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Toward the Healthy City.

Planning for climate justice: a workflow to support project areas selection and design scenarios choice

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Summary

The strong drive for urbanisation that has been characterising the last decades, especially since the fifties, led to a fast and disorganised development of the city, causing a significant worsening of the quality of urban life. In this context the concept of Healthy City becomes fundamental. Indeed, as defined by the World Health Organization (WHO), the Healthy City is not a static concept but consists in a process that the city undertakes to achieve the goal of health, programming specific actions to improve physical and social environments. Becoming aware of the role and importance of health and well-being for all citizens is the first step towards a Healthy City. The current organisation of cities, however, often tends to exacerbate economic and social vulnerabilities which, combined with unfavourable microclimate conditions, can cause significant differences in the quality of life in some disadvantaged neighbourhoods. Climate inequalities are certainly an obstacle to be faced in order to achieve the Healthy City's goals.

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Specifically, the focus of the research is to understand how, through digital tools such as analysis, mapping, modelling and simulation software, support can be given to microclimate planning aimed at reducing climate inequalities. The research proposed in this PhD concerns models and tools to support the planning and design of outdoor urban spaces for the mitigation of heat risks combining microclimatic analysis with the socio-economic data at the neighbourhood scale. It is believed that, in this context, the use of software to support the planning processes can help both the choice of the most vulnerable areas where to act with priority and the choice of the best project scenario in the perspective of climate justice. We aim to understand how we can promote the use of these digital tools to make them become part, in a systematic way, of urban microclimate design.

Urban planning is influenced by many variables and the outdoor comfort of citizens does not depend only on microclimatic conditions. From this point of view, it is important to think that this research must be inserted, to improve the quality of life of people in the outdoor urban spaces, in a more complex mechanism that connects the physical and environmental variables to the social and psychological ones.

The first year was focused on a systematic literature review (reported in Chapter 3) that has been useful not only to understand the background of the research topics and the state of the art, but also to build a solid foundation for the next steps of the work.

During the second year I worked mainly in two directions: the study of digital tools related to the connection between extreme heat, health and vulnerability, and the analysis of plans, programs, projects and research related to extreme heat events and phenomena. The aim of the work carried out is to create a workflow, explained by step by step guidelines, for the use of digital tools which, introduced in extreme heat planning processes, can support municipalities in the choice of the most vulnerable areas and the best project scenario from the point of view of microclimate, taking into account health and socio-economic conditions of people living in the project area, especially the vulnerable ones.

The work of the third year has been divided into two blocks: the first dedicated to the definition of the workflow (described in the step by step guidelines) for the use of digital tools in planning to tackle climate injustices; the second to the application of this workflow in two case studies, Turin and San Antonio, and to the validation of the workflow.

This document reports the research topics, the state of the art of the main thematic, the research work carried out and the possible next steps. In particular, the first chapter is devoted to the research topic, the second to the research question, the third to my topic and my research framework, the fourth to the methodology, the fifth to the research developments, to explain what I have done, the sixth to the guideline for the implementation of the workflow, the seventh to discussion and validation of the research, the eighth to the conclusions.

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Chapter 1

Research topic

1.1 Title

Toward the Healthy City. Planning for climate justice: a workflow to support project areas selection and design scenarios choice

1.2 Research topic

The concept of Healthy City involves many aspects of urban context and the microclimatic conditions that affect the comfort of people are obviously part of it. Climate change is causing many extreme heat phenomena, like Urban Heat Islands and Heat Waves, that need to be urgently addressed to minimise the health risks, especially for vulnerable people, and to improve the quality of outdoor spaces.

The research aims to identify how tools such as analysis, modelling, simulation and visualisation software can be an efficient and effective support to microclimate planning. Specifically, the goal is to give decision makers guidelines to facilitate the use of the proposed workflow to select both the project area and the strategies to implement, especially to address risks related to extreme heat for vulnerable people.

1.3 Keywords

Healthy City; Heat-related risks; Microclimate planning; Vulnerabilities; Climate inequalities

Chapter 2

Research question

2.1 Motivations

The research adopts an interdisciplinary approach because of the motivations from where it started that are related to current and future climatic conditions, demographic, social and economic factors and many other variables affecting the design and planning of interventions to improve the quality of life in our cities.

Climate change is a problem that needs to be addressed with extreme urgency as it negatively affects all aspects of people's lives (WHO, 2018). Precisely because of its cross-cutting characteristics, it is a complex challenge that must be addressed at multiple levels, from governmental to local, from global to national (Wilson, 2006), by promoting mitigation and adaptation policies and strategies (Kalafatis, 2018).

In this context, one of the most urgent problems to address for human health, is the urban heat and the stress caused by that. Heat stress is a prolonged exposure to environments with very high temperatures that can lead to an increase in morbidity and mortality (in these case it is "heat-related"). More and more often, in recent years, extreme heat events occur, especially in the city, and there has been a noticeable increase in both frequency and intensity of very hot days (Luber and McGeehin, 2008). Events like the Heat Waves¹ and phenomena like the Urban Heat Islands² are increasingly common and should be taken into account when planning interventions in the city as they significantly affect people's well-being and health. Prolonged exposure to extreme heat can cause not only respiratory and cardiovascular problems, with the possibility of premature death for the most

¹ The definition of heat waves is closely linked to the regional context in which it occurs. One of the most widely used definitions identifies Heat Waves as the periods of at least three consecutive days with maximum temperatures (Tmax) $\geq 30^{\circ}\text{C}$ leading to increased mortality and morbidity, especially in vulnerable people (Huynen et al. 2001; Kysely, 2004).

² Urban heat islands (UHIs) is the phenomenon that characterize the cities where urban area has higher temperatures than its surrounding rural area (Oke, 1982)

vulnerable people such as children and the elderly (Zhang et al., 2018), but can also affect psychological well-being (Reid et al., 2009; Ebi et al., 2021; Jay et al., 2021).

The most critical aspect of climate change from the human being point of view is indeed that it affects health both directly and indirectly (Intergovernmental Panel on Climate Change, 2014). So far, research on the effects of climate change on people's health has focused mainly on heat stress, extreme weather events and infectious diseases, as it appears from the literature review results (chapter 3). Lately, however, the influence that variables such as social, demographic and economic conditions may have on human health when facing the adverse effects of climate change, is also being evaluated (McMichael et al., 2006).

The effect of climate change on people's health may vary according to their social, demographic and economic conditions and climate justice is therefore becoming increasingly important. Climate justice, in fact, is a branch of environmental justice that focuses, specifically, on the unequal distribution of the effects of Global Climate Change (Walker, 2012). In this sense, the issue of climate change is also relevant from an ethical and political point of view and it is necessary to think about policies to create equity and justice in living conditions in relation to climate, especially in cities (European Union, 2017). Climate justice applies both on a global scale, with the consequences of climate change, and on a local scale, because environmental changes can significantly and directly affect a person's life and condition (Bernetti et al., 2020). In the latter case it is linked to local inequalities and factors.

This research works precisely on the local scale of climate justice, at the level of neighbourhoods and spaces between buildings. Recent research on urban environment highlights the role of the spatial and social factors at the neighbourhood-scale to promote health and well-being (Setola & Rinaldi, 2025). Spatial planning and design are important tools both for mitigation and adaptation to climate change and for addressing vulnerability issues so, as architects, we can contribute to improve the research and the applications in this field.

Digital tools acquire, in this perspective, a relevant role. Despite the availability of advanced tools to support planning, their integration into these processes is still limited. Specifically, on this topic, in recent decades, new tools like the CFD (computational fluid dynamics) software, have been developed. This kind of software allows to model buildings, neighbourhoods, entire cities, and simulate the microclimatic dynamics that characterise them and the thermal comfort indices, to

evaluate the quality of the space for people. ENVI-met³, for example, is considered user-friendly and accessible by less experienced users (Elnabawi et al., 2013).

These tools, therefore, give architects and planners the opportunity to experiment and evaluate their project or their intervention's strategy before implementing it. The undoubted advantage of this system lies in the fact that, in this way, you can avoid or limit errors because you identify any improvement and change during the design phase. At present, however, this and other tools are only partially used in planning and there is still potential to explore and experiment with.

In this context, the research and the university sectors can be included, bringing into urban planning, especially at the neighbourhood level, the potential of new digital tools to improve the process of scenarios' choice.

Usually the academic and political spheres, responsible for decision-making in planning, do not speak or do not interact with each other in a systematic way. A constant communication between these two, would make the public system always up to date on news in the field of research and digital territorial application tools that are always changing. This research work can also provide a bridge between them.

2.2 Specific research questions

In response to the challenges described in the previous section, this research investigates how planning decision-making can be supported through integrated territorial mapping and analysis. The study is guided by a main research question and a set of complementary sub-questions.

³ "ENVI-met (CFD software) is a three-dimensional microclimate simulation software that enables the creation of sustainable living conditions in a constantly changing environment. ENVI-met's interactive applications can scientifically analyze the effects of different design scenarios developed by architects or urban planners. The calculation modules of ENVI-met cover a wide range of scientific disciplines - from fluid dynamics and thermodynamics to plant physiology and soil science. The guiding principle of ENVI-met is to integrate all these different approaches into a single model, so that all elements can interact and reproduce the observed synergies. This distinguishes ENVI-met from other modeling platforms for environmental simulation." (envi-met.com)

Main research question

How can digital tools and integrated territorial mapping, support planning decision-making, at the micro-urban scale, in addressing extreme heat and climate inequities?

The research question concerns the planning of micro-urban spaces with particular attention to the health and well-being related to heat risks and vulnerability factors. Specifically, it is a matter of identifying useful tools to improve planning decision-making processes, developing a specific workflow (and step by step guidelines) to support project area's selection and design scenarios' choice to make digital tools usable in a simple and effective way by technicians and decision-makers.

To answer this complex main research question, however, it has been also necessary to think of other preliminary and preparatory questions.

The first sub-question regards the existence of experiences in which data from different fields (microclimatic, health, demographic, social and economic data) were combined in one unique map or study. This question guided the literature review carried out during the first year of the PHD (chapter 3).

Secondly, from a technical and technological point of view, the issue of the tools at our disposal has been investigated from different point of view:

- *What digital tools are used and/or can be used for integrated territorial mapping?*
- *What digital tools are used and/or can be used to map demographic, social and economic data?*
- *What digital tools are used and/or can be used to combine climate, demographic, social and economic data?*
- *What digital tools are used and/or can be used to test and simulate the effects of different project scenarios?*

To answer these questions, a specific preliminary research on digital tools for microclimatic planning was fundamental. Obviously also the results of the literature review showed and identified the most used tools in this type of research. An additional study of plans, programs, projects and research on the risks of extreme heat has been equally useful from this point of view.

Finally, on this last point, it is important to ask two related questions:

- *Are there plans or programmes or projects or research at municipal level that use climate mapping combined with health, demographic, social and economic data?*
- *If such plans exist, are they exclusively analytical or do they also propose schemes and projects to promote climate justice and minimise inequalities?*

To answer these questions, I studied and analysed some municipal, national and international plans, programs, projects and research that respond to the risks related to extreme heat (a theme that underpins the research but is confirmed as relevant to the theme of planning also by the results of the literature review).

2.3 Objectives

The objectives of the research derive directly from the main research question, translating it into specific and operational goals. They frame the development of an integrated territorial mapping approach to address the complexity of planning decision-making related to extreme heat and climate inequities.

The main objective of the thesis is to develop an integrated territorial mapping workflow, supported by a set of operational guidelines. The workflow would assist planners and decision-makers in the use of digital tools to select the project and to choose the best project scenario, responding to the need of mitigating and eliminating climate inequity within the cities.

In order to achieve this main objective, the research is structured around a series of specific objectives, which collectively contribute to the development of the proposed workflow and guidelines.

The first specific objective is to map the digital tools currently used to analyse and map climate inequalities. This has been achieved through a first preliminary research on digital tools for microclimatic planning and the literature review. These investigations enable the identification of research and experiences already carried out in this field, defining also the gaps.

The second objective focuses on mapping existing plans, programs, projects and research that, at local and municipal level, deal with the issue of extreme heat. This analysis helps determine both whether such initiatives are purely analytical or also operational and if they consider other variables beyond heat (e.g. social, demographic and economic factors). This goal was partially achieved through the systematic literature review as some papers reported experiences included in this type of program but also through a more in-depth research of grey literature⁴. Interviews with experts were also organised to obtain both clarifications on their work and research, as well as feedback on my idea.

The third specific objective is to establish a dialogue with the experts to discuss and validate the workflow and the guidelines. By engaging participants, first in semi-structured interviews and, at the end, in a structured workshop, the research assessed the applicability, the effectiveness and the potential transferability of the workflow to other urban planning contexts.

NOTE: It is important to clarify that initially the research and, consequently, also the research questions, were mainly focused on the effects of a specific phenomenon concerning the microclimate, the Urban Heat Islands (UHIs). In the course of the research work, however, it has emerged that these are part of the wider context of the issues related to extreme heat, of which also belong, for example, the Heat waves, all important and related. For this reason it was decided to expand the field of research to the whole range of "heat risks". The initial scoping review was carried out with the thematic filter of the UHIs but all the other activities, for example the systematic literature review, are updated in order to integrate the publications concerning all the "heat risks". Throughout the discussion reported in this document, reference will be made to all the "heat risks" but this update will be essential.

⁴ Grey literature: is the literature, printed and/or in electronic format, produced by governmental organisations, universities, business and industry sectors, that do not carry out as main activity the publication (Farace & Frantzen, 2004). Grey literature includes reports, theses, conference proceedings, newspapers, fact sheets, websites, policy documents, unpublished research and data (Higgins & Green, 2011)

Chapter 3

Literature review

3.1 Introduction

The literature review is a research methodology that allows to identify, analyse and synthesise in an explicit, systematic and replicable way, the literature produced in a specific field by researchers, scholars and professionals (Fink, 2019). The literature review is usually used in the early stages of research.

In the context of the PhD the literature review serves to build a clear picture of the background and the state of the art on the issues addressed. In this way it is possible to understand if someone has already answered the proposed research question or if there are already contributions that have dealt with it even in part and from which to start the work. Specifically, the literature review is usually used to analyse if in the specific topic of interest there are some gaps. To achieve these results, it is essential to build an effective, specific and precise research question.

In addition, the literature review is a tool that helps reviewers (in this case the PhD student) to clearly define the boundaries of their research and specific objectives. It's actually important to make the work original and contribute, although in a modest way, to the advancement of scientific knowledge.

In the specific case of this work, the literature review was also fundamental to define other research that are necessary and preliminary to the next stages of mine. In addition to finding the gaps, the literature review is very useful to elaborate new ideas and identify new perspectives that can also radically change the initial orientation of the research for which it was carried out.

When deciding to conduct a literature review, depending on the objective for which it will take place, in addition to building an effective research question it is important to choose the methodology that best suits the research topics, and the scientific field in which it is inserted, which may be characterised by different types of literature (for example, scientific papers or books or grey literature) and different types of data (for example, quantitative or qualitative or quali-quantitative).

3.2 Methodology

Literature research and study can be conducted differently depending on the objectives, research process, evaluation, synthesis and analysis that are chosen. Some examples are the Mapping Review that aims to delineate and classify the existing literature, identifying gaps in research or the Scoping Review that aims to identify the nature and extent of studies in a specific field. In this research work it was decided to conduct a systematic literature review that, in general, aims to examine the literature in a comprehensive and complete way (Grant & Booth, 2009). Specifically, we also wanted to develop the work so that the literature review is systematic to reduce the risks of "bias".

For this purpose, it was important, first, to have a clear and focused research question, explaining the criteria for inclusion and exclusion of the identified studies. The researcher must start from the choice of the theme, thinking about one or more specific objectives and the audience it wants to address. The acronym SMART can be used to understand what should be considered in defining the purpose of research (Alves, 2018):

- S - Specific
- M - Measurable
- A - Achievable
- R - Realistic
- T - Time-limited

Following the construction of the research question, the research strategy is elaborated, identifying the resources, the type of literature and data that characterise the specific research field and the methodology to be used. The methods and protocols planned to conduct and report the review must be specified from the beginning of the work and each phase of the review must be documented with exhaustive explanations for each decision taken in the research process (eg: resources and strategies).

For the documentation of the process, graphic supports such as tables, diagrams and graphs can be used to make both the methodology and the evaluation, analysis and synthesis of the studies' characteristics included in a research that is clear and transparent. Finally, the limits of the literature review must be highlighted

explaining and justifying them in relation to, for example, scarce staff or time resources (Booth et al., 2022).

In summary, in order to conduct a systematic literature review, once the research question has been constructed, all the studies that respond to it should be identified, selected (the relevant ones), evaluated and their data must be extracted and synthesised (Brereton et al., 2007).

Literature searching is the fundamental phase of the literature review process and it is possible to identify some "key stages" that characterise it (Cooper et al., 2018):

- definition of who should conduct the research, which in some cases, such as the PhD, is a single person, in others a group
- definition of the objectives and purposes of literature searching, for example whether you want to carry out a comprehensive literature search or have a selective approach
- preliminary investigation of literature (Scoping process) to assess the nature and quantity of literature and define boundaries
- research strategy design, defining the resources to be used and how to conduct the research
- searching the bibliographic databases, identifying which are the most suitable for the field on which you are working
- additional research, considering grey literature, the study of key authors and citations
- reference management, that can be facilitated by the use of specific software
- report of the research process, written keeping track of all the activities as they take place.

3.3 Literature review process

The literature review, as already mentioned, was based on a systematic approach and was reported according to PRISMA (The Preferred Reporting Items for Systematic reviews and Meta-Analyses).

Figure 2 (page 25) is a PRISMA flowchart, which schematically describes the identification of studies with paper numbers for each phase. In this scheme I outlined my literature review process but in the subsections from 4.3.1 to 4.3.7, the different phases will be explained in detail.

The literature review process started with preliminary investigations (4.3.1) and then continued with the definition of the objectives and the research question (4.3.2) but before starting the research of literature (4.3.4) it was fundamental to choose a strategy, the database in which to apply it and the methodology for reporting each step (4.3.3), to identify the inclusion and exclusion criteria (4.3.5) required for the screening (4.3.6) of the papers that, following this phase, have been read, analysed and synthesised (4.3.7).

The literature review is always in progress because it needs to be updated, for example every six months, to see if there are new studies on that topic.

NOTE: As already mentioned in the paragraph on research questions (2.2) it is important to point out that initially both the scoping and the literature review phase were conducted with the thematic filter of the UHIs, but now the literature review have been updated in order to include the publications concerning all the "heat risks". This update was crucial especially to identify plans and programs that, in most cases, do not focus only on a specific phenomenon but on all those related to the risks related to extreme heat.

3.3.1 Preliminary investigation of literature (Scoping review)

Before defining the research question, it was fundamental in this work to carry out a preliminary scoping process to understand if there was already literature on the identified issues. The scoping review aims to "map" the most important literature in a sector or on a topic, both its nature and its extension, to understand

what has already been written on those thematic (Arksey & O'Malley, 2005). In addition, the scoping review can give interesting insights regarding the most used words in the topic addressed, which can then be used in the definition of the research question of the literature review and in the string to be inserted in the database.

So I did a research that was dictated by the fact that it was necessary to understand if there were already literature reviews on the correlation between health and the microclimatic environment. This process of scoping had therefore the objective to not replicate a work already carried out by other researchers and, at the same time, in the event that it had already been done, to understand the gaps to fill.

The scoping review was then carried out asking the question: "Are there reviews on the correlation between health and UHI effects? Which are the gaps?" (only UHIs are indicated for the reasons given in the note on page 5). In particular, the string used on "Scopus" database was as follows:

(TITLE-ABS-KEY (review) AND TITLE-ABS-KEY (health* OR "well being" OR comfort* AND NOT healthcar*) AND TITLE-ABS-KEY ("Urban Heat Island" OR "UHI")) AND (LIMIT-TO (LANGUAGE,"English"))

From the research results 191 papers and this denotes an interest in the subject. Through the screening of titles and abstracts I selected 58 papers and I analysed for each of them mainly three characteristics: objectives, methodology, limits of the review and gaps of the research field identified. In particular, the first research also aimed, as already mentioned, to identify the most important issues and terms in this field in order to use them for my literature review.

From this first work, in fact, the term and the thematic of vulnerabilities of both people and cities emerged. It was evident that, in most publications, this factor was not considered or addressed as relevant to health, and in many cases this was highlighted by the papers themselves as a limit or gap in research (González-Trevizo et al., 2021; Mavrogianni et al., 2010; Campbell-Lendrum & Corvalán, 2007).

3.3.2 Objectives decision and research question definition

The second phase of the work was characterised by the identification of the objectives and the research question for the literature review. Although the main

themes of the PHD were already fixed by the thematic program (as I already mention), defying the specific objectives and the research question for the literature review required an important synthesis work. The topics of the PhD are in fact very broad and it was necessary first to define the aim and the research question of the main research (paragraph 2.2) and then to identify objectives and research questions for the literature review. Specifically, for the literature review question, it was important to generate it with a “SMART research” approach (Specific, Measurable, Achievable, Realistic, Time-limited) (Alves, 2018).

When a thematic is so broad, it is crucial to identify a clear point of view or a more specific topic of interest, especially as regards the definition of research question that should guide the literature review.

In the specific case of this research the construction of the question was guided by the topic proposed from the scholarship of PHD and by the results emerged from the scoping reviews. In particular, as already mentioned, I decided to focus my attention on the issue of the “vulnerability” linked to the microclimate that, although not explicitly mentioned in the description of my doctoral scholarship, underlying all the topics covered, as it emerges from the scoping review.

The objectives of this Systematic Literature Review were therefore:

- 1) to know if there were already experiences and research on the link between health, microclimate and vulnerability (state of the art);
- 2) to understand the terminology used in this field;
- 3) to identify any intellectual and application gaps in this field;
- 4) to analyse which survey, research and design methodologies were used in the experiences reported in the papers.

The research question for the Systematic Literature Review, to reach these objectives, was: "Are there plans, programs and projects in the urban context (with a specific attention to the neighbourhood scale) combining climate (specifically extreme heat), health and vulnerability (demographic, social, economic)?"

To answer this question, a string of research has been built taking as references the main topics to be addressed: health and well-being; microclimate conditions; phenomena and events related to heat; vulnerabilities, from those related to demographic factors to social ones.

3.3.3 Choice of research strategy design, bibliographic databases and research process report methodology

The first months were devoted not only to study the thematic of my PHD scholarship, but also to search for examples of literature review and texts that explained how to carry it out in the most systematic and rigorous way. In particular, the reading of the text "Systematic approaches to a successful literature review" (Booth et al., 2022) was useful to understand the different phases to be considered and to better organise the time available.

I decided to carry out a systematic literature review because this approach, through the application of an objective and explicit method, allows one to answer a specific question by identifying the studies and research published up to that moment (Moosapour et al., 2021).

Once the research methodology was chosen, the "Scopus" database was selected. I initially decided to do the literature review simultaneously on both "Scopus" and "Web Of Science", the two principal citation indexes used by the global science community (Asubiaro et al., 2024). Then I preferred to start from the first one in order to read the papers and realise the limits of literature review to correct it before publication. I intend to use "Web of Science" to update the literature review before publication but directly with the new modified string that will include some terms that emerged from reading the papers of the literature review already carried out.

Finally, I chose the reporting methodology for my Systematic Literature Review: PRISMA protocol (The Preferred Reporting Items for Systematic reviews and Meta-Analyses). The PRISMA approach is in fact preferable for research like mine because it allows to keep the control of all the phases of the process and to clearly show all the steps and criteria of research in a clear, synthetic and, above all, replicable way (see <http://prisma-statement.org>).

