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Biomimicry approaches to mitigate the urban heat island

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DECLARATION

This dissertation is my own original work and has not been submitted elsewhere in fulfilment of the requirements of this or any other award.

ABSTRACT

Mitigating Urban Heat Island Intensity (UHII) requires a comprehensive understanding of its relationship with global climate change, the underlying reasons, and adoption of all sorts of ideas from multidisciplinary fields. The biomimicry approach can be a remarkable option to this global concern, which has been emphasized by many scientists, researchers, and experts since the nineteenth century. However, it is yet to be acknowledged and widely practiced, especially in urban planning and design to safeguard a sustainable urban environment. The purpose of this study is to introduce a descriptive guideline on biomimetic urban design process, based on climate analysis at a neighbourhood scale. The study area, Paleficat of Toulouse in France, is a prospectus development area, a mixed-use area. Urban planners seek for a design that will cause the least environmental effect from the development. Both qualitative and quantitative study approaches are used in this study. Primary information is collected through field observation and secondary data is collected from The Laboratoire Interdisciplinaire Solidarités, Sociétés, Territoires (LISST). The climatic analysis is done in the laboratory by using R-Language and QGIS for wind and temperature at city scale. Primary analysis done on vegetation, hydrological courses, building topology, building material, topography, UHII, heat stress, and wind has been carried out. Later, from both field study and literature review, this study stresses on formulating a guideline, which describes what component the neighbourhood should consider while designing the area such as: vegetation and hydrological courses, existing built structures, vehicular accessibility, heat stress and wind analysis, and height of the building. The guideline will enhance thermal comfort for the residents. Besides, the study has inferred that if the street network is built by following a naturally existing pattern like a leaf structure the area will cause minimum heat island in the future. Overall, identification of right biomimetic approach can help to reduce local heat stress. This approach gives the ability to creatively design an adaptive built environment that acknowledges that a city grows and evolves over time. Biomimicry helps planners to deal with the complexity of city planning in a multidisciplinary approach that aligns with the natural systems.

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1. INTRODUCTION

1.1 Background

According to the United Nations (2018), 68% of the world's population is projected to be living in urban areas by 2050. As a result urban areas are expected to have much tighter spatial interrelationship among buildings that may raise several urban environmental issues. Rapidly increasing urbanization is the main cause of urban heat islands (UHI), which is reaching epidemic proportions. There are examples of approaches to mitigate urban heat Island intensity in micro scale urban physical infrastructures using the concepts of biomimicry. The notion of biomimicry is the idea that the natural world has been doing research and development for 3.8 billion years refining responses to environments that humans as recent species have only begun to understand. The biomimicry approach is to learn the lessons of nature and understand how nature has designed itself in response to environmental conditions and design the world accordingly.

Globally cities are being regenerated and readjusted according to visionary ideologies to accommodate necessities for achieving thermal comfort and ensuring the well being for urban dwellers. These cities can benefit by adapting solutions embedded in nature which can be implemented in an urban neighbourhood scale to mitigate several climatic issues like urban heat island effects.

1.2 Aim and Objectives

Urban heat island is a phenomenon, which is mainly caused by densely constructed surfaces that absorb solar radiation more than the natural surfaces and anthropogenic cooling mechanisms. Another significant cause of UHI is due to the buildings blocking wind that stops cooling by convection. Urban heat island is a significantly large urban area or metropolitan area that is warmer than its surrounding rural areas (Solecki et al. 2005). The initial part of the research is to analyse the climatic conditions of neighbourhood scale of an urban area that have significantly increased solar absorptions and the existing wind conditions.

Brown and Kellenberg (2009, 60) mentions that biomimicry at a broad spatial scale might be more effectively confronting ecological degradation and climate change adaptation. These encourage designers to envision urban built environments based on principles of biomimicry. In the realm of academia, it has been encountered that almost all current ecological solutions applied to suffice the criteria of sustainability aligns with concepts of biomimicry. Even in the professional field of urban design, there are several attempts to derive solutions of urban climate related problems, using biomimicry approaches. Although biomimicry is counted as a new approach in the field of architecture and urban design, there is still no adequate access for architects and urban designers to utilize biomimetic design strategies in projects (Chayaamor-Heil et al. 2017). Snillen (2018) states that biomimicry suggests looking into nature to explore possibilities through investigation of natural and environmental features of a specific site. One of the core objectives of this research is to produce a rich resource for urban design professionals to make use of biomimetic work processes in building climate sensitive urban design projects.

1.3 Scope of work in an existing urban development project

For the aid of research involving climatic data possible site for analysis, there was a unique opportunity to work at The Laboratoire Interdisciplinaire Solidarités, Sociétés, Territoires (LISST), which is a public research laboratory under the supervision of the Centre of National Scientific Research (CNRS) and the Toulouse University. In addition to that, LISST is also a research team belonging to Centre for Interdisciplinary Urban Studies (CIEU), which deals with housing, relationship between the economy and urban spaces, urban sustainability (Masson et al., 2015). Their researches question the interface between city and environment such as the urban climate and the adaptation of cities to climate change.

The initial masters internship task was regarding wind analysis for urban planning recommendations in Toulouse. The research work was supervised under Dr. Julia Hidalgo, the proponent of the CNRS/LISST wind analysis for urban areas projects. As mentioned earlier obstacles that block wind flow majorly contributed causing urban heat island. Thereby, this project helped to identify a specific problem caused by wind. It was crucially insightful to collaborate with other interdisciplinary urban researchers involved in other relevant projects.

During the masters internship at LISST there was scope to be involved in a new urban development project in Toulouse. Inside the Toulouse metropolitan boundary, the remaining places allocated for a new urban settlement is an area called Paleficat. There was a scope to be involved in a research exercise to conduct a primary feasibility analysis of the area and later prepare a proposal. The project is handled by the Toulouse Metropole, which is a public planning agency that supports the French ministry in charge of town planning. An urban professional from Toulouse Metropole, Benoit Brandon was the personnel who provided all the available information about the project. Beniot also practiced and propagated biomimicry approaches in design and planning processes. Several analysed graphical data and recommendations were presented to Toulouse Metropole. The presentation and discussions were held in person and during the later phases the online meeting and email correspondence were the only means of discourse. Based on the feedback received; helped construct the design and planning guidelines using a biomimicry approach.

2. LITERATURE REVIEW

The literature search included journal articles in electronic databases where most studied materials included previously done academic publications and other relevant reports. Refworks was used to electronically arrange the articles and research papers. There were limited resources available about biomimicry as it is a relatively new field in urban design and planning, like ecosystem services. “All the articles reviewed were written in the last thirteen years, with the majority (82%) written in the last four years, providing some evidence that the integration of ecological systems thinking with urban design and planning is a relatively new and expanding field of research” (Wang et al.2016). Comparatively more resources available about ecological systems are available in contrast to biomimicry. Several relevant literature were found in the other foreign languages like French and Japanese.

2.1 The Basic Definitions:

In 1997 Janine Benyus published the book “Biomimicry: Innovation inspired by Nature” which is still devoted as the origin of most of the literature on biomimicry. The idea of replicating nature is not new and imitating living organisms inspired several groundbreaking innovations in vehicles and machineries. The definitions of several terms related for Biomimicry are provided to demonstrate the differences and similarities of their conceptual basis.

Bionic

Bionic the scientific study of nature’s models and inspiration from these plans and processes to solve human problems. “It is emphasized that the process of building is made by humans inspired by nature and not imitation of nature.”. “Architects of higher quality seek primary source means nature and discover qualities of nature by careful observation of nature.” (Jaleh, 2007).

Biomimicry

Biomimicry consists of two words “Bio” which comes from the Greek word “Bios” and “Mimicry” which means imitation. Hence, biomimicry simply means imitation of life. Biomimicry is a new human centric design solution in any field of work that is inspired from nature. (Yousef et al.,2016)

Ecology

Ecology is a combination of two words “Echo” which is derived from the word “Oikos” that means canvas, Biological context or a region and the word “logos” which means Identifying science or knowledge. In 1896, German biologist Ernest Hagel first coined the term “Ecology” as a new field of study in biology, where he tried to comprehend the determining interaction between the organisms and its environment. (Ardakani, 2009).

Echomimicry

As explained earlier “eco” comes from the Greek word “oikos” which also means extended family. Echomimicry is the approach where vernacular architecture is imitated in other fields of design. (Yousef et al.,2016)

2.2 Design Lessons from nature

Baumeister S, 2014 mentions in her publication the various ways that design lessons can be derived from nature. Nature is adaptive to change in conditions, which incorporates diversity, maintains integrity through self-renewal and embodies resilience through variation, redundancy and decentralization. It also establishes responsiveness that encourages using locally available material and energy that cultivate reciprocal relationships. Being resource efficient by using low energy processes, multi-functional design and recycling materials are resource efficient methods driven from biological processes. Inspiration given by nature is "bottom up" building process that is self-organized to integrate development with growth. Moreover nature teaches to survive by replicating strategies that work, integrating the unexpected and reshuffling information.

2.3 Scope of Biomimicry at different scales

CEEBIOS is the European centre of excellence in Biomimicry Senlis, their aim is to facilitate and encourage the development of bio-inspired French territory habitats, Their primary activity is to assist actors involved in a sustainable development project in building scale or that of the eco-neighbourhood. The "Habitat, Bio-inspired summary report 2018" is a compilation of many up to date advancements where biomimicry contributed in building sustainable cities of the future and evoke rethinking of cities as a living ecosystem, The publication highlights the idea about how the association of inspiration from nature to design built environment is not a new such as vernacular architecture, Japanese, green architecture. All these concepts converge to biomimicry (CEEBIOS, 2018).

Biomimicry in design disciplines can be adapted in three different levels (Figure 1):

Figure 1 Three levels of imitation in biomimicry (CEEBIOS, 2018)

a. **The organization**: Association of physical demonstration to the shape and dimension of the natural organism, it can be mimicked entirely or only in part.

b. **The behaviour**, or functional dimension: It is possible to imitate an aspect of the partial or entire behaviour and the relationship with the context.

c. **The ecosystem**: This is a replication of the interaction between species and overall functioning ecosystems.

This report is a great resource to know about the pioneer researchers in the field of bio-mimicry working in various different fields of biomimicry. Antonio Gaudi (1852 - 1926) is one of the first architects to replicate biological organic forms into building design. Later Richard Buckminster Fuller and Frei Otto also presented us with marvellous structural innovation derived from nature. Satoshi Sakai, professor at Kyoto University designed a shading roof structure that contributes to reducing urban heat island effects. His inspiration came from establishing similarities between concentrated cities and dense forests. (CEEBIOS, 2018). Architectural researchers like Estelle Cruz and Dr Natasha Chayamor-Heil are working in CEEBIO and CNRS respectively. They are leading several research teams for the transposition of biological principles to architectural design and urban planning. Estelle Cruz participated in research of biomimicry and architecture in four renowned universities around the world for a span of one year. Since this field of subject is still emerging, such an un-orthodox research method is important to establish the role for biomimicry in the future of planning our cities.

2.4 Previously done state of the art research project to mitigate Urban Heat Island with bio-inspired solutions

Yilong Han from Virginia Polytechnic Institute and State University mentioned how the previous studies state urban heat island occurrences due to dense construction surfaces that soak more solar radiation than the permeable surfaces. But In his study, Han indicates that urban areas having a more congested spatial relationship among the build structures as the core issue for the rising urban environmental problems. He also claims that urban geometry also plays a particular role in establishing building and urban behaviors and urbanization is challenging the attempts to achieve a more sustainable built environment. Even many of the cities in Nordic countries will experience the same summer conditions as cities in tropical regions by 2050 (AFP, Washington, 2019).

Recent studies show that interrelationships between buildings within a neighbourhood periphery of buildings, which is named Inter-Building Effect (IBE), contributes in causing inaccuracies of solar radiation absorption budget (Han, 2015). This inspired the researcher to make an in-depth research on the inter-building relationships from the perspective of heat re-radiation in order to mitigate urban heat island.

Accordingly, he conducts a biological research to identify this specific trait in botanical systems; in particular flowers. Han finds an uncanny similarity between building envelopes with flower petals, the inter-building area enclosed by building with intrafloral area encircled by petals and building occupants with the pollinators. It is known that pollinators are mostly attracted to the flowers due to the attractive bright colours and the food (nectar). Studies show that pollinators like insects are also attracted due to the elevated temperature in the intrafloral area; in some cases more than nectar itself. Similar to UHI effects in building clusters, the introfloral area encircled by petals also inhabits a heat island effect. But in the case of flowers and pollinators who gain advantage from the high air temperature. But recent studies found that flowers and their pollinators could not afford to cope with excessive warming due to the physiological reasons. Researchers found species to evolve using several cooling mechanisms like evaporation and self-shading, but what intrigued the writer was the self-reflective physiological property found in a central European flower species called Galanthus nivalis. He studied the retro-reflective properties of the flower petals, which contributed to the cooling effect, later implied a bio-inspired retro-reflective pattern to real scale building envelopes (Figure 2).

To measure the performance, he modelled the implemented building envelope in “Energy Plus” a building energy simulation program. Han concluded that retrofitting the building facade according to the retro-reflective pattern on the surface of the flower petals could achieve lower surface temperature of the building over the course of the simulation period. Although more research needs to be there that looks into inter-building relationships from perspective to mitigate urban heat island.

This research is a key resource to claim that there is adaptation in natural species to cope with the extremities in climates. And these subtle modifications can be replicated in the man-made physical manifestations. Although most of the emphasis has been given on the detailed aspects in building façade; biological research could be used to implement a holistic solution in neighbourhood scale. This is the gap that has been noticed where relevant biological investigation can be used for neighbourhood scale urban projects.

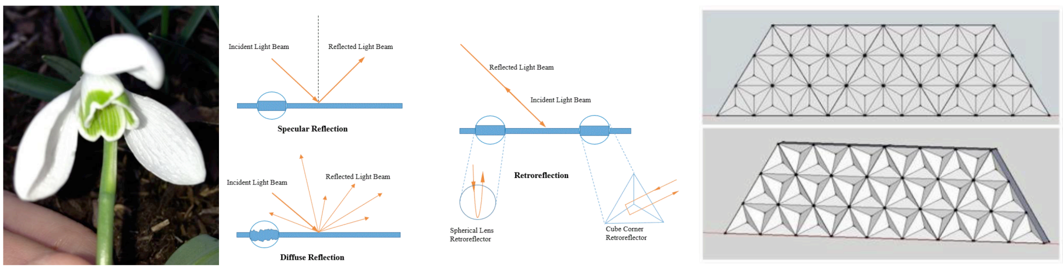

Figure 2 Illustrations from a research paper of Yilong Han showing the inspiration from the surface texture of a flower petal to design a climate sensitive building fenestration. (Han, 2015)

2.5 An demonstration of biomimicry approach to mitigate city scaled climatic problems

In summer Kyoto city is relatively warmer than the suburbs as the concrete surfaces are warmer than the forests in the countryside. Professor Sakai from University of Kyoto spots specific places in the satellite map of the urban heat island of Kyoto, which are remarkably hotter than the rest. Most of these hotspots were covered with vast flat roofs installed with hundreds of large solar panels. But surprisingly one of these hotter places was a flat golf course covered in green grass. He explains the heat is trapped in the densely grown grass on the golf course, which needs prevailing wind for the heat to be ventilated (Sakai, 2012).

