIES OPTIMIZATION



Finally, the centroids of each mass are linked to the access points found previously with the external crowd simulation and the same algorithm is used to create a pedestrian path inside the building. Since the algorithm can work only in 2D space, the simulation has been conducted for each floor and by manually adding distribution elements. These elements, in particular safety stairwell, have been used as the starting propagation points for the first floor, in this way minimal distances are created between each programmatic element and safe exits in order to allow a quick evacuation in case of danger.

Arrived at this point a whole conceptual volumetric building is obtained and need to be translated in architectural drawings. To do that different ways are possible, but the one chosen is to import the model in Autodesk Revit in order to give to this research the possibility to be extended with future studies and consider the aspects related to the final stage in the delivery process thanks to BIM opportunities. To achieve this translation, Grevit plugin has been used to send the architectonical elements from Grasshopper to Revit and so helping in the automatization of the creation of drawings.

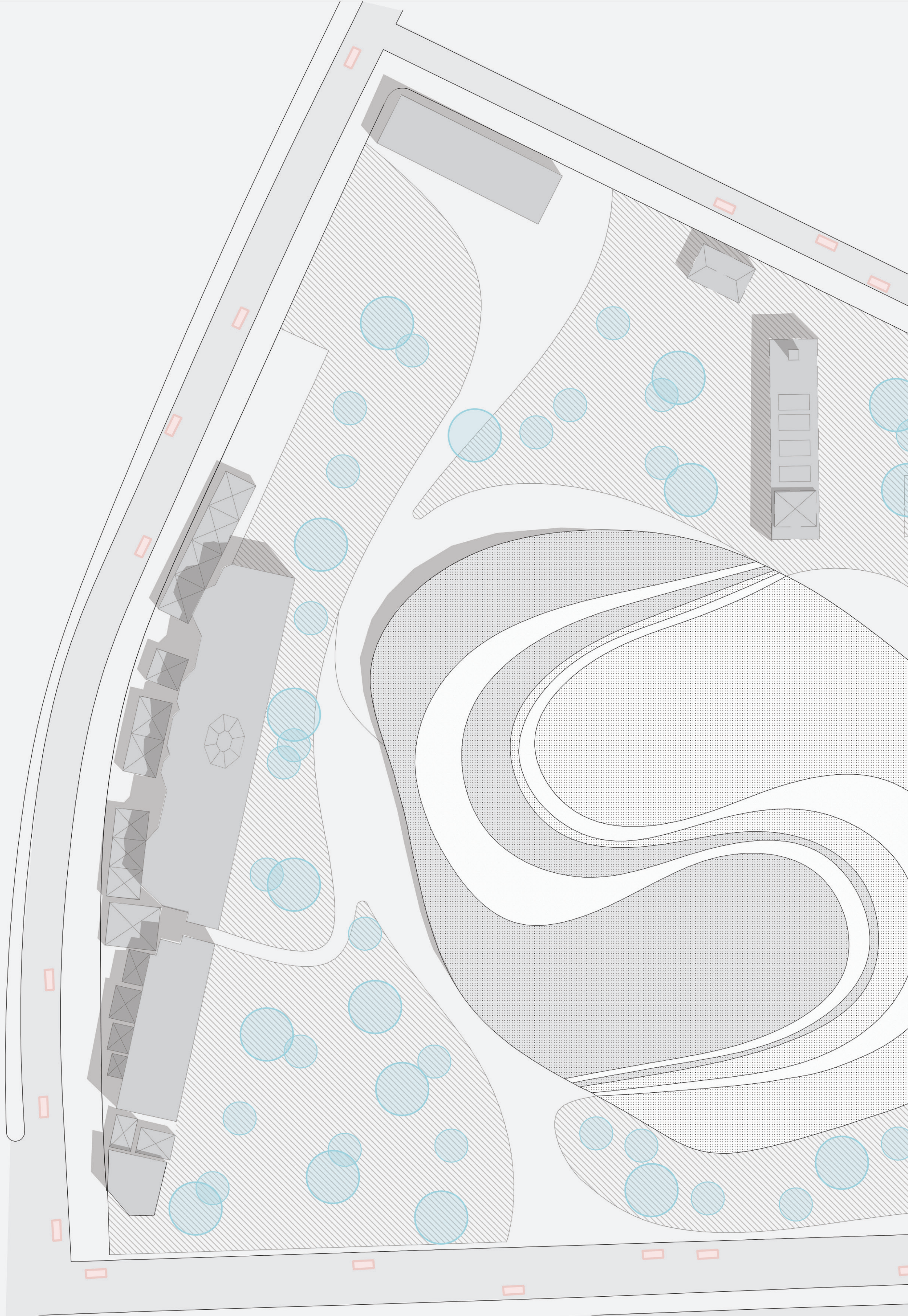
GROUND FLOOR



FIRST FLOOR