In addition to this tool I used an excel file for the title and abstracts screening phase, while word files for full text analysis, to have a catalogue with all the most relevant information from the papers.

3.3.4 Literature research

The actual research phase of the literature was based on all the previous and preliminary ones, from the definition of the objectives to the research question, from the identification of the databases to the choice of the review methodology. First it was important to define a list of keywords, based on the descriptive text of the PhD thematic program but also on what emerged from the scoping review process.

This first phase is fundamental for the definition of the research string for which it is necessary to define which concepts to include in the search, which one I need to exclude and which terms to treat as synonyms.

I tried to run the research at first with the keywords I identified and it emerged that some words were not suitable, written like I did, for the research because they narrowed the field of the results too much (excluding papers interesting for my thematic) or they widened it excessively (including papers not on my topics because of the wide meaning of the term). To avoid the narrowing risks, for example, as for the term "health", because the concept was so extensive, in addition to being the root of other words, enlarging excessively the range of results, I decided to exclude from the research the words related to "healthcare" (putting in the string "AND NOT healthcar*").

Another important element in the construction of the string was to organise the terms in "clusters". Specifically, I decided to follow, doing this step, the topics I identified from my research question: health and well-being; climate and microclimate conditions; phenomena and events related to heat; vulnerabilities, from those related to demographic factors to social ones; urban context in different scales; planning and design.

From the string it was possible to recognize these four "thematic clusters" that had to characterise all the studies. Inside the cluster, in fact, there was the term "OR" to include all the studies with one or more of those terms; among the different clusters, instead, the term "AND" was inserted so that the papers contained at least one word of each thematic.

Based on these premises, the research string, used on "Scopus", turned out like this:

(TITLE-ABS-KEY(health* OR "well being" OR comfort* AND NOT healthcar*) AND TITLE-ABS-KEY("Urban Heat Island" OR "UHI" OR heat OR "heatwave*")) AND TITLE-ABS-KEY(social* OR inequalit* OR vulnerab* OR fragil* OR discrimin* OR dispar* OR injust* OR elder* OR child*) AND TITLE-ABS-KEY(urban* OR city OR cities OR town OR neighbo* OR municipal*) AND TITLE-ABS-KEY(climat* OR microclimat*) AND TITLE-ABS-KEY(plan* OR design* OR map* OR project*)) AND (LIMIT-TO (LANGUAGE,"English"))

From the research of the search strings (applied only to Scopus) have turned out numerous publications and in this phase of the job it is important to organise and manage them efficiently. In the specific case of this search a software, Mendeley, and Excel sheets were used.

3.3.5 Inclusion and exclusion criteria

To reduce the number of papers that the database identified it was then necessary to make a selection to have the opportunity to read only those that were actually relevant and interesting for the research.

To achieve this goal, two selection levels have been set according to specific criteria (Li et al., 2022): primary and secondary inclusion and exclusion criteria (Table 1).

Table 1: Inclusion and exclusion criteria

Primary criteria		Secondary criteria	
Inclusionary	Exclusionary	Inclusionary	Exclusionary
Articles, Books, Book chapters, Review	Duplicate records	Relevant to research objectives	Irrelevant to research objectives
Published in English	Conference paper, Editorial, Note	Relevant to heat-related risks	Irrelevant to heat-related risks
Full-text available online			

The first selection phase of inclusion and exclusion was carried out directly and automatically on "Scopus" and, later, for the elimination of duplicates, on Mendeley. Through this selection I went from 981 to 977 papers.

The second phase was carried out through screening (more details in section 4.3.6) of the papers' titles and abstracts according to the secondary criteria of inclusion and exclusion. In this case I went from 912 papers to 116 papers.

3.3.6 Literature screening

The process of selecting relevant publications for research is implemented in several stages. At first through the "Title screening", then with the "Abstract screening" and ultimately through the "Full text screening" (Booth et al., 2022). In all cases, what is used to determine whether or not publications are selected are the criteria for inclusion and exclusion explained in the previous paragraph.

Figure 1 represents the PRISMA flowchart in which all the literature screening process is reported in detail.

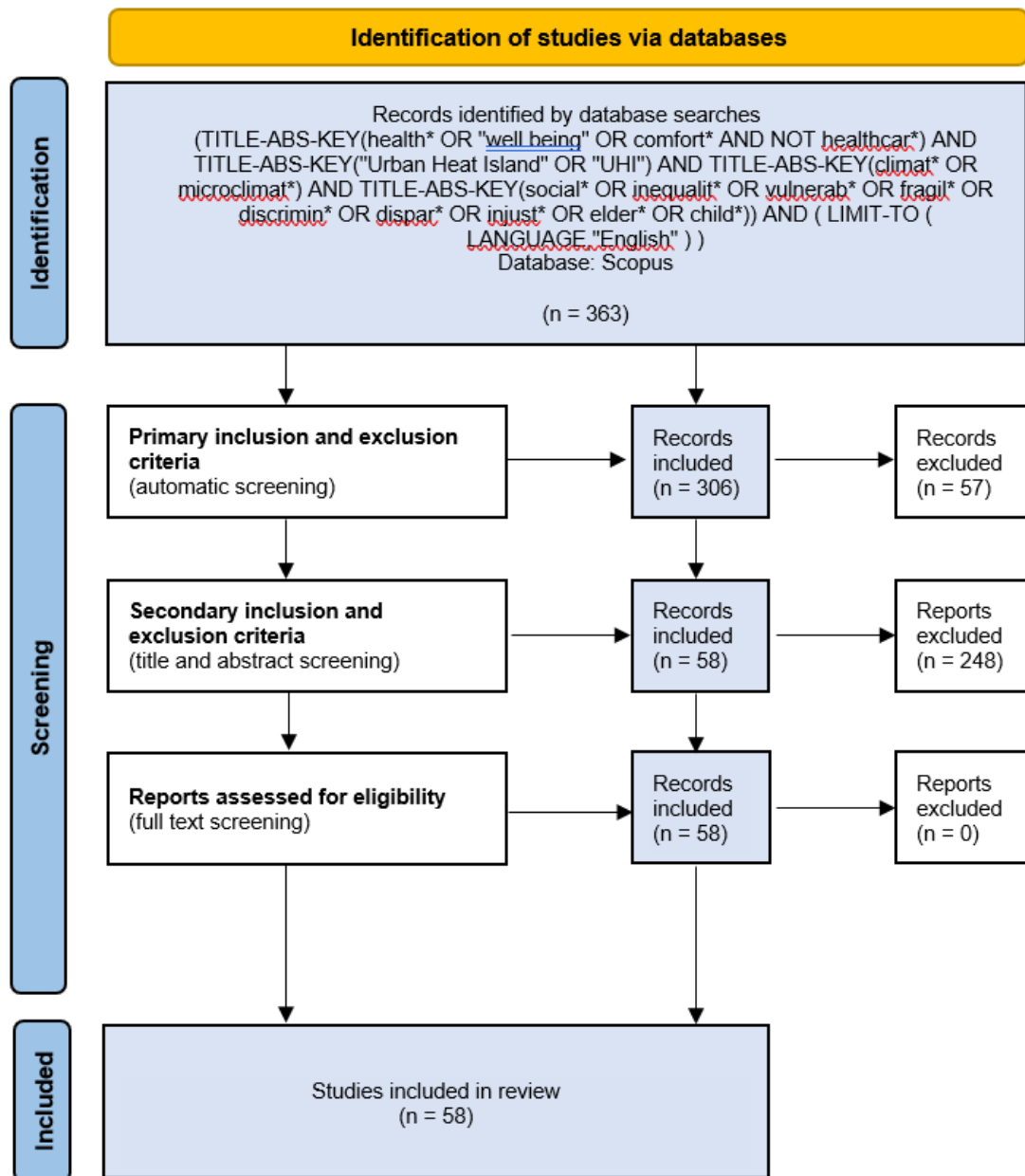


Figure 1: PRISMA flowchart reworked by the author with research data

I screened titles and abstracts using an excel file (Fig. 3) in which I reported, in addition to all the information related to the paper (such as title, authors, year of publication, link) also comments on abstract parts that were more interesting for my research and the relevance of them related to the inclusion and exclusion criteria.

Authors	Title	Year	Link	Abstract	Relevance (1, 0, 5, 0)	Important concepts	Incl. Criteria	Exclus. Criteria
(Leon) Wang L., Shu C.	Assessment of the Effects of Urban Heat Island on Buildings	2021	https://www.sciopus.com/record.uri?eid=2-s2.0-85067900068&doi=10.1007%2F978-981-33-4050-3_2&partner=D=40&md5=9cb0d1d9c1ba063e4ba4bfc65901dc	Climate change and global warming have been indisputable as supported by mounting evidence of more extended, severe, and frequent occurrences of extreme weather events (EHEs), in particular, summertime heatwaves in recent years. EHEs often interact with buildings in urban area centers, which are densely packed by building blocks with vulnerable populations: the homeless, elderly, children, socially disadvantaged people, the physically challenged, or the sick, creating a unique natural phenomenon, urban heat island (UHI). This chapter covers a comprehensive effort to assess the UHI impacts on buildings and the potentially vulnerable populations through a series of surveys and field	1	_extreme weather events (EHEs) often interact with buildings in urban area centers, which are densely packed by building blocks with vulnerable populations: the homeless, elderly, children, socially disadvantaged people, the physically challenged, or the sick, creating a unique natural phenomenon, urban heat island (UHI) _this chapter covers a comprehensive effort to assess the UHI impacts on buildings and the potentially vulnerable populations through a series of surveys	Relevant to research objectives Relevant to heat-related risks	

Figure 2: Example of excel sheet for title and abstract screening

3.3.7 Literature reading and analysis

Following the screening of titles and abstracts, as explained in the previous paragraph, I carried out the full text screening. In this last phase I decided to proceed with a catalogue of papers. I created for each paper a word file (Fig. 4) in which, at the beginning of the document, as I read the text, I reported all the information most important for my work.

The notes at the top of the page can be about interesting references mentioned in the article, interesting case studies, indexes that I could use in my research, definitions of concepts and the main points set out in the paper. This analysis was also important to simplify the subsequent stage of the research, the synthesis of results.

In the rest of the document I inserted the extracts of the paper that I thought could be useful for my research so as to have them always available in a simple and fast way.

Note:

- Interessante la metodologia e soprattutto l'esposizione dei vari passaggi e dei dati in mappe e tabelle (in parte per l'OPP ma in parte per il paper finale che scriverò sulla tesi) (anche testo evidenziato in rosso)
- Interessante perchè si individua cosa viene trattato e cosa è trascurato nei piani municipali sugli aspetti dell'urban heat
- Si parla di gruppi marginalizzati
- Si parla di "GINI coefficient of income inequality", si potrebbe approfondire
- Hanno individuato numerose categorie individuando in quanti piani sono state nominate specifiche parole o concetti come "heat", "equity" ecc. per esempio nei piani climatici o quelli emergenziali
- **Fanno un'analisi interessante su quanto spesso vengono affrontate queste tematiche nei piani**
- Interessante distinzione tra quando viene affrontato il tema EHE (Extreme Heat Events) o UHI
- **Gap su concetti come: "thermal comfort"; "disparity"**
- Interessanti le variabili del dataset (appendice alla fine)

How are cities planning for heat - Analysis of United States municipal plans

This study examines 175 municipal plans from the 50 most populous cities in the United States to understand which aspects of urban heat are included or not in city plans and what factors explain inclusion.

We find that a majority of plans mention heat, but few include strategies to address it and even fewer cite sources of information.

The term 'extreme heat event' (EHE) is significantly more likely to be paired with institutional actions as a part of hazard planning, while 'urban heat island' (UHI) is more likely to be paired with green and grey infrastructure interventions as a part of general planning. Disparity and thermal comfort framings are not significantly related to any solutions and are used least.

Fundamentally, the term 'heat' describes a thermal state determined by multiple climate-related variables including air temperature, radiation, humidity, and air movement that have consequences for the human body and biophysical systems (Oke 1982, Parsons 2002, Kuras et al 2017).

The combined effects of global and urban-scale warming are disproportionately felt by **marginalized groups** due to higher heat exposure and lesser capacity to cope with hot conditions (Harlan et al 2006, Eisenman et al 2016, Hoffman et al 2020, Dialesandro et al 2021).

Figure 3: Example of word analysis sheets

3.4 Results

The Literature Review revealed information that are useful both in understanding how far the research has come and in identifying the gaps to bridge with the present work.

The results of literature research have shown a strong interest in the subjects investigated both at the national level and, above all, at the international level (Fig. 4) which has grown considerably over the last ten years (Fig. 5). Indeed, the Scopus analysis has shown that there is a recent increase in interest in these issues and that the United States is more active, even though the contributions of European countries together are roughly equal to theirs.

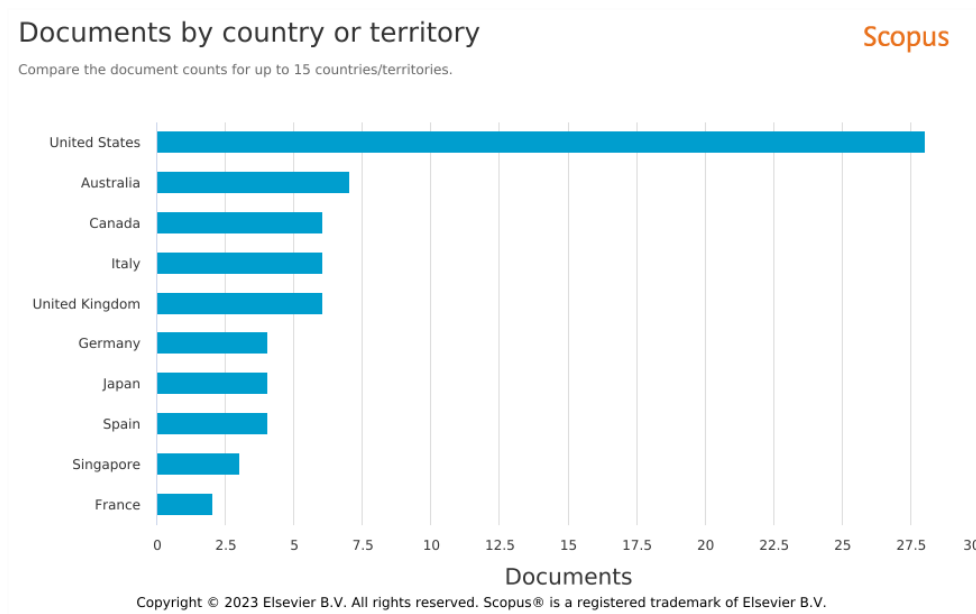


Figure 4: Literature review documents by country or territory (Scopus)

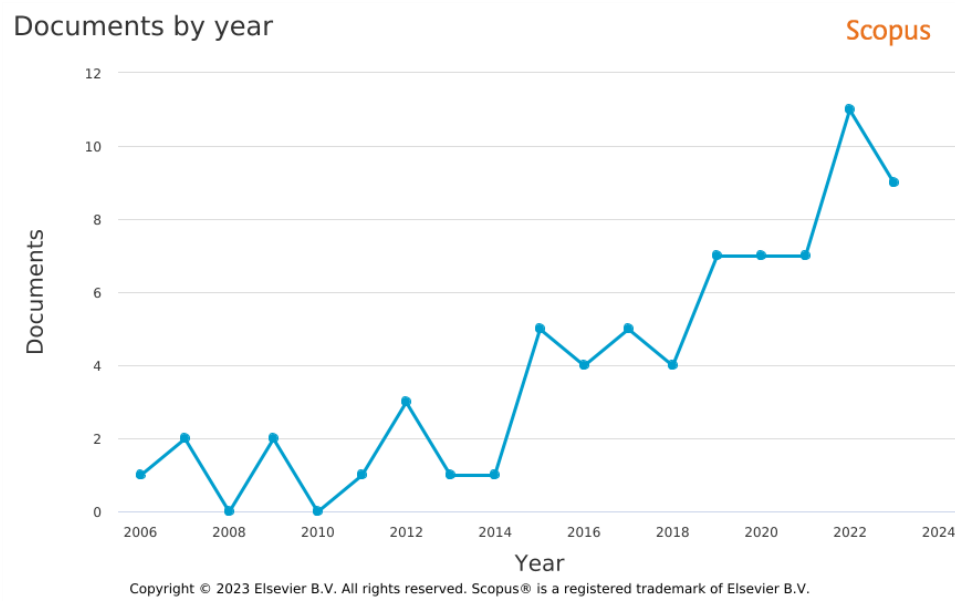


Figure 5: Literature review documents by year (Scopus)

It can also be noted (Fig. 6) that the thematic is trans-disciplinary. Although environmental and social sciences are the areas most concerned by these issues, there is also a strong push for research by medicine, earth sciences and engineering.

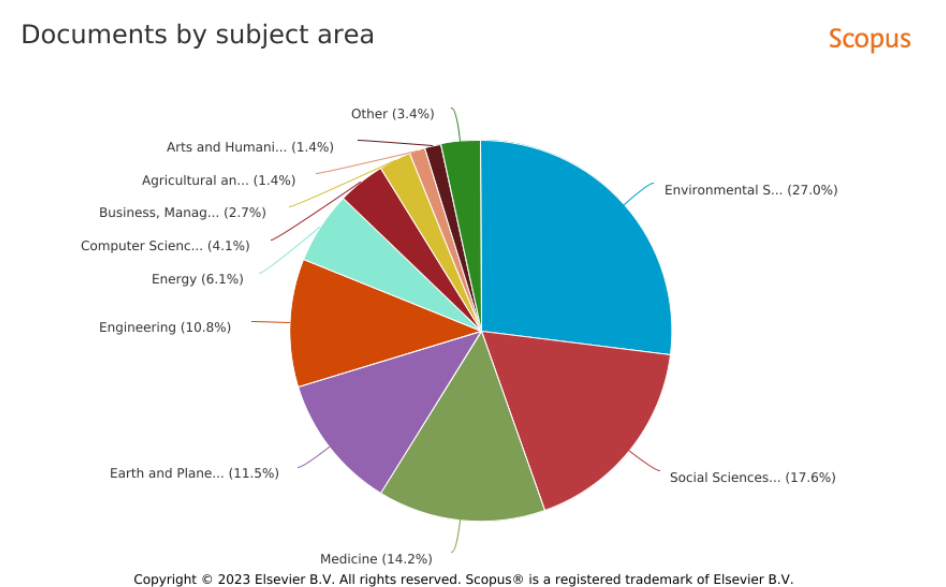


Figure 6: Literature review documents by subject area (Scopus)

The research question that guided this literature review aims to investigate the correlation of very different data, spatial, social, economic, affecting many disciplines and that must find a way to dialogue.

Therefore, I decided to analyse (Fig. 8) (done with VOSviewer, a software tool for constructing and visualizing bibliometric networks) the keywords of the selected papers to understand which ones were most used and their links. In this case too, the trans-disciplinary nature of the issues is evident, as there are numerous relationships between terms that belong to very different research fields, such as “remote sensing” and “social vulnerabilities” or “climate change” and “health risk”. In particular, it emerged that the scientific literature in this field tends to identify three thematic macro-categories: the first concerns climate change and associated concepts such as UHI, adaptation, temperatures; the second focuses on the human factor, considering climate, demographic and social characteristics related to vulnerabilities; the third takes into consideration the spatial component, in this case, the city and the neighbourhood.

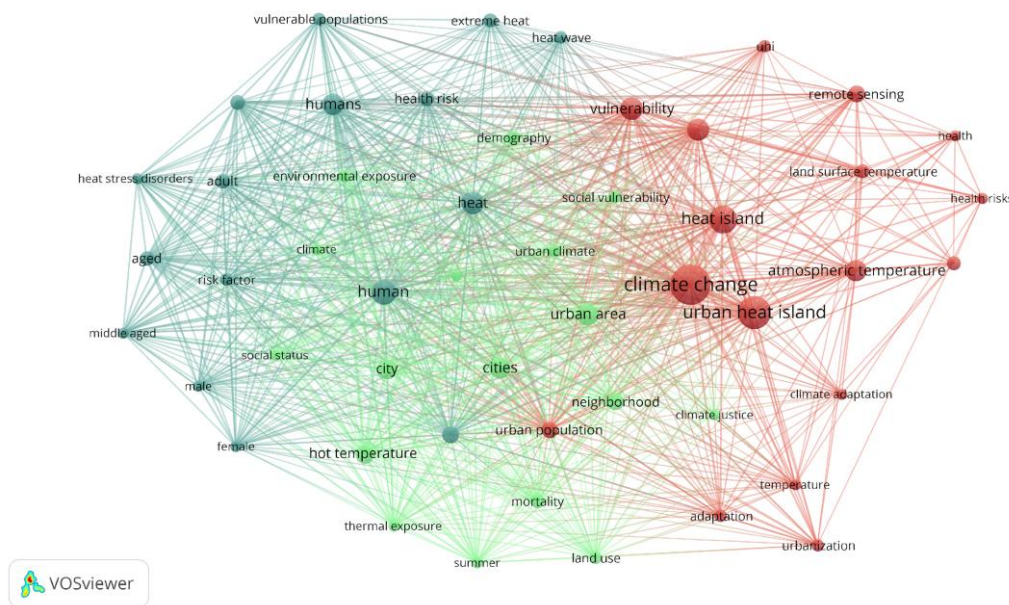


Figure 7: Literature review papers’ keywords analysis (VOSviewer)

In the following paragraphs there will be reported the scientific background emerged from the reading of literature review papers that I decided to divide by thematic areas. The first theme (4.4.1) concerns climate and the extreme events that characterise it. The second (4.4.2) focuses on vulnerabilities and reports which are the most recognized in the literature. The third and final issue (4.4.3) that will be

addressed concerns the effects that the combination of these two factors, climate and vulnerabilities, have on people, with particular attention to health and well-being.

For each topic, definitions will be presented but I will also list and describe methodologies and data that concern them and that are used in the scientific literature.

3.4.1 Environmental and climatic factors

The cluster on environmental and climate factors will focus mainly on the characteristics of spaces that have been and are still being modified by climate change such as extreme heat events and phenomena. There are, of course, many common themes in the papers from this point of view. Since in the string between the words it was indicated the phenomenon of the Urban Heat Island, this term is obviously present in a preponderant way but it is interesting to note that there are other words, not inserted in the literature search string, however much used. Firstly, the theme of climate change remains central in all publications as it is the basis of all phenomena related to extreme heat. The phenomenon of climate change, due to its complexity, must be tackled urgently using a multidisciplinary approach, involving different points of view, from design and engineering to the socio-environmental disciplines (Pisello et al., 2017). In fact, in recent decades these issues have attracted the attention of many disciplines, public opinion and the scientific community (Derkzen et al., 2017).

In particular, the growth of urbanisation, as predicted by many experts, will lead to increasingly negative and evident effects of climate change (Iping et al., 2019), especially extreme heat events (EHEs) that will become more and more severe and long in duration (Lulla et al., 2015). In particular, in urban areas, the effects of climate change are leading to a sharp increase in temperatures (Santamouris et al., 2015; Santamouris, 2015). Some example of this phenomena are UHIs (Janković & Hebbert, 2012; Levermore et al., 2017), heat waves (Iping et al., 2019) and urban heat in general (Coutts et al., 2016).

The UHI phenomenon consists in observing higher temperatures in the city than in the suburban and rural surrounding areas (Heaviside et al., 2017), mainly due to the presence of urban structures and infrastructure's material characteristics (Adams & Smith, 2014). Specifically, UHIs, have developed mainly due to the strong push to urbanisation and the consequent increase in urban density and population (Xie & Zhou, 2015) becoming today one of the most serious environmental problems to be addressed in our cities (Lee et al., 2017).