A three-dimensional structure designed with inspiration from the tree canopy was constructed, that does not get hot under the scorching sun and is effortlessly airy. He noticed how the growth pattern of the tree and its leaves follows the fractal geometry. Sakai found a close abstraction of the tree canopy the structure of Sierpinski tetrahedron, which is formulated through fractal geometry. At first glance they do not look similar but they function alike. Initially an experiment was done, by substituting a flat tin roof with a solid Sierpinski tetrahedron. And it was observed that the experimented shade structure does not get heated up like the flat roof, therefore the infrared rays do not transfer underneath and it also lets the wind pass through. The large overhanging fractal shade was like an artificial tree canopy, which created a shadow like a tree over the city.

According to professor Sakai this fractal shade can be used to cover the whole city and the city will be like a forest and the city dwellers will feel much more comfortable to live in. In 2009 “Sierpinski forest”, a large fractal roof was built at the entrance of Miraikan - National Museum of Emerging Science & Innovation located in Tokyo city (Figure 3).

Figure 3 Photograph of Installation exhibited at Kyoto showing the Sierpinski tetrahedron as a shading device (Sakai, 2012).

2.6 Case Study: Biomimicry and Echomimicry in Iranian architecture and its similarity with the Iranian desert architecture.

Introductions

There are similarities between biomimicry and echomimicry, such as modern science in architecture and Iranian desert architecture can be found. Invention power of mankind is not enough for the survival of generations on planet to ensure survival, inspirations from other living species and maintaining harmony is equally crucial. Ancient architecture often replicated nature, which can be seen in the iconic monuments and its structural features like column head and low reliefs of Greek edifices. The creation of vernacular architecture happened 5 million years ago when human began to resist adverse conditions of nature. Unique climatic solutions of each territory was found "By using the elements of the land and construction tools appropriate for the needs in the interaction with nature and climate." (Yousef et al.,2016)

Climatic conditions in Iran and its climatic design solutions.

Like most parts of the Middle East Asia, Iran mainly has a dry climate. The country consists of central desert and surrounded by major mountains that block entrances of rainy clouds into the watersheds. Lack of precipitation, cloud and humidity leads to high temperature in the area. Like most dry areas there is a drastic difference in temperature between daytime and the night hours. Due to scarcity of water Iranians invented the aqueduct, by which they channelled water from the underground waterbed to the earth surface. (Yousef et al. 2016)

Water was channelled from a distance of 20 to 40 kilometres apart. Reducing exposure of solar radiation, the Iranian urban settlements are congested and contiguous. In most cases the residential units are very compact and the residential units are connected to other units from all the surroundings. An ecological technique is adapted to minimize the intense reflection of the sun to reach the settlement. Green belt of dense plantations, mostly farmland encloses the congested urban space that also protects the central parts against desert winds and dust, enhancing the natural ventilation. The road network of urban desert is often meandering and disoriented. This helps prevent the uncomfortable wind and also keeps the pedestrian under shade throughout his or her journey. Many features of individual households simultaneously serve the outdoors spaces that collectively create a sense of social bonding.

Many passive equipments and systems are used in desert cities like " Air holes", "Windy and watery water mills", " Water storages" which are currently replaced by electric energy consuming mechanisms. One such installation element is an air hole that acts as a breathing system of the city. In the hot days of summer, air holes maintain a suitable temperature for the city dwellers creating a flow of air inside the building through connections between open and semi open areas with the enclosed areas. Hollow vertical shafts like wind towers are required for the proper function of "air holes". Outside cool air is drawn inside through a high fan places on top of the higher wind tower and the wind passes through the spaces inside, where the trapped hot air beneath the ceiling is pushed outside through the other tower. Thick mud brick walls and high ceiling adds to creating a comfortable indoor temperature. It should be mentioned that the materials used to construct the structures are naturally found materials and locally sourced, which are environment friendly like mud straws.

The urban desert buildings of Iran can be perceived as a living organism. The flow of wind, water and energy are not only used for improving the living conditions within the site but it also improves the surrounding environment. Natural cooling systems make it possible to sustain urban environments despite the harsh forces of nature and these mechanisms are self-sufficient in case of energy consumption. This also proves that Echomimicry and biomimicry can lead to sustainable solutions in the future (Yousef et al.,2016). According to the case study it can be derived that orientation of the road networks is one of the major methods to reduce heat in urban settlements is to determine that wind flows freely smoothly without obstacles. This brings thermal comfort in outdoor spaces and has a huge impact in ensuring thermal comfort for indoor spaces.

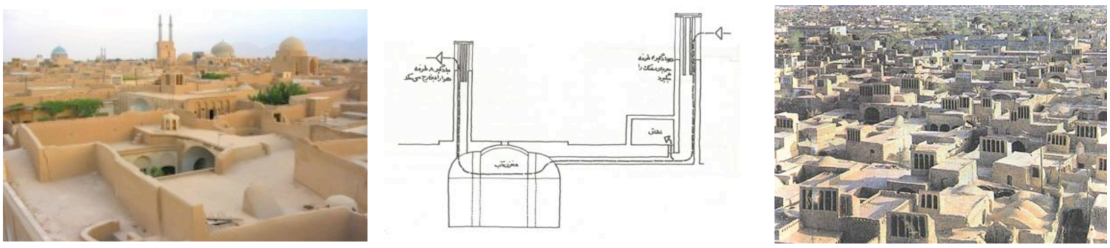

Figure 4 Photographs and diagrams for the Wind tower in the desert city of Meydob, Iran. (Yousef et al. 2016)

Although literature on biomimicry approaches in mitigating urban climatic issues are scarce. Many articles promote the potential of using biomimicry in large spatial scale, such as Baumeister (2014), CEEBIOS (2018), Han (2014), Sakai (2012) and Brown et.al (2009). Also concepts related to biomimicry like Echomimicry provide a perspective about how biomimicry can be broadly implemented in a neighbourhood scale like Paleficat.

3. METHODOLOGY

3.1 Methodological Approach

Urban climate maps are graphical representations of climate data, which are increasingly essential tools for sensitive urban design and planning. The initial phase of the methodological approach was to understand the state of the art urban climate maps and how different climate phenomena are graphically presented from a meteorological perspective. Later a neighbourhood scaled site was chosen for the exercise. The urban climate data relevant for the site and its scale were extracted and analysed to prepare a microclimate study. The case studies aided in identification of relevant design solutions were derived from a biomimicry approach. As shown in figure 5, a later phase was intended to make a performance assessment to strengthen the proposed solution.

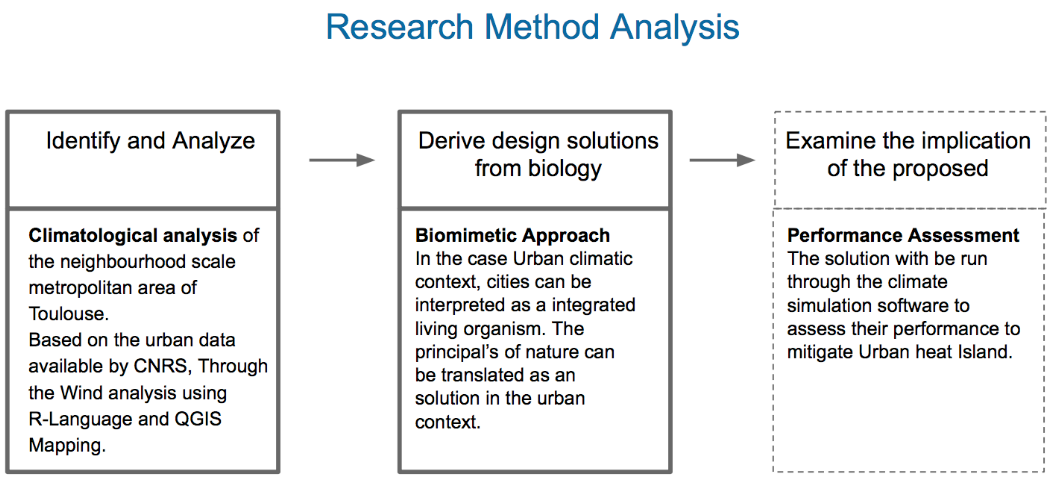

Figure 5 Research method analysis diagram

3.3 Urban climate data using R-Language and QGIS

Climatological analysis of the neighbourhood scale metropolitan area of Toulouse was selected on a set of urban maps. Wide availability of urban data was provided by the research center, for instance wind data (from meso-scale numerical modelling or observations), urban data at the building scale, land-use (in particular blue-green infrastructure) and topographic data. There was computer aid of climate simulation programs that allowed the study of wind and solar radiation at the building to neighbourhood scale, which were linked with urban/building morphology over the on-going Metropolitan projects piloted by the local government of Toulouse. Data available are observations from meteorological networks from 40 stations, numerical simulations with Meso-NH/TEB at 250x250m of horizontal resolution and other urban data like projecting master plan.

3.4 Exemplary Climate analysis and representation

In order to suggest a wholesome climate sensitive solution to the city-scales area; it is essential to analyze and take into consideration all the climatic forces acting upon the region. It is equally important to represent the finding that will be comprehensible to all relevant stakeholders that participate in the planning, designing and feasibility phase of the project. Climatic attributes like air temperature easy to portray but graphical representation of wind analysis is rather difficult. Many important phenomena of wind analysis visualization are an unexplored territory that urban designers do not take into account.

3.5 Cartographic representation of climate data for urban planning

Germans are the historical pioneers in formulating climate analysis representations. In 2006 Hong Kong produced the first Urban Climate Maps, but most emphasis was put on the thermal stress as the region belonged to a geographic location that belongs to a long and intense summer. Also Hong Kong has one of the most unique built densities. Therefore, it focused mostly on building volume density and ground coverage for having high density and high-rise urban morphology. In 2009 urban environmental climate maps (UECM) were generated in Japan that included climate analysis maps (CAM) and recommendation maps (RM). Subsequently, Sweden, Switzerland, Norway, Greece, Poland, Brazil and Thailand produce urban climate maps studies. In 2015 the Associate of German Engineers (VDI) produced an exemplary new version of this guideline for the urban climate map and digital environmental atlas where they emphasized on analyzing building morphology and ground coverage. (VEREIN DEUTSCHER INGENIEURE., 2015.)

The significance guideline produced by the German institute is that it contains consideration of climate and air quality at different planning levels. And its recommendations deal with air pollution mapping in city and urban heat Island mitigation techniques. Most importantly climate maps and planning recommendation maps are produced in urban and regional levels. The guideline is affiliated with future oriented German policies like “Adaptation action plan” and “German Adaption Strategy”.(VEREIN DEUTSCHER INGENIEURE., 2015.)

Climate maps (CM) consists of the climatic and urban characteristics called the climatopes:

Water body
Open land Climate
Forest Climate
Urban Green space for planning
Garden city climate
Suburban climate
City Climate
Inner city climate
Commercial and Industrial
High Density area
Railways

Figure 6 shows multiple climatopes for the city of Berlin, which is produced by the Associate of German Engineers. All the major climatic aspects that should be considered for a climate sensitive urban planning and designed are graphically represented. Consecutively, a recommendation map (RM) is produced that contains the climate phenomenon, which are suggestive representations to communicate between climatologists and urban professionals. The climate phenomenon of Berlin city are listed below:

- Cold Air Production areas
- Cold air drainage area
- Obstacle to cold air drainage
- Cold air stagnation
- Warm slope zone
- Mountain/valley breeze systems
- Ventilation lane
- Wind field changes
- Heat Island
- Wind Direction and wind speed
- Air Pollution

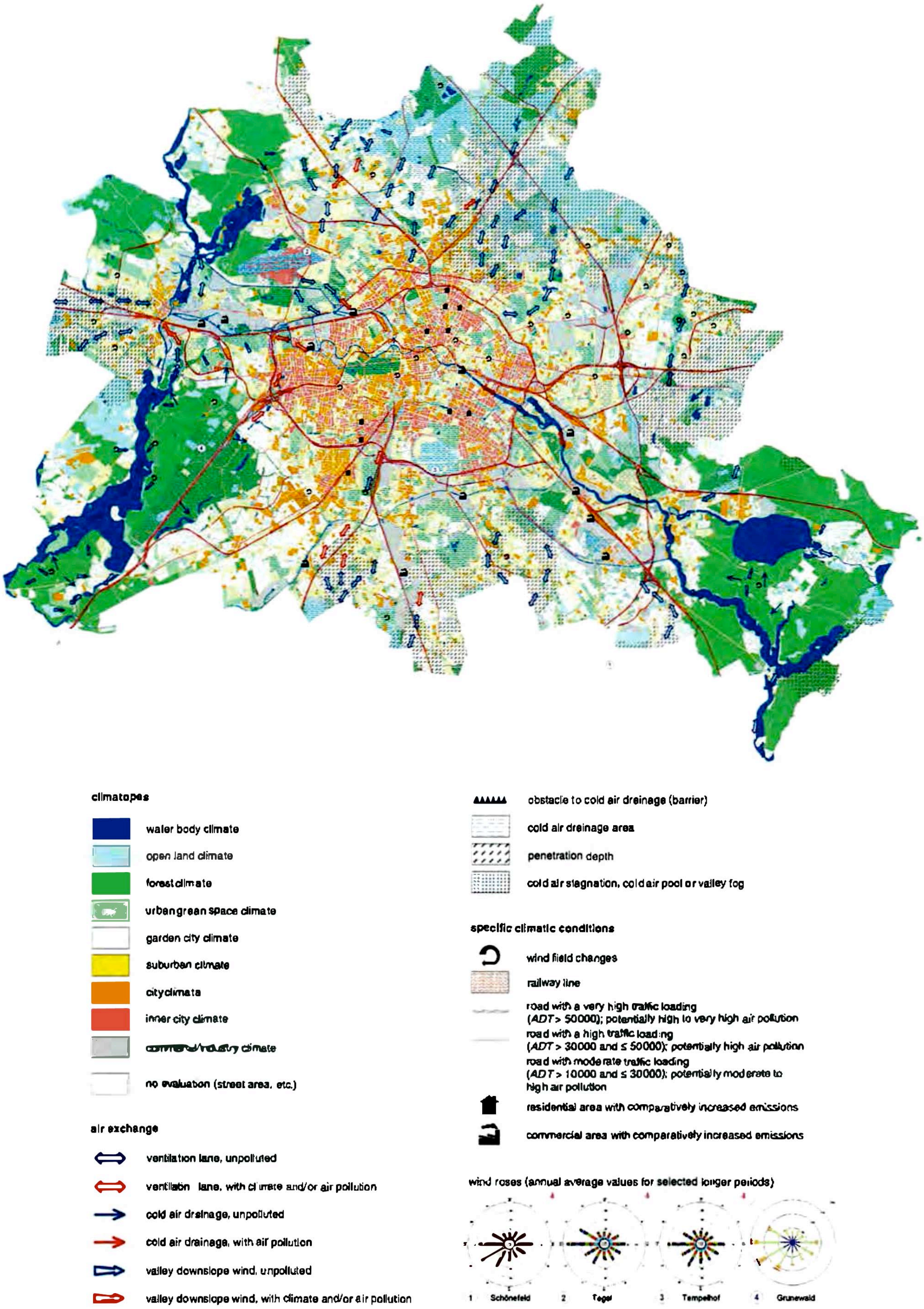

Figure 6 Climate analysis map using example of the City of Berlin (General view, scale: 265000; source: Senate Department for Urban Development and the Environment, Environmental Atlas

4. ANALYSIS

4.1 Microclimate Study of Paleficat

Paleficat sector which is located in the north-east of Toulouse, France is the site selected for a micro climate study (Figure 7). This area of 96 hectares is the remaining piece of land within Toulouse metropole that will be transformed in the following years for large neighbourhood development to accommodate the urban migration .Figure 8 shows the demarcation of the site allocated for the new development and a secondary boundary showing the area in between which is denoted as “Urban integration zone”.Characterization and mapping of the urban environment is an essential step in urban planning exercises. The climatic information presented covers from regional to local and neighborhood scales. It is based on:

- The context in terms of regional climatology and major climatic atlas for Toulouse region.