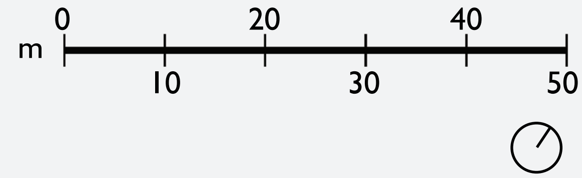
CHAPTER FIVE

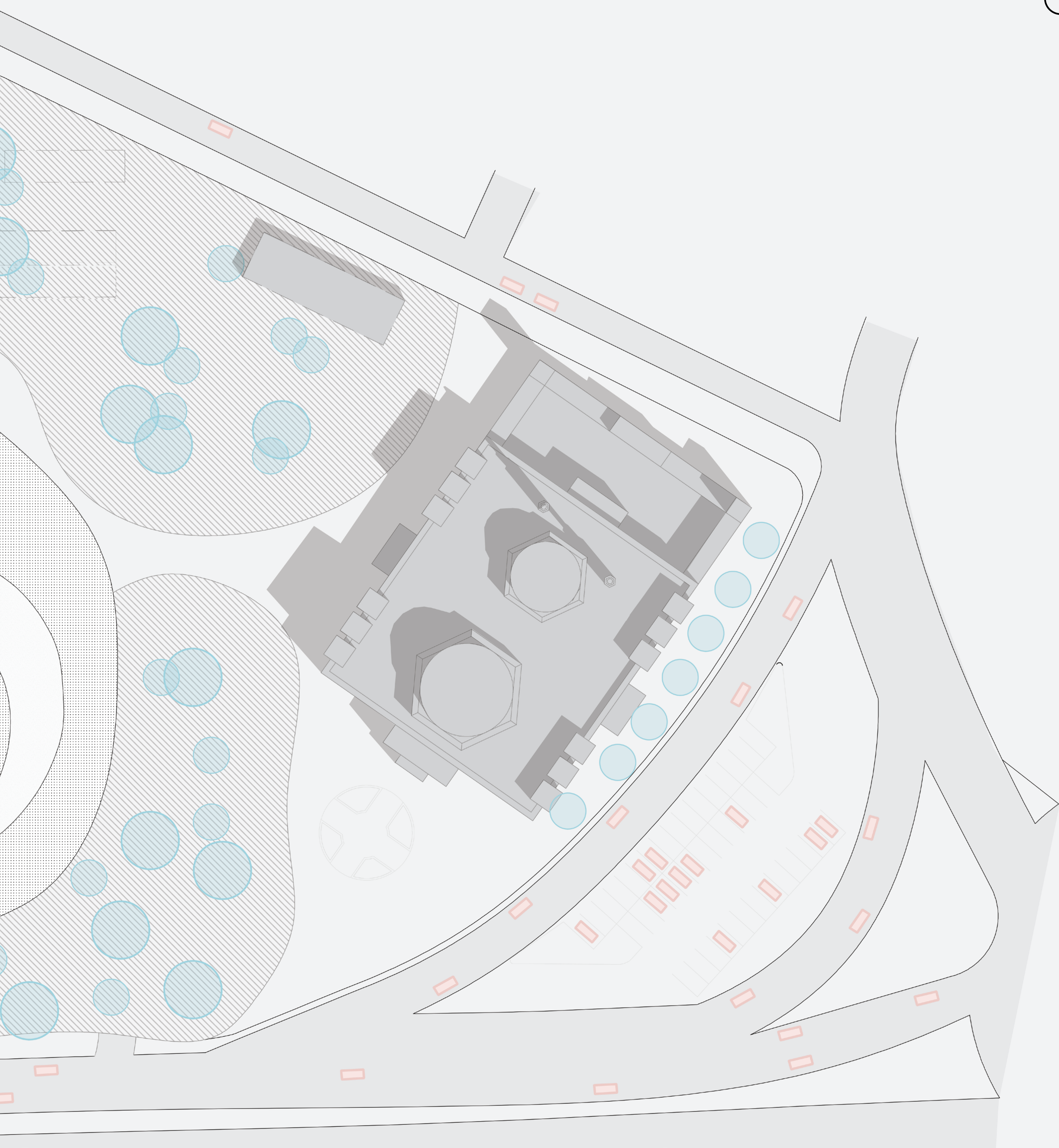
the drawings



site masterplan

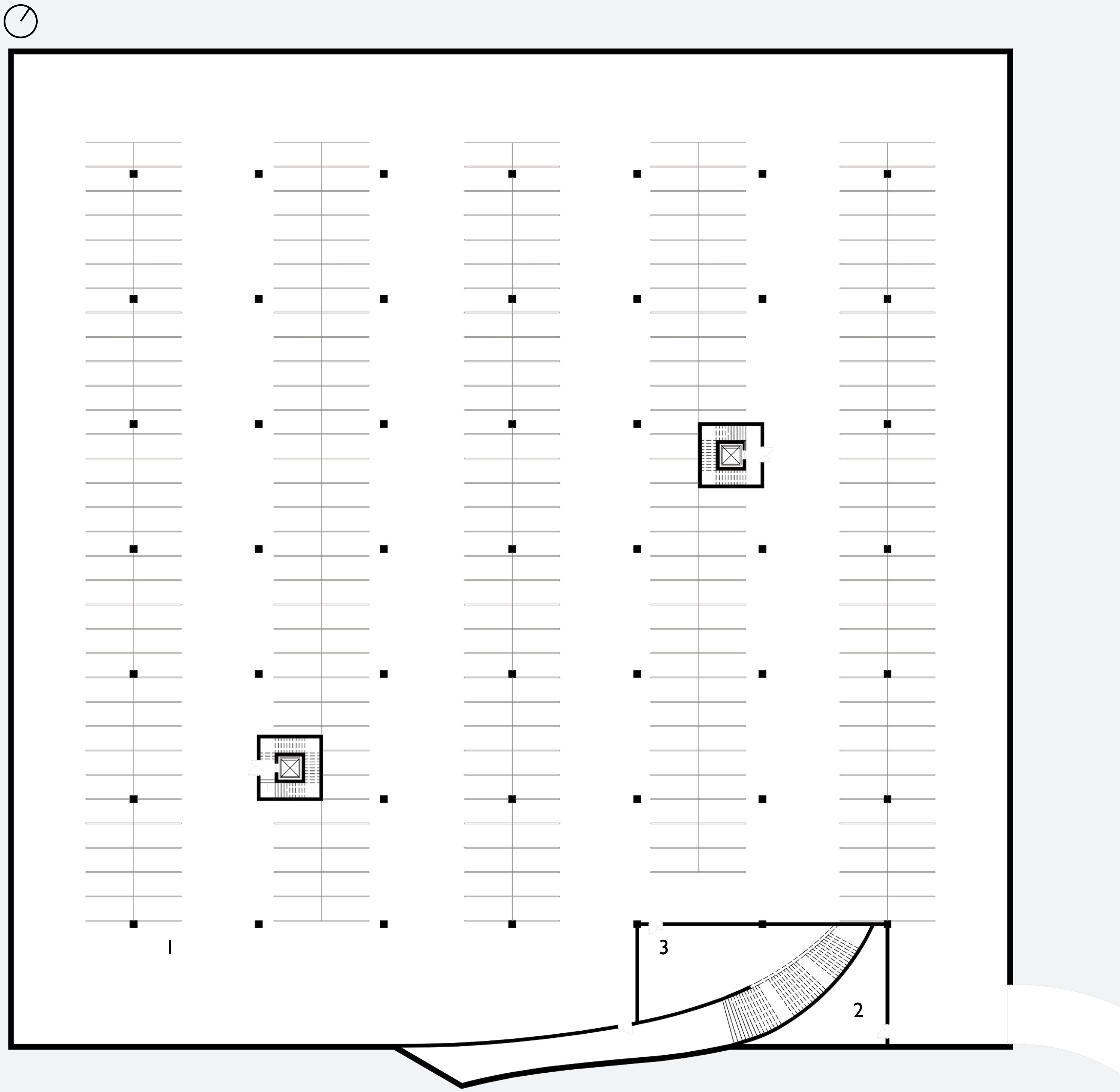
scale



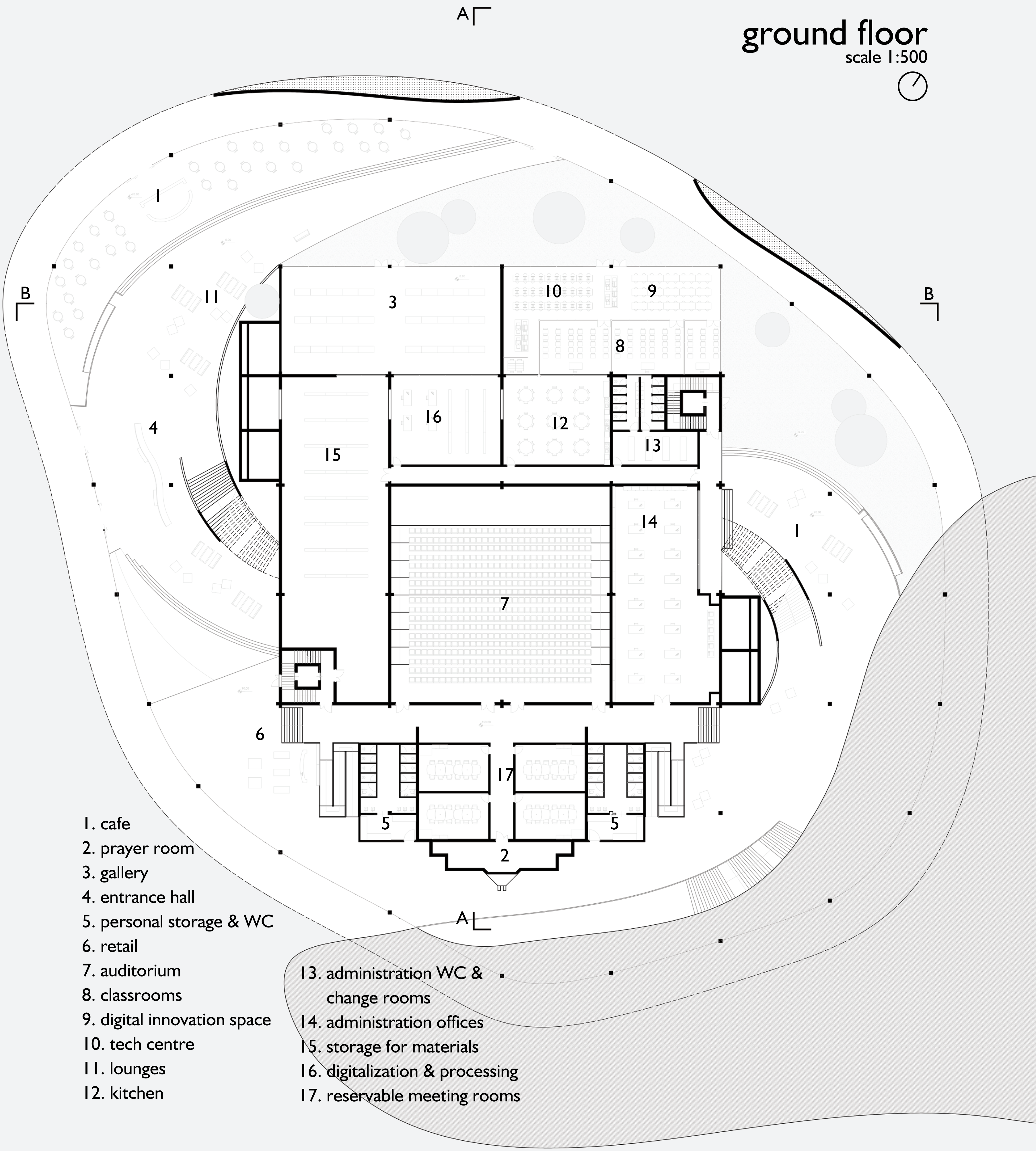


underground floor

scale 1:500



1. parking
2. server room
3. AC room

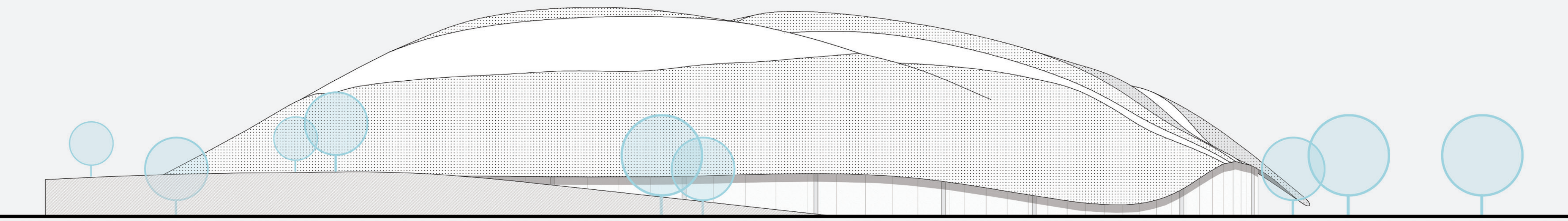


1. cafe
2. prayer room
3. gallery
4. entrance hall
5. personal storage & WC
6. retail
7. auditorium
8. classrooms
9. digital innovation space
10. tech centre
11. lounges
12. kitchen
13. administration WC & change rooms
14. administration offices
15. storage for materials
16. digitalization & processing
17. reservable meeting rooms