Another event closely related to climate change are also the Heat Waves (Sagris & Sepp, 2017), which can be defined (although it depends a lot on the location where you are) as periods of extreme heat that last at least three consecutive days with maximum temperatures (Tmax) of 30°C (Huynen et al. 2001; Kysely, 2004).

Data related to these events and phenomena are very useful for analysing both their evolution and effects. There are now many tools that allow you to measure, analyse and map environmental and climate factors and evaluate them quantitatively.

Data, indicators, indices, methodologies and tools most used to analyse the environment and climate, in the selected papers, are:

- Data sourcing:
 1. Remote sensing: sensors and satellites like Landsat and MODIS satellite to perform land cover classifications and thermal behaviour of various urban surfaces (Lee et al., 2017; Declet-Barreto et al., 2016; Van Der Hoeven & Wandl, 2015)
 2. Measurements: fixed-station or meteorological station and car-traverse measurement, to detect UHI intensity and the air temperature (Kolokotsa et al., 2009; Saaroni et al., 2000)
- Modelling, analysing and mapping: with tools like ArcGIS, QGIS, ENVI-met, OpenFOAM, FLUENT, STAR-CCM+, PHOENICS and Grasshopper 3-D and Meerkat (which are based on Rhinoceros software), used especially for urban microclimates (Zhu & Yuan, 2023; Van Der Hoeven & Wandl, 2018; Sabrin et al., 2020)
- Environmental indicators
 1. natural environment: LST (Land surface temperature), vegetation cover and air temperature and heat duration, humidity, heat events, thermal radiation and heat flux, air condition, and weather (Hashemi et al., 2024; Li et al., 2022)
 2. urban environment: accessibility to cooling spaces, land cover/use, and building information (including building density, height, and type), transportation, infrastructure, and urbanisation into consideration (Wu et al., 2022; Jacobs et al., 2019)
- Environmental indices: Normalized Difference Vegetation Index (NDVI) (Abrar et al., 2022; Sabrin et al., 2020; Weber et al., 2015), Fractional Vegetation Cover (FVC) (Sagris & Sepp, 2017), Heat Index (HI), Humidex, and Wet Bulb Globe Temperature (WBGT) (Ncongwane et al., 2021; Li et al., 2022)
- Comfort indices: predicted mean vote (PMV) (Lee et al., 2017), physiological equivalent temperature (PET) (Hashemi et al., 2023), universal thermal climate index (UTCI) (Ellena et al., 2023)

- Environmental categorization systems: for example local climate zone (LCZ) system, which categorise landscapes based on a typical range of values for surface cover, urban structure, fabrics and anthropogenic heat flux (Mounayar & Florentin, 2022; Hashemi et al., 2023; Li et al., 2022)

3.4.2 Vulnerabilities

The vulnerability theme is very vast and complex. The definitions are multiple because it is a factor influenced by a large number of personal variables that can then be combined (as will be explained in paragraph 4.4.3), even to the environmental ones.

It can be defined as “vulnerable persons” people who, due to specific sensitivity, susceptibility or poor adaptive capacities, cannot respond to hazards. It is therefore important, through the study of these characteristics, to understand the elements, factors and conditions that make a person vulnerable (Lulla et al., 2015).

Vulnerabilities can be classified into two main categories: social and biophysical.

In particular, the social ones refer to the demographic, social and economic conditions of people. In this sense, therefore, the factors that can influence this type of vulnerability are, for example, age, gender, ethnicity, education, income, housing conditions, health conditions (Lulla et al., 2015; Iping et al., 2019). Demographic and socio-economic characteristics often reflect the sensitivity and adaptive capacity of the population (Li et al., 2022). For example, regarding age, infants, children, and the elderly are usually more vulnerable (Zhu & Yuan, 2023; Arnberger et al., 2017; Jung et al., 2023).

The factors that determine biophysical vulnerability arise directly from exposure to specific environmental conditions, such as extreme heat or cold (Lulla et al., 2015).

Discussion on risks and vulnerabilities focused on how these factors are unevenly distributed across the city (Iping et al., 2019). For this reason, more and more research and experiences on vulnerability mapping has been developing in recent decades.

Data, indicators, indices, methodologies and tools most used to analyse vulnerability factors, in the selected papers, are:

- Data sourcing: census datasets (Ellena et al., 2023; Huo et al., 2020; Sabrin et al., 2020), community survey (Badaloní et al., 2023), local official socioeconomic datasets or public themed datasets, and WorldPop Global Population Data, datasets published by the Ministry of Health (Li et al., 2022)
- Vulnerability indices: Heat Vulnerability Index (Abrar et al., 2022, Heaviside et al., 2017; Zhu & Yuan, 2023; Johnson et al., 2012; Wolf and McGregor, 2013), Social Vulnerability Index (SVI), Environmental Vulnerability Index (EVI) (Hashemi et al., 2023; Sabrin et al., 2020), Urban Environment and Social Inclusion Index (UESI) (Chakraborty et al., 2019; Hsu et al., 2020), Urban heat island vulnerability index (Abrar et al., 2022), Social Vulnerability Index (SoVI) (Weber et al., 2015)
- Vulnerability indicators (already explained in the paragraph): demographic, social and economic (age, gender, ethnicity, education, economic status, social isolation, employment, language ability, housing conditions, household facilities, health conditions, disabilities (Lulla et al., 2015; Li et al., 2022; Badaloní et al., 2023)

3.4.3 Impact of climate and vulnerabilities on people

The third cluster identified includes the theme of the impacts that one or more of the factors discussed in the previous paragraphs (climate and vulnerability) can have on people.

It is clear from reading the papers included in the review that, especially in recent years, a particular focus was developed on how climate change impacts our lives and health (Ngarambe et al., 2022). In fact, health is becoming an increasingly relevant issue as temperatures rise due to global warming, cities grow and the population becomes increasingly elderly (Iping et al., 2019). Extreme heat deaths are the most frequent when compared to others caused by weather-related natural disaster (Hartz et al., 2011) but also heat-related diseases such as heat exhaustion, heat cramps, heat rash and the heat stroke, are becoming increasingly frequent (Wallace et al., 2007; Lee et al., 2017).

The physiological and psychological response to extreme environments is indeed very complex and prolonged exposure to heat can easily cause a feeling of strong discomfort. Thermal comfort, in fact, is defined as a physiological interval that allows the human body to be satisfied with the thermal environment in which it is (Lee et al., 2017).

As has been pointed out, climate issues are increasingly affecting people's health, well-being and quality of life, but this is not being done in an equal way, because this is part of the theme of environmental justice, and specifically, climate justice (Lulla et al., 2015; Iping et al., 2019). Climate justice was defined in 2000 as the moral obligation to create a just world for all populations, especially those suffering the most from the effects of climate change (European Economic and Social Committee [EESC], 2018). Global warming is not only an important issue to be addressed from an environmental point of view but also from a political and ethical point of view (Bernetti et al., 2020).

Reading the papers it is evident that it is necessary to focus on the factors that determine inequalities, caused by climate change and its related phenomena, between people in different cities (Sanchez-Guevara et al., 2019), in the same city but different neighbourhoods (Tomlinson et al., 2011; Abrar et al., 2022), in similar contexts but with different demographic, social and economic characteristics and vulnerabilities (Ellena et al., 2023; Sagris, Sepp, 2017).

The integration of social and biophysical risk data in spatial analysis and planning is therefore crucial to understand the disproportionate distribution of the effects of climate change at the urban micro-scale, where vulnerability and inequality becomes more pronounced (Lulla et al., 2015).

Data, indicators, indices, methodologies and tools most used to analyse the combination of climatic and vulnerability data, in the selected papers, are:

- Data sources: remote sensing, census datasets (Lee et al., 2017; Declet-Barreto et al., 2016; Van Der Hoeven & Wandl, 2015; Ellena et al., 2023; Huo et al., 2020; Sabrin et al., 2020)
- Heat-vulnerability indices: Heat Vulnerability Index (Abrar et al., 2022, Heaviside et al., 2017; Zhu & Yuan, 2023; Johnson et al., 2012; Wolf & McGregor, 2013), Social Vulnerability Index (SVI), Environmental Vulnerability Index (EVI) (Hashemi et al., 2023; Sabrin et al., 2020), Urban Environment and Social Inclusion Index (UESI) (Chakraborty et al., 2019; Hsu et al., 2020), Urban heat island vulnerability index (Abrar et al., 2022), Urban Heat Risk Index (UHRI) (Jung et al., 2023), Social Vulnerability Index (SoVI) (Weber et al., 2015), Urban Liveability Index (Mounayar & Florentin, 2022; Higgs et al., 2019) (many of these are the same as those indicated for vulnerability, since they obviously concern both general and specific vulnerabilities relating to the environment and climate)
- Modelling, analysing and mapping (with tools like ArcGIS, QGIS, ENVI-met but also field observation): for risk maps, to investigate the impacts of temperature on comfort, to map and visualise the spatial

distributions of heat vulnerability, to calculate and estimate the ambient temperatures corresponding to potential heat risk indicators (Hashemi et al., 2023)

- Methodologies: like “population vulnerability framework” and “risk triangle framework” that combines hazard, exposure, and vulnerability, to calculate heat risk (Li et al., 2022)

3.4.4 Critical analysis and gaps

The literature review highlighted a strong focus on both the effects that climate change has on the environment and how these can have an impact on people and, in particular, on vulnerable populations.

Despite this, however, as confirmed by numerous papers, especially by the literature review of Li et al. (2022), which focuses precisely on the evaluation methodologies of the Urban Heat Vulnerability, there is not yet a systematised and unique methodology for evaluating this combination of factors. This observation is demonstrated both by the fact that in the papers read there are many different approaches and by the fact that almost all the papers are set city by city.

It is therefore important to identify, in a unique and efficient way, planning strategies and approaches aimed at mitigating the effect of these phenomena in order to improve people’s quality of life and their health. In this sense, in the first place, the evaluation of urban spaces in relation to heat may be useful to identify health risk areas in order to intervene with a healthy urban planning (Huang et al., 2020). The topic of heat risk assessment is however much treated while what is missing or that is present only in a small part of the literature is the transition from mapping to heat planning (Turner et al., 2022).

In most cases, in fact, the aim is to identify and evaluate the heat vulnerability without considering the subsequent phases of planning such as that of verification of both design and predictive scenarios (considering possible changes in climatic and/or vulnerability conditions) (Li et al., 2022). Mapping is in fact seen as the preparatory work for the creation of policies and projects and not as a tool to be used in the different stages of planning. In fact, the potential of these tools to support the process of implementing strategies and projects for the reduction of heat-related diseases and for the improvement of the quality of life (Lee et al., 2017), is already known but the application of this concept seems widespread. In the future it will be important to include design and planning parameters as well as the assessment of the heat-related risks combined with vulnerabilities, with the aim to favor human health, well-being and safety (Lee et al., 2017).

To facilitate and simplify this transition from theory to practice there are now many digital tools, also exposed during the report of the results of the literature review, that can be used in the field of microclimate planning in general and heat planning in particular. For example, you can use these tools to make a spatial overlay and combine both physical/climatic and socioeconomic data (Hashemi et al., 2023).

In the selected scientific literature is also evident the complexity of the issues addressed, especially those concerning the human and individual component, for example demographic, social and economic. It emerged that there are not many vulnerability indices (especially when compared to environmental ones) and above all there is a low possibility of finding data on this issue. The difficulty in finding data sources is certainly due to the fact that they concern personal characteristics and for privacy issues the dissemination is difficult. A further difficulty when addressing these issues is that the data that would be used to calculate vulnerability indices have a fairly large grain, usually that of the census, which lends itself only in part to reasoning on the neighbourhood scale and does not allow significant differentiation.

The same applies even more clearly to health data. There are few studies that refer to this data, despite the fact that the term "health" was present in the research string. This is probably due to the fact that health data is even more difficult to find than the demographic, social and economic ones, which I talked about earlier.

Remaining on the health theme, among the selected papers, very few refer to the effect of extreme heat on mental health and well-being (Arnberger et al., 2017). In this case, probably, the difficulty in finding the data is not given only by privacy issues but also by the fact that their collection is mainly based on qualitative methodologies, more complex both to be fielded and systematised.

The last point concerns precisely the issues that are central to my research work: climate justice and climate inequalities. Although we talk about vulnerabilities, very few papers explicitly mention these issues that should therefore have a greater spread.

3.5 Literature review intellectual/scientific contribution

The importance of health in relation to microclimatic conditions is considered, in recent years, one of the main topics of public debate, especially in relation to emergencies caused by UHI and air quality in urban environments. The introduction of mitigation and adaptation strategies can improve people's quality of life and health in urban settings (Singh et al., 2020).

My work is therefore part of a very active debate.

This literature review aims at reporting a series of research and experiences in the field of “heat-related risks” linked to vulnerabilities and with the specific focus on health and well-being.

Between the papers selected, there was also a literature review similar to mine for the thematic addressed (Li et al., 2022). Specifically, they focused their attention on reporting methodologies and research on the assessment of urban heat vulnerability, especially on approaches, indicators and data used for this aim.

The two reviews, however, are not overlapped and this point is confirmed by the fact that the majority of the papers are not in common between the two literature reviews.

Between the original contributions of my literature review, as already mentioned, there is the focus on health and well-being, included also in the research string. This specific thematic makes the work more complex but also more exhaustive because, if one wants to talk about vulnerabilities, often linked to a fragile mental and physical condition, and about heat-related risks for people, it cannot be ignored the comprehension of this typology of information, data and correlations.

The second contribution of this work consists in the fact that selected papers’ analysis and synthesis were addressed specifically following the perspective of the planning support. This approach reflects research perspectives that promote the integration of environmental analysis into planning and design processes. The assessment tools, from this point of view, is not only evaluation instruments but also active components of urban transformation strategies (Pollo et al., 2021)

The focus in my case is in fact on the role that this type of analysis had or could have had in the planning and design of outdoor spaces to have a better quality of life and oriented to climate justice at the micro-urban and neighbourhood scale (the one that was chosen for research work).

3.6 Limits and next steps

As already mentioned, the literature review has three main limits:

- the research has been carried out on just one database (Scopus);
- the research on the database was carried out more than one year ago.

To solve the first problem, for the scientific publication I am working on, I will I will run the research again both on Scopus and Web of Science.

For this thesis I updated the systematic literature review with the same inputs of the first one to have a comparison (see next paragraph).

3.7 Literature review update (2024-2025)

To update the Systematic Literature Review (SLR), conducted during my first PhD year, this section has the aim to integrate the most relevant scientific publications, selected with the same process used for the first one. This update takes in consideration the recent studies (from 2024), highlighting new findings, innovative methodologies and gaps to understand how the research is studying the topic of this thesis. In this update review, specific attention was paid to the evolution of the three clusters (climate and environmental factors, vulnerabilities, and their impacts on health and well-being) identified in the first version of the SLR, highlighting trends and shifts in the research focus.

In recent years, literature on heat-related risks, vulnerabilities and health has grown, reflecting the urgency to understand the effects that climate change has on urban populations (Guo et al., 2025). New findings are emphasizing the importance of integrated mapping at a fine-spatial scale.

Environmental and climatic factors are still the most frequently used in this field of the literature. Contemporary approaches are increasingly incorporating more detailed spatial and temporal resolution for data as in the case of the Land Surface Temperature (LST). Normally this data was derived from remote sensing while now high-resolution thermal imagery, mobile sensing and in situ monitoring are used to deeply understand heat-exposure variability across the neighbourhood (Lee et al., 2017). Studies using satellite-derived LST are still the majority and they are combining this information with census data, such as socio-economic conditions and demographic characteristics, to prove that these factors influence the heat exposure. From these analyses it emerged that disadvantaged populations experience higher urban heat stress (Sahani et al., 2024; Russo et al., 2025).

The most common topics from this point of view are extreme heat and Urban Heat Islands (UHIs) and their analyses are conducted using not only remote sensing but also physical measurement and, in some cases, modelling (ENVI-met, OpenFOAM, ArcGIS) (Zhu & Yuan, 2023). The heat stress risk is not only caused by the direct effect of heat so many studies are investigating and developing indices, integrating other factors as humidity to have an accurate assessment of the thermal comfort conditions (Hashemi et al., 2023).

These growing interest confirmed that environmental and social vulnerabilities are interdependent and the role of the combination between heat, urban morphology and socio-economic factors is a tool to analyse the urban disparities (Abrar et al., 2022; Guo et al., 2025).

New studies are also investigating the dynamic interaction between the microclimatic conditions and urban morphology, showing that some specific characteristic such as street orientation, building density and the presence of green infrastructures can influence the effects of the extreme heat, modulating local heat distribution and, in general, thermal environment (Yang et al., 2025).

The assessment of the vulnerability is having a strong evolution. The indices identified in the first Systematic Literature Review (such as the SVI and the HVI) are becoming more sophisticated considering in their evaluations also local data on age, health, income, housing (Ellena et al., 2023). For vulnerability, several studies are emphasizing the importance of an intersectional analysis to integrate multiple factors and have a clearer frame of the actual risks. The main variables considered are demographic factors, health conditions (chronic illness in particular), social isolation (Sahani et al., 2024).

From recent contributions a limitation in vulnerability assessment emerged. The misalignment between the neighbourhood scale and the census-based data, evidenced the traditional datasets can underestimate the local vulnerability, so a finer scale is needed (Guo et al., 2025). It is interesting to notice that some new studies are considering also mental health and well-being as indicators in vulnerability analysis addressing one of the gaps identified in the first SLR (Arnberger et al., 2017; Russo et al., 2025).

The last cluster identified is combining the heat exposure to human health and well-being and it is still a strong focus for the scientific research. Heat-related morbidity and mortality are the most documented outcomes but, new findings highlighted the effects of prolonged heat exposure on the quality of life from different pints of view, going from the sleep disruption to mental health stressors, and accelerating the chronic disease progression (Ngarambe et al., 2022; Singh et al., 2025).

The combination of these three topics, climate, vulnerability and health problems related to these factors, is a relevant topic in the scientific debate. From neighbourhood scale analysis emerged that higher heat stress, with all the health consequences related to it, is experienced by residents with low-income living in high-density areas (Tomlinson et al., 2011; Wang et al., 2024). This disproportional effect, highlighted by several studies, underscore the importance of climate justice considerations in urban planning but, in policy and planning sector, this specific topic is still underrepresented (Li et al., 2022; Palanisamy et al., 2024). The use of vulnerability and environmental indices to develop heat risk maps is increasing but

the translation from mapping to actual policy, planning, or design interventions is still limited (Turner et al., 2022; Ho et al., 2025).

The updated Literature Review is characterized by a focus on the need of transdisciplinary approaches for planning processes. Numerous tools now allow the use in formal planning of integrated territorial analysis for microclimate and vulnerability. The integration of these kinds of analysis, anyway, is still sporadic, reducing their potential and practical impacts (Singh et al., 2025; Palanisamy et al., 2024). Even if in the recent studies, higher-resolution data are considered, gaps persist for modelling design scenarios and predictive planning (Russo et al., 2025; Guo et al., 2025).

In conclusion, the literature review update confirms the previous findings and gaps identified. Addressing these gaps is the direction and aims of this thesis and future research.

The Systematic Literature Review will be published, in its updated version, in the next months.

3.8 Schematic analysis of some selected papers

In the following tables are presented 8 of the 104 papers selected, which have specific interesting features for my research. In the first table (Table 2) there are only references of authors, year of publication and title. In the second table (Table 3), the article is presented with a brief description and some important information such as data, tools, indexes and scale. The third table (Table 4), instead, highlights the gaps identified by the analysed paper.

YEAR and AUTHORS	TITLE
2009_Richardson G.R.A., Otero J., Lebedeva J., Chan C.F.	Developing Climate Change Adaptation Strategies - A Risk Assessment and Planning Tool for Urban Heat Islands in Montreal
2011_Tomlinson C.J., Chapman L., Thornes J.E., Baker C.J.	Including the urban heat island in spatial heat health risk assessment strategies - A case study for Birmingham, UK
2018_Van Der Hoeven F., Wandl A.	Hotterdam: Mapping the social, morphological, and land-use dimensions of the Rotterdam urban heat island
2019_Chakraborty T., Hsu A., Manya D., Sheriff G.	Disproportionately higher exposure to urban heat in lower-income neighbourhoods - A multi-city perspective
2022_Mounayar R., Florentin D.	Enlarging the Human Climate Niche: Integrating Urban Heat Island in Urban Planning Interventions
2023_Jung M.W., Haddad M.A., Gelder B.K.,	Examining heat inequity in a Brazilian metropolitan region
2023_Ellena M., Melis G., Zengarini N., Di Gangi E., Ricciardi G., Mercogliano P., Costa G.	Micro-scale UHI risk assessment on the heat-health nexus within cities by looking at socio-economic factors and built environment characteristics: The Turin case study (Italy)
2023_Hashemi F., Poerschke U., Iulo L.D., Chi G.	Urban Microclimate, Outdoor Thermal Comfort, and Socio-Economic Mapping: A Case Study of Philadelphia, PA

Table 2: Data of eight representative papers

REFERENCE	BRIEF DESCRIPTION	DATA, TOOLS, INDEXES and SCALE
Richardson et al. (2009)	• How to develop and implement evaluative tools and policies for adapting to UHIs in Canada (the purpose of this paper is to help fill that gap) • A two-part approach to developing UHI adaptation strategies: first, evaluate and map the risk to human health, and second develop site specific actions for those areas most at risk • Using a risk based resource allocation methodology they first identified residential areas on the island where UHI exposure and vulnerability are most pronounced	- GIS - UHI phenomenon examined at the city and block scales of analysis
Tomlinson et al. (2011)	• The purpose of this interdisciplinary study is to integrate remotely sensed urban heat island data alongside commercial social segmentation data via a spatial risk assessment methodology in order to highlight potential heat health risk areas and build the foundations for a climate change risk assessment • This paper uses the city of Birmingham, UK as a case study area • When looking at vulnerable sections of the population, the analysis identifies a concentration of very high risk areas within the city centre, and a number of pockets of high	- Remote sensing, GIS - Risoluzione di circa 1 km

	risk areas scattered throughout the conurbation	
Van Der Hoeven and Wandl (2018)	• The Hotterdam study accordingly measured urban heat and modelled the surface energy balance in the Dutch city of Rotterdam • It identified in detail the city's social, morphological and land-use dimensions using a geographic information system (GIS), 3D models and satellite images • It used analyses to determine the links between temperatures and social, morphological and land-use aspects • The Hotterdam study did establish a link between the urban heat island effect in Rotterdam and the health of its population • They mapped these aspects in two heat-maps that help in setting priorities for implementing climate adaptation measures	- GIS (ArcGIS), satellite images - Regression analysis - Surface UHI (SUHI), surface albedo, normalized difference vegetation index (NDVI), leaf area index (LAI) - 100x100 grid