- The significant past climatic events (heat and cold waves, episodes of intense rain) and the long-term climate change observed and projected in future climate scenarios reported in the “Profil Climatique de Toulouse Métropole, 2015”.

- The weather situation analysis favorable to a developed nocturnal urban heat island reported in the “Fiche synthèse pour la classification par Types de Temps Sensibles pour Toulouse”.

- Three climatic indicators produced using numerical simulations of climate for those meteorological situations presented on the “Guide de recommandations sur la prise en compte du climat dans l’Aménagement du territoire à destination des services de Toulouse Métropole, 2019” and the atlas “Intensité de l’ICU sur le territoire de Toulouse Métropole, 2015”.

    - **The thermal stress** during the day time because it strongly impacts the comfort of citizens and must make the use of air conditioning in many industries.
    - **Air temperature at night** because it influences the ability of buildings to cool during the hours of night rest and thus the health of residents. This information is characterized by the intensity of the urban heat island.
    - **The air flow conditions** because they can identify favorable areas for natural ventilation and those with an air gap. They are characterized from the prevailing wind corridors, generating areas slope breezes, areas for producing fresh air (or vegetation water for example) or hot air (highly mineralized areas or which employ air conditioning by example) and areas which hinder the wind.

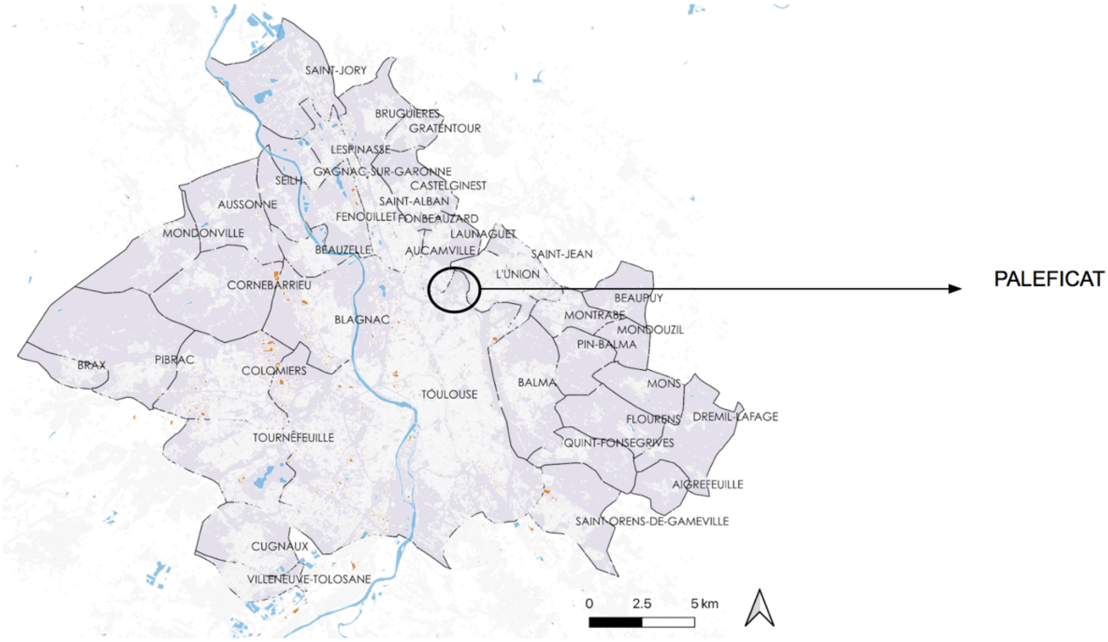

Figure 7 Map showing location of the site on Toulouse Metropole. (Council of the Metropolis, 2018)

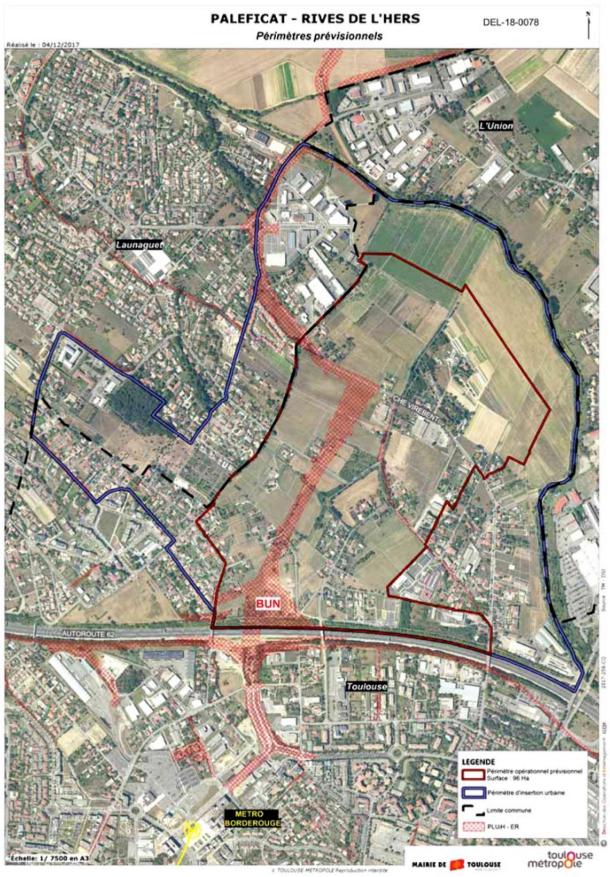

Figure 8 Map illustration showing boundary of the site for new urban development and its Urban integration zone. (Council of the Metropolis, 2018)

4.2 Climatic Context

In Southern French territory, there is a large climate variability that comes in depending on the location and topography. The categories usually used are oceanic climates, Mediterranean, semi-continental mountainous and mixed regimes have degraded forms of the preceding climate categories (As shown in figure 9). Toulouse is a continental city situated in the south-west and for this reason falls under the type of climate called “climat continental dégradé” . This type of climate concerns a composite geographically area of several regions (Aquitaine, Languedoc) and centered on the mean area of the Garonne. For convenience, it is locally referred to as the "South Western Basin". It is characterized by an average of high temperature (above 13 ° C) and a high number (> 23) of hot days while the days that exhibit a lower freezing to -5 ° C are rare. The annual temperature range is high (15 to 16 ° C) and the variability of the winter and summer temperatures is low (Hidalgo, 2018).

In winter the rainfall is less than 800mm and a bit more during summer. The frequency of rain is more common in winter, about 9 to 11 days and in summer the rainfall is less than 6 days. This distribution indicates that the intensity of rainfall is low in winter which is due to the oceanic rainfall and more in summer which is mostly caused due the stormy disturbances coming from Spain and the Bay of Biscay.The interannual variability of rainfall is average.

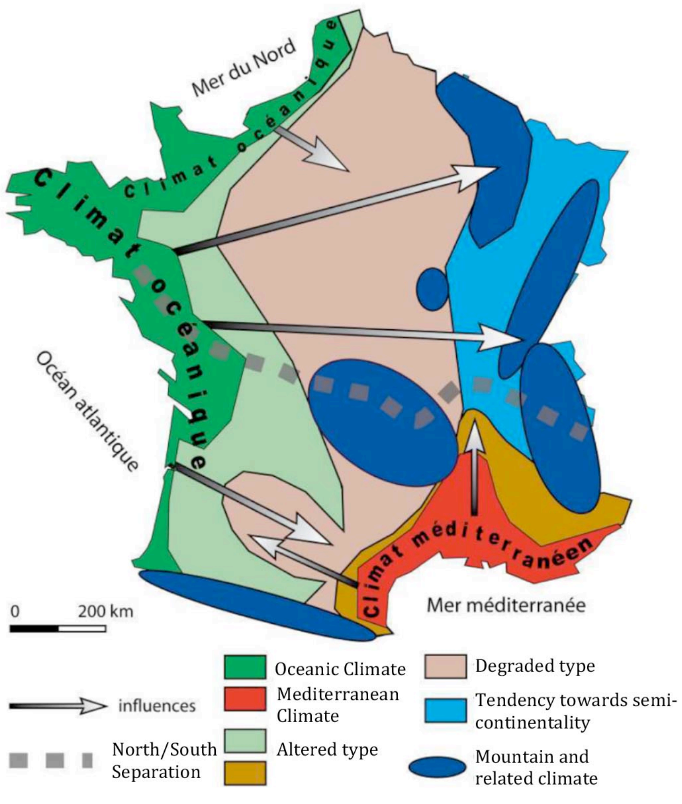

Figure 9 Illustration Showing different climatic zones in France based on the topographical characteristics. Source: Météo France, (2014)

From the perspective of the evolution of long-term climate, France expects a high probability of an increase in minimum and maximum temperatures. Higher frequency, duration and intensity of heat wave episodes will occur throughout France and especially in the Mediterranean (Figure 10). Locally, this has been confirmed by the Climate Profile Toulouse Métropole which was established in 2015. The annual average temperature has already risen by 1.2 ° C with a marked rise in temperatures in the mid-1990s (2003, 2011 and 2014 were particularly hot). Looking at the evolution of seasonal temperatures, this warming is very clear for spring, summer and fall. The precipitation standpoint, there is little or no change, but rising temperatures promote evaporation and extended drought effects are increasing. These facts point to an interest to focus specifically on the issue of summer comfort for this territory (Hidalgo 2018).

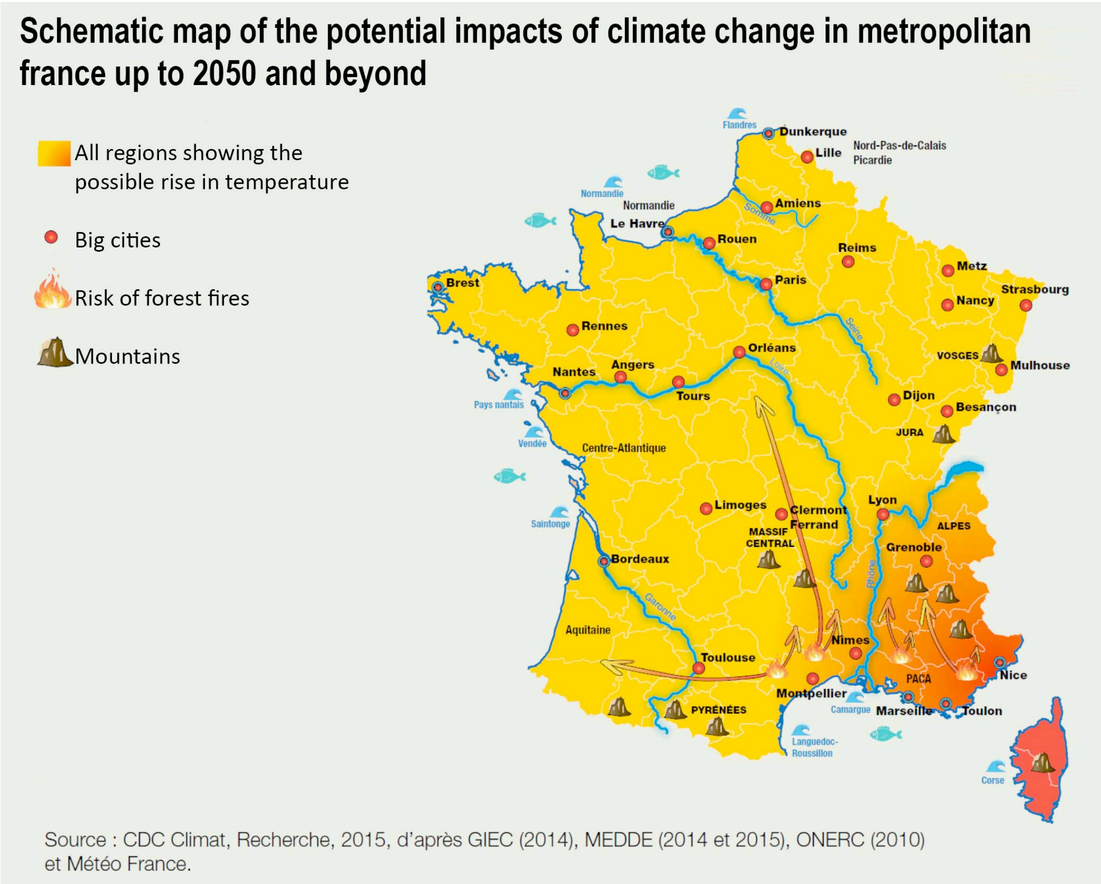

Figure 10 Map illustration of the potential affected areas in France due to climate change

In order to deal with the problem of summer thermal stress, the analysis focused on three local weather types. The local weather types are used to describe the climatic context of this urbanized area that explains the plurality of weather. This classification method has been coded in an R script and is used for climatic analysis, which is believed to be a good practice for performing climatic contextualization (Hidalgo, 2018). The three local weather types are selected for their situations conducive to high daily temperatures and to the development of a consequent night heat island or both. The three weather types are explained below:

Local weather type 7

Typical sunny summer day with southeast wind (22% of summer days)
This is a type of summer weather situation whose temperature can reach 40 ° C. It is characterized by a large temperature difference between day and night and a persistent but weak south-easterly wind (2 - 3.5 - 2.5 m/s in the morning, in the afternoon and in the evening respectively).

Local weather type 8

Typical sunny summer day with northwest wind (37% of the days)
Although present in other seasons, it is the most frequent type of situation in summer.
The temperature remains relatively high in summer, the maximum temperature is 30 ° C, but it is softer than in the previous situation. The northwest wind can be relatively strong and humid, with peaks of 4 m / s in the afternoon.