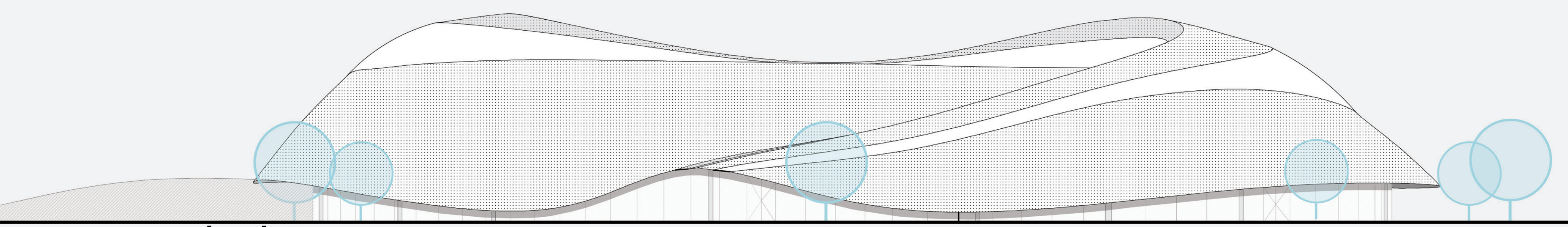
first floor

scale 1:500

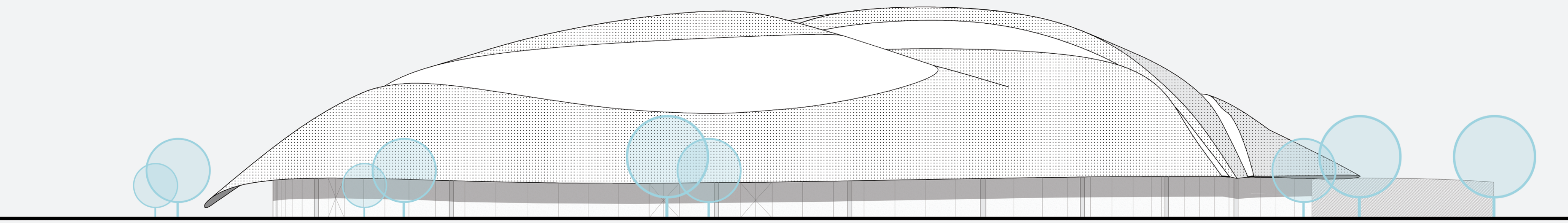
1. stacks
2. teen zone
3. children library
4. IT stations
5. lounges
6. open reading areas
7. carrels
8. private reading room
9. rare book storage
10. periodicals
11. informal reading materials