Chakraborty et al. (2019)	• Since the UHI intensity varies not only across, but also within cities, intra-city variation may lead to differential impact of urban heat stress on different demographic groups • To examine these differential impacts, they combine satellite observations with census data to evaluate the relationship between distributions of both UHI and income at the neighborhood scale for 25 cities around the world • In most (72%) cases, poorer neighborhoods experience elevated heat exposure, an incidental consequence of the intra-city distribution of income in cities • This finding suggests that policymakers should consider designing city-specific UHI reduction strategies to mitigate its impacts on the most socioeconomically vulnerable populations who may be less equipped to adapt to environmental stressors	- Satellite observations with census data - UHI
Mounayar and Florentin (2022)	• This article explores the potential of linking the human climate niche and heat island research • Literature review on the relationship between UHI and health • Not done yet: find solutions and conceptualising the cumulative impacts of urban heat island on health and vulnerable populations • Based on the coupling of ENVI-met computational simulation and the local climate zone method, this article quantifies	ENVI-met and local climate zone UHI

	mitigation solutions and associates the frequency and intensity of heat stress and health-related symptoms in various urban settings • Drawing on a real-case urban intervention in Paris, it offers a more effective health-related and comfort-focused approach to urban planning and interventions to expand the human climate niche	
Jung et al. (2023)	• Literature on climate justice, specifically heat inequity, there are very few studies about Global South urban areas • The study examines the spatial relationships between heat risk, urban form composition and vulnerable social groups in Belo Horizonte Metropolitan Region (BHMR), in Brazil • Non-White population, low-income residents and the elderly population were statistically significantly associated with heat risk • The case study exemplifies that climate justice is not taking place in BHMR, and specifically, heat inequity is being experienced by vulnerable social groups	Regression analysis, satellite images (Land Surface Temperature), urban heat risk index (UHRI) combining LST, standardized value of land surface temperature and standardized values of NDBI and NDVI, ArcGIS Pro
Ellena et al. (2023)	• No common metrics have been defined yet on assessing the risks associated with the heat-health nexus in urban areas • The objective of this study is to provide an empirical example of a flexible and replicable methodology to estimate the micro-scale UHI risks within an urban context which takes into account all the relevant	- Micro-scale - Census tract

	elements regarding the heat-health nexus • The city of Turin has been used as a case study • The risk framework presented here used a quantitative estimate per each census tract within the city based on the interaction of three main factors: hazard, exposure, and vulnerability • Georeferenced maps for each indicator to increase the local knowledge on the spatial distribution of vulnerability drivers	
Hashemi et al. (2023)	• Intensity of the UHI effect is influenced by a variety of factors, including urban morphology, which can vary from one area to another • To investigate the relationship between outdoor thermal comfort and urban morphology in different urban blocks with varying social vulnerability status, this study developed a geographic information system (GIS)-based workflow that combined the “local climate zone” (LCZ) classification system and an urban microclimate assessment tool called ENVI-met • To demonstrate the effectiveness of this methodology, the study selected two different urban blocks in Philadelphia, Pennsylvania - with high and low social vulnerability indices (SVI) - to compare their microclimate conditions in association with urban morphological characteristics such as green coverage area,	- UHI, thermal comfort, urban morphology, social vulnerability - GIS, “local climate zone”, ENVI-met - “Social Vulnerability Index” (SVI) - Outdoor thermal comfort: predicted mean vote (PMV), physiological equivalent temperature (PET), universal thermal climate index (UTCI), standard effective temperature (SET) - “Mean radiant temperature” (MRT) - Grasshopper 3-D e Meerkat, Dragonfly

	sky view factor (SVF), albedo, and street height to width (H/W) ratio • The investigation discovered that reduced SVF, along with increased albedo and H/W ratio, had a beneficial impact on the microclimate at the pedestrian level within the two studied urban blocks • This study provided an effective and easy-to-implement method for tackling the inequity issue of outdoor thermal comfort and urban morphology at fine geographic scales	
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Table 3: Content synthesis of eight representative papers

REFERENCE	GAPS
2009_Richardson et al.	- UHI adaptation strategies should be neighborhood specific, responding to local physical, demographic and socio-economic characteristics - Need for more and better data to assess UHIs and evaluate the temperature reduction potential of different strategies - When deciding among UHI reduction strategies: include future climate change and urban development scenarios, as well as socio-demographic projections - Further progress toward tackling UHI risk requires ongoing collaboration between many different disciplines

2011_Tomlinson et al.	- Further analysis looks at household level data which yields a complicated picture with a considerable range of vulnerabilities at a neighbourhood scale - No explicit temperature values have been mentioned (it is deliberate as the focus has been the spatial identification of risk groups) - They assumed that a single day “snapshot” of UHI data is representative of varying conditions
2018_Van Der Hoeven and Wandl	- A data that describes the weather in the various neighbourhoods of the city of Rotterdam does not exist (but they used remote sensing and crowdsensing) - The dimension of the grid is related to the resolution of satellite images and to the smallest spatial unit for demographic data
2019_Chakraborty et al.	- Able to collect income as a crude proxy of neighborhood-level socioeconomic status available for all cities in the sample - With more granular socioeconomic data, a more consistent unit of analysis may be possible in future research - Use of the Earth’s surface temperature instead of air temperature to estimate the UHI, since air temperature is more strongly coupled with heat stress - Monitoring intra-urban variation in air temperature is necessary to better quantify the spatial distribution of urban heat and its consequences - This initial analysis consists of a single snapshot in time
2022_Mounayar and Florentin	- Microclimatic modelling almost exclusively from a temperature-oriented perspective - They voluntarily disregarded some other major elements influencing urban interventions and specifically economic ones - Socio-political dimension should be taken into account in long-term perspectives

	- Need to combine the results with additional elements to target vulnerable locations and populations
2023_Jung et al.	- To deeply understand urban heat inequity: conduct more studies across the globe to allow comparison under different urban forms - Further research analyzing the difference between past and present vulnerable socio-economic status in relation to UHIs - Future qualitative research to understand how cities from the Global South can include and implement climate justice in their CAPs and justice-related strategies for UHIs
2023_Ellena et al.	- The indicators have each been combined with the same value (i.e., weight), in any future investigations, the indicator weighting processes must take into account - This study did not include engagement with local stakeholders (such as health policy makers, urban planners) despite being highly recommended as iterative processes
2023_Hashemi et al.	- The research involved a 24-h simulation cycle, while it is recommended for future studies to extend the timeframe to 48-h or 72-h cycles - ENVI-met models were supplemented with generic data from the LCZ datasheet for building typology and properties - The research solely concentrated on outdoor weather variables and comfort levels - The research concentrated only on Philadelphia, PA, from the U.S. Northeast region

Table 4: Gaps synthesis of eight representative papers

Chapter 4

Research methodology

4.1 Introduction

This chapter presents the methodological framework adopted for this research. The research has been developed in a sequence of steps to address the research question. The methodology ensures a rigorous and reproducible approach, starting from the systematic literature review, passing through the digital tools analysis and the validation of the workflow applied to two case studies and validated thanks to the experts' participation.

The research has been developed over the three years of the PhD and each year has been characterised by specific objectives to be achieved and different methods of investigation, analysis and implementation. The research objectives implied a path that goes from the general, with the study and analysis of the state of the art, to the specific, with the development, the implementation and the validation of the workflow to support project areas' selection and design scenarios' choice in planning for climate justice.

The choice of this theme was dictated, as previously stated, by the need for responses through planning to climatic emergencies and vulnerabilities exacerbated by these phenomena. Currently, in the literature there are numerous studies that analyse the effects of extreme heat on vulnerable people and many of these also carry out mapping to visualise if there are inequalities. There are also numerous programs and plans, at the municipal level, that address issues related to extreme heat and that use this type of mapping to identify the most vulnerable areas, also crossing the demographic, social and economic data. The output of this research will support decision makers in using these kinds of tools to choose the area of interest based on risk mapping, but also to develop and identify the best design strategies, through the simulation, in the post-design phase.

The choice of this topic also reflects a strong personal interest. Prior to the PhD, I focused my work on understanding how public spaces (outdoor and indoor) can

foster physical, social and psychological well-being. Putting health and a good quality of life at the centre is in fact one of the objectives that planning must set with respect to every decision to be taken. I approached planning with the idea that health, well-being and the quality of life should be central in projects, strategies and policies. The research group I have been collaborating with investigates the relationship between environmental quality and human health, studying, in particular, the parameters affecting outdoor comfort. Specifically, through the activities of research and tutoring, I had the opportunity to deepen the use of a CFD software (ENVI-met) that allows the simulation and evaluation of key microclimatic parameters relevant for outdoor comfort.

4.2 Methodology and aims of the research

The research process, as already mentioned, is characterised by different phases that have specific methodologies and objectives. Research is mostly based on digital data and tools that have a predominantly quantitative nature. For this reason, in the course of the work, reference will be made, in most cases, to quantitative methods of investigation and analysis.

Nevertheless, when I involved the experts for both the interviews and the workshop, to discuss and validate the workflow, I used qualitative survey methodologies.

In general, the phases of the work were: theoretical (I year); development (II year); implementation and validation (III year).

During the first year, in fact, I carried out the literature review using a systematic methodology to avoid or limit biases and following the PRISMA method (The Preferred Reporting Items for Systematic reviews and Meta-Analyses), to report all stages of the work in a clear and transparent way (more details in Chapter 3).

The second year was dedicated to the analysis of the digital tools already available and the plans for heat-related risks of municipalities. Both these analyses were useful to define the workflow and the guidelines. These "tools" (workflow and guidelines) are the main outputs of my PhD research.

During the first part of the second year I carried out the selection of digital tools to be included in the model, guided by the systematic literature review carried out during the first year (more details in Chapter 3) and a more oriented literature research on digital tools for microclimate planning (more details in Chapter 5).

The second part of the second year was focused on three main activities (more details in Chapter 5):

- 1) digital tools study: study and experimentation of the digital tools identified during the first part of the year to find their potential in the planning processes for extreme heat risks' mitigation (more details in Chapter 5)
- 2) plan and programmes analysis: research and analysis of plans and programmes, national and international, which, at the municipal level, address the issue of "extreme heat risk" (more details in Chapter 5)
- 3) workflow draft: definition of the draft of the "workflow" for the integration of digital tools within national and international plans and programmes, which, at the municipal level, address the issue of "extreme heat risk", through the integrated territorial mapping (more details in Chapter 5)

In this phase of the work the definition of the digital tools to be used for the development of the "workflow" (the base for the guidelines) was important. In particular, following the results of the literature review (chapter 3) and literature research on the digital tools for microclimatic planning (chapter 5), I decided to use the combination of ENVI-met and QGIS⁵ software. ENVI-met is not used, in this case, to predict heat waves (a question of climatology and meteorology) but to understand, based on the input of meteorology, how local situations can worsen or improve inequity and, in perspective, how changes can be effective.

It was also very important to analyse the mechanisms that underlie the plans for the "extreme heat risks" to understand how it is limited the use digital tools in the

⁵ "GIS stands for 'Geographical Information System'. A GIS consists of: Digital Data - the geographical information that you will view and analyze using computer hardware and software; Computer Hardware - computers used for storing data, displaying graphics and processing data; Computer Software - computer programs that run on the computer hardware and allow you to work with digital data. A software program that forms part of the GIS is called a GIS Application.

With a GIS application you can open digital maps on your computer, create new spatial information to add to a map, create printed maps customised to your needs and perform spatial analysis." (qgis.org)

process of drafting. The analysis was also useful to identify the main characteristics of the plans and programmes on these topics: scale of interest or intervention (urban, neighbourhood, building), aims and outputs (operational, analytic, informative), methodologies and tools.

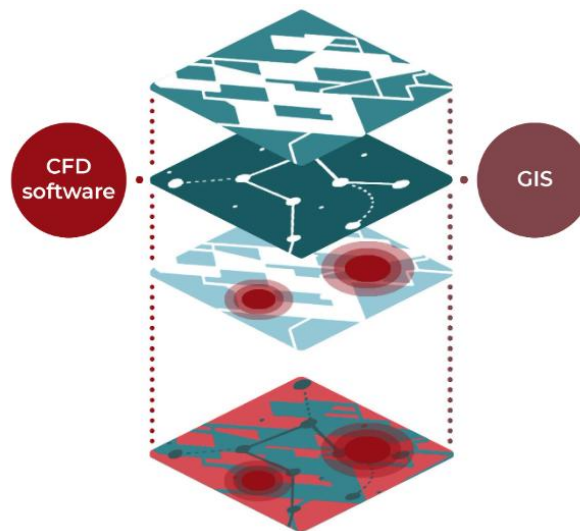


Figure 8 - Schematic workflow diagram

The third and final year has been characterised by the closure of some activities started during the second year (the draft of the workflow) and the implementation of the tool (workflow to support project areas' selection and design scenarios' choice) in two case studies and its validation. The application of the workflow was not limited to an Italian case study (Turin) but I also used an international one (San Antonio, Texas). The opportunity to collaborate with foreign universities has been very useful and interesting.

It is easier to make contacts and collaborate with organisations that have already developed an awareness of the importance of these issues in urban planning, so this was one of the main criteria for my choice (more details in chapter 5). I created a dialogue with some universities, both Italian and foreign, that have collaborated in the drafting heat plans or have conducted research on this topic. Through qualitative surveys (semi-structured interviews), I collected information on how these types of plans work, on what role they play in the overall urban planning and design system

and what could be useful to consider for the workflow development to improve the effectiveness of the plans.

The interviews have been useful also to find a host university for my period abroad, the University of Texas at San Antonio. My period abroad allowed me to relate to a different context, both from an academic point of view and for the diverse planning conceptualization and processes.

The general aims of this research concern both the conceptual and the operational framework.

As for the conceptual, the research is part of the scientific debate on the correlation between the environment, especially the microclimate, and the goal to create good conditions of health and well-being, equal for all. The relevance of this topic is evident also talking about new digital tools and their use in planning, a very important thematic to be addressed.

From an operational point of view, the results and the outputs (workflow and guidelines) of the research can be used directly in planning and design processes of urban outdoor spaces, simplifying and optimising these activities, in order to fully develop the potential of new technologies.

4.3 Expected results

Based on the background, the research objectives and the methodological framework adopted, this section presents the expected results of this research.

During the course of the PhD, some of the initial expected results of this research were partially or totally revised to be aligned to methodological and technological developments that emerged during the process.

In particular, there has been three elements that changed the expected results of this research. They are outlined below:

- initially, the research aimed to develop a methodology to simplify the integration of climate and demographic, social and economic data, by promoting interoperability between microclimate simulation software and other data visualisation tools. However, in 2024, during my second year of PhD, the release of a QGIS plug-in for ENVI-met, facilitates

the data integration. This tool was therefore used in this research workflow, incorporating it in the process;

- the research originally planned to develop a methodology to map climatic data by crossing them with those of vulnerabilities related to demographic, social and economic factors but it emerged from the literature review that there are already tools and approaches addressing this objective. Rather than duplicating the existing methods and data, the research adopts these tools, with a specific focus on improving climate data sources and resolution (more details later in this paragraph).
- the original intention of this research was to develop a new planning tool, at the municipal level, to support the choice of the areas to design and of the best project scenario. During the research, as already mentioned, extreme heat risk plans analysis showed that most of them are mainly analytical rather than operational. The proposed workflow aim to integrate digital tools into these planning processes to support the selection of intervention areas and the choice of the best project scenario, within this existing typology of plans. The aim, in this case, is to strengthen the link between analysis and future-oriented planning actions (more details later in this paragraph).

The updated expected results of this research consist of: a systematic literature review on the correlation between health, microclimate conditions and vulnerable people; a replicable “workflow” for the use of digital tools to support decision-makers in project areas’ selection and design scenarios’ choice, translated into practical step-by-step guideline to facilitate its application by decision-makers.

The first result of this research, the literature review, provides a comprehensive overview of the current state of research and the experiences carried out so far addressing the correlation between health and well-being, climatic and microclimatic conditions and vulnerabilities related to demographic, social and economic factors. This result also enabled the identification of several gaps in this area. Some of these gaps are addressed through the other result of this work (workflow and guidelines), others will be exposed and may be directions for future research.

The second result of this research consists of a replicable workflow that structures the use of digital tools to support decision-makers in project areas’ selection and design scenarios’ choice. This workflow can be applied both for the

development of new “extreme heat risks” plans and for the integration and revision of existing ones. Its practical implementation is ensured through step-by-step guidelines to integrate some digital tools both during territorial analysis, in the project areas’ selection, and in the design phase to choose the best alternative project scenario.

4.4 Contribution of the research

The contribution of this research lies in its response to key gaps identified both in the systematic literature review and the analysis of the planning practices. By targeting these gaps, the research aims to provide methodological and operational contributions to the climate justice field and debate.

The first gap that emerged from the literature review relates to the limited experience of integrating climate justice principles with the use of microclimate simulation tools in scientific research and practice, both in the analytical and design phases. This research contributes by encouraging the systematic use of these tools, demonstrating their relevance and potential in the planning and design phases. The proposed workflow is intended to support public administrations, which often face difficulties or delays in adopting new technological and digital tools. By developing the workflow, and the guidelines to facilitate its application, the research seeks to strengthen the link between territorial analysis and design choices, integrating also microclimate simulations into planning processes.

The second gap, identified through both the literature review and the analysis of plans, programmes, projects and research on these topics, concerns the difficulty of translating climate emergency strategies into operational tools at the micro-climate scale. Existing plans and programmes are often highly analytical or strategic, without a clear application, especially at the neighbourhood scale. This research addresses this issue by proposing a replicable workflow, tested through two case studies, adaptable to different territorial contexts, and transferable to other geographic and climatic conditions. While in this research, the workflow is applied to extreme heat and vulnerabilities, it may also support decision-making processes related to other types of urban interventions, including cooling strategies, air quality improvement, climate shelters planning.

By addressing these gaps, this research aims to move beyond purely analytical approaches and to support a more context-sensitive and equitable planning.

4.5 Target subjects

The main target of this research is represented by the public administrations responsible for the planning of urban spaces, with a particular focus on sectors addressing environmental policies and climate change mitigation and adaptation strategies. Specific attention is given to institutions and actors involved in the development of plans and projects addressing extreme heat events and phenomena. Decision-makers are considered as the main audience for my research outcomes, particularly for the guidelines to facilitate the use of the workflow. In this perspective, this research also addresses public administrations with the aim of strengthening their understanding of the role that urban outdoor spaces as key components of climate-responsive strategies to improve the thermal comfort and the quality of life.

Then research targets also the practitioners engaged in urban and environmental planning, including freelance professionals, consultants, and researchers working on climate change mitigation and adaptation. In this case, the research aims to raise the awareness of the potential of digital tools as effective supports for daily work activities, demonstrating how they can enhance analytical capacity and inform design and planning decisions.

Citizens and local communities are also identified as a further target group of this research. The use of territorial integrated mapping is intended to make spatial inequalities and exposure to climate risks, more visible and understandable. By increasing awareness of the challenges posed by extreme heat and microclimate conditions, this research aims to promote a more informed and responsible engagement of the citizens. This awareness can support greater acceptance of, and collaboration with, planning strategies that can involve trade-offs or temporary discomfort for citizens, but are intended to improve the quality of life and urban environments.

All these targets reflect the multi-level and multi-actor nature of climate-responsive urban planning.

Chapter 5

Research development

5.1 Introduction

The three-year doctoral research was structured into five phases: background framing (5.2); territorial mapping and analysis: plans, programs and projects for extreme heat risks response (5.3); workflow development (5.4); workflow testing and application (5.5); guidelines definition (5.6). This chapter illustrates the development of this research through these phases.

From the first phase of the research, the systematic literature review, provided the conceptual and theoretical foundation for the entire doctoral work. This state-of-the-art analysis enabled the identification of relevant experiences and research on the relationship between extreme heat, health and vulnerability, as well as the limits and gaps in this field. These findings played a key role in orienting the subsequent steps of the research.

Based on the outcomes of the literature review, a second phase focused on the analysis of selected experiences. This phase is preliminary and fundamental for the subsequent construction of the research methodology and the creation of the workflow. In particular, plans, programmes, projects and research which have themes and objectives similar to the present research were analysed. In particular, this analysis highlighted the importance of data and indicators that can be visualized and integrated through spatial mappings.

The third phase focused on developing a workflow to be applied to spatial planning, to counter extreme heat and its consequences on the health of people, with particular attention to vulnerable populations. At an operational level, the guidelines (5.5 Guidelines definition) describe the workflow to produce territorial mappings that integrate and analyse climate data (especially those related to extreme heat) together with vulnerability indicators and urban morphology.

Following the workflow development, the methodology was applied to two contexts, one at the national level (Turin) and one at the international level (San

Antonio). In this phase, territorial integrated mappings of these two cities were produced, based on the proposed workflow. The resulting maps were analysed to identifying the potential use of these tools within urban planning processes.

The final phase of the research development focused on the definition of the guidelines. This phase translated the workflow, synthesising the entire research process, into a structured and transferable set of guidelines for climate-responsive planning and design processes.

5.1.1 Visiting research period at the University of Texas at San Antonio

My time spent in University of Texas at San Antonio allowed me to learn about the work that the Climate-Sensitive Design Lab (CSDL), created by Professor Farzad Hashemi, is leading on their research topics and to understand what new steps we could take together to carry forward research in the field of climate justice and digital technologies for the adaptive design of urban spaces. A relevant and important thematic nowadays.

First of all, we defined the objective of experimenting my PhD research digital workflow in both cities. In short, the workflow consists of the analysis of microclimatic, vulnerability and morphological data of the city, developed through mappings, simulations of microclimatic conditions, design of adaptation strategies and simulation of project scenarios with related results' analysis. It was therefore decided to carry out a parallel and comparative work on the cities of Turin, Italy and San Antonio, Texas (USA).

To ensure that this comparison was based on solid foundations, my visiting period was fundamental. In fact, I had the opportunity to get to know the city of San Antonio by discussing and analysing the mappings and data processed by the Climate-Sensitive Design Lab (CSDL). Furthermore, no less importantly, I had the opportunity to directly observe the city, especially some vulnerable areas on the Westside.

The analyses and direct observation led us to develop common analysis criteria for the two cities to make the research results comparable. The variables examined are microclimatic (we take into consideration the summer period), vulnerability (analysing the income and selecting areas of low, medium and high income range)

and morphological (working on areas of LCZ 6, which is the most present category characterizing the two cities).

The collection and analysis of these data together with the definition of the future objectives for our research between the two cities was an important first result of this collaboration and this visiting period.

5.2 Background framing

The systematic literature review described in Chapter 3 was the initial step of this research. The final phase of the review focused on an analysis to extract the key concepts and tools useful for the construction of the workflow.

This phase has been organised into two complementary directions:

- identification of key concepts and tools to be used in research (5.2.1)
- identification of gaps to be filled by my research (5.2.2)

5.2.1 Key concepts and tools from literature

The analysis of the previous studies in this field highlighted several concepts and tools fundamental for this research.

First, previous research was predominantly based on quantitative methodologies and approaches and often used digital tools for territory analysis of the. These tools are useful to evaluate vulnerability patterns, urban morphology and intervention impacts. Their application and integration in urban planning processes can be relevant and can ensure that decisions are grounded in evidence and reproducible methods, a key objective of this research and the workflow proposed.

Another important concept highlighted in the literature is the use of vulnerability indices, a well-established method for linking social, economic, demographic factors to environmental and climatic conditions. These indices provide a comprehensive assessment of risks and susceptibility, capturing complex interrelations and relationships that a single indicator cannot represent. In particular, as required by the research string itself, this work focuses on linking

climatic conditions, urban morphology and vulnerability, especially in relation to demographic, social and economic factors. Previous studies have already worked on what factors make individuals and communities vulnerable (as discussed in chapter 3). In spatial analysis, these data are often integrated into composite indices to capture all the complexity of this thematic but also to operationalize these factors. As already pointed out in paragraph 3.4.2, the indices vary in nature and in the factors they include, depending on their purpose. Indices are crucial tools: vulnerability cannot be assessed without a framework to reflect the multiple dimensions of this concept. This research considered only indices that are validated and supported by scientific publications.