Local weather type 9

Sunny day, very hot in summer, with northwest wind (22% of the days)
It is also a very common type of weather situation. In summer, the temperature can rise to 40 ° C. The wind blows from the west in the morning to northwest in the afternoon and then southwest in the evening. The wind speed also varies between 2 m/s in the morning, 4 m/s in the middle of the day, and 2 m/s again at the end of the day. This type of situation is very favorable to the formation of an important night heat island on the territory.

4.3 Information about the area:

Project: Development with establishment of necessary public facilities of new housing, economic activities, public spaces and public facilities for the neighbourhood.

Location: Paleficat Sector , Toulouse, France
The site is located at the northern-east boundary of Toulouse Metropolitan. And is it surrounded by municipal boundaries of L Union and Launaguet communes on the east and west side of the site consecutively. This site is restricted from the north and south by the Natural Plains of Hers and the ring road consecutively (Figure 11).

Area: 96 hectares

Provisional structures to be built: 6720 household units

Possible users: 19,200

Project Time Frame: Two years between 2019 to 2020 is allocated for the feasibility of the projecting the selected site

Figure 11 Photographs of the site and surrounding long side the newly constructed road.(Source: Author)

4.4 Geographical and urban aspects

4.4.1 Vegetation

From a microclimatic perspective, It is essential to identify the vegetation as they carry physical properties that influence reduction of solar energy absorption. In addition, certain types of vegetation, such as trees, hanging vegetation or shrubby vegetation, can provide shade and minimize heat gain from shaded surfaces (pavement, walls) and reduce the building's energy demand for indoor cooling. Plant evapotranspiration reduces local air temperature, which significantly improves thermal comfort.

From the Figure 12 & 13, it can be concluded that there is significant presence of vegetation in early summer season. About 60% of the site is covered with shrubs and tall trees. Quantitative study can be conducted to measure the exact ratio of vegetation in the site with respect to the built structures.

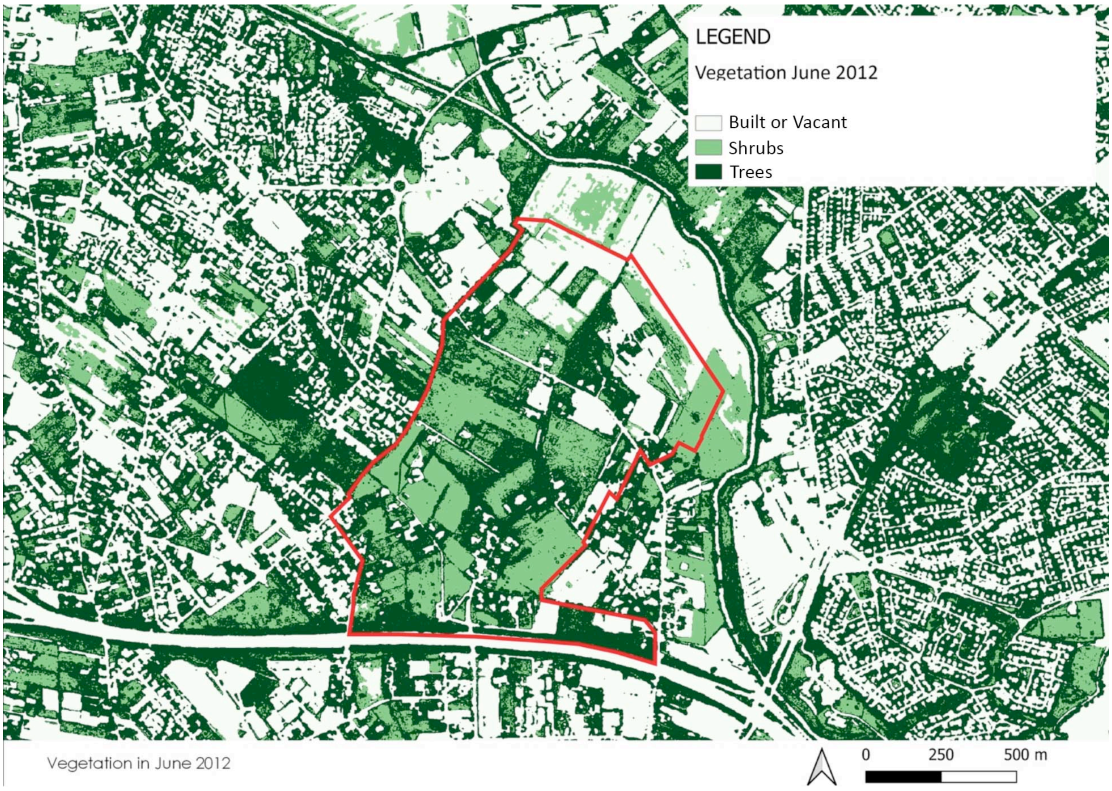

Figure 12 Map of vegetation in the month of June 2012 (Source: Author)

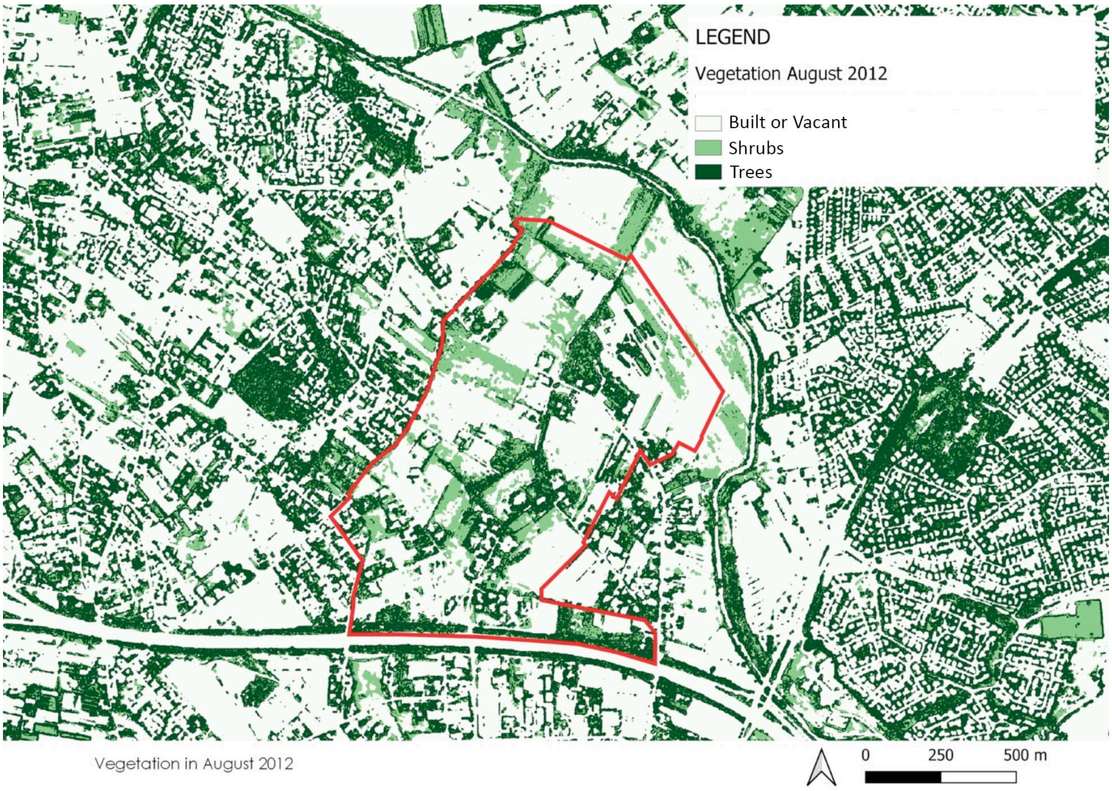

Figure 13 Map of Vegetation in the month of August 2012 (Source: Author)

The evapotranspiration locally reduces the temperature of the air, which greatly improves the thermal comfort. Vegetation management can help mitigate urban heat Island effects at different spatial scales:

- **The inclusion of vegetation across the organization** (e.g. incorporating landscaping or vegetation around buildings). It is preferable that the vegetation is planted in the ground and it is composed of species adapted to the local climate, which offers shade and a good ability to evapotranspiration while consuming little water. The roofs and green walls are less effective at mitigating adverse climatic conditions than the ground vegetation because even if they have many virtues (aesthetic, social, biodiversity), they have a minor effect on the islets urban heat in the climate context Toulouse.

- Parklands and open spaces throughout the district. This category is referring to medium-sized farms with a compact or linear form within the urban area and commonly located near residential areas or along riverbanks. These spaces provide localized thermal comfort and their effect often remains confined to its borders (a hundred meters), however it is possible to significantly increase their effect on neighboring areas artificialized combining the presence of vegetation with adequate ventilation.

- **Green corridors in the urban scale to improve ventilation.** Large urban parks, forests and reservoirs on the periphery or in the central areas of the city have a significant impact on the local microclimate. There are also called islets freshness. They provide not only a better thermal comfort inside of them, but can also bring freshness to nearby urban areas, contributing to the regulation of heat buildup and ventilation throughout the urban area. The group of species, forest cover, size and shape of the parks in relation to regional climate mainly determine their refreshing effect. However, the beneficial effects of these great urban green spaces on the air temperature is estimated at between 1.5°C. and 4°C.

4.4.2 Hydrological courses

Water bodies of all sizes can be used to improve pedestrian comfort and reduce to some extent the overheating of the built elements. Presence of water hydrological courses with in the site has multiple ecological benefits, which should be explored and properly utilized.The beneficial effect of the presence of water is related to several factors:

- During the day, the temperature at its surface does not rise as much as the rest of the urban area and can be inconsiderable as islands of coolness. On the other hand, at night, due to its greater thermal inertia in relation to the air, its temperature decreases slowly and water can be a source of heat compared to the surrounding air.

- Water evaporates and increases the humidity of the air. Depending on the regional context, this can have a positive impact on the thermal feeling especially in hot and dry climates such as Toulouse in summer.

- The cooling effect is mainly linked to the related vegetal and woody wefts. Depending on their composition and size this vegetation can provide shading and evapotranspiration, constitute ventilation corridors for fresh air to the surrounding environment.

Although figure 14 shows the multiple water courses flowing through and around the demarcated sites; most of these are not on the surface rather they can be termed as dry watercourses.

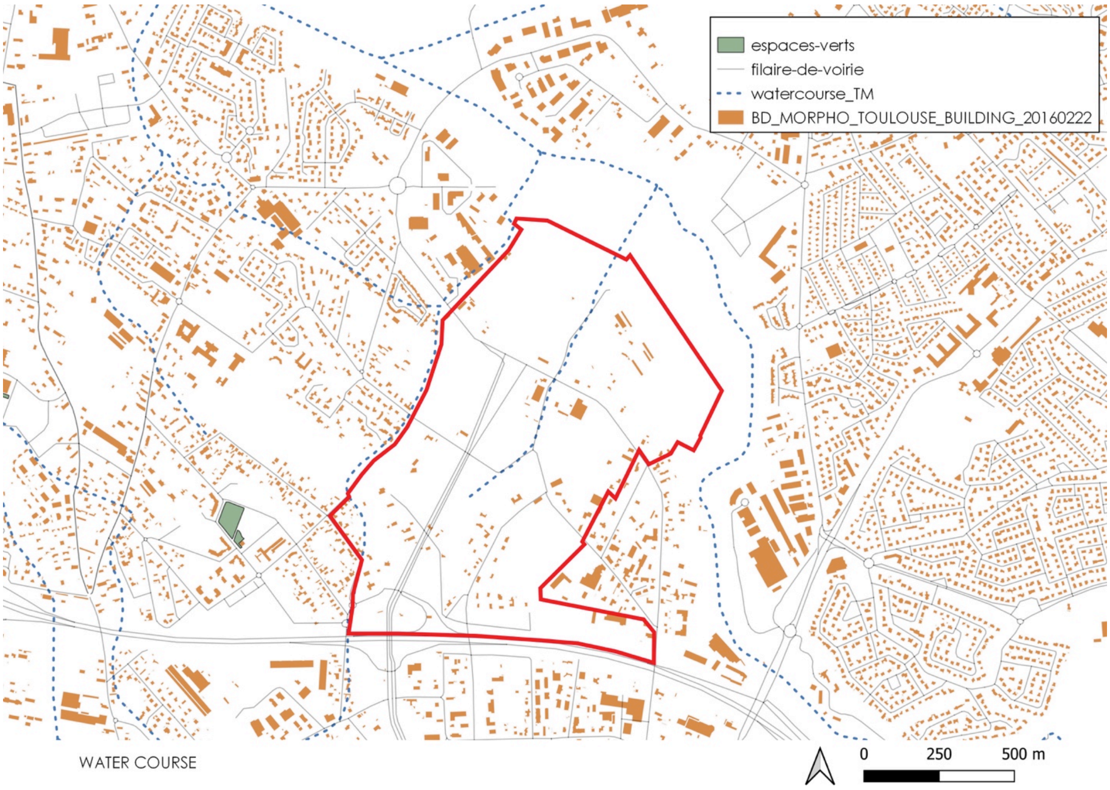

Figure 14 Map of hydrological courses and the built structures (Source: Author)

4.4.3 Building typology and heights

The urban form , building height, geometry and location of urban elements - are variables that affect the thermal performance of the urban area. They offer great potential for making the most of the natural potentialities of the territory, regional climate and air flows, developing appropriate air circuits to eliminate accumulated urban heat in order to attenuate the urban heat island and improve thermal comfort. Urban geometry affects the spatial distribution of shaded areas and the windy environment. These are the two most important variables for improving local thermal comfort.

Figure 15 Map showing the building heights (Source: Author)

Figure 15 shows that the site does not have much built structures. The site and surrounding mostly have buildings of 1 story and 2 stories respectively. Moreover, Figure 16 signifies that most of the built structures are used for residential purposes and about one-fourth of the surrounding area used for industrial purposes. Similar to the quantitative study proposed for vegetation, another possible study is to find the percentage of built structures in the site and surrounding. Such studies may help to analyze the correlations for climatic phenomenons like urban heat Island.