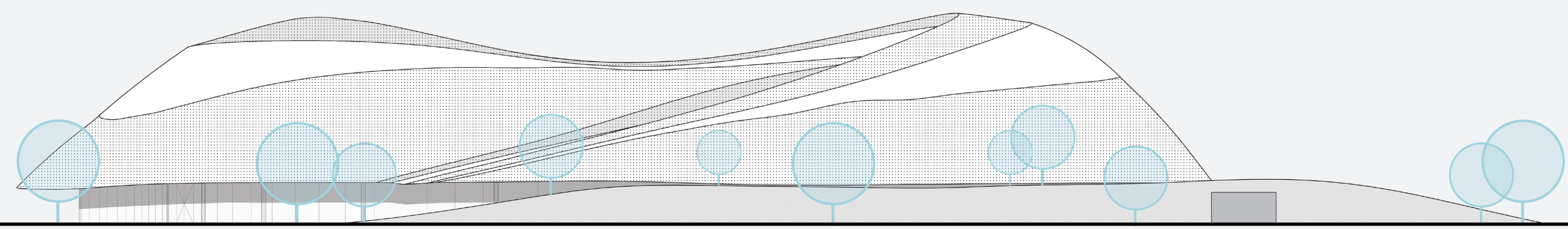
east elevation
scale 1:500



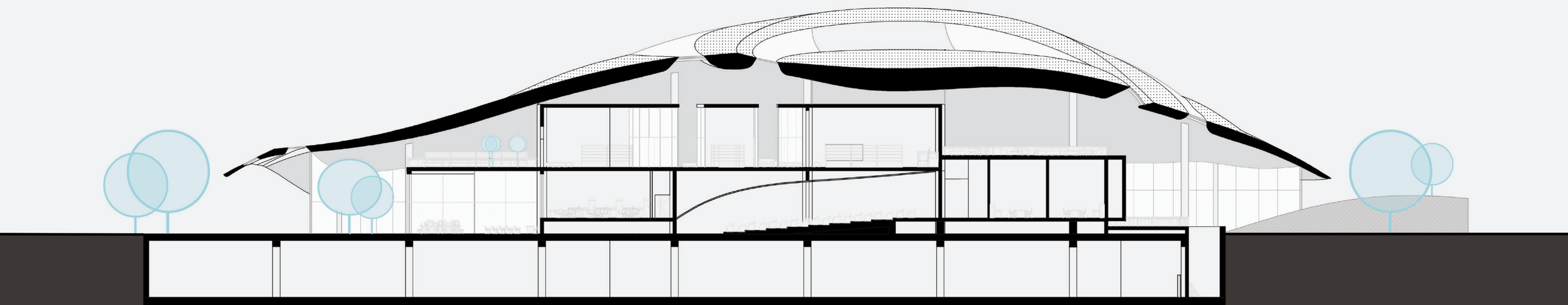
north elevation
scale 1:500



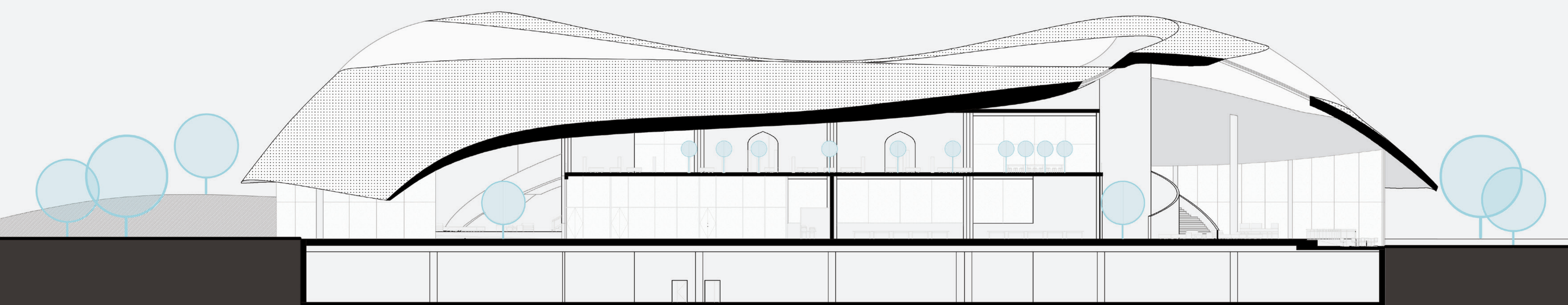
west elevation
scale 1:500



south elevation
scale 1:500



AA section
scale 1:500



BB section
scale 1:500

Outdoor

night

Outdoor

Sandstorm

Indoor

Stairs

Indoor

Teen zone

CHAPTER SIX

evaluation

BACK TO THE ORIGIN

Usually, what comes after designing, is the evaluation of the results achieved and to do that the Revit model has to be reimported in Grasshopper environment. Since Grevit and other plugins like it work only in a one-way direction, it has been impossible to automatically reimport the new architectural model in the parametric world, and, unfortunately, neither an extension for Revit does exist. Because of that, it has been tried to develop a translation the most fluid as possible. To do that the Revit file has been exported in a Rhinoceros file (.3dm) where each family of elements (wall, ceiling, floor,…) belong to a different and recognizable layer. At this point, the .3dm file has been opened into Rhino and by selecting the whole object under a layer the geometries were collected in a single Grasshopper component that subsequently has been translated in a Honeybee geometry. Indeed is possible to create Honeybee geometries starting from macro-groups of architectonical elements, the same of Revit families.

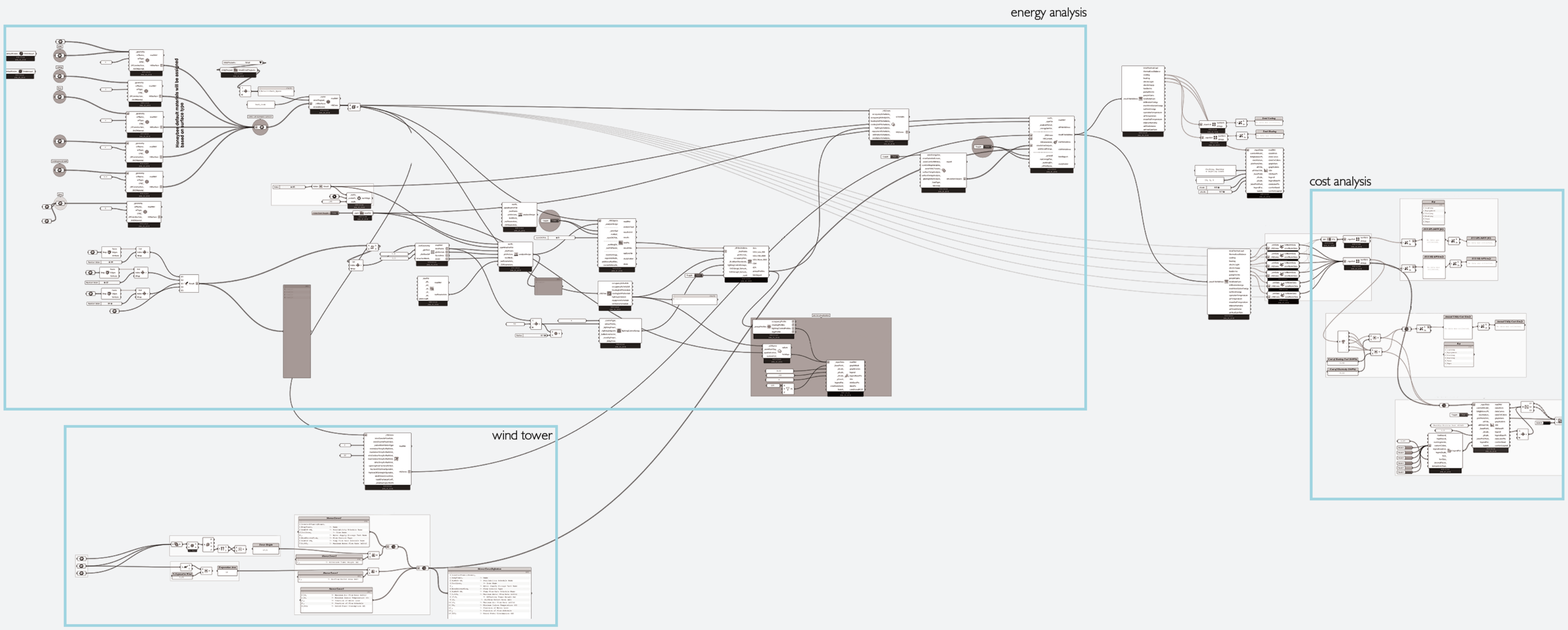
Once the building has been translated in a parametric way and hence in Honeybee Geometry, they are merged together to create an energy model of the building divided into zones usable by EnergyPlus for energy simulation.