The literature also shows a strong link between the quality of spaces (both open and closed), human health and vulnerability. It is now widely and scientifically recognized that the quality and the characteristics of spaces can influence physical, psychological and social conditions in a positive or negative way. Vulnerabilities can be reduced, amplified or even created by the spatial environment (depending for example on their accessibility, design and maintenance) that people inhabit or frequent daily, such as workplaces, schools and residential areas. In the specific case of this research, focusing on the neighbourhood scale, it is therefore essential to study the spatial distribution of health and vulnerability data. Understanding how and which spatial factors influence well-being, provides insights into where interventions can improve public health and enhance the quality of life.

In this sense, numerous studies highlighted the need to address justice and equity in urban quality of life. Within cities, certain neighbourhoods are more vulnerable from several points of view such as for the impact, effects and consequences of extreme heat, the limited presence of vegetation, the poor quality of the open spaces, the reduced access to services. These areas are often inhabited by people already experiencing demographic, social, or economic vulnerabilities. Although it is evident that addressing these disadvantages requires political will and resources allocation, a clear understanding of the underlying causes may encourage and stimulate such policies and interventions, motivating both top-down and bottom-up actions. This research, on a small scale, aims to raise awareness of these disparities and provide a practical tool (the guidelines for the workflow) to support, stimulate and encourage interventions that promote equity and resilience.

5.2.2 Gaps identified in literature

The analysis and critical reading of scientific literature have also revealed gaps that this and other research can and must address.

Firstly, one of the most relevant issues concerns data, especially in relation to spatial analyses. Availability, resolution and quality of data strongly influence analytical outcomes, emerging as critical limitations in many studies.

This research focused on climate, economic and morphological data, fundamental for understanding the urban vulnerability patterns.

With regard to climate data, the literature shows that most studies, research and projects rely on satellite sources, which often lack fine spatial resolution (Sagris & Sepp, 2017; Heaviside et al., 2017). While some research integrates satellite data with direct measurements (Li et al., 2022), only a limited number of studies (Mounayar & Florentin, 2022; Hashemi et al., 2023) employ simulations to enhance spatial accuracy using software allowing to achieve resolutions of up to one meter, such as ENVI-met. Satellite data are widely used due to their immediate availability but their rough resolution may not be suitable when addressing design-oriented objectives, especially at scale smaller than the entire city. For this research, which investigates and focused on the neighbourhood-scale environments and the configuration of spaces between buildings, higher level of detail is required. For this reason, this research prioritizes tools and datasets capable of supporting a fine-scale.

Vulnerability and health data have further limitations related to their scale and their availability. Due to their sensitive nature, which concerns highly personal aspects of individuals' lives, these data are rarely openly available and are usually owned and managed only by public authorities, at different administrative levels (state, regional or municipal). When these kind of data are available and accessible for research purposes, they are typically aggregated to protect individual privacy, reducing their spatial resolution. Depending on the scale of aggregation, different types of analysis can be conducted. In this research, previously developed analysis produced by public authorities and institutions, are used, when providing sufficiently detailed information for neighbourhood-scale investigations.

The data usually used to determine vulnerabilities (demographic, social and economic data) have much in common with health data for limitations related to privacy, spatial resolution and accuracy. Across different geographical contexts, in

it interesting to note that census tract data are the most frequently employed, as the census remain the most comprehensive and standardized source for such information in many countries. The census-tract scale can sometimes oversimplify complex realities or require further aggregation, being too detailed or too rough. In addition, in some countries (as in Italy) the census is carried out on a voluntary basis and this makes the data potentially incomplete and not entirely accurate. Despite their limitations, census data offer the advantage of public availability. Alternative data sources, such as targeted surveys (such as questionnaires or interviews) or project-based data collections (for example in European programs), are sometimes more interesting or suitable for a specific research purpose but they are less common and often not fully accessible. This research adopted census-tract datasets considering them an appropriate compromise, available in both countries analysed and offering sufficient detail for district-level analysis (as supported also by the scientific literature).

Beyond data-related issues a further gap is constituted, as already mentioned, by the limited role of spatial mapping, which is often confined to analytical and descriptive purposes. To effectively support planning response to extreme heat and vulnerability it is not sufficient to understand existing territorial conditions. Mapping is rarely used to support planning decisions or evaluate the effects of the proposed interventions. To tackle extreme heat and the effects that it may have on vulnerable people it is important to have a clear picture of the current territory but it is equally relevant to understand how the space will change after the interventions to know if they are effective for the final purpose. Currently, public planning rarely incorporates pre-intervention simulations or scenario evaluations (to verify in advance the effects of a project), involving spatial mapping. This research aims to bridge this gap by integrating mapping into a workflow that supports planning actions to mitigate extreme heat impacts on vulnerable populations. This approach can improve complex decision-making processes, particularly in the design of public spaces involving multiple disciplines. Although such evaluations may appear time-consuming, they can reduce errors and enhance sustainability. In fact, scenario simulation and evaluation allow planners to assess potential outcomes before the implementation of a project, identifying optimal design solutions (in this specific research, from a microclimatic point of view). This research, and this specific approach described, represent an original and innovative contribution compared to the previous studies

Finally, from the scientific literature it emerges that mapping related to extreme heat and vulnerability is rarely done for a municipal initiative, or integrated into

official plans and programs. Such mapping activities are mainly conducted by academic institutions or research agencies. This gap appears to be linked to the complexity of municipal planning processes which, as mentioned above, involves multiple competences and require coordination across different departments. The result is a complex process which needs to be simplified. Although some cities have begun to develop vulnerability-focused mappings, these initiatives are poorly documented in scientific literature and are mostly reported in grey literature or official websites.

5.3 Territorial mapping and analysis: plans, programs and projects for extreme heat risks response

In order to have a clearer picture of the plans, programs and projects in response to heat risks, an analysis was conducted to identify the main features of these planning tools. In this critical reading it is also relevant to understand the use of mapping as a support for planning processes in response to heat-risks.

In planning terms, heat-related risks should be addressed as a matter of priority and in a systematic and organized manner, since they have adverse effects on the well-being and health of people. Mitigation and adaptation strategies must be implemented as soon as possible, not only to reduce extreme heat but, in general, to tackle all the problems related to climate change (e.g. flooding, sea level rise) (Lindley et al. 2006; Wilson, 2006). A very broad knowledge needs to underpin these planning strategies. The cooperation of climate scientists, public health specialists, risk managers for an interdisciplinary and scientific approach is fundamental. The challenge in these processes is to coordinate actions and objectives of all the actors and stakeholders, involving the different departments working on planning but also citizens (Richardson et al., 2009; Corburn, 2009).

Another topic to consider in urban planning for climate change, is the scale of the above mentioned issues. Extreme heat is a phenomenon which can be understood only through a careful analysis of local conditions (Richardson et al., 2009). There are many physical, social and economic variables which can greatly vary its effects. Recently, some researchers have started to talk about climate inequality. Inequalities can, in fact, be caused by environmental factors, for example there may be differences between cities or neighbourhoods (Sanchez-Guevara et al, 2019; Tomlinson et al., 2011; Abrar et al., 2022). Individual

characteristics of people, their demographic, social and economic conditions can also influence this inequality (Ellena et al., 2023; Sagris & Sepp, 2017).

In some cases, cities have begun to address extreme heat. In most of these experiences, they didn't associate this problem with health and vulnerability. Some exceptions have developed interesting correlations between these factors (Gabbe et al., 2021; Keith et al., 2023) through plans, programs and projects, promoting analyses or strategies (Voelkel et al., 2018; Office of Sustainability, City of Philadelphia, 2020). In other cases, these analyses and research have been carried out by public research organizations (such as universities) or private ones, for municipality commissions or for scientific interest (Van Der Hoeven & Wandl, 2015). In both cases, as already mentioned, these studies, mappings, projects are published only on the official municipal websites and they are not reported or analysed in a scientific way, making their collection complex. The experiences in this field are very interesting, however, and some researchers have begun to do this collecting work, studying and analysing them.

In a comprehensive and systematic analysis, Turner et al. (2022) have recently developed a research on the topic of planning in response to extreme heat and, specifically, evaluated the contents of the plans and programs developed by some American cities in this field, increasingly present in the scientific literature (Rupp, 2015; Keith et al., 2023). The plans identified by Turner et al. (2022) in their paper differ in nature and objectives, they can be hazard, general, climate, sustainability, resilience plans. They are all developed and promoted by a municipality but they have different objectives and, consequently, different contents.

In some of these cases analysed, such as in Portland (2015), a "Climate Action Plan" was drawn up that had among its main objectives to promote greater equality by reducing the disproportion in exposure to heat waves. Even in this case, it emerges that the plan was not sufficiently operational so only a few actions were implemented (Voelkel et al., 2018).

Another approach was carried out by the city of Philadelphia in which it was decided to develop plans in collaboration with citizens. Their sustainability office has identified, through research, which areas of the city are most vulnerable to the consequences of climate change. It was then decided to proceed with an application experience in one of the most disadvantaged neighbourhoods from this point of view: "Hunting Park". From this initiative they decided to create, in 2018, the "Beat the Heat Hunting Park", a community heat relief plan. The goal of this initiative

was to identify causes for heat disparities and, at the same time, promote actions to reduce them (Office of Sustainability, City of Philadelphia, 2020; Hammer et al., 2020).

Some of the cities that have addressed extreme heat in a more indirect way are, for example, Amsterdam and Rotterdam. The research "Amsterwarm" and "Hotterdam" (conducted in the cities of Amsterdam and Rotterdam respectively and commissioned by the two municipalities to university researchers) was based on a specific focus: understanding how the urban heat island manifested itself in that specific city (Van Der Hoeven & Wandl, 2015). In this case, for example, the work was based on mapping UHI and studying its distribution (derived from the combination of different data such as climate, social, demographic). They studied these topics without translating the analysis into operative actions, nor trying to understand how these effects could have been countered through mitigation strategies.

What emerged from the analysis of these plans, programs, projects and research is that it is fundamental to study what is the current state of the spaces. This thesis is based on considering equally important the forward-looking aspect of urban planning, largely missing or underdeveloped until now. Including scenarios of urban development, climate change and socio-demographic conditions can clarify, in planning processes, which are the best strategies to apply for specific objectives and in specific locations (Gill et al., 2007).

As regards the tools for these type of analysis of the state of the facts, many studies have already used GIS-based approaches, combining demographic, social, economic and climate data, especially in the field of risk assessment (Tomlinson et al., 2011). On the other hand, experiences based on future scenarios are still limited.

This type of research and analysis can be a very useful tool for planners, as it can guide and support decision-making processes in the short and long term from a strategic planning perspective (Ellena et al., 2023).

5.4 Workflow elaboration

My research, as outlined in the previous chapters, aims to support planners, decision-makers and in general the operators involved in urban planning, with a particular attention to the risks related to extreme heat. In line with this objective,

the contribution that this research can make in this context, with the skills and expertise as researchers, architects and planners, focuses mainly on the analysis of the territory developed through multifactorial and multi-thematic mapping. These maps are based on the integration and overlay of data of different nature (such as climate, vulnerability, morphology) and they allow to describe the complex dynamics that characterize the urban spaces.

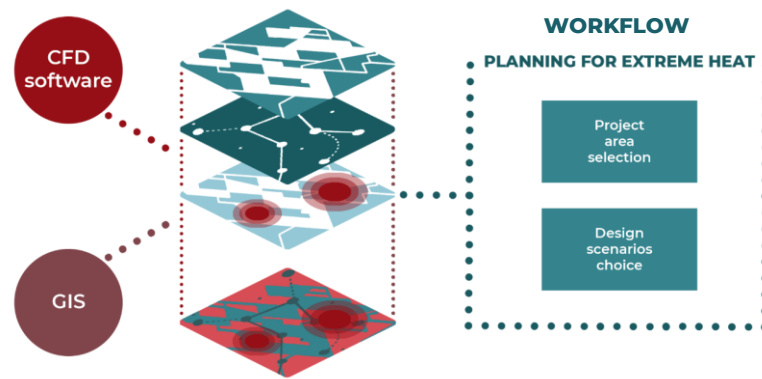


Figure 9: Schematic workflow diagram

First, it was decided to build a workflow for the mapping development, involving various digital tools (paragraph 5.4.1) but also key theoretical concepts (paragraphs 5.4.2, 5.4.3), which would allow:

- to map the territory and identify areas most at risk from extreme heat, overlapping climate data with others such as vulnerability, health, mobility, green spaces, public and private services, morphological data;
- to simulate the before and after of project scenarios to facilitate the choice of the best strategies for climate change adaptation in extreme heat situations.

In the specific context of this research, mapping is proposed for both spatial analysis and project evaluation.

The planning process is very complex, therefore, some considerations were necessary when thinking and deciding how to develop the workflow. One of the

main challenges was to understand what “shape” the final product should have to be offered as a planning support.

The workflow to be developed in this work should be clear and immediate to pass on to those who are involved in planning. The public officers working for urban planning may not have the specialised skills or knowledge and must learn how to use these digital tools quickly and easily. The workflow must also be replicable, built in such a way that it can be used in different contexts (for example in different cities). Finally, an added value is certainly flexibility. The workflow must also be usable with other factors and data so that it is not too sectoral and specialized (for example, the overlapping of climate data must be able to be performed with data of another nature and not only those related to vulnerabilities).

Having these requirements, guidelines were identified as a functional and practical tool explaining the workflow proposed by this research which will be, in this way, understandable, replicable and flexible.

In order to define the workflow for the construction of maps and to create guidelines to understand and replicate it, it was necessary to identify the most appropriate theoretical and practical tools. The systematic literature review, the analysis of experiences already developed in this field and the discussions with experts were essential for this purpose.

In the workflow, specifically, there are four types of tools, each with a specific function:

- 1) digital tools: for the construction, by overlapping the data, of maps, their visualization and analysis (also for the before-and-after design scenarios) (more details in paragraph 5.4.1)
- 2) vulnerability indices: for the spatial identification of the population in greatest difficulty (more details in paragraph 5.4.2)
- 3) climatic data and thermal comfort indices: to gain a clear picture of the climatic conditions in the areas under study and to understand how they affect people’s comfort (more details in paragraph 5.4.3)
- 4) Local Climate Zones system: to make it easier to compare different realities and make the workflow more replicable (even in the absence of some specific data) (more details in paragraph 5.4.4)

5.4.1 Digital tools for mapping

One of the advantages of the use of spatial data management, modelling and simulation software is that it can accurately reproduce different geographical and climatic conditions on which action must be taken. In this way, strategies will respond more effectively to the needs of different situations.

Analysing, evaluating and comparing strategies at the project stage allows interventions to be adjusted before they are implemented and, in general, to choose the one that best meets the specific needs identified. This process, if integrated and systematized in planning, can lead to substantial cost savings and enhance the quality and comfort of outdoor spaces.

In some cases, modelling and simulation help reveal dynamics and interactions between specific building forms and surrounding spaces. In a study conducted on urban courtyards, simulations were used to evaluate microclimatic conditions and energy requirements of various courtyards designs. The objective of the study was to define optimal design solutions for urban courtyards, comparing different morphologies in three different climates (warm, temperate and cold) (Bat et al., 2022).

To operationalize these considerations, in addition to the systematic literature review, a preliminary review on digital tools for urban planning with a specific focus on the subject of microclimate was also conducted.

This review focused on the identification of digital tools currently used in planning and design at the micro-urban level. For this purpose, the following search string was used on "Scopus":

(TITLE-ABS-KEY (software) AND TITLE-ABS-KEY ((plan* OR design* OR model* OR simul*)) AND TITLE-ABS-KEY (urban) AND TITLE-ABS-KEY (microclimate))

The search revealed numerous software tools for data visualization, management and urban dynamics modelling and simulation (288 publications). Having included in the research the term "microclimate", the results are focused on digital tools that designed to evaluate and improve the comfort conditions of outdoor spaces.

The results of this research indicate a strong and growing interest in the assessment and comparison of possible territorial transformation scenarios for the mitigation and adaptation to extreme heat events. Through these tools it is possible to model numerous planning strategies that have this purpose and simulate the dynamics that occur in that specific portion of the city in relation to these interventions (Salman & Saleem, 2021; Widiyannita et al., 2021). Different

software can be used to evaluate the effects and effectiveness of these and other strategies, both for spatial data management, such as ARCGIS and QGIS (Fischer et al., 2022; Biryukov et al., 2021), and for modelling and simulating microclimate conditions and dynamics at different scale, such as ENVI-met (Widiyannita et al., 2021; Przesmycka et al., 2022; Calzolari et al., 2023), uhiSolver (Teichmann et al., 2021), TRNSYS (Bat et al., 2022).

The literature review indicates that ENVI-met is the most commonly used CFD software, appearing in 153 of the 288 studies reviewed. This widespread use confirms that ENVI-met is one of the most established software tools in this field, and it has been used in previous research by me and my research group. This consideration is also confirmed by a Systematic Review that identifies in ENVI-met the software more commonly used for microclimate analysis (Wai et al., 2022).

This specific research helped identify the most suitable software for modelling, simulating and visualizing microclimate data to be used in the workflow proposed in this research.

NOTE: as mentioned before, recently, a plug-in for QGIS was introduced to integrate ENVI-met simulations, facilitating the combination of microclimatic, demographic, social, economic data. This tool has been used in the workflow described in the guidelines.

5.4.1.1 Mapping with QGIS and ENVI-met

As declared in the previous paragraph, recent developments have significantly improved interoperability between ENVI-met and QGIS. QGIS now allows automatic model creation using attribute table data from relevant layers, and direct simulation launch, for ENVI-met licensed users. This new tool could be very useful as it:

- 1) facilitates data integration, previously complicated due to non-geolocalized ENVI-met models; this was a manual and mechanical passage to be done every time that it was needed a combination of spatial data;
- 2) facilitates the access to non-expert users, widening potential stakeholders (as already mentioned this could be very important in the context of municipalities where multiple actors are involved in planning projects and it can be beneficial to have a user-friendly tool that does not require special skills);
- 3) promotes interdisciplinary collaboration across planning, environmental, social, health domains;

- 4) QGIS is widely used in spatial planning and design context; many users are already familiar with this tool so they only need to learn the use of the new plug-in.

During my second PhD year, these tools have been studied, attending courses and tutorials introducing the individual software (QGIS and ENVI-met) and the ENVI-met plug-in within QGIS.

The people who created ENVI-met claim that thanks to this plug-in:

“Urban planners can now visualize how different scenarios will affect microclimates, helping them to design more sustainable and livable cities.”

The plug-in requires specific steps, which are described in detail in the guidelines (see Chapter 6).

5.4.2 Vulnerability indices

The literature review (see paragraphs 3.4.2) identified several indices describing population vulnerability. Most of these indices can be mapped to show the spatial distribution of these vulnerabilities and of people in difficulty.

Some indices describe general social, economic and demographic vulnerabilities, while others already combine this information with those relating to extreme heat.

The two vulnerability indices most cited and most interesting for this research can be classified respectively in these two categories. In the first group of more "generic" vulnerability indices there is the Social Vulnerability Index (Hashemi et al., 2023; Sabrin et al., 2020). In the second category of indices, more focused on heat, there is the Heat Vulnerability Index (Abrar et al., 2022; Weber et al., 2015; Heaviside et al., 2017; Zhu & Yuan, 2023; Johnson et al., 2012; Wolf & McGregor, 2013).

The Social Vulnerability Index (SVI) identifies areas in need of improved social parameters and wellbeing (Sabrin et al., 2020) and measures how a community, based on existing vulnerabilities, responds and recovers from a disaster effectively (Flanagan et al., 2011).

In the United States, the Agency for Toxic Substances & Disease Registry (ATSDR) at the Centers for Disease Control and Prevention (CDC) compiles the SVI (consultable on the site www.atsdr.cdc.gov) (figure 9). This SVI uses census data to identify communities requiring priority assistance during emergencies

(Hashemi et al., 2023). It is developed for the whole territory of the United States, and it is based on 16 variables organized in four thematic areas: socioeconomic status, household composition, minority status, and housing & transportation (Hashemi & Adib, 2024).

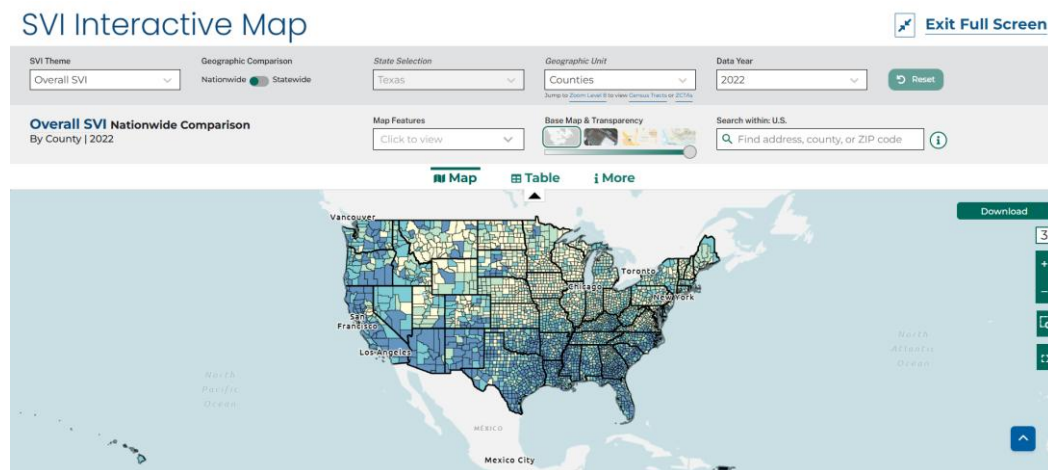


Figure 10: SVI (www.atsdr.cdc.gov)

The Heat Vulnerability Index (HVI) uses demographic, socio-economic and environmental risk data. Its indicators are grouped into three categories: exposure, sensitivity and adaptive capacity. Exposure measures the intensity and spatial distribution of high temperatures during extreme heat events. Sensitivity measures the population's ability to cope with extreme conditions and how much damage it can cause (for example, populations in warmer regions may be less sensitive to heat than those in cooler regions). The adaptive capacity refers to the population's ability to implement strategies to mitigate the damages and the impact of extreme events (for example, access to cooling systems, such as the air conditioning, can enhance adaptive capacity) (Abrar et al., 2022).

In London (United Kingdom), an HVI was developed integrating data relating not only to socio-economic status but also to housing, population density, access to heating and air conditioning, health status of the population (Heaviside et al., 2017).

5.4.3 Climatic data and thermal comfort indices

Climate data and comfort indices are essential elements to understand how heat is distributed and what effects it can have on the perception and quality of spaces, especially under extreme heat conditions, as addressed in this research.

The most interesting and cited climate data when it comes to extreme heat are primarily air temperature and surface temperature. These two variables can be used to evaluate the intensity of the urban heat island for example (Sagris & Sepp, 2017).

Air temperature is relevant because it has been associated in numerous studies with both increased mortality and morbidity (Zhu & Yuan, 2023) and increased energy use in buildings (Hashemi et al., 2023). Nevertheless, air temperature is rarely used in empirical studies and research (Zhu & Yuan, 2023), probably due to the greater difficulty in finding it compared to other types of data (for example Land Surface Temperatures). Air temperature is obtained by direct measurements made with meteorological stations or mobile sensors (Sagris & Sepp, 2017).

Surface temperature is usually measured by remote sensing (Land Surface Temperatures - LST), which has the advantage of covering large areas. The LST also allows transcalar studies as it can be used both for global climate reasoning and at the city scale to talk about the microclimate (Sagris & Sepp, 2017). This data is more readily available and for this reason it is used in most studies and research focused on extreme heat (Zhu & Yuan, 2023), especially when addressing UHI, since the LST is often used as a proxy to measure UHIs (Jung et al., 2023).