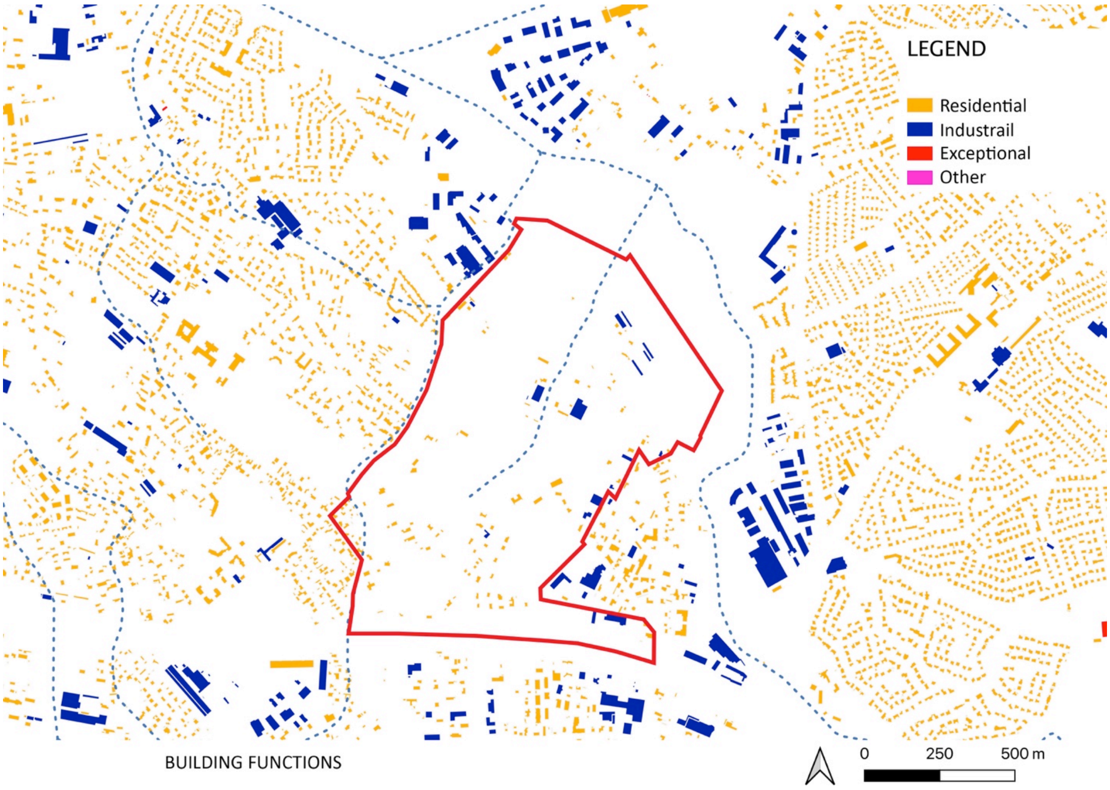

Figure 16 Map of functions of the building (Source: Author)

4.4.4 Surface and materials

Two types of surfaces predominate in terms of urban composition: buildings (insulation, structural work, roofing) and floors. These surfaces, which are interdependent, have an impact on outdoor thermal comfort (streets, places) and interior (dwellings).

The two important aspects are :
Concerning the external thermal comfort, according to the thermal properties of the materials, the energy received during the day is more or less stored or reflected. At night, the materials will cool down and release this energy which heats up the air.

Regarding indoor thermal comfort, the materials must make it possible to find a balance between heat loss in winter and thermal comfort in summer. Thus the use of air conditioning and heating is reduced, allowing to limit the discharge of hot air outside and the overall energy consumption of the building. It would be beneficial for the project if the percentage of the permeable surface area within the site limitation can be calculated.

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4.4.5 Topography

The site in Pelifate is positioned in a flat surface surrounded by higher altitude on the north-western side (Figure-17).

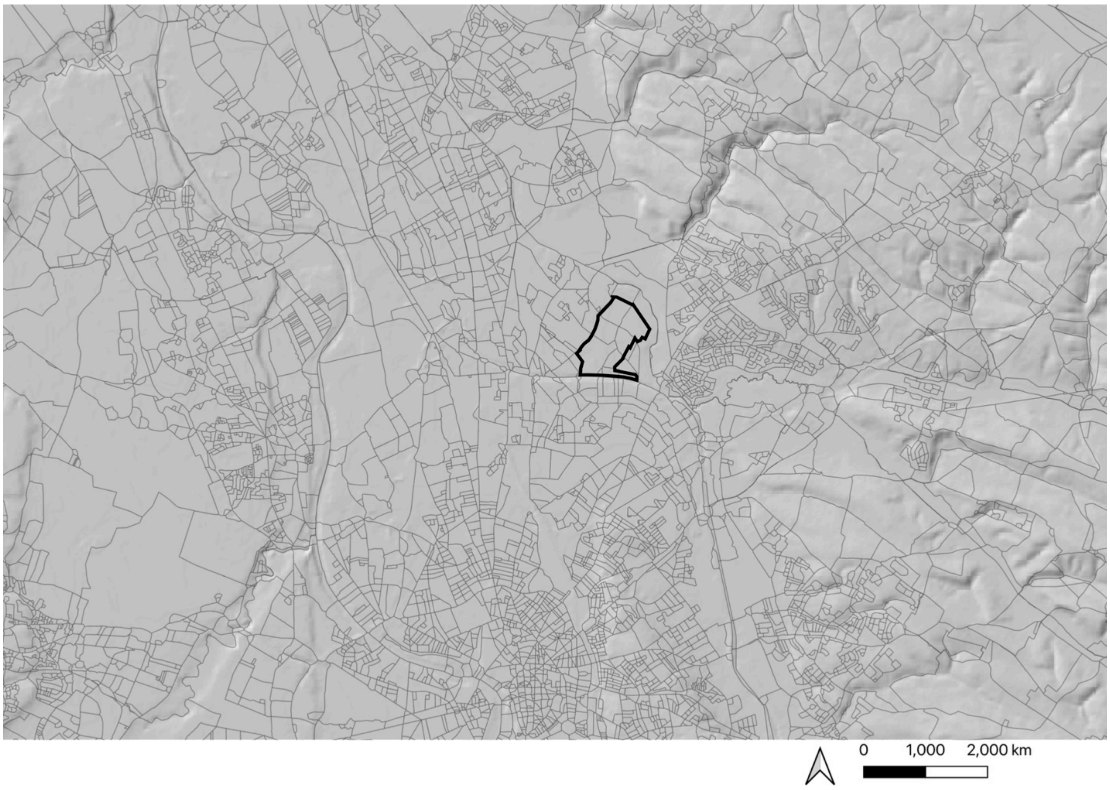


Figure 17 Map of ground height elevation (Source: Author)

4.4.6 Urban heat island intensity and Heat stress

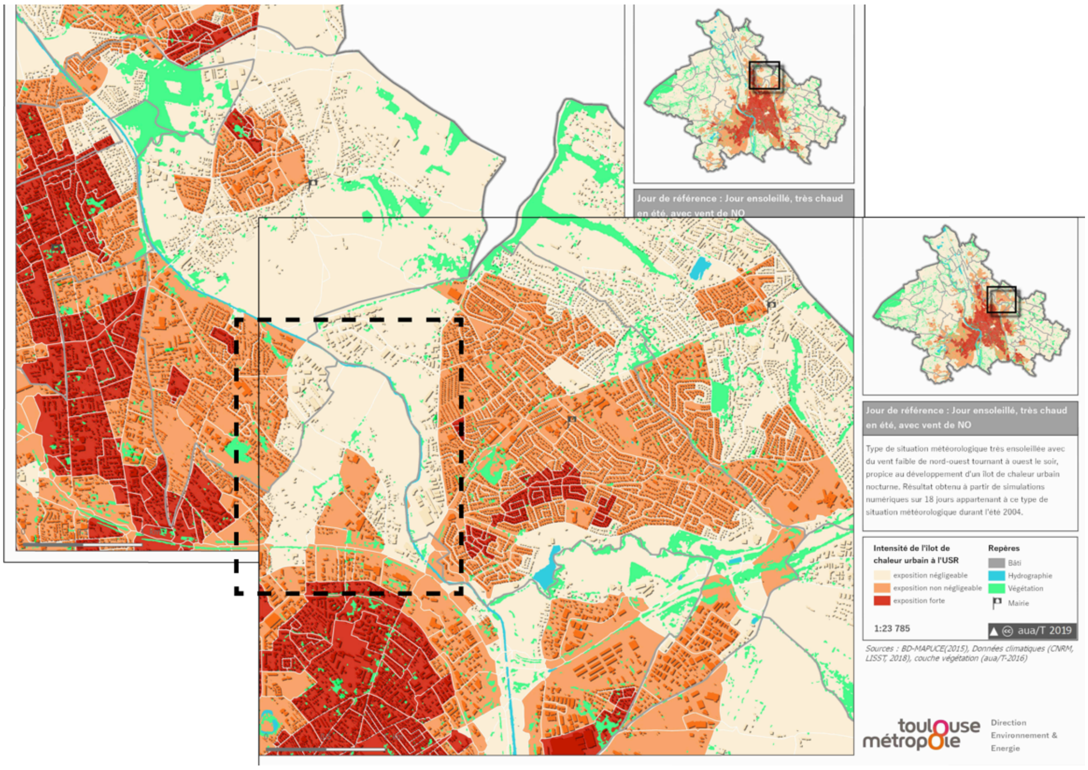


Figure 18 Map of Context at the "Commune scale" from the Atlas (Source: Author)

The site selected for the project falls n between two different communes of Toulouse Metropole – Laynaguet and L'Union. Figure 18 shows the urban heat intensity inside the site area is remarkably less than the surrounding islet of the city, as most of areas within the site experiences moderate heat stress. Which is significantely lower than the surrounding areas which are facing extreme heat stress. The demarcated site has less built structure and predominantly covered with dense vegetation, which locally decreases the urban heat Island effects. Figure 19, 20 and 21 shows the map of the heat stress during local weather type 7, 8 and 9 consequetively. The level of heat stress is signified in 4 primary classification: low, medium, high and extreme. In comparison to all the three maps thermal heat stress maps; the thermal heat stress illustrated Figure 19 during local weather type 7 shows the maximum thermal heat stress.

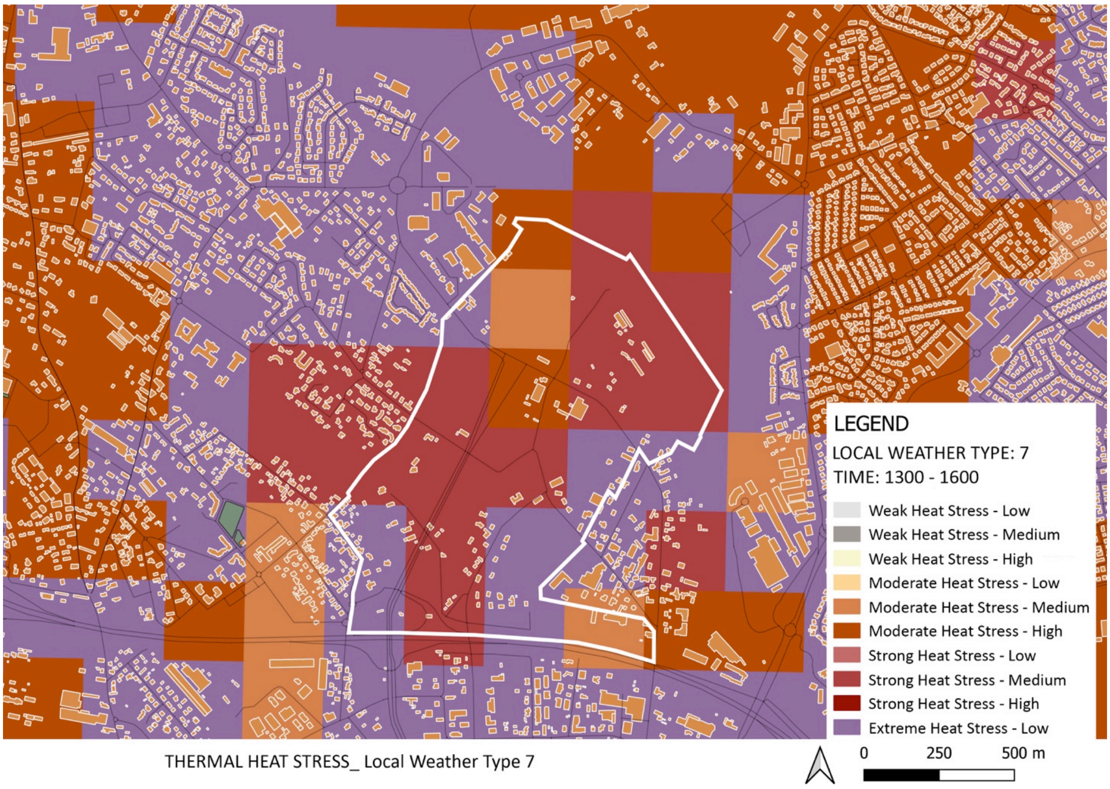


Figure 19 Map of different level of heat stress recorded in local weather type 7 (Source: Author)

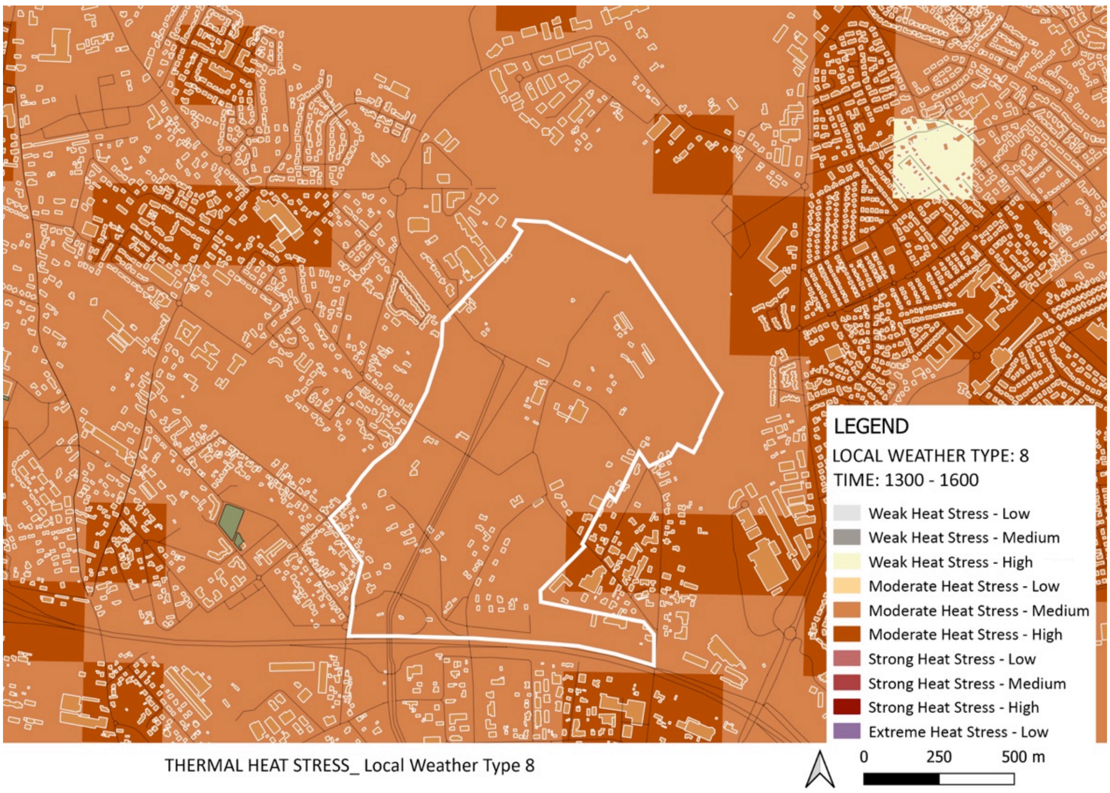


Figure 20 Map of level of heat stress recorded in local weather type 8 (Source: Author)