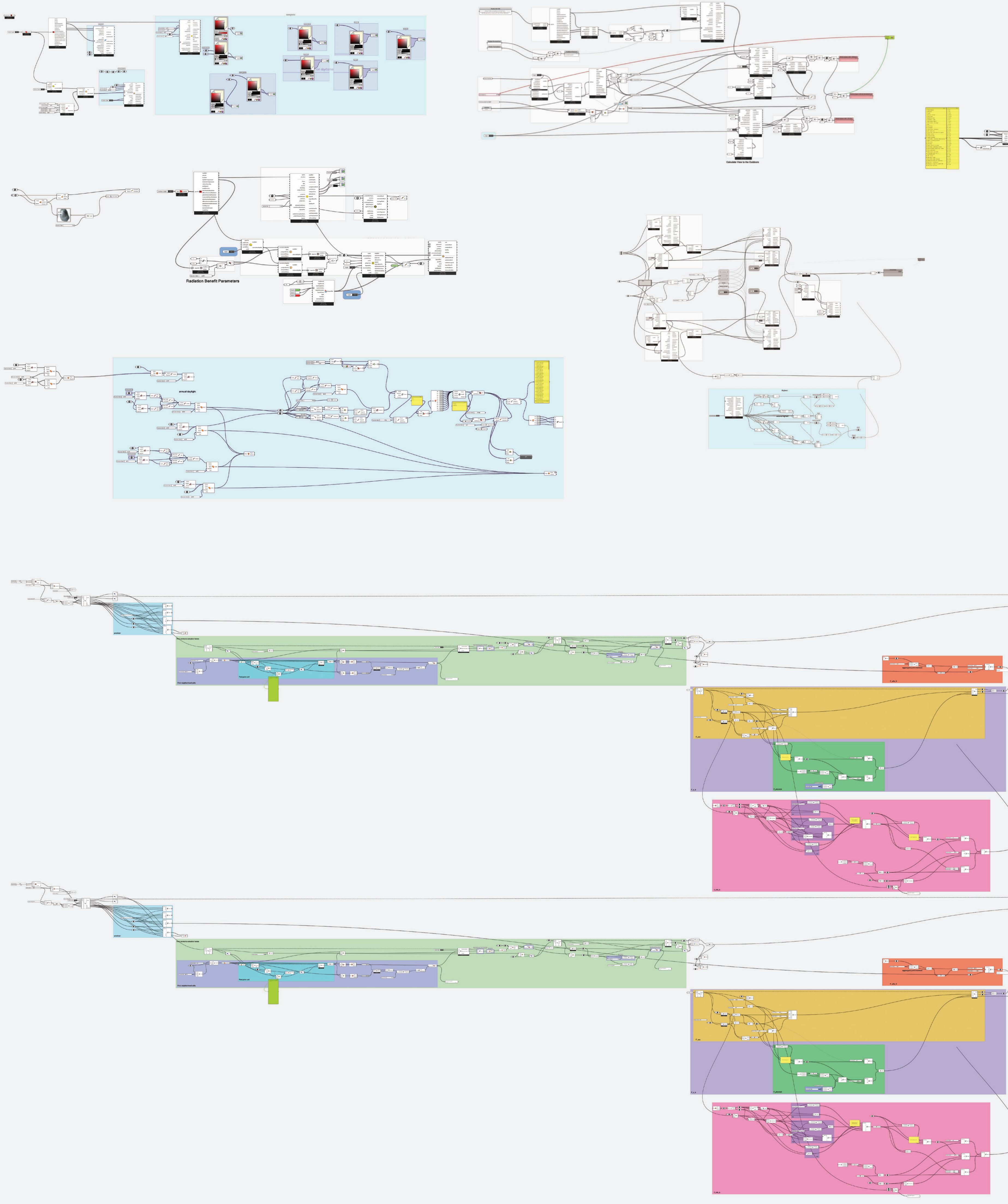
At this point, the top surfaces of the floors are extracted and used to create a grid for daylight evaluation. Furthermore, the same grid is used to place at a set and customizable distance a lighting device. In the same time from the Weather file (the same .epw file used previously), parameters about daylight are extracted and used to run a daylight analysis. Once concluded data coming from this simulation and the ones about lighting devices are collected together to generate a lighting schedule. This schedule is hence linked to the Honeybee zones and then used to feed the energy simulation component. To this same component also a definition to simulate the evaporative cooling towers is introduced. It works by extracting the geometry of the tower and the evaporation area.

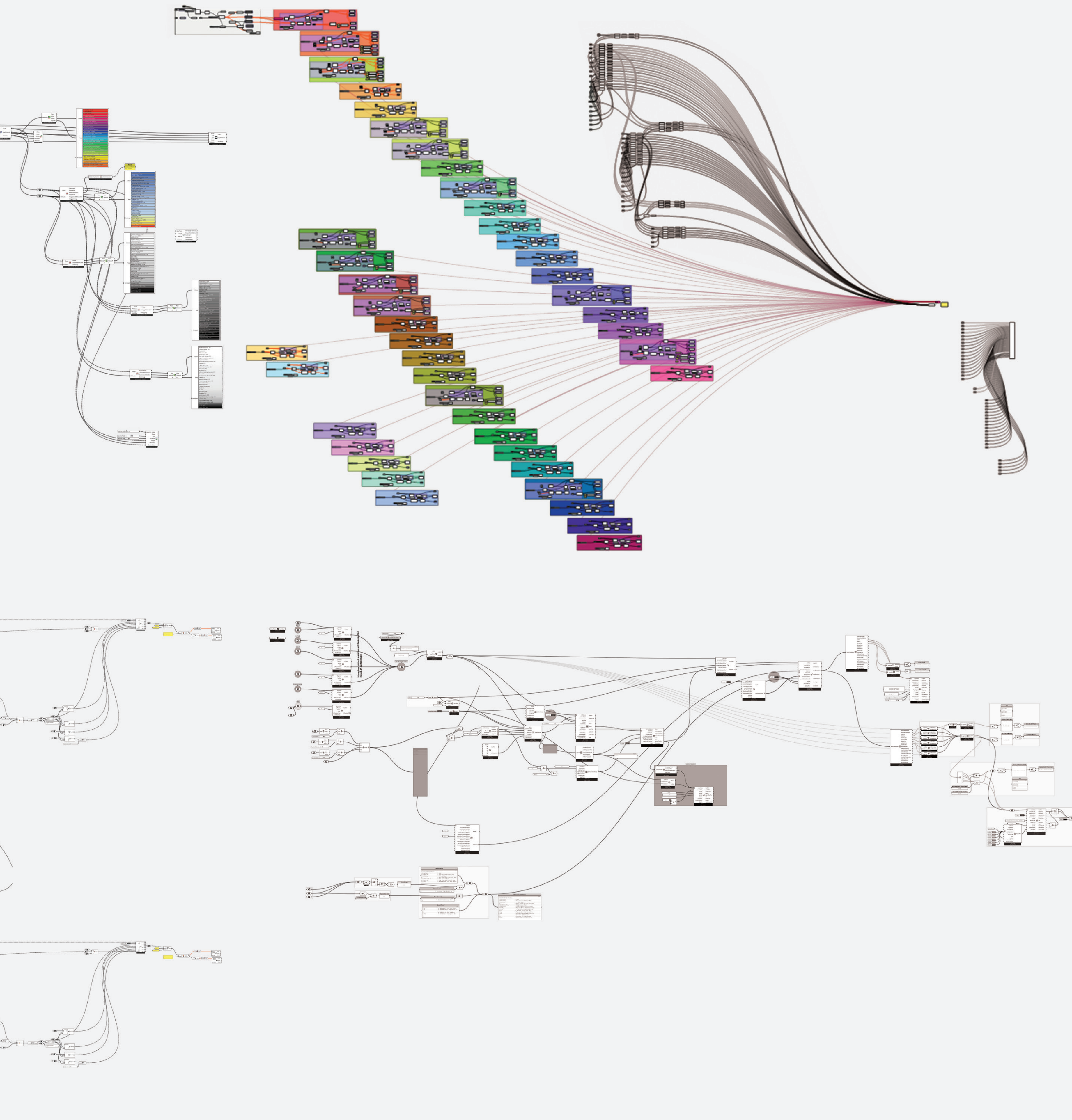
Then the natural ventilation component of Honeybee is introduced to mitigate the temperature in the zone where the cooling towers work. At this point, it's all linked to the energy simulation component and make it runs. The results are given under a graphic form where energy loads are divided depending on the provenience. Finally, the energy consumption value for each category is normalized with respect the floor area and then multiplied for the cost of energy obtaining the energy consumption in term of costs per meter square. By knowing the amount of energy requested by the building is then possible to calculate the number of photovoltaic panels necessary to cover the full amount of energy used by the building.