Numerous researchers are studying the link between these two data that have indeed been found to be closely related but their relationship depends on factors that cannot be easily simplified (Sagris & Sepp, 2017; Tomlinson et al., 2011). In other cases, these two data are compared to see which is most effective for describing urban heat phenomena. Some studies suggest a preference for air temperature as directly linked to heat stress and health risks related to extreme heat (Chakraborty et al., 2019; Zhu & Yuan, 2023).

In some cases, however, it can be useful to use a parameter or index that represents the thermal comfort that a person experiences in an environment, to understand whether it is satisfactory or not. Thermal comfort occurs when people are within the physiological range that allows them to tolerate that environment and perform activities (ASHRAE, 2003; Lee et al., 2017). The thermal comfort indices are generated by crossing different factors such as air temperature, relative humidity, water vapour pressure, wind speed, mean radiation temperature, worn clothing and the activities of the person among others (Chakraborty et al., 2020; Lee et al., 2017). Especially when applied to outdoor spaces, thermal comfort indices are very complex as they collect and explain the dynamics of all the variables of the environment. Some of the most commonly used comfort indices

are: Predicted Mean Vote (PMV), Physiological Equivalent Temperature (PET), Universal Thermal Climate Index (UTCI), and Standard Effective Temperature (SET), Human Thermal Comfort Index (HTCI) (Hashemi et al., 2023; Chakraborty et al., 2020; Lee et al., 2017).

5.4.4 Local Climate Zones

The last key concept used in this research is that of Local Climate Zones (LCZs). The interest in this tool and the decision to adopt it in this study emerged primarily from scientific exchanges with experts in the field, in particular with Professor Farzad Hashemi from the University of Texas at San Antonio (with whom I worked in the experimental phase of the research).

Local Climate Zones are formally defined by their creators Iain Douglas Stewart and Timothy R. Oke as "regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometres in horizontal scales". The name comes from the fact that they are "local" in terms of scale, "climatic" by the nature of the classification and "zonal" by how they are represented (Stewart, 2011; Stewart & Oke, 2012).

The classification is partly based on previous studies. LCZs are constructed as a simple and generic classification based on both urban and rural climates. In the literature, the term "urban" is used to describe very different realities, since the characteristics of these areas can differ considerably depending on the cities and countries under consideration. Urban areas in this classification are distinguished by specific characteristics such as their structure (building/street dimensions), cover (permeability), fabric (materials), metabolism (human activity), and potential to modify the natural, or "pre-urban" surface climate (Stewart & Oke, 2012).

These properties of spaces, as already discussed earlier in this thesis, are fundamental as their differences are responsible for phenomena such as urban heat islands. The characteristics of urban spaces modify the effects of heat, for example by acting on natural surface energy and radiation balances and causing a considerable rise in temperatures (Oke, 1982; Lowry & Lowry, 2001).

The contribution of this information to urban planning can therefore be of considerable importance in a period such as ours in which climate change has ever greater consequences and effects on our daily lives. The difficult communication between these two areas, urban climatology and city planning, has so far made their integration complex (Oke, 1984 and 2006; Mills, 2006). Local Climate Zones can, in this specific case, simplify this collaboration for example in the field of climate mapping (Stewart & Oke, 2012).

The Local Climate Zones were developed with two main objectives:

- "to facilitate consistent documentation of site metadata and thereby improve the basis of inter-site comparisons" (Stewart & Oke, 2012)
- "to provide an objective protocol for measuring the magnitude of the urban heat island effect in any city" (Stewart & Oke, 2012)

The landscape is then divided into 17 categories, classified as "built types" 1-10 and "land cover types" A-G (Figure 10). The properties of individual LCZs are reported in illustrative datasheets (Figure 11) to be applied in case study analysis with this classification (Stewart & Oke, 2012), as I did in this research.

Built types	Definition	Land cover types	Definition
1. Compact high-rise 	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees 	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact midrise 	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees 	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact low-rise 	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub 	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open high-rise 	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants 	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open midrise 	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved 	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open low-rise 	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand 	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight low-rise 	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water 	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large low-rise 	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	VARIABLE LAND COVER PROPERTIES Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.	
9. Sparsely built 	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	b. bare trees	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.
10. Heavy industry 	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.	s. snow cover	Snow cover >10 cm in depth. Low admittance. High albedo.
		d. dry ground	Parched soil. Low admittance. Large Bowen ratio. Increased albedo.
		w. wet ground	Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Figure 11: LCZs classification (Stewart and Oke, 2012)

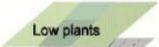
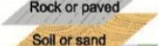
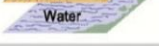
LCZ KEY	ZONE NAME	#
ZONE DEFINITION		
Form: Description of building geometry, construction materials, land cover, tree density, and human activity. Function: Land uses most likely associated with this zone. Location: Expected location of the zone (core, periphery; city, countryside). Correspondence: Comparable zones in the urban classification systems of Oke (2004) and Ellefsen (1990/91).		
ZONE ILLUSTRATION		
Objects  Buildings heavy materials  Dwellings lightweight materials  Trees/plants Land cover  Low plants  Rock or paved  Soil or sand  Water		
High-angle photographs (© I.D. Stewart, Can Stock Photo Inc.) 		
Low-level photographs (© I.D. Stewart, Can Stock Photo Inc.) 		
ZONE PROPERTIES		
Sky view factor ψ_{sky} 0 – 1	Fraction of sky hemisphere visible from ground level. Varies with height and spacing of buildings and trees. Affects surface radiational heating/cooling.	
Aspect ratio H/W 0 – 3⁺	Mean height-to-width ratio of street canyons (LCZs 1–7), building spacing (LCZs 8–10), and tree spacing (LCZs A–G). Affects surface airflow and radiational heating/cooling.	
Mean building/tree height z_H 0 – 50⁺ m	Geometric average of building heights (LCZs 1–10) and tree/plant heights (LCZs A–F). Affects surface reflectivity, flow regimes, and heat dispersion above ground.	
Terrain roughness class 1 – 8	Davenport <i>et al.</i> (2000) classification of effective terrain roughness (z_0) for city and country landscapes. Affects surface reflectivity, flow regimes, and heat dispersion above ground. See Table 5 for class descriptions.	
Building surface fraction λ_b 0 – 100 %	Proportion of ground surface with building cover. Affects surface reflectivity, flow regimes, and heat dispersion above ground.	
Impervious surface fraction λ_i 0 – 100 %	Proportion of ground surface with impervious cover (paved or rock). Affects surface reflectivity, moisture availability, and heating/cooling potential.	
Pervious surface fraction λ_v 0 – 100 %	Proportion of ground surface with pervious cover (bare soil, vegetation, water). Affects surface reflectivity, moisture availability, and heating/cooling potential.	
Surface admittance μ 500 – 2,500⁺ J m⁻² s^{-1/2} K⁻¹	Ability of surface to accept or release heat at local scale. Affects surface heat storage and heating/cooling rates. Varies with soil wetness and material density. In dense tree canopies (LCZ A), the “surface” is undefined and admittance is unknown.	
Albedo α 0.02 – 0.5	Surface reflectivity at local scale and under a clear midday sky. Affects surface radiational heating potential. Varies with surface color, wetness, and roughness.	
Anthropogenic heat flux Q_F 0 – 400⁺ W m⁻²	Mean annual anthropogenic heat flux density at local scale. Heat sources include vehicle engines, industrial/domestic combustion processes, space cooling/heating, and human metabolism. Varies significantly with latitude, season, and population density.	

Figure 12a: Example of LCZs datasheet (Stewart & Oke, 2012)

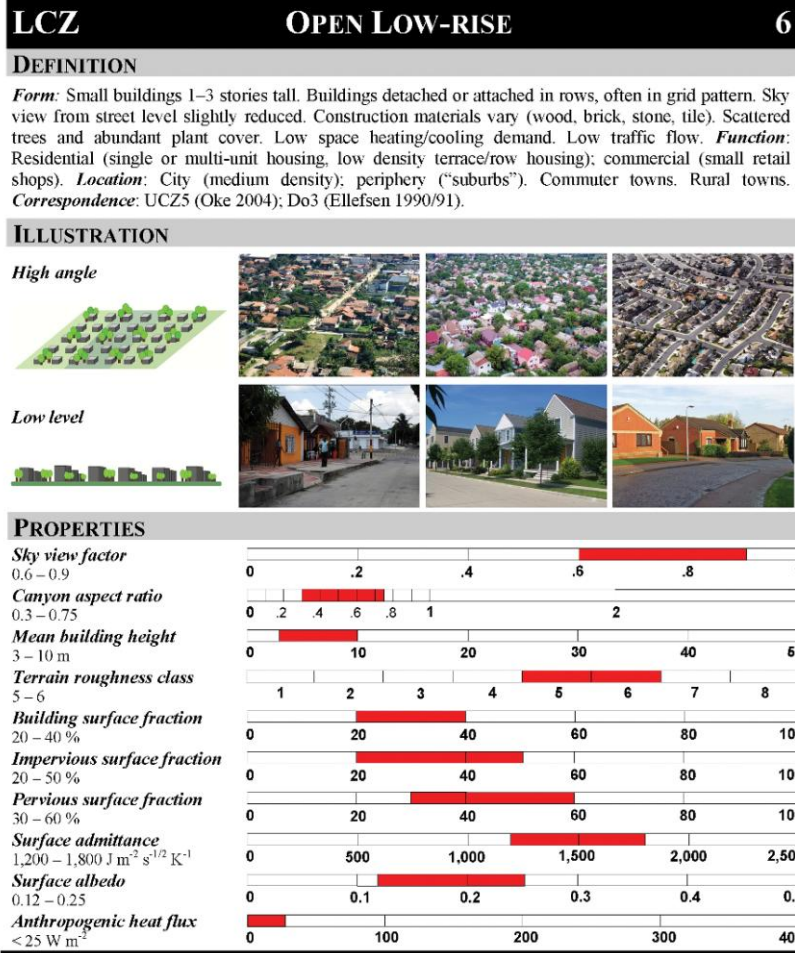


Figure 12b: Example of LCZs datasheet (Stewart & Oke, 2012)

The quantitative data reported in these datasheets are derived from urban climate observational literature and numerical modelling (Stewart & Oke 2010; Stewart 2011).

Some data, properties or variables are not yet integrated into the reasoning of LCZs (e.g. wind and humidity) (Stewart & Oke, 2012) and this research can be an interesting opportunity to go in that direction because digital microclimate modelling and simulation tools also take these factors into account.

5.4.5 Workflow definition

The workflow and the accompanying guidelines build on the concepts discussed so far and aim to simplify the application of the tools described above for climate change mitigation and adaptation planning.

Specifically, the guidelines (see Chapter 6) provides a detailed description of how to carry out the workflow, based on three stages of work, exposed in this paragraph. Each stage is distinguished by its purpose, the final product to be obtained, the size scale (in relation to the city) and the tools to be used.

The workflow operates across multiple scales. Initially, the city as a whole is analysed to identify areas where interventions are needed with priority. Then, within these areas selected, more detailed studies at the neighbourhood scale allow understand the most critical specific zones. Finally, at the project level, specific strategies can be tested and evaluated. This approach ensures that planning interventions are guided by both a comprehensive overview of the city and detailed local information and conditions.

This paragraph describes the workflow in its main steps and sequence of phases. Its practical application to case studies, including results and insights, is presented in paragraph 5.5, while the guidelines to support decision-makers in the use of this workflow are provided in Chapter 6.

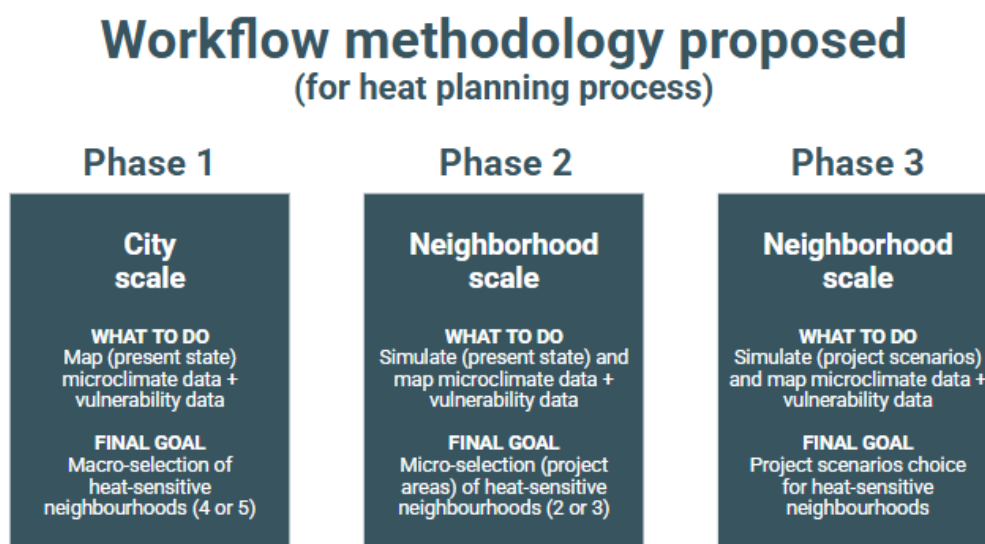


Figure 13: Workflow process

5.4.5.1 Phase 1 – Data collection and hotspot identification

The first phase aims to identify the city areas most exposed to heat-related health risks considering both climatic conditions and the vulnerability of the population living there. This step can be enriched integrating also other data, considering the final aim of the specific project that guided the creation of the risk map (in the application to the case studies, for example, in this research, also morphological data have been used; see paragraph 5.5 Workflow Application).

In this phase, the final product will be a map that highlight priority hot spots for planning interventions.

The scale will be that of the city to have a comprehensive overview of the condition of the individual areas, necessary for comparison and choice of hot spots.

For this initial phase, the main tool proposed is the Geographic Information System (GIS), which is widely used both in scientific literature and planning. This tool enables the overlay of different datasets for visualization and analysis. In particular, for this workflow QGIS has been used, as it is free and therefore more accessible. The data and parameters used for the workflow will always depend on the purpose of the integrated territorial map needed as an output of this first phase, and on their availability.

Operationally, in this first phase it is necessary to understand whether a map linking the parameters we want to use already exists. If this is already available, it will obviously be necessary to check the input data and ensure that those relevant to the project in progress have been included. For example, if the planning intervention is oriented towards promoting mobility of elderly people, it will be important to check whether datasets on elderly people have been used among those of vulnerability and whether a specific map exists for this target group. If, on the other hand, a map is not already available, it should be produced with scientifically validated methodologies, taking as reference other maps previously developed for other cities.

In this first phase, the mapping will represent the current conditions of the city, using climate data from satellite images and the LST. For the other data to overlay, they will have several sources compared to their nature. For example, collecting demographic data, in most cases means taking them from the Census but of course, if they exist, other datasets can be considered.

The first phase of the workflow end with the identification of the areas most exposed to risks. In this specific research it has been decided to select 3 areas for each city to deepen in the second phase (see 5.5 Workflow Application).

5.4.5.2 Phase 2 – Neighbourhood scale microclimatic analysis

The main objective of the second phase is to identify intra-neighbourhood spatial vulnerability of microclimatic conditions within the areas identified as hot spots in the first phase.

The main results of this phase are detailed maps of the districts previously identified as critical. The added value of these maps is information on which parts of these areas are the first to intervene at design level to reduce the effects of extreme heat.

In this case the scale will be more detailed, compared to the first phase, the neighbourhood one, according to the need to be appropriate and suitable to support urban design interventions.

At this stage, an additional digital tool is introduced in combination with GIS (QGIS in this workflow proposed): a microclimate simulation software. The addition of the microclimate simulation tool is driven by two main reasons (already explained in part in the rest of the thesis): the detailed scale that can be achieved with a map using this software is higher than that achievable through satellite imagery, whose spatial resolution is often too coarse; with regard to extreme heat, the microclimate simulation software, allows to simulate, in a detailed way, the dynamics of the worst day or days of the year from this point of view (with satellite images the analysis is constrained by both the moment of acquisition of the images and by the presence of clouds that make some images unusable).

The suggested microclimate simulation software, described in details in the guidelines (Chapter 6 Guidelines), is ENVI-met. It is one of the most widely used tools in scientific research to investigate the scale of the neighbourhood.

In 2024, as already mentioned, a QGIS plugin has been developed enabling direct interoperability with ENVI-met and offering several advantages (see 5.4.1.1 Mapping with QGIS and ENVI-met). Two advantages are particularly relevant for the present work:

- firstly, it makes the parametric model of the areas faster thanks to the use of data collected in GIS (for example the height of buildings, distribution of trees, etc.) to elaborate it in a “semi-automatic” way (process described in detail in Chapter 6 Guidelines);
- secondly, the opportunity to visualize the different maps (for example climate and vulnerability) directly in QGIS and to integrate analysis of multiple parameters.

The data to be used as input for the parametric model on which the simulation will be launched can be derived from databases that many cities now make available

to everyone. If these are not available, LCZ data can be used to construct a “simplified” model that is as closely as possible to the area being modelled.

As for the input climate data, to launch the microclimate simulation, the data from the meteorological stations closest to the point of interest needs to be used: in particular, the air temperature, relative humidity, wind direction and speed. The simulation will then obtain various data and climate parameters in mapping, for example air temperature, surface temperature, but also, and especially, thermal comfort indices such as PET and UTCI.

Here too, the final mapping of microclimatic data and parameters can be overlapped on social data from the census or other projects (with an adjustment to the more detailed scale of the model).

At an operational level, this phase will have to start with the parametric modelling of the areas identified as hotspots in the previous phase. This modelling process is carried out through the interoperability between QGIS and ENVI-met, in case there are the necessary datasets or relying on LCZ-based representations when such datasets are not available.

Once the parametric models of the selected areas have been developed, the microclimate simulation can be performed. The simulations are run using meteorological data referring to a selected representative day (this can correspond either to the hottest day of the previous year, to capture extreme conditions, or to a typical summer day, to obtain intermediate values).

The outputs of this process consists of detailed maps for each area, showing microclimatic variables such as air and surface temperatures, and allowing the identification of the most critical zones within each area. In addition, the use of ENVI-met enables the calculation of some thermal comfort indices such as PET and UTCI, which provide an integrated assessment of the human thermal comfort conditions, based on multiple climatic parameters.

By overlapping these microclimatic data with other typologies such as vulnerability or health-related data, it is possible to further narrow down the areas of interest. For the subsequent phase, it is proposed to select only two or three areas according to two main criteria: first, those that emerge as most at risk when heat exposure and other data are analysed together at this more detailed scale; those in which the most critical zones correspond to public spaces, where urban planning and design interventions can effectively improve outdoor comfort under conditions of extreme heat.

5.4.5.3 Phase 3 – Design scenarios and post-design simulations

The main objective of the third phase is the identification and evaluation of design strategies for extreme heat effects' reduction.

The main product of this phase the mapping of areas identified in the previous phase, under future scenarios, with the prediction of microclimatic changes resulting from different design strategies applied. It is possible to make a “before-and-after” comparison of the areas in the maps that predict the results of different design options.

Also in this case, the neighbourhood-scale is used (to compare the “before-and-after” in the maps of phase two and three they need to be in the same scale).

To create the models for the “after project scenarios”, the model created in phase two is used as the base. In phase three, project strategies are added to that model. There will be one model for each scenario.

The input climate data should be the same as in the second phase so that models “before-and-after” the application of project strategies are comparable.

In this case, the overlapping of the final maps of data and microclimatic parameters to the others, such as the vulnerability ones, is particularly relevant to define which are the most effective strategies to apply precisely where the vulnerability of the neighbourhood is greater.

The third stage operationally follows a similar workflow of the second. It is advisable, however, to consider only 2 or 3 design solutions for each area under consideration reduce the long-time of the simulation phase.

The results of the simulations will then be two or three maps of the “after project” to compare each with the pre-project maps. This applies to a single parameter that can be for example the PET but the process can be repeated for all the others, evaluating which is more interesting according to the final objective of the planning intervention.

5.5 Workflow application

5.5.1 Objectives and role of the case studies

The application of the above workflow in two case studies has several objectives:

- 1) to verify that the different steps are correct and consistent with the specific objectives: the construction of the integrated territorial mappings; and with the final overall objective: the creation of guideline that simplify and support the planning processes;
- 2) to assess if there are elements or phases to add or edit;
- 3) to include concrete examples in the final guidelines (through images and detailed case-specific insights) that help to understand each step to be replicated;
- 4) to verify that the workflow and guidelines are applicable to different contexts with different data and conditions.

The application of the workflow and its evaluation reply to the need of comprehensibility, replicability and flexibility.

The proposed workflow is design to be a flexible framework to integrate climatic data with non-climatic datasets. This part of the research, for the application of the workflow in two case studies, focused on three specific data: extreme heat, in the form of SUHII (see paragraph 5.5.3.1 Phase 1 – Data collection and hotspot identification); economy; urban morphology. This selection reflects the central role of these variable in shaping both heat exposure and vulnerability.

In the following sections the selection of the case studies and the workflow phase applied are described.

5.5.2 Case studies selection and contextual framework

Two cities were selected as case studies: Turin (Italy) and San Antonio (Texas, USA). This choice was driven by two considerations. First, it was important to test the workflow in different contexts to avoid relying on a single case study. Secondly, it was necessary to limit the number of case studies due to the computational effort requires by high-resolution microclimatic simulations (especially considering that between the mapping of current conditions and those of the different project scenarios, there will be many to carry out for each case study).

The selection of the two case studies was based on the following criteria:

- 1) cities where research has already been carried out in this field to facilitate the access to reliable datasets and, above all, to find out whether there is already an urban map that integrates extreme heat, economic and urban morphology data, or something similar
- 2) cities where other universities or research institutes have already been working on similar projects; contexts in which ongoing research allows

for scientific exchange and expert feedback for this experimental phase of the work

- 3) cities with documented exposure to extreme heat events and phenomena and the presence of vulnerable groups of people
- 4) one national and one international city to understand how the workflow can work in different planning contexts.

As already mentioned, the final case studies were Turin and San Antonio. Research in this field has been developed in both cities and I have made contacts with some experts in the field who supported me in this work. The two cities experience significant exposure to extreme heat and have been previously investigated in urban heat and climate vulnerability research for this reason (Pede et al., 2024; Hashemi & Adib, 2024). Despite their different climatic, cultural and urban morphology contexts, both cities exhibit pronounced spatial inequalities related to heat exposure, making them suitable for comparative analysis.



Figure 14: Case studies location

Turin is the fourth most populous city in Italy (approximately 857,000 inhabitants). Its compact urban form reflects a legacy of twentieth-century industrialization followed by deindustrialization, resulting in heterogeneous land-use patterns and localized thermal variability. Recent planning initiatives increasingly emphasize climate adaptation and mitigation, particularly through urban regeneration and green infrastructure strategies (Pede et al., 2024).

San Antonio is the second-largest city in Texas and a major economic and cultural centre in the southern United States. Rapid population growth and historically rooted socio-economic segregation have produced uneven environmental conditions across the city. Lower-income neighbourhoods typically exhibit reduced vegetation cover, higher impervious surface fractions, and elevated temperatures, contributing to disproportionate heat exposure and heightened vulnerability to extreme heat events (Hashemi & Adib, 2024).

The application of the workflow was driven by a hypothetical planning question, formulated to mirror real world decision-making processes concerning priority areas and intervention strategies for extreme heat reduction.

I developed an activity program, for each case study, that is based on the 3 phases of the proposed workflow but modifying/adapting it to the specific objective of the hypothetical planning question proposed.