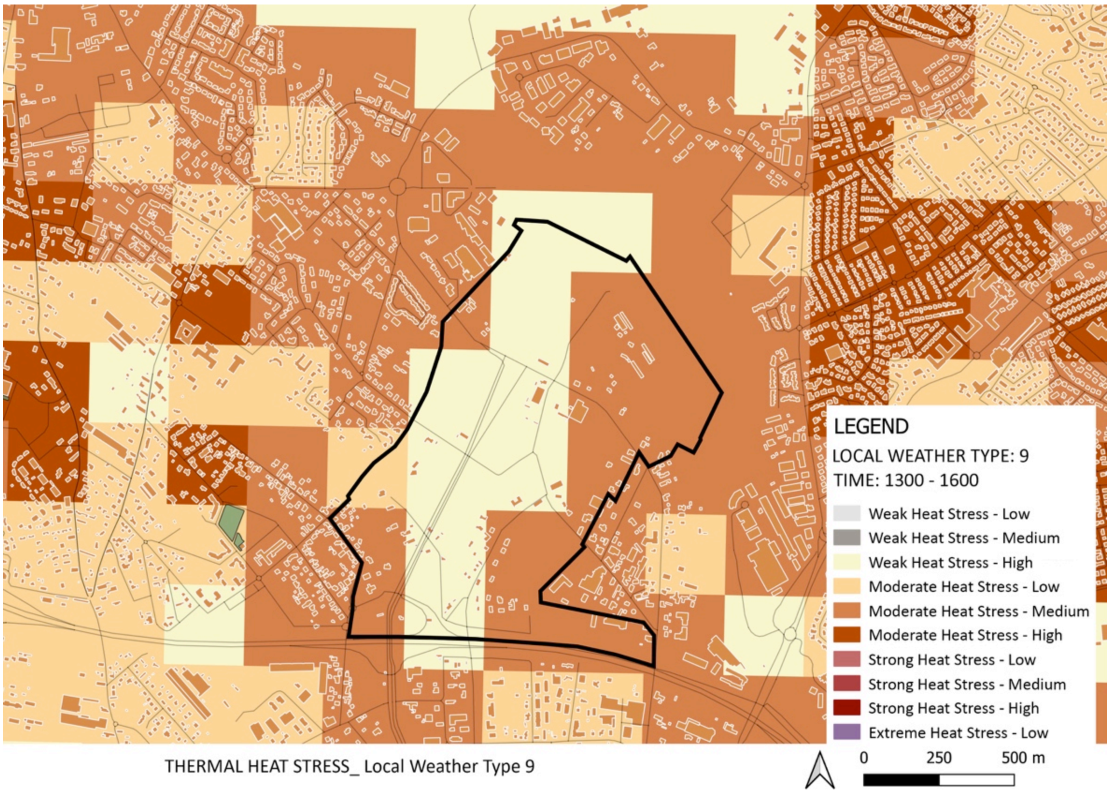


Figure 21 Map of level of heat stress recorded in local weather type 9 (Source: Author)

4.4.7 Wind analysis

There are two aspects of wind analysis that are essential characteristics for visual interpretation which may aid in the urban design. They are the magnitude of the wind speed and its direction. Two different time zones are selected to register the information; once in the daytime between “1 am to 4pm” and consecutively during night hours between “ 3am to 6am” The maps shown in figure 22 to 27 represents the wind analysis of local weather types 7,8,9 during night and day time. The data about the direction and speed of wind is combined to make simple graphical representation of the character of wind. Wind approaching the site from all 8 directions are separately classified in 3 different wind speed: weak, intermediate and high. Instead only showing the direction of wind with an arrow; the most frequent wind entering the site is spatially represented in the prepared maps (Figure 22 to 27). It can be derived from the wind analysis maps that the direction of the wind dynamically varies with respect to the different weather types. But the magnitude of wind mostly observed to be dependent on typography of the site and surrounding.

Figure 22 Map of wind characteristics in local weather type 7 during daytime. (Source: Author)

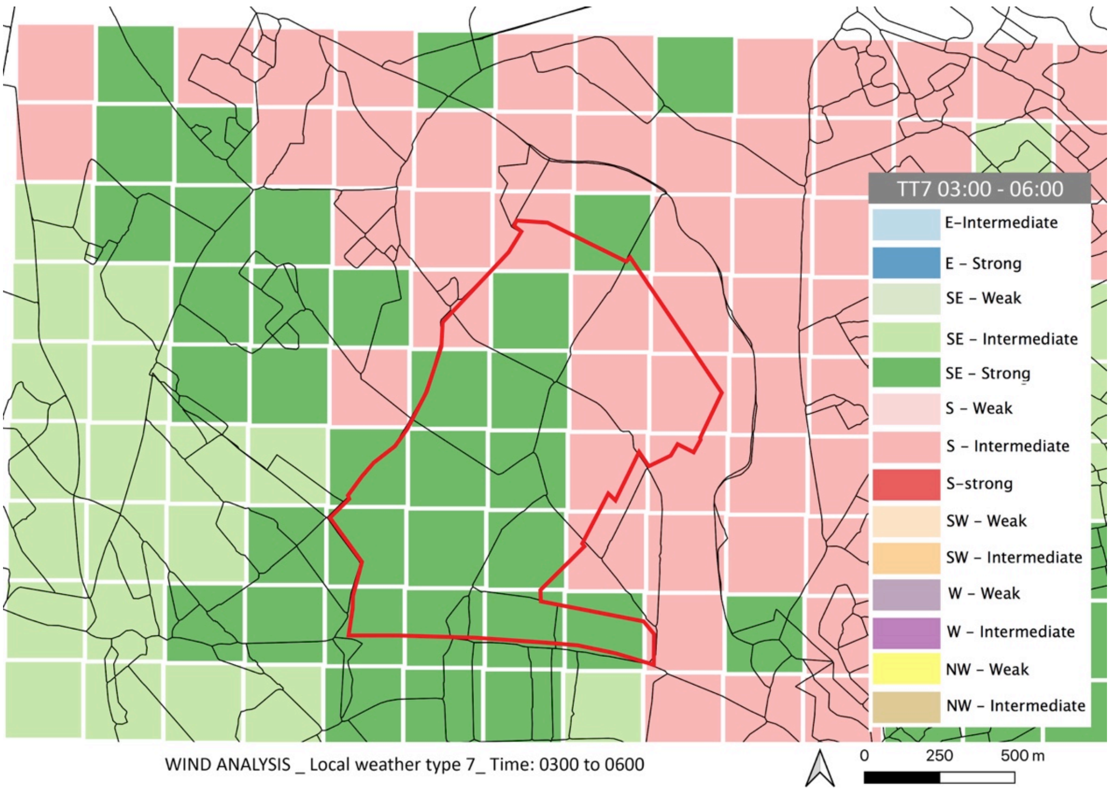


Figure 23 Map of wind characteristics in local weather type 7 during night-time (Source: Author)

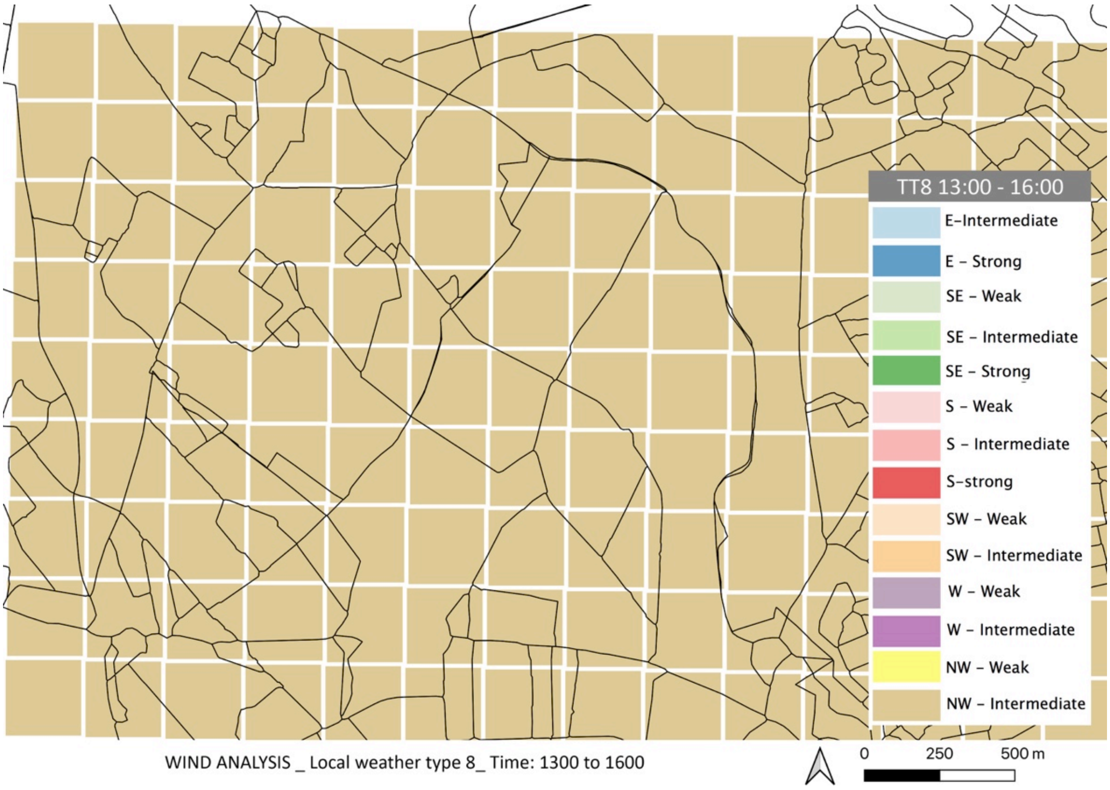


Figure 24 Map showing wind characteristics in local weather type 8 during daytime. (Source: Author)

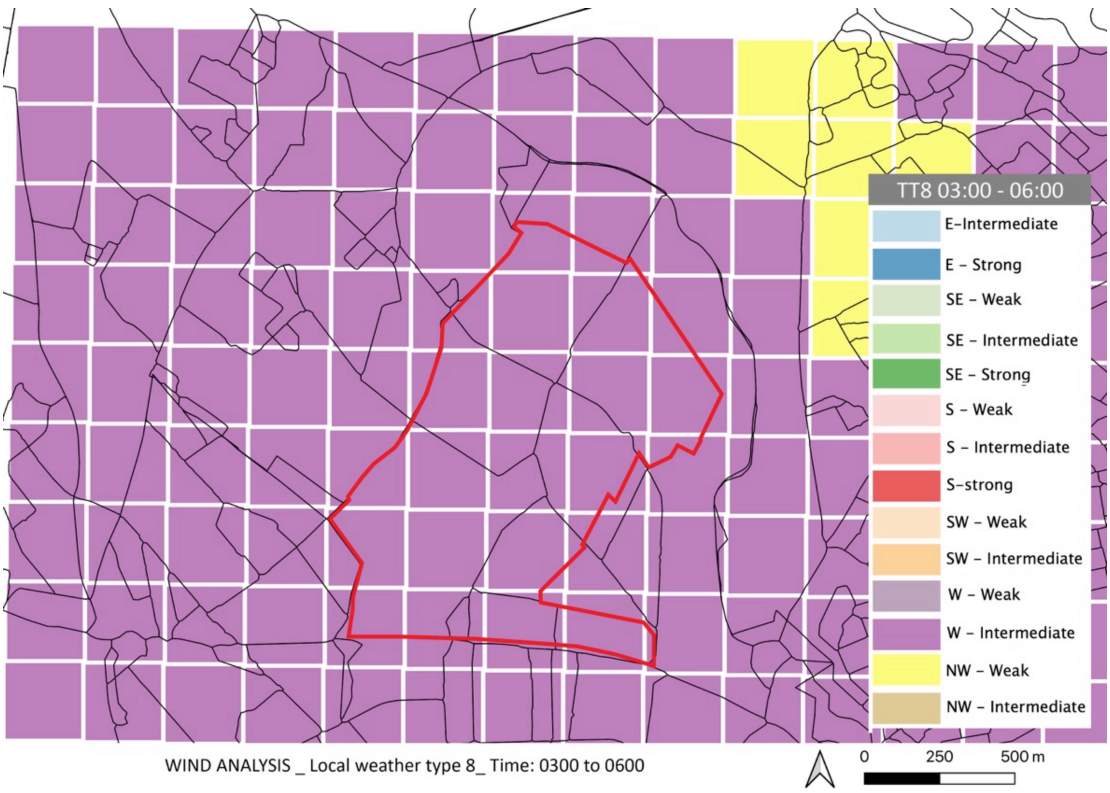


Figure 25 Map of wind characteristics in local weather type 8 during night time. (Source: Author)

Figure 26 Map of wind characteristics in local weather type 9 during daytime (Source: Author)

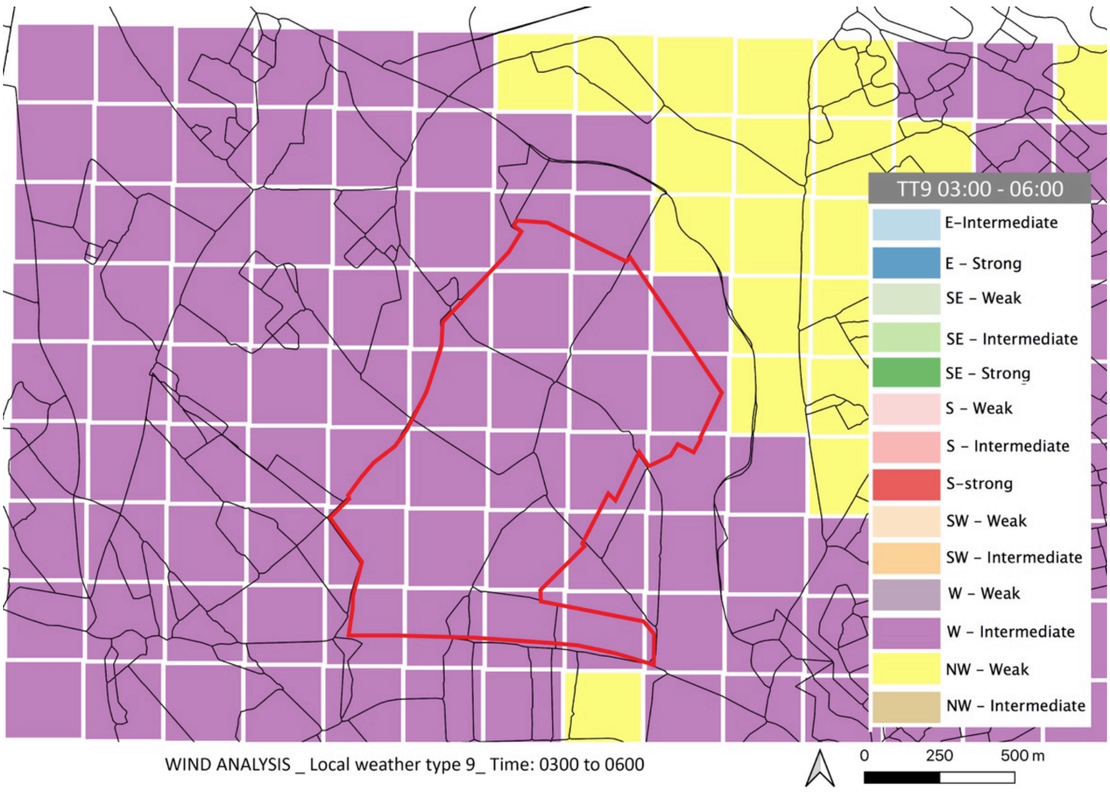


Figure 27 Map of wind characteristics in local weather type 9 during night time. (Source: Author)