However, this definition of the evaluation process has not possible to be tested, since the power of the computer used has not been enough to undergo the whole workload to complete. This is also due to the fact that Grasshopper can't handle with easiness great load of work without giving some freeze problem, if not stop working. Nevertheless, it has been decided to present it anyway since the nature of the work to present an example of workflow the most complete possible, but also because highlight an important fact that should be taken in consideration when drawings conclusions.

EVALUATION




Calculate View to the Outdoors
Radiation Benefit Parameters
annual daylight



CHAPTER SEVEN

Discussion & Conclusion

DISCUSSION

This work shows how it's possible to translate and manage in a parametric way the behaviour and the characteristics that emerge from relationships between different fields, design choices and elements of the building intended as a complex model. This approach allows having a greater conscience of the interactivity and mutual influence that a single aspect could have on the whole system itself. And so, understanding the influence, is possible to drove the design strategy towards more targeted choices.

Furthermore, a recurring theme in this work is the concept of optimization, intended as a way to find optimal solutions where complex thinking is required. It's important to underline how the solutions found with this method are one of the optimal solutions but not the optimal one. It's possible also to say that having a rose of optimal solutions the one that more fit to the case have to be decided by the designer. And the designer is the central point in all the operations that have been done since here. Indeed, even if it may seem that all this whole definition works in an automatic way starting from a bunch of input data, in the reality the designer choice is what influence the output. For instance, by deciding the weight of a relation in an optimization process or to decide how much far outputs can be useful and could generate an architecture usable.

It can be said that the optimization process works on optimizing a design idea, since it's influenced from the start by the taken decisions. What is possible to notice is how working in a parametric way, all this definition can be used for different situations, with correcting maybe some little value. By the other hand is necessary to be said that the first time it requires a lot of time to be developed, since the need to be tested, debugged and retested if it works also under other circumstances. And this could become a problem in the very first time since quite all architectural works are to be done for a deadline and spending too much time in defining all the necessary aspects could drive designers out of time. However, this happened in this case since the need to construct a literature and knowledge background to support the creation of the algorithm and recognizing eventual mistakes.

By working in a team group, where each member is specialized in some field could be successful since there is no need to construct before a basis where to start. This could help in defining the elements in the complex system, but when it comes to relations is just about the strategy and idea to use to make them all working together. Again this is just as if the designer is drawing the process more than a physical object, and this is the meaning of computational design. And it is in the definition of these relationships that emerge all a series of problems and opportunities that weren't visible when working on the single element itself.

As previously said, this work is not intended to be exhaustive towards the whole building complex system but looks to propose a methodology that can be further developed. Indeed the potential of this way of design is very high since every aspect of a building such as specific types of environmental performances, structural design and so on can be modelled alone and in a second step bounded together by making them mutually influential. If I should translate this concept in an image it could be something like a tree, where leaves are the single elements or aspects of the building, while trunk and branches are the relationships that bound all together and make the system work.

There are no boundaries between elements but, it's more like a whole continuous system, a continuous flow where changes happening in a part are translated in a modification of the behaviour to answer to those changes. And it is, with this in mind, that this research fits: trying to deploy, even if just for a small part, the complexity and changes of relationships happening in the building.

Of course, all that glitters is not gold. In deploying all these aspects, there are two main problems that nowadays hinder to a fluid workflow and usage with daily standard tools. First the lack of plugins to be used in defining characteristics and aspects of the building, or more often the lack of documentation or tutorial in understanding the role of each component of that plugin. A possible solution in the first case is to write from zero a plugin that does what is asked, and it's something like to what has been done in the crowd modelling part.

However defining a whole new algorithm with Grasshopper components could be not a very clean work, with issues in the case to update it in a second time (spaghetti-like linking system start to become very confusional at a certain point), or in the case to make it available and usable by thirds. In this situation, a better approach is indirectly coding it, but it requires, of course, scripting capabilities, but lot more it requires a lot of time before it could be used with too many issues or bugs. Secondly, the main constriction to the creation of a single whole algorithm that deploys all the relations is the computational power, as can be seen in the evaluation chapter. A lot of calculation power and memory is requested to allow the computer to solve the requests and this could be a big problem for ordinary devices. Of course, this limit is something that will be easily solved, since the exponential growth of processor performances and technological innovation: it's just a matter of time.