An additional strength of the case study selection lies in the direct field experience conducted in both Turin and San Antonio during the doctoral research period. Site visits and on site observations provided an opportunity to investigate the physical and social characteristics of the two cities at a level of detail that could not be achieved through spatial analysis alone. Fieldwork included the observation of streets, sidewalks, public spaces, vegetation patterns, building configurations and mobility infrastructures.

These activities made it possible to identify recurring spatial practices, patterns of public space use, and local behaviours related to outdoor thermal conditions. Such observations highlighted differences in the ways urban environments are experienced and used in the two cities, revealing aspects that are not fully captured by quantitative datasets or microclimatic indicators alone. Field experience also provided a qualitative basis for interpreting the simulation results and understanding how local communities interact with streets, sidewalks, green spaces, and urban infrastructures under summer heat conditions.

The integration of field observations with GIS-based analyses and microclimatic simulations strengthened the interpretation of the results by connecting thermal performance to everyday urban life and spatial practices at the neighbourhood scale.

5.5.3 Workflow implementation

All spatial processing was conducted in QGIS version 3.40 Bratislava and microclimatic simulations were performed using ENVI-met version 5.8.

5.5.3.1 Phase 1 – Data collection and hotspot identification

Data source and processing

To address the research objectives, the first phase focused on the collection of datasets regarding all the factors previously mentioned, which characterize and influence the risks associated with extreme heat. Given the integration of multiple data categories, information was collected from different sources. The data collection phase was divided into two distinct steps: primary datasets for climatic, economic and morphological data integration, to identify the hotspots; secondary datasets and meteorological inputs required for microclimate simulations.

The research, as previously stated, focuses on a integrated territorial analysis combining different data: climatic, economic and morphological (primary datasets). The first phase therefore concerned the collection of all these data which had to be available in formats compatible with GIS-based analysis.

Surface Urban Heat Island Intensity (SUHII) was selected as the climatic indicator to represent the extreme heat conditions. This parameter is used in numerous studies as it is considered “a measure of the urban contribution to additional heat exposure” (Yao et al., 2024).

Income level was selected as a proxy for socio-economic vulnerability. As previously highlighted, in the literature, this characteristic is recognized as one of the factors associated with increased vulnerability to heat exposure. In the case of Turin, the available and public income data were mainly on a city scale and therefore too generic. Data for 2023 income at the census level were provided by a private company interested in the research, “GEO Marketing”, allowing a neighbourhood-scale analysis. In the case of San Antonio, the income data were downloaded directly from the United States Census Bureau online portal (data.census.gov), again, divided by census tract relating to the year 2024 and referring to households.

Urban morphology datasets are less immediate and it was required to have a specific classification framework. The choice was a framework used in numerous scientific studies: Local Climatic Zones (LCZs). Local Climate Zones are formally defined by their creators Iain D. Stewart and Timothy R. Oke as “regions of uniform surface cover, structure, material, and human activity extending from hundreds of meters to several kilometres on a horizontal scale”. Urban areas in this classification are distinguished by specific characteristics such as their structure (building/street

size), coverage (permeability), fabric (materials), metabolism (human activity), and potential to modify the natural, or "pre-urban" surface climate (Stewart & Oke, 2012).

Table 5: Local Climate Zones Classification (Stewart & Oke, 2012)

Built types	Land cover types
1 - Compact highrise	A - Dense trees
2 - Compact midrise	B - Scattered trees
3 - Compact lowrise	C - Bush, scrub
4 - Open highrise	D - Low plants
5 - Open midrise	E - Bare rock or paved
6 - Open lowrise	F - Bare soil or sand
7 - Lightweight lowrise	G - Water
8 - Large lowrise	
9 - Sparsely built	
10 - Heavy industry	

For both cities, LCZs were available through a global classification dataset: lcz-generator.rub.de⁶ (Demuzere et al., 2021).

⁶ As part of the WUDAPT (World Urban Database and Access Portal Tools) project (2015), a protocol was developed that allows the mapping of cities in LCZs. The LCZ generator further simplifies this process by providing an online platform that maps LCZs (the web application is available at <https://lcz-generator.rub.de>).

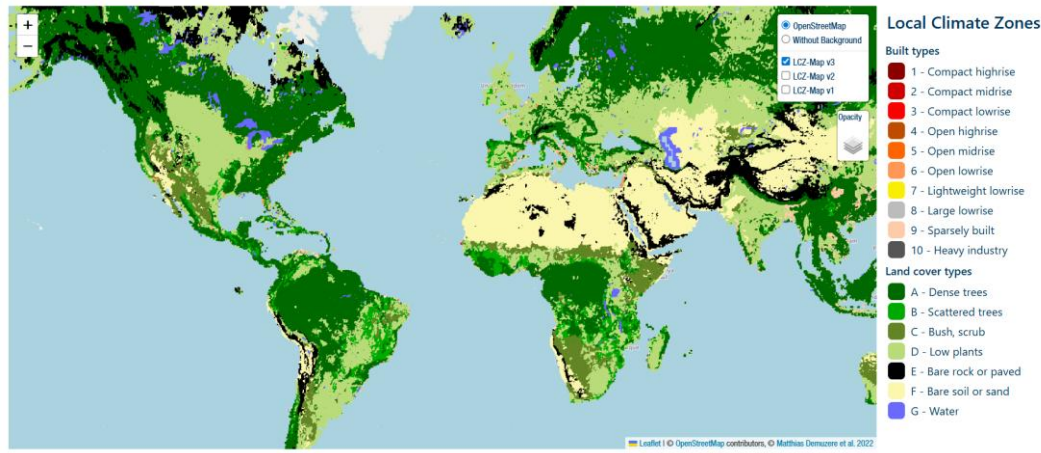


Figure 15: Global Local Climate Zones Classification (lcz-generator.rub.de)

The secondary datasets were collected to model the areas of interest for which the simulations were conducted and but also to run the simulations.

For modelling, the data concerned land use (buildings, roads, sidewalks, green areas), buildings (footprint and heights), trees (location, species, heights) and surface materials.

For the city of Turin, data regarding buildings (footprint and heights) and some data for land use (residential, roads, sidewalks, green areas) were collected from “BDTRE” (Base Dati Territoriale di Riferimento degli Enti) a data catalogue available for the Piedmont region (where the city of Turin is). Data for trees (localization, species, height of each tree) were available on “AperTO” portal (open data portal of the City of Turin).

For the city of San Antonio, building data (footprint and heights) were collected through the FEMA website (Federal Emergency Management Agency) (https://disasters.geoplatform.gov/USA_Structures) and some data for land use derived from the San Antonio city GIS portal (www.sanantonio.gov/GIS) (roads, sidewalks, green areas). In this case the trees data were available just in a format locked for both downloading and editing (an online data inventory for trees in San Antonio called: “NGA_San_Antonio_TX_Trees_3D_Trees_2012”). It enabled to know approximately the locations, the heights and the typology of trees but it was not possible to upload them as a layer. Because of this limit visual observation of the aerial imagery has been fundamental for the modelling phase.

For both cities the surface materials information was derived through visual observation of the aerial imagery too.

For the simulation, hourly climate data were required, in particular air temperatures, relative humidity, wind speed and direction for the specific day on which the microclimatic simulation were conducted. The day of the year used for the simulations was selected between those with an average temperature equal to that of the three summer months to mirror a typical summer day without being among the coolest or warmest. In both cities, the weather stations closest to the point of interest were chosen.

In Turin we used the data provided by ARPA Piedmont for the weather station called “Torino Via della Consolata”.

In San Antonio we used data provided by NOAA (National Oceanic and Atmospheric Administration) for the weather station called “72253012921”.

Hotspot identification criteria

At this stage, as introduced in the previous sections, the aim was to identify three representative areas for each city (Turin and San Antonio) according to the predefined common criteria:

- economy: one area for low income, one for middle income and one for high income
- morphology: all within Local Climate Zone 6
- size: all areas with a minimum diameter of 400 - 1000 m (Stewart & Oke, 2012)
- use: residential
- climate: with the highest Surface Urban Heat Island Intensity values

The economic criterion required a categorization of the areas into low, middle and high income. For both cities, the median value per household was used. The range values identified for the two cities are shown in the table.

Table 6: Income ranges

Income	Turin	San Antonio
Low	0 - 22.529,25 €	0 - 59.790 \$
Middle	22.529,26 - 60.078 €	59.791 - 159.442\$
High	60.079 € and above	159.443 \$ and above

From the morphological point of view, Local Climate Zone 6 (Open Low-Rise) was selected, as it was the most prevalent type in both cities.

The minimum size of the analysed areas was chosen according to the neighbourhood scale and a criterion linked to the LCZs: minimum diameter of 400-1000 meters, consistent with LCZ definition (Stewart & Oke, 2012).

Regarding the use of the selected areas, only residential areas were considered, as the income data are associated with the households' locations.

The SUHII criterion was applied to select among the possible areas when multiple options met all the other criteria. The SUHII calculation was based on the difference in Land Surface Temperature (LST) between the urban and rural contexts ($SUHII = LST_{urban} - LST_{rural}$), using satellite data from the USA online government portal "USGS EarthExplorer", which provides global coverage (9).

5.5.3.2 Phase 2 – Neighbourhood-scale microclimatic analysis

The aim of this phase was the development of detailed neighbourhood-scale 3D models, the simulation of the local microclimatic conditions and the thermal comfort assessment.

Once the areas of interest were selected, the 3D models for the microclimatic simulations were developed.

For this purpose, the plug-in previously described, was use: "Geodata to ENVI-met". The plug-in allows information stored in QGIS layers attribute tables to be used to generate the 3D models for ENVI-met in a semi-automatic way. To clarify this mechanism, the main model components generated using this plug-in, are described below (also corresponding to the specific functions of the plug-in used for this research):

- Buildings
- Surfaces
- Vegetation

Normally, in ENVI-met, the buildings are modelled one by one by, drawing each cell and assigning each of them the height value of the construction. This value is usually derived from aerial imagery or from the number of floors indicated on urban maps. In this case, however, the footprints and the heights of the buildings were data available as attributes in QGIS layer “buildings”, found in the secondary data collection phase. In particular, regarding height, this was one of the fields in the building layer attribute table. Using the plug-in, buildings could be generated with the correct heights, as the software was able to use the building footprints extruding them according to the height attribute stored in the layer.

As for surfaces, the ground geometries are derived from the different elements of the layer itself. Materials properties can be assigned by adding a field to the attribute table indicating the ENVI-met ID of the material. The plug-in “Geodata to ENVI-met” connects directly to the ENVI-met database. This approach and method applies to any horizontal surface of the layer so it is possible to decide the level of detail to have in material definition, for the model generation.

The vegetation section of the plug-in is divided into two steps: simple plants (green areas) and 3D plants (trees or elements that develop in height). As for green areas, different types can be distinguished, following the same procedure explained for “surfaces”. As for 3D vegetation elements, the mechanism is similar. ENVI-met includes a tree-specific database with species distinction, heights, canopy geometry, and other very specific information that influence the simulation.

The plug-in also allows to use the standard IDs for materials. This option is useful for further speeding up model construction when detailed materials information is not available or not required.

Once the process of associating IDs is complete, the model scale and set and other settings on resolution and size are defined, the model is developed automatically through the plug-in and can be viewed, even in 3D, in the ENVI-met software.

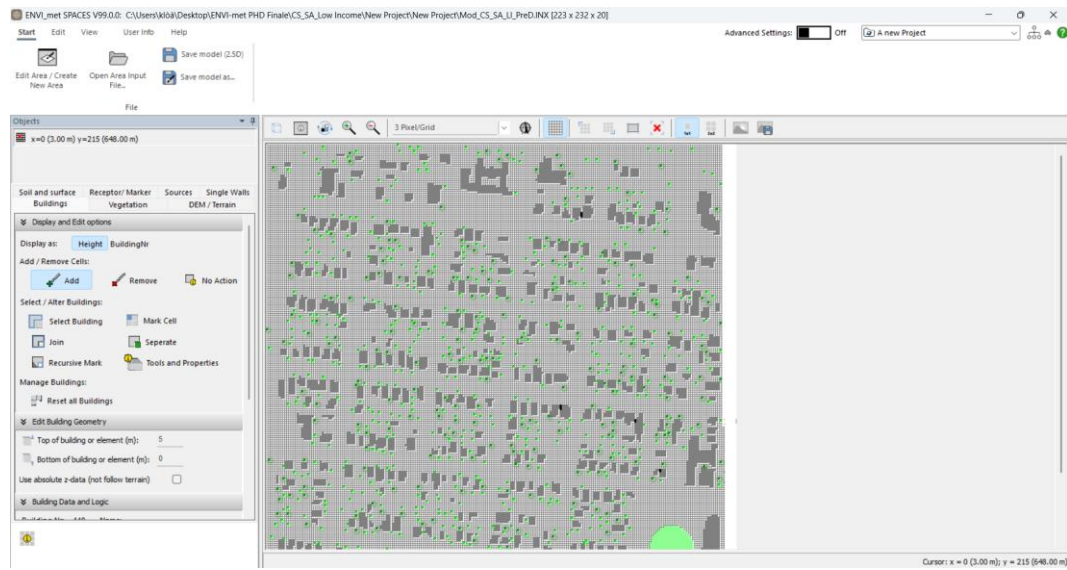


Figure 16a: Model visualization on ENVI-met

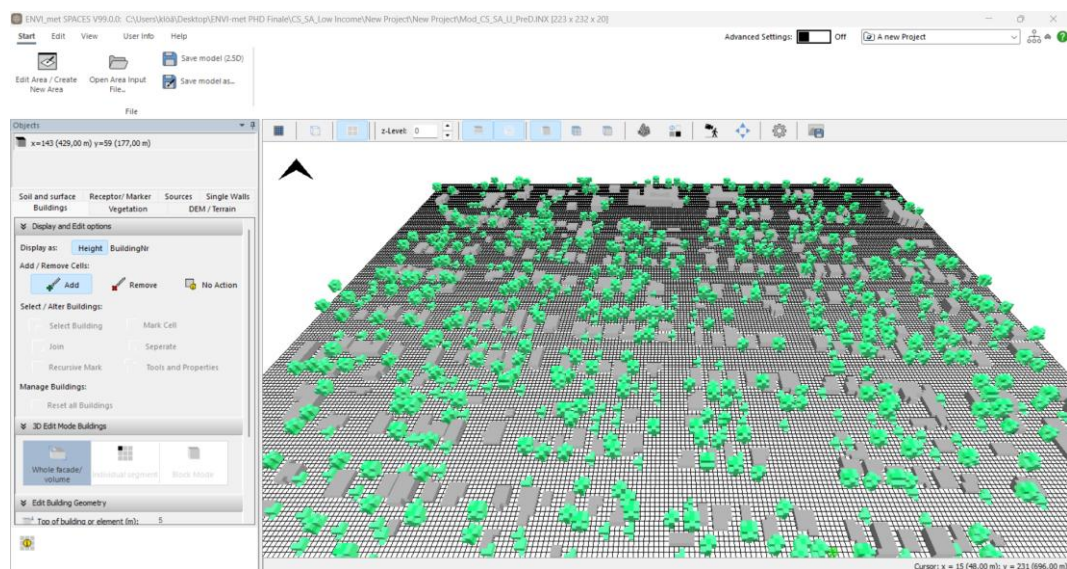


Figure 16b: Model visualization on ENVI-met

After developing all the models of the selected areas, I ran the microclimatic simulations of the current conditions.

For both cities, the year 2023 was selected as the reference year both to align ourselves with the other previously cited studies that used this year (Pede et al.,

2024; Hashemi & Adib 2024), and because for the two case studies, Turin and San Antonio, it was recorded as one of the warmest in the recent decades. Regarding the choice of day to simulate, a “typical day” in summer was selected, with average temperatures compared to the summer season so that it was neither excessively hot nor very cool. For Turin, June 21st was selected. For San Antonio, June 23rd was chosen.

To run the simulations, it was also necessary to collect, as already mentioned, hourly climate data. Specifically: air temperatures, relative humidity, wind speed and direction.

The final step consisted of calculating, directly through ENVI-met, the PET (Physiological Equivalent Temperature). PET is a thermal comfort index based on the human heat-balance model. It is a well-known and validated thermal comfort index for open spaces, used in numerous scientific studies to quantify thermal comfort and heat stress (Höppe, 1999).

5.5.3.3 Phase 3 – Design scenarios and post-design simulations

Phase 3 of the workflow application focuses on defining and evaluating design strategies aimed at reducing the effects of extreme heat. This phase is based on the microclimatic analysis carried out in phase 2. The objective of this part of the process is to evaluate how different levels of intervention influence microclimatic conditions and outdoor thermal comfort. In particular, the role that both public and private actors can play in improving climate adaptation outcomes is discussed and investigated.

Based on the results of the simulations conducted in phase 2, which provide an overview of current conditions, two alternative project scenarios were developed for each selected area. In order to compare the two scenarios with each other and with current conditions, the scale is always that of the neighbourhood.

The two scenarios are based on a comparison between urban planning based solely on the application of climate adaptation strategies in public areas and integrated approaches that also involve private spaces. The design interventions in public spaces are those that characterize conventional planning. However, scientific studies show that extending adaptation strategies to private properties can significantly amplify microclimatic and thermal comfort benefits as well as urban resilience (Bowler et al., 2010; Norton et al., 2015). The comparison between the first and second scenarios aims to understand the potential of coordinated public-private participation in planning to reduce the effects of extreme heat.

The first scenario considers the implementation of design strategies to reduce extreme heat exclusively in public spaces. The interventions were applied to roads (both the roadway and the sidewalk), squares, parks, and other open areas accessible to the public. This scenario is certainly the most realistic and systematically adopted by the public administration for planning and design in the urban context.

The second scenario applies the same type of strategies to private spaces as well, while maintaining the interventions implemented in public spaces. The private spaces considered are courtyards, backyards, and vacant and abandoned spaces. In this case, it is therefore imagined that extreme heat reduction measures are applied through a coordinated approach involving both the public and private sectors. The purpose of this scenario is not to propose an idealized or mandatory model, which would obviously be unrealistic when it comes to private property. The second scenario explores and analyzes the microclimatic benefits that could be achieved if private individuals decided to actively contribute to reduce the effects of climate change, such as extreme heat.

The selection of design strategies to be applied to both scenarios was guided by the results of the simulations carried out in phase 2 and by the morphological characteristics of the selected areas, all belonging to Local Climate Zone 6. The most well-known strategies for reducing the effects of extreme heat and improving outdoor thermal comfort were identified and applied differently depending on the specific areas. The strategies chosen are vegetation, shading, and modification of surface materials. Scientific research has long supported that increasing vegetation, both in terms of green spaces and trees, can significantly improve outdoor thermal comfort. These elements can enhance shading and evapotranspirative cooling (Gomaa et al., 2025; Wong et al., 2021). Shading from vegetation such as trees has been shown to reduce extreme heat in dense built environments, especially when combined with high albedo surfaces (Moncada-Morales et al., 2025; Ciacci et al., 2025). The characteristics of surface materials are important for extreme heat reduction. The use of cool, reflective pavements can contribute to reducing air temperature and heat stress, especially in urban areas (Elgendy et al., 2025; Elmagri et al., 2024).

From a methodological point of view, the models used to conduct simulations on the two design scenarios for each selected area of the two cities are based on existing conditions and on the parametric models built for phase 2. Two alternative models were therefore generated for each area, corresponding to the two design scenarios. All simulations were conducted using the same spatial resolution, model extent, climate input data, and representative simulation day adopted in the pre-design phase. This ensured that any differences observed in the results could be attributed exclusively to the design strategies implemented.

Microclimate simulations were launched for two scenarios associated with each area. Detailed maps of thermal comfort conditions were then produced. The

analysis of the results for the comparison of the pre-project situation and the two scenarios focused on thermal comfort and, in particular, on the Physiological Equivalent Temperature (PET). These comparisons made it possible to understand the effectiveness of the proposed solutions and the differences between exclusively public intervention and public-private collaboration.

The maps can also be useful as a concrete tool to support decision-makers in communicating with private individuals and helping them understand the benefits of sustainable actions. This approach can highlight how also private spaces can contribute to reducing the effects of extreme heat.

5.5.4 Results

5.5.4.1 Analytical framework and baseline conditions

To investigate the effects of extreme heat in the two cities and understand their differences and similarities, we conducted two parallel analyses. The first is quantitative, so we studied the climatic and microclimatic conditions for each city, comparing them. The second analysis is qualitative and we decided to investigate the urban form and cultural contexts. These analyses allow us to understand the dynamics that characterize each city (inter-city comparisons) and the different areas of the same city (intra-city comparisons).

Comparing Turin and San Antonio climates, clear differences emerge in terms of temperature, humidity, wind, and seasonal patterns.

San Antonio has a humid subtropical climate with hot, humid summers (average highs around 35° C in July-August) and mild winters (average lows around 10-12° C), with average relative humidity of about 63-65% and average wind speeds around 10-16 mph (NOAA NCEI, 1991-2020). Turin has a temperate continental climate with hot summers (average highs around 21° C in July) and cold winters (average lows around 3° C in January) (ARPA Piemonte, 1991-2020), relative humidity around 71.6% with seasonal variations and its mean annual wind speed is approximately 7.1 km/h (~4.4 mph) (Atlante Climatico Italiano, 1971-2000).

These climatic differences influence urban microclimates and outdoor comfort. In this study we decided to investigate the microclimate at the neighbourhood scale, focusing on the pedestrian-level thermal comfort through the use of the PET.

5.5.4.2 Baseline thermal comfort patterns

For visualization purposes, PET maps are presented using consistent value ranges within each city. Different ranges are adopted for Turin and San Antonio because the focus of the analysis is to compare intra-city spatial patterns and differences in relation to the income classes. PET in Turin was analysed in the three areas previously identified, selecting as the reference time the one in which the three areas presented a higher PET value and therefore a greater discomfort: 2:00 PM. Analysing these maximum PET values, it can be seen that they are very similar to each other: 59.32° C in the low income area; 59.48° C in the middle income area; 58.84° C in the high income area. We also analysed the average values of each area and, in this case, there are greater variations: 48.10° C in the low income area; 47.49° C in the middle income area; 44.53° C in the high income area. Finally, we analysed the minimum values: 33.80° C in the low income area; 31.52° C in the middle income area; 31.84° C in the high income area.

These results indicate that, as the data confirm but as it was also already evident from the mapping, despite the area with high income having very similar peaks in discomfort (but also in the minimum values) to the others, it differs significantly in the average values. The motivation can certainly be found in numerous variables and one of these can be the presence of vegetation and trees on all roadsides and sidewalks. These two elements ensure on the one hand a lower absorption of solar radiation thanks to the grassy surface and on the other a good shading thanks to the trees.

For the city of San Antonio, as for Turin, we chose the time with the highest PET value as the representative time of day, from the point of view of our research: 4:00 PM. The analysis of the maximum values in this case too does not show any notable variations even if, unexpectedly, the area with “high income” stands out negatively: 59.78° C in the low income area; 60.05° C in the middle income area; 60.11° C in the high income area. Analysing the average values, however, we find that they are very similar to each other too: 50.90° C in the low income area; 51.28° C in the mid-income area; 50.94° C in the high income area. We found the same for the minimum values: 42.39 ° C in the low income area; 42.70° C in the mid-income area; 42.05° C in the high income area.

The similarities, despite the different social and economic contexts of the three areas, may be motivated by the fact that, albeit with some differences, they all present a classic layout of widespread American cities: a strong presence of surfaces that are not permeable for vehicular circulation. Trees certainly play a fundamental role in shading but they act only on heat shielding since their range is exhausted (a short distance from the end of their canopy).