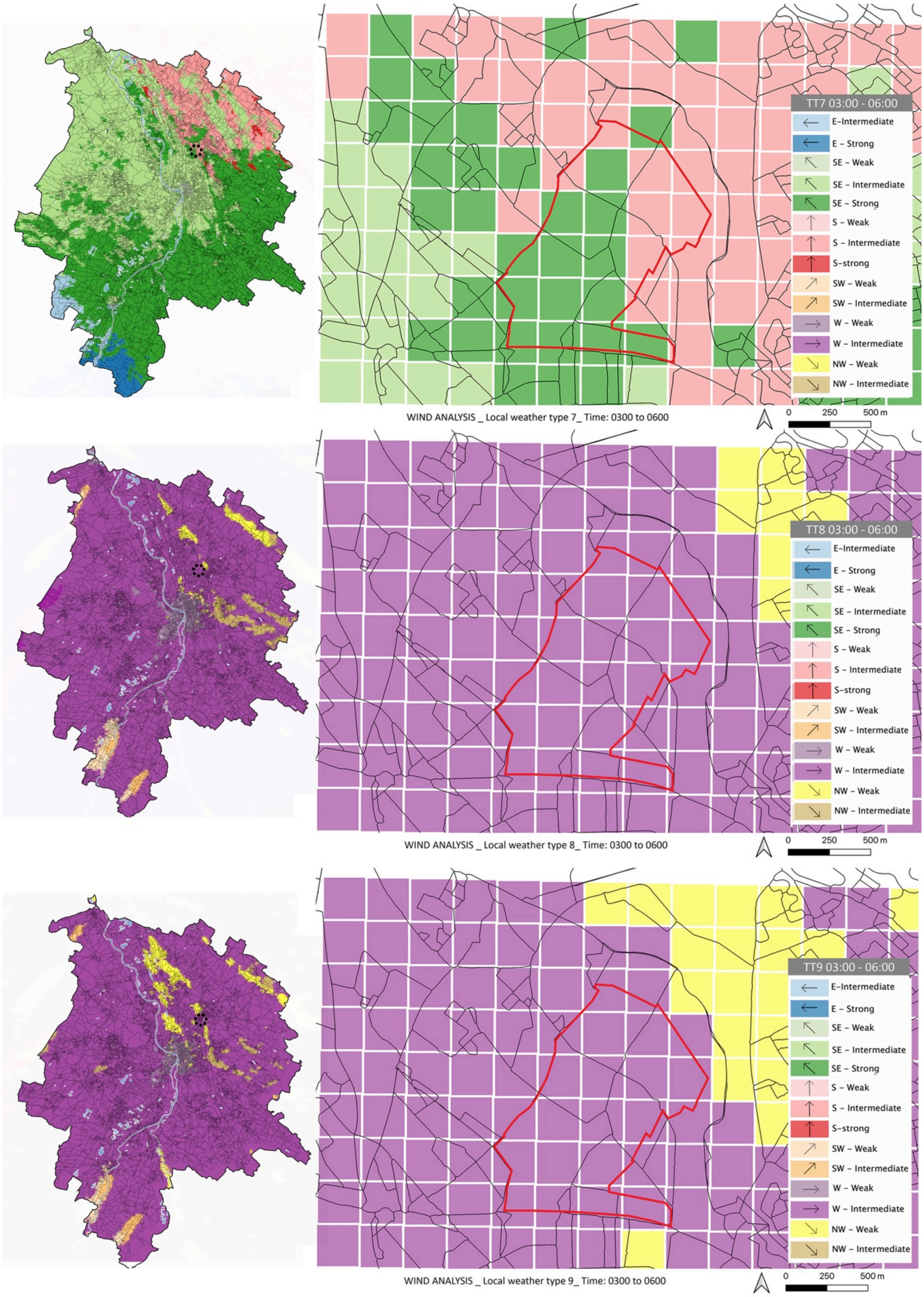
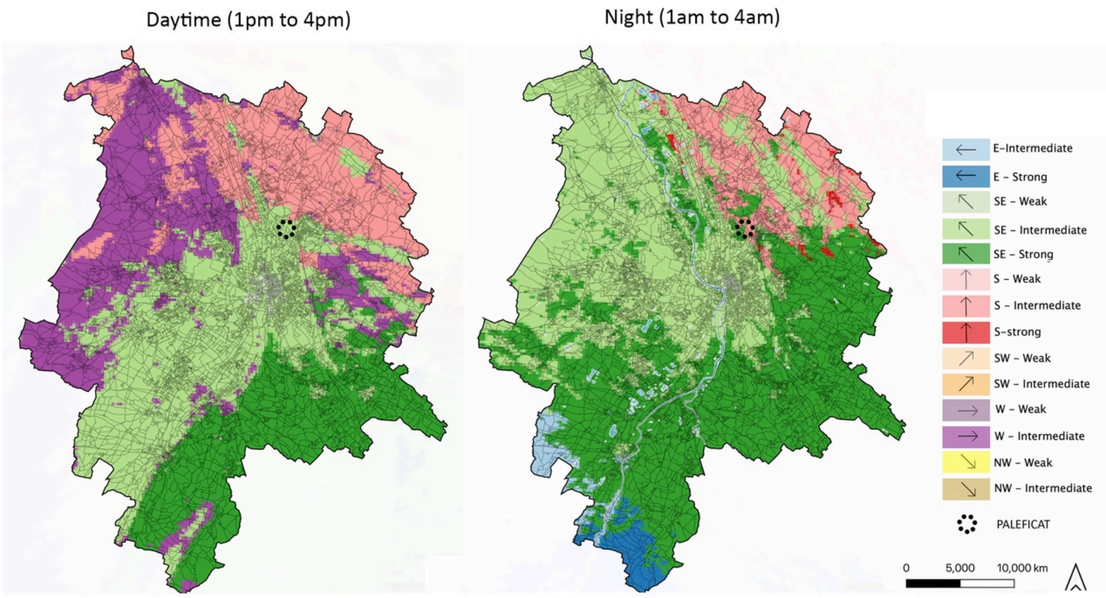
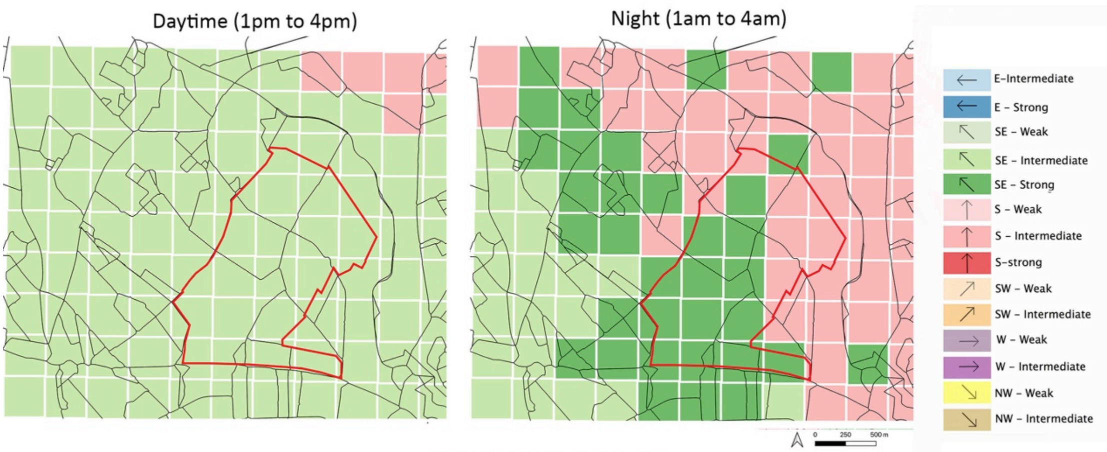


Figure 28 Maps comparing wind conditions in three different weather types and neighbor scale and in city scale. (Source: Author)



WEATHER SITUATION n°7
Typical summer day with sunny Southeast wind



WEATHER SITUATION n°7
Typical summer day with sunny Southeast wind

Figure 29 Maps comparing between day and night wind condition in weather type 9 (Source: Author)

By comparing the wind conditions during Local weather type 7,8 and 9 it can be seen that there is a constant presence of wind flowing in from North-western and South-eastern directions (Figure 28). Therefore, it can be deduced that this particular diagonal path passing through the site should be emphasized while designing the new development in Paleficat. Figure 29 shows that in local weather type 7 when the heat stress is maximum among all the summer days; the strength of wind is stronger at night than daytime. If the new development in Paleficat is designed in a manner where the strong wind can flow through the diagonal corridors with minimal built obstacles; it will hugely contribute in reducing temperature due to urban heat island.

5 RESULTS

5.1 Feedback

There were multiple presentations and meetings with the project manager from Toulouse Metropole and meteorologist from LISST regarding the microclimatic analysis of Paleficate. Based on the maps of the microclimatic analysis; it was collectively determined that the issue of summer comfort at the neighbourhood level should be addressed through the following criterias.

- **Optimising the ratio between natural and artificial surfaces**: working on the different land use classes and their distribution or organisation on the territory.

- **Reducing the impact of sunlight:** through shading and by working on materials and insulation (e.g. by using materials with high albedos or insulation from the outside) as well as urban form.

- **The optimization of ventilation at three spatial scales:** Firstly, at the scale of the building dealing with openings or windows, dimensions and geometrical form of the building. Secondly, at the urban block where the height of the buildings, width and length of the streets is considered. And lastly at a neighbourhood scale which fits into the urban scale with regard to the dominant ventilation corridors.

- **The reduction of anthropogenic heat flows:** these flows are produced by air-conditioning systems, industry and transport. There is a strong link between urban forms, energy networks and travel.

After identification of the problem, the time-tested solutions were explored that already exist in nature.. For seeking biomimicry approach there were further collaboration with Benoit Boldron (Project manager) from Toulouse Metropolitan and other personnel from CEEBIOS (European Center of Excellence in Biomimetics of Senlis) who provided thier publications of related fields of work.

5.2 Guideline for the planning of urban project in Paleficat, Toulouse.

5.5.1 Initial planning and design decisions

Vegetation and hydrological courses

As vegetation plays a big role in mitigating the urban heat Island issues; the existing vegetation should be used or accentuated. These patches of lush greenery guide the new urban development and hold priority in the plan. The dry hydrological sources present on site are potential open spaces of swallow water bodies that can invite biodiversity and help reduce the air temperature during hot summer.

Existing built structure

Compared to the whole site there are very few existing buildings in the area. They are mainly used for residential purposes and few of the buildings are used as old industrial purposes. Most of these buildings are built in privately owned lands and they do not have a cohesive spatial connectivity.

Vehicular accessibility

The new road that has been constructed through the middle of the site has encroached a significant amount of vegetation. Yet, this road has dedicated bus routes and bicycle routes that promote sustainable mobility. The positioning of this main vehicular accessible road plays an integral role to formulate the plan of the neighbourhood.

Heat Stress and wind analysis

According to the microclimate study it is observed that maximum heat stress inside the site occurs during weather type 7. Simultaneously there is an advantage that among the three weather types when there is more probability of thermal discomfort due to heat stress; the wind with the maximum speed approaches the site from southeast direction

Height

The height of the buildings also plays a big role. Variation of the height can be explored for the incremental growth of the project over various phases. The guideline can narrow down to the clusters of the neighbour where the design and planning interventions can affect the thermal comfort. The clusters in the neighbourhood can be arranged in a manner that approaching wind flows over the cooler area with vegetation and the water body before reaching the clusters.

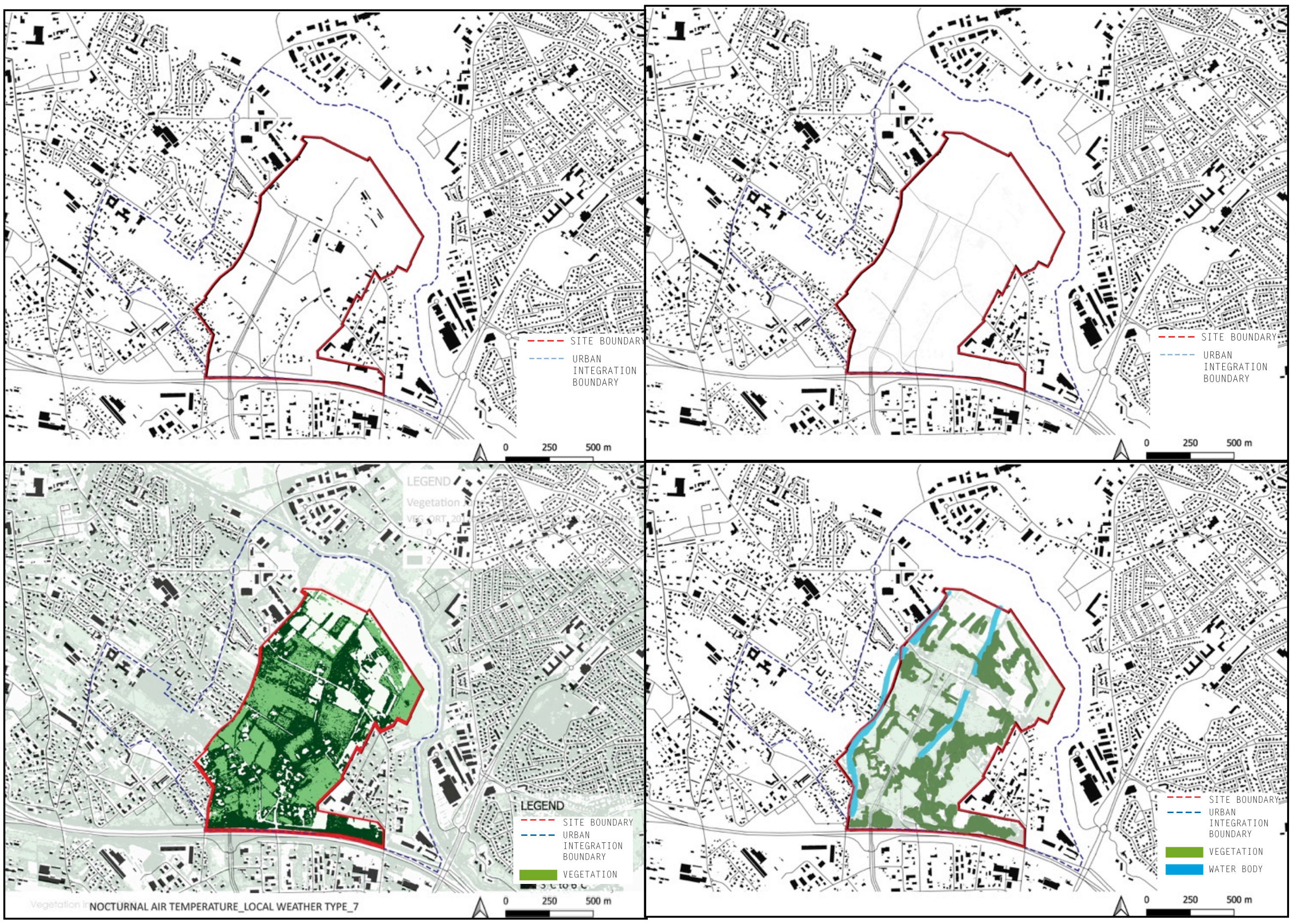


Figure 30. Series of maps in sequencing showing the process of extraction of vegetation and hydrological courses in the site

5.5.2 Biomimicry approaches to planning and designing of the urban development in Paleficat

After the primary design decision, biomimicry approaches started with biolization of the site and its contexts. Where existing ideas about how nature would solve the problem are explored that give connections with the system. As shown in the illustrated map in Figure 31, a new prominent vehicular road has been built within the site boundary that runs through the middle of the site. This road is well connected to the public transportation, which makes it accessible to travel all over the Toulouse city. Moreover, this road divides the site into two halves, which have resemblance with a structure of a leaf. As shown in Figure 31, a structure of a leaf is juxtaposed over the map of Paleficat and the midrib of the leaf is aligned to the road. Later the half of the structure of the leaf was vertically flipped to align the veins with direction to southeast wind direction.