However, at the time this work is written, expansive workstations are required (something that big firms or research centre could have) or the need to send this calculation to external server farms, with implicit costs but also possible issues in verifying and find the farms that have the same software installed in order to fully work.

CONCLUSION

The theory of complex systems applied to the design and construction development expresses the potential of a new way to think to, and perceive the role of architects during the creation and development process.

Until now the architect has to spend energy in relating to a wide range of actors, where each one contributes is in some ways to the project but in some way results to be not truly connected to the original idea. Let's think to structures that put constraints to shapes and spaces designed, or energy production seen as an addition to the building itself rather than an integrated strategy. The methodology proposed tries to shift this paradigm to a new one, where are relationships the main bricks with which building takes shape. Indeed, while every specialist can work on a specific element or aspect, such as structures or lighting, the designer can interface to see how all the elements work and relates together. And by deciding and attending to the flow between fields, he can manipulate the emerging behavioral pattern and pushing the shape and performances towards new limits.

And in this dynamism that the continuum between elements could be achieved: structures that become spaces, spaces that become community, community that become economy. It's just like linking dots, what may seem isolated is in reality part of a bigger order, of a superstructure that all contains but that change all.

Parametricism become in this way even more a way to design a process rather than a building. The infinity power of computational control compensates the finite management skill of human and could drive the design process towards new boundaries. But has seen, physical limits create obstacles towards the application of this methodology with standard daily tools. The potential of this method is huge since the possibility to be applied to every aspects of the design and building process, and, freeing from these constraints result to be quite simple thank to the technological advancement of our society. It's just matters of time.

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IMAGES

Acknowledgment

A conclusione di questo lavoro è doveroso ringraziare tutti coloro che hanno contribuito al raggiungimento di questo obiettivo e che mi sono stati vicino e sostenuto in questo periodo della mia vita. Tuttavia devo fare una premessa: non sono molto bravo in queste cose, quindi sappiate che il mio affetto e la mia stima per voi vanno ben oltre a queste semplici righe.

Desidero ringraziare il professore Grosso Mario, relatore di questa tesi, per la sua grande disponibilità, solerte guida e cortesia dimostratami. Il suo aiuto è stato un caposaldo fondamentale per la stesura di questo lavoro.

Un ringraziamento davvero speciale va alla professoressa Nigra Marianna, senza la quale tutto ciò non sarebbe stato possibile. Ringraziarla per la sua guida, l'aiuto datomi e la profonda sapienza dimostrata è d'obbligo, ma risulta alquanto semplicistico. Ritengo necessario ringraziarla ancora di più per le opportunità fornitemi, per la sua travolgente energia ed entusiasmo che mi hanno spronato nella realizzazione di tutto questo, e per l'immensa crescita personale che per me lei ha significato.

Non penso di trovare le parole giuste per ringraziare tutta la mia famiglia, e in particolare i miei genitori. Vorrei che questo mio traguardo fosse un premio anche per loro, per tutti i sacrifici fatti e per tutto il possibile e l'impossibile che hanno fatto affinché potessi arrivare fino a qua. Penso che le parole non possano bastare a dire quanto sia grato per il continuo sostegno, incoraggiamento, per esserci sempre stati e per aver fatto di me quello che sono oggi. Senza tutto il vostro aiuto sicuramente oggi non sarei qui. So che può sembrare poco, ma a voi va il mio grazie più grande, con la più grande accezione che questa parola può avere.

Un enorme grazie va al mio amico di vecchia data Gianni, il miglior compagno di avventure che potessi desiderare. Il tuo è tra i ringraziamenti più difficili da scrivere, perché dopo tutto il tempo che ci conosciamo ormai certe cose si danno per scontate e per questa volta vorrei che non lo fossero, quindi ci provo. Grazie per esserci sempre stato, per aver sopportato "le mie stranezze" o più in generale avermi sopportato e basta. Ma grazie ancora di più per tutte le risate, le chiacchierate, le serate e le giornate indimenticabili e i momenti unici che abbiamo passato. Potrei continuare a ringraziarti all'infinito e per infinite cose, e so che non sarebbe abbastanza. Senza di te sicuramente non sarei mai arrivato fino a qui.

Un altro sincero e speciale grazie va a Sophie. Anche se ci conosciamo "solo" da qualche anno è come se fossimo amici da una vita. Grazie anche a te per avermi sopportato fin da subito, per tutti le risate, le infinite chiacchierate su Harry Potter e le interminabili chiacchierate in generale, le giornate alle mostre, le serate e per tutti i momenti che abbiamo condiviso, che per me sono indimenticabili. Grazie anche per tutto il supporto nell'ultimo periodo, sia nei giorni si ma soprattutto in quelli no. So bene che questi ringraziamenti non sono abbastanza, ma ti basti sapere che il nostro incontro per uno spritz è una di quelle poche cose che rende migliori le mie settimane.

A Silvia, Pierpaolo e Marco un ringraziamento speciale. Anche se ci siamo conosciuti praticamente alla fine di questo percorso, le grandi risate, chiacchierate e giornate che abbiamo passato assieme hanno reso tutto ciò ancora più incredibile e divertente. Chiaramente grazie anche per tutto l'aiuto e i consigli che mi avete dato nella stesura di questo lavoro.

Un altro sentito grazie va a Paolo e Cecilia, prima amici e poi coinquilini. Grazie per tutti i momenti passati insieme, le serate passate a ridere sulle nostre povere vite da studenti, e quelle invece passate per capire Twin Peaks. Grazie per esserci sempre stati anche solo per una chiacchierata alla fine di una lunga giornata e soprattutto per il supporto che mi avete dato durante questo ultimo periodo.

Un ringraziamento particolare a tutte le mie colleghe di lavoro, alle responsabili e soprattutto ai capi, Davide e Claudio. Grazie mille in primo luogo per l'enorme flessibilità datami sui turni di lavoro per poter studiare e concludere questo lavoro. Ma grazie ancora di più per tutta la fiducia che avete riposto in me e per tutte le opportunità che mi avete dato e che mi hanno permesso di crescere molto sia professionalmente ma soprattutto personalmente. Questo lavoro è sicuramente stato possibile anche grazie a voi.