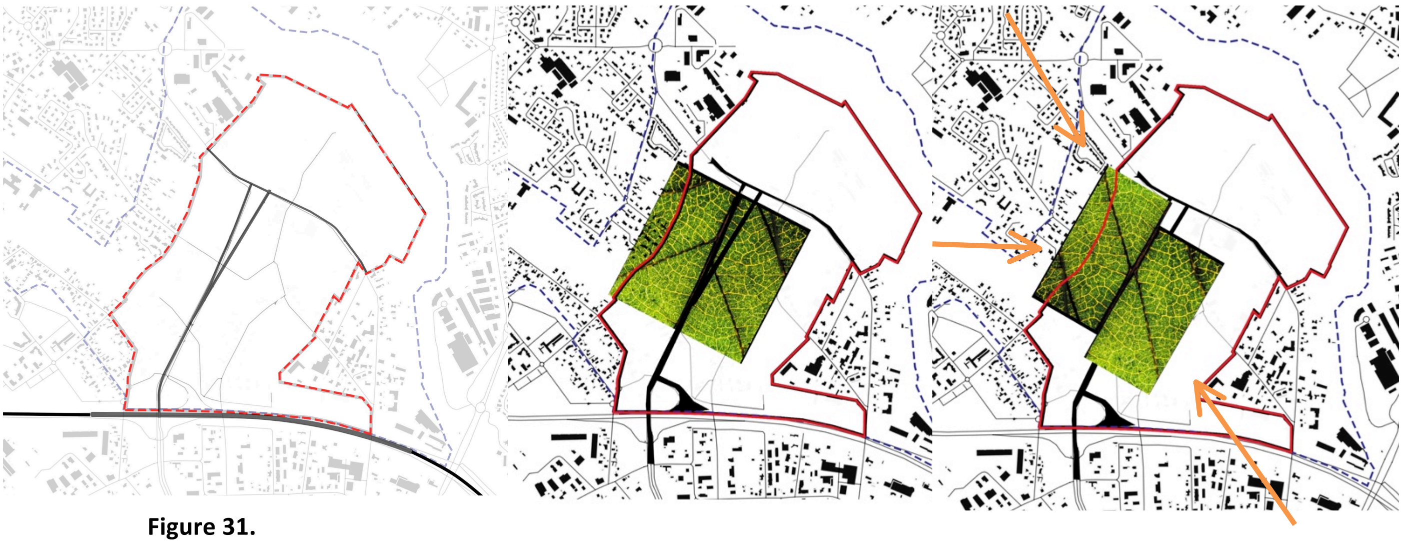


Figure 31.
Maps sequentially arranged to show the steps of how the site was "biolized" Aligning a naturally existing structural system of a leaf, to derive a street network that responded to the prevailing wind direction.

The biological mechanism of the leaf structure was relevant to the site for two characteristics. The plot sizes of the neighbour settlements matched the in-between spaces of the veins. And the veins resembled the meandering street network. This pattern of street network is suitable for wind to reach all the households and provide comfortable outdoor space for pedestrians navigating in the neighbourhood. As shown in figure 32 the vein structure of the leaf is extracted and it is replicated in other areas of the site.

Figure 32. Illustrated map where the structure of a leaf is extracted and the prototype is replicated throughout the site.

As shown in Figure 33 the existing vegetation and hydrological courses are juxtaposed over the leaf structure. And the remaining leaf structure is extracted. The new development should be well connected with the surrounding road networks. Figure 34 shows how the proposed road network branches out to join the existing roads in the surroundings. The development should be implemented in phases. The initial physical infrastructure should be built next to the predominant roads and streets as shown in figure 34.

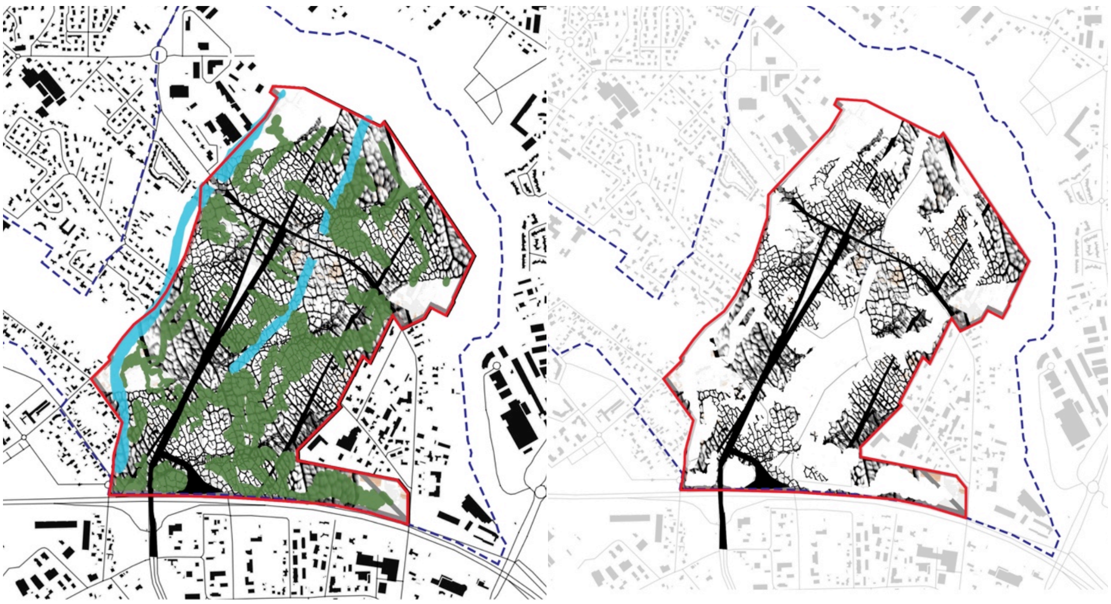


Figure 33. Illustrated map showing the process of subtracting the existing green spaces and the hydrological courses from the derived street networks throughout the site.

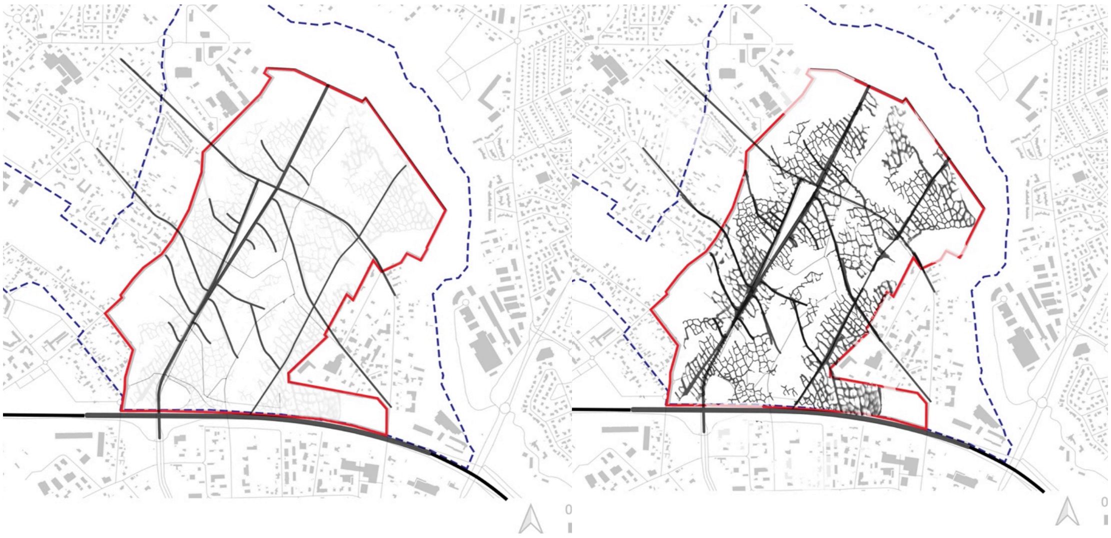


Figure 34. Illustrated map showing the initial phases of the new development in Paleficat

After abstraction, the next step was the proposing design that fits into the system. Where the abstracted version of natural models was translated into human adaptation. As shown in figure 34 the in-between plot sizes for each household are adequately drawn which fitted the scale and usability. Aim was not to make an exact replica of a natural form but to extract the design principles that aids in formulation of the problem solving.

Figure 35. The illustrated map showing the final planning phase of the new development in Paleficat

Figure 35 shows the final planning outcome of the development. The preserved green spaces can ensure the thermally comfortable outdoor spaces that become pockets of spaces that allow cooler wind to flow through the street and the meandering narrow streets (Figure 35). Designing the street orientation is not enough for stagnant warm air to be pushed out of the site. It is also important to think about the three-dimensional aspects of the design outcome. Figure 36 shows the proposed height restrictions of building in relation to the road network. The height of the building next to the primary wide roads are restricted to lower height buildings as it creates less obstruction for the wind to easily enter and exit the site. The buildings situated further from the wide roads allocated for buildings with maximum heights, which accommodate tall mixed-use residential apartments.

Figure 36. The proposed areas allocated for different heighted buildings for urban development.

6. DISCUSSION AND CONCLUSION

6.1 Statement of the result

The result presented a possible approach to design a new neighbourhood where biomimicry has been chosen as a prime inspiration to reduce the possible effects on urban heat island. Climatic and existing natural environmental aspects governed the proposed design where socio economic aspects were not overlooked as well. The proposed new development also addresses the inclusive nature of different housing typologies that need variation in plot sizes and other attributes. The maximum height restrictions were set that accentuates and enhances the wind flow.

6.2 Other results

During early January 2020, a congress called " Faire la Metropole Bio-inspirees" was held at Jean Jaures University of Toulouse regarding biomimicry approaches in urban thinking. One of the participatory exercises was on Paleficat where students took inspiration from a concept called "Tiny forest". Tiny forest is a method used by the Japanese botanist Dr. Akira Miyawaki who experimented on forest creation based on potential natural vegetation theories. The students used these theories to adopt an incremental growth of the building where vertical extensions of the buildings can take place to maintain and support the increasing population without "artificialization" of vegetative permeable surfaces in the site. These ideas aided in determining the three dimensional visualization of the project.

Moreover, two design competitions were held previously in adjacent areas of the site. One of the locations is in the Paleficat castle and the other is situated on the banks of the Hers. " The first is named Agriville, which allows the park to be renovated in order to welcome families, workers and residents around an ecosystem linked to urban agriculture. Equipment and services will make it a new centrality of the future Paléficat eco-district. The second, named Agriparc, highlights a hybrid space crossing agricultural land, housing, public space and green spaces preserved along the banks of the Hers" (QUARTIER PALÉFICAT, 2020). The submitted proposals from this competition focused more with urban integration of the existing socio economic conditions and public interaction.

6.3 Scope for Further Advancement

For the first time in Toulouse Metropole, the concept of Biomimicry has been incorporated during the initial phase of the new neighbourhood scale urban planning and design. The importance of an urban designer with expertise in Biomimicry that has been established at the Toulouse Metropole for the Paleficat project, due to this research and other previously designed proposals by students and urban professionals. Several unique features of the site in Paleficat were analysed to provide a climate sensitive design solution derived from the principles of biomimicry. The proposed solution of Paleficat was intended to run through climate simulation software like ENVI-met to ensure its effectiveness in mitigating the adverse climatic conditions. It requires long time and high computer configuration to make comprehensive climate simulation of the proposed complex scenario. Even then few "Hotspots" could be extracted from the whole site to be separately analysed. An estimated collective understanding of the overall proposed design could be pictured from all the segregated small tests. In addition to deduce the effectiveness of opting a suitable biomimicry approach; repeated ENVI-met tests would have been necessary to refine the design over time and be more climatically appropriate.

6.4 Limitations of the approach

The spatial attributes were more emphasized as the research was more inclined to address the climatic aspects and the built infrastructures. Although the restrictive height of the buildings was suggested but apart from housing other functions were not allocated. The open spaces can be converted to integral public spaces where the city dwellers can engage in social interaction. The valued aspect of this research project is the partially participatory process, which was held between local urban professionals, meteorologist and architect. Inclusion on the local's feedback on the proposed design and planning is also a valuable input to formulate a sustainable solution.

6.5 Concluding Statement

New neighbourhood developments like Paleficat are being built in almost all cities to accommodate the increasing urban population. Simultaneously city dwellers are also more conscious about the ecological benefits of the unbuilt areas of cities. Adopting biomimicry approaches can be a key area of discourse while involving all stakeholders from multidisciplinary professions including ordinary city dwellers to conduct an interactive urban planning. The emerging tools like GIS and ENVI-met enable climatologists and urban professionals to collaboratively analyse huge amounts of climatic data. This analysis and their graphical representation makes it more justifiable for biomimicry experts to incorporate radical ideas to creative design decisions. Urban interventions of such planning and design in neighbourhood scale can collectively have a positive impact in building a sustainable city.

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