Comparing the analysis of PET values reveals interesting differences between Turin and San Antonio. In terms of PET data, the two cities are both strongly experiencing this thermal stress crisis.

Maximum PET values are similar in all six areas. This may suggest that peak thermal conditions are primarily determined by regional climatic forcing rather than urban morphology and specific environmental characteristics. Both cities reach conditions of severe thermal stress.

In the average values, however, we can observe some differences, both within the same city (as previously mentioned) and between the two cities. Turin's values are a little lower than San Antonio's. An explanation for this phenomenon may be the fact that there are cooler local microclimates in some areas of Turin (shadows, vegetation, permeable materials and/or with greater albedo). Ventilation, on the other hand, is usually lower in Turin, so it can be ruled out that this factor can't explain the variation.

The most notable contrast is observed in the minimum PET values. In Turin, some areas reach approximately 30° C, whereas in San Antonio minimum values remain around 40° C. The minimum PET at the same peak time suggests that some areas of Turin are significantly cooler than other areas of the city and San Antonio. The significant difference can be explained by air temperatures, humidity levels, all of which contribute to raising or lowering PET values. In some cases, moreover, there are probably urban elements such as shaded areas or vegetation that are effective in reducing PET.

When analysing areas from the perspective of people's comfort, it is important to keep in mind the combination of climatic factors at the macro-scale, those at the micro-scale, and all the specific and local physical elements capable of reducing thermal stress.

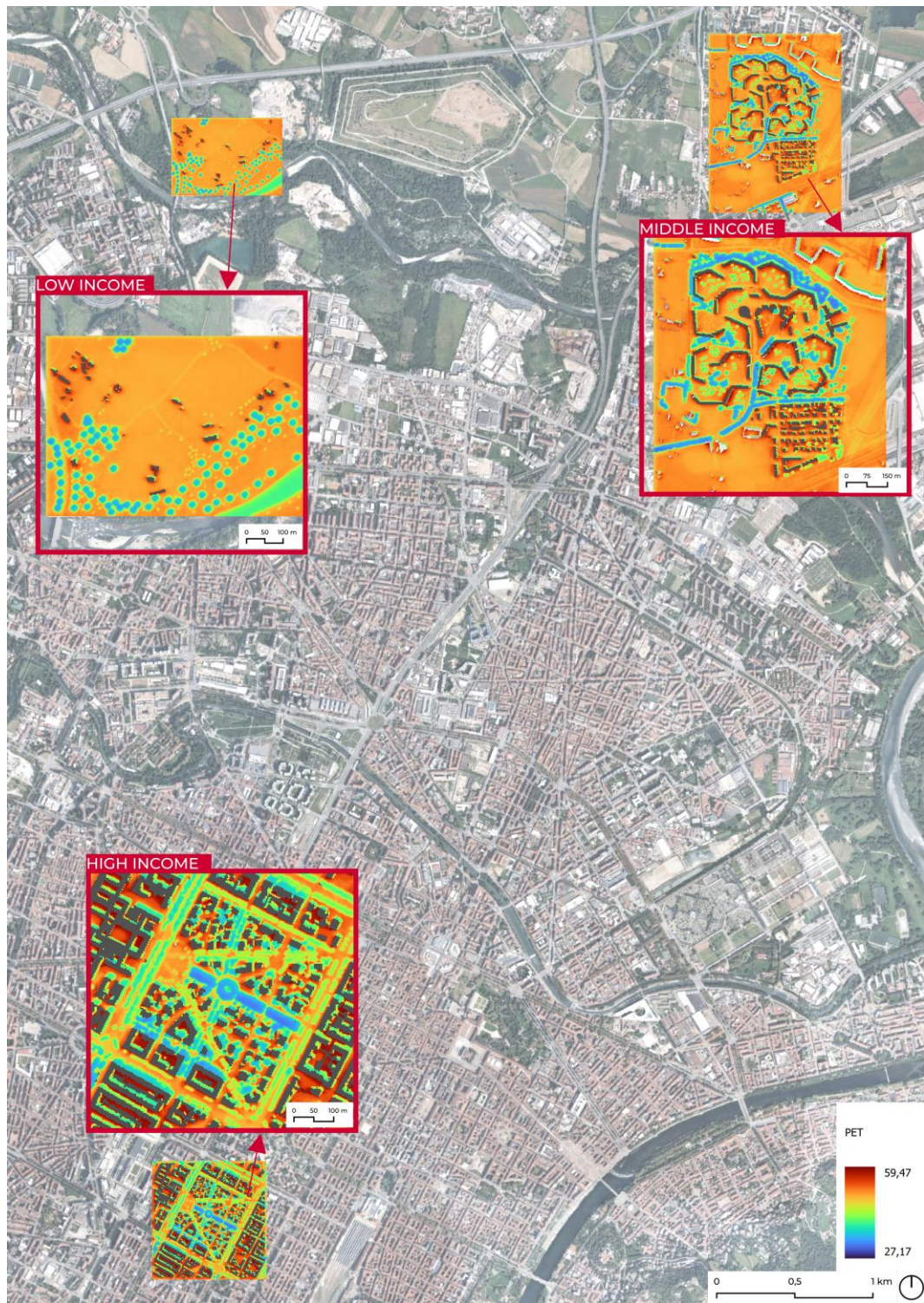


Figure 17: Turin pre-design PET map

Table 7: Turin PET

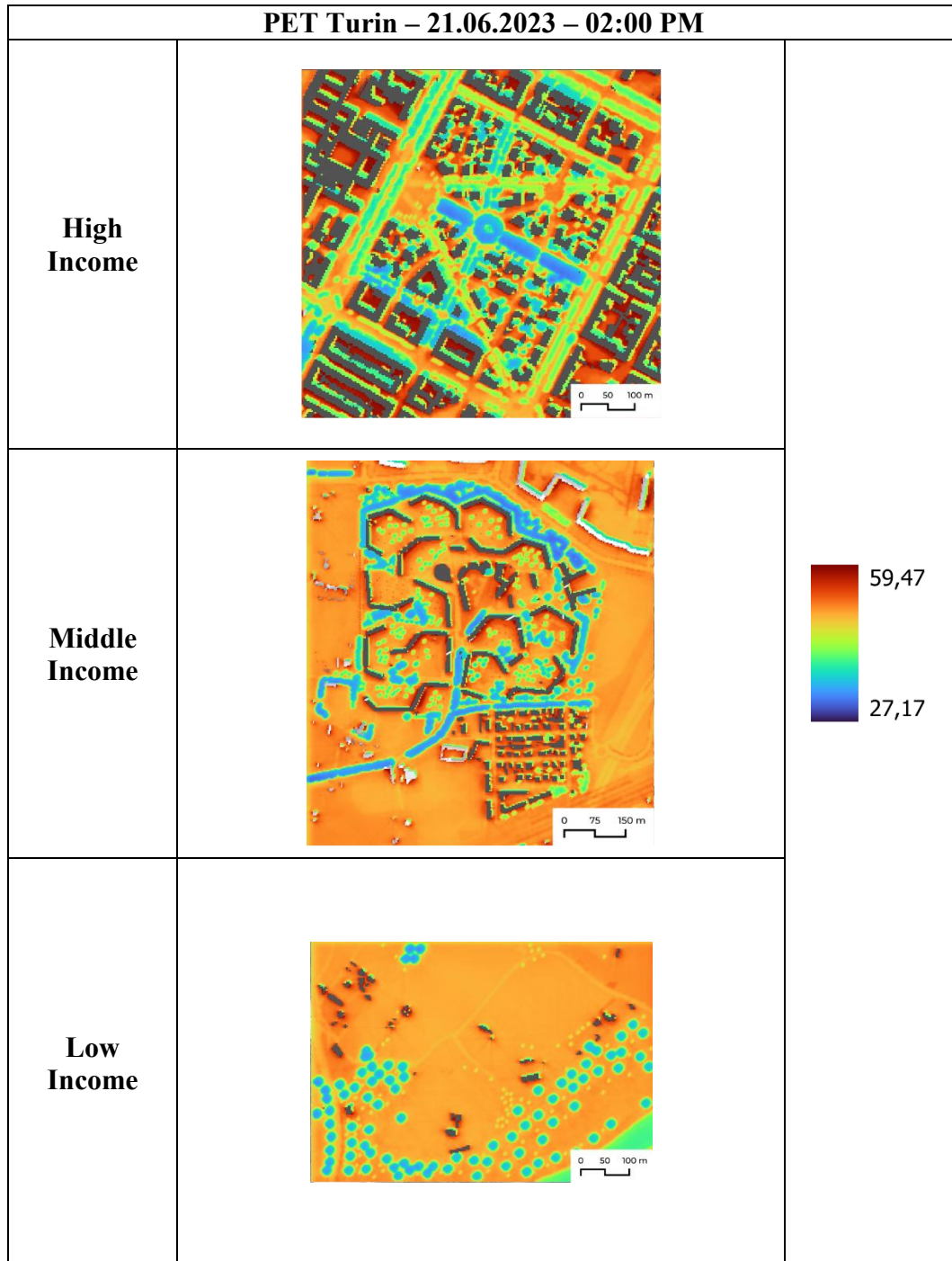




Figure 18: Views of the high income area in Turin (Google Earth)



Figure 19: Views of the middle income area in Turin (Google Earth)



Figure 20: Views of the middle income area in Turin (Google Earth)



Figure 21: Views of the low income area in Turin (Google Earth)

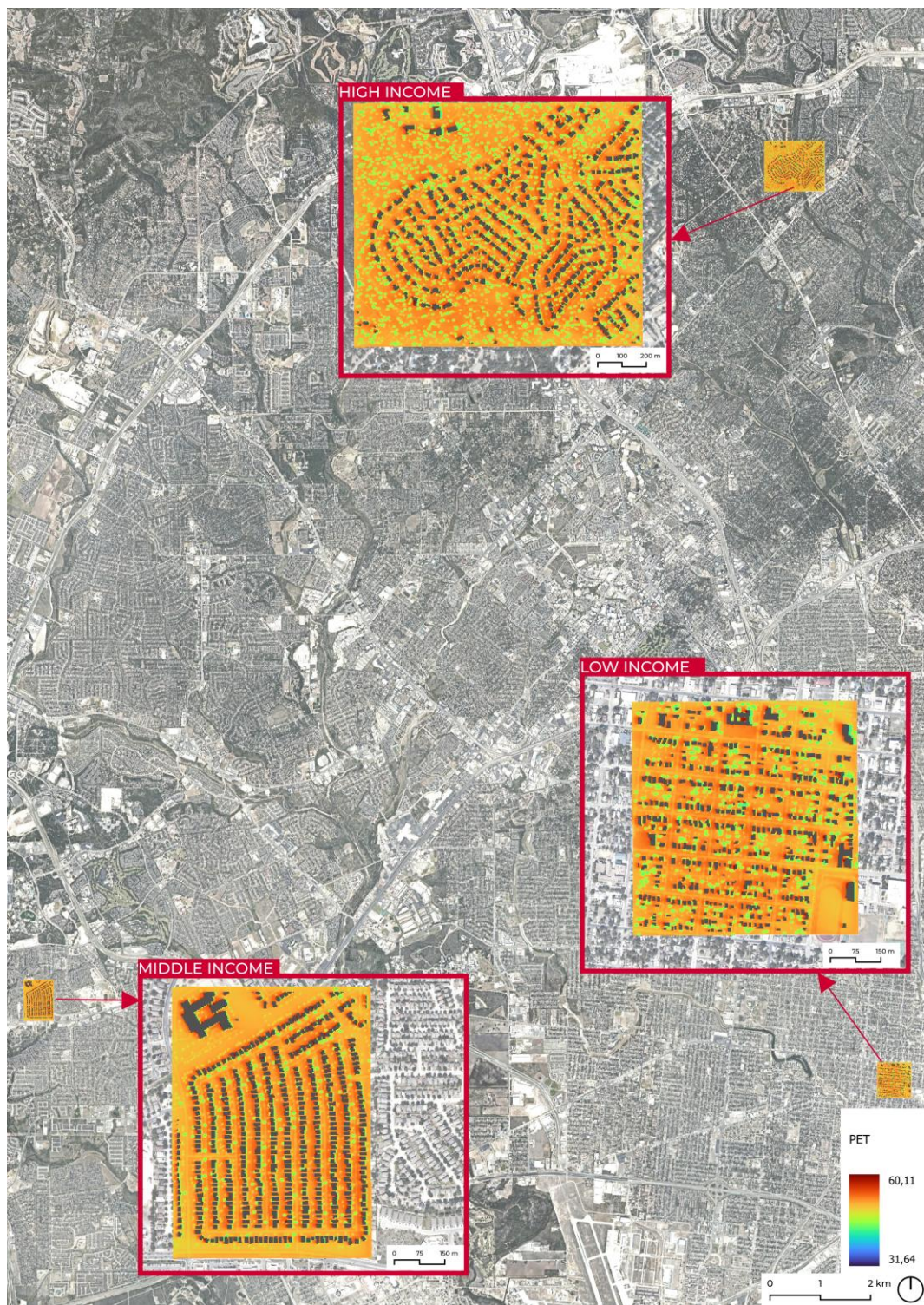


Figure 22: San Antonio pre-design PET map

Table 8: San Antonio PET

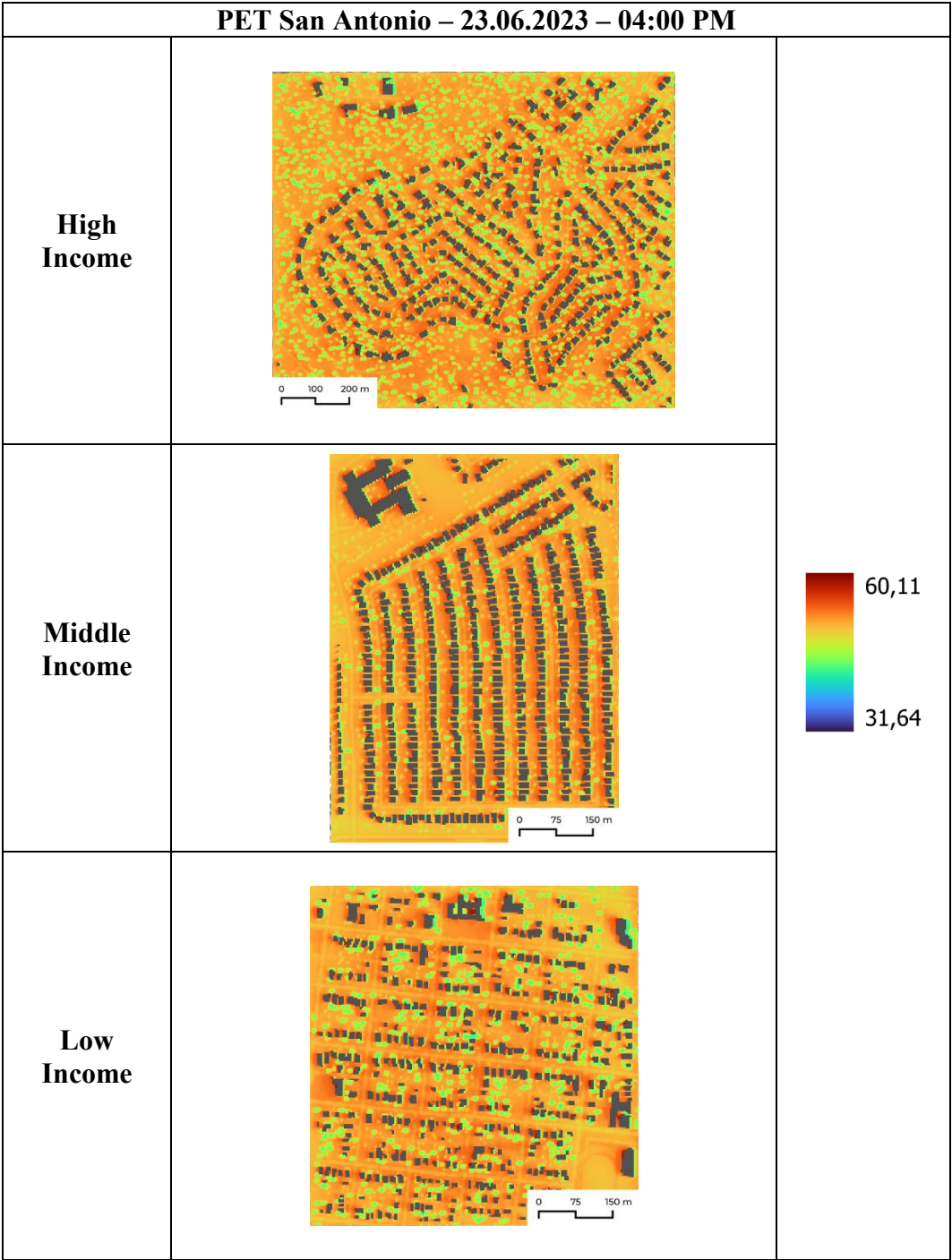




Figure 23: Views of the high income area in San Antonio (Google Earth; <https://nextdoor.com/neighborhood/inwoodtx--san-antonio--tx/>)

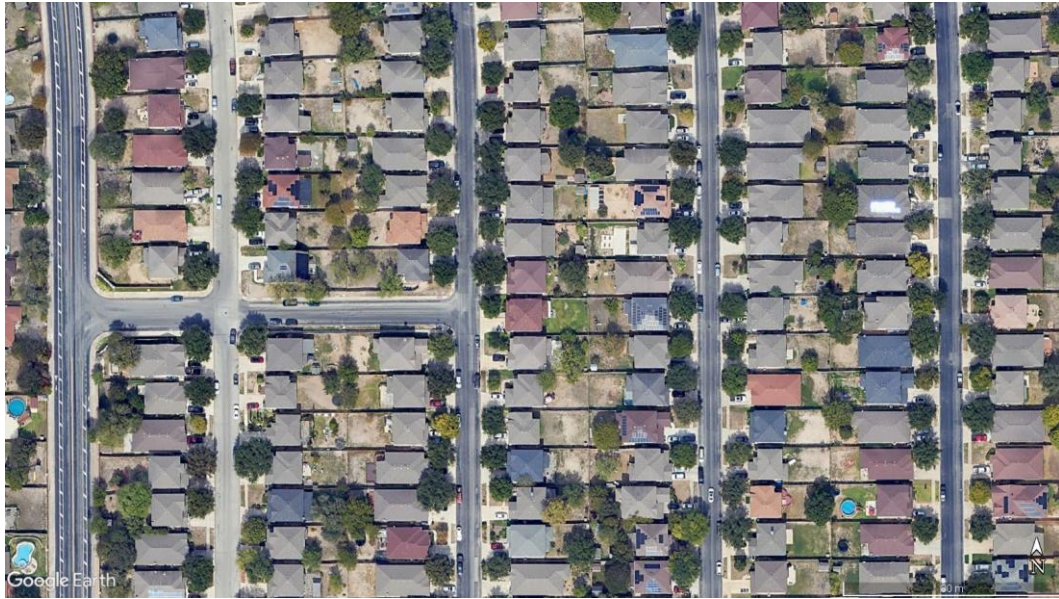


Figure 24: Views of the middle income area in San Antonio (Google Earth)

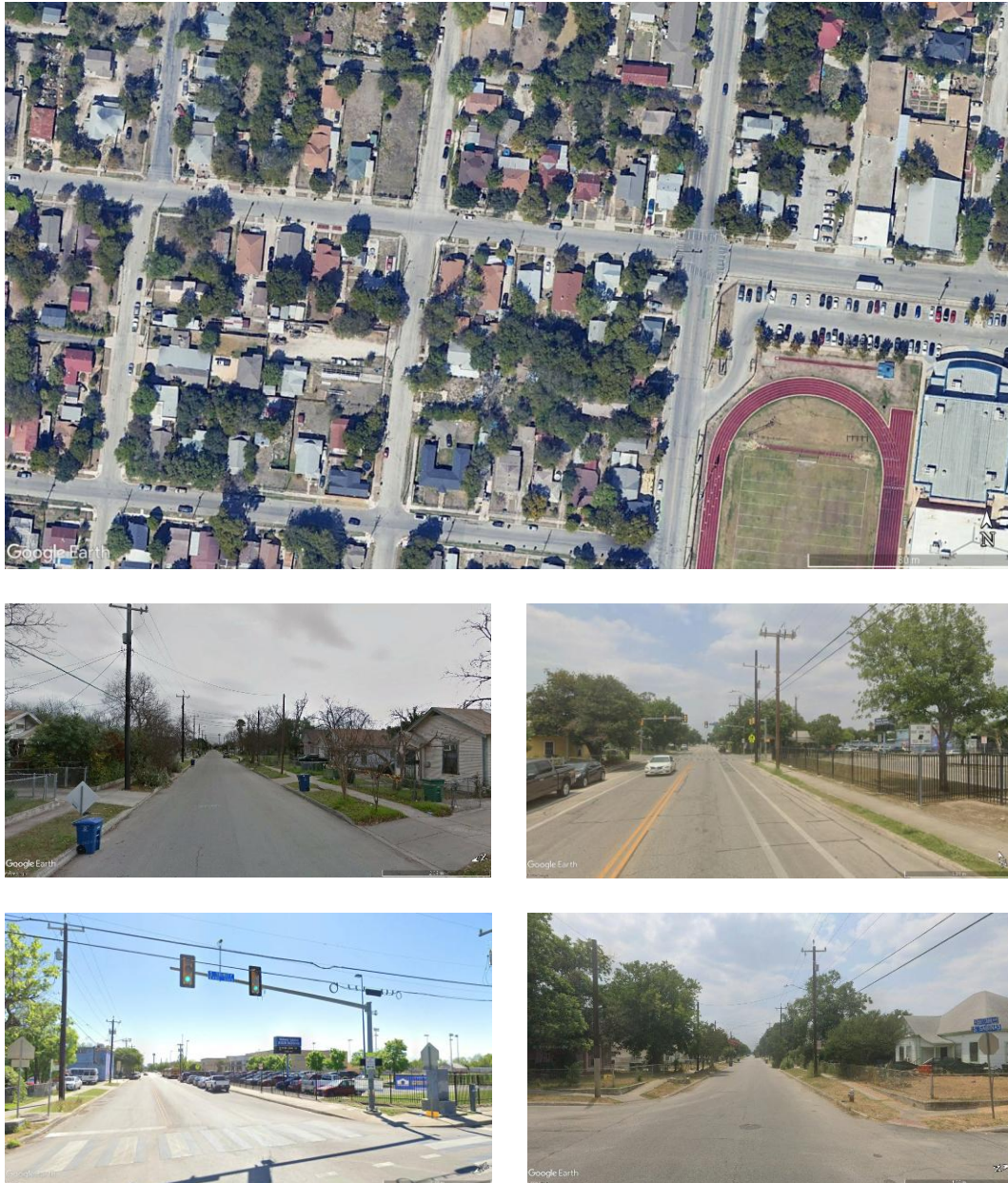


Figure 25: Views of the high income area in San Antonio (Google Earth)

5.5.4.3 Urban form, cultural context and interpretation of baseline results

The results of the first analysis already highlight the specific characteristics of the two cities shapes. However, analysing urban form allows us to understand the cultural and identity constructs that characterize each of the two cities. In fact, urban form is the result of an evolution that lasted decades, centuries, or millennia, guided by political and social dynamics that vary over time.

In the case of Turin, but more generally of Europe, it is very difficult to identify all the processes of urbanization that characterize a city, due to the stratification that occurred in previous centuries and millennia. However, two different ways of conceiving the city of Turin can be distinguished, one pre-industrial and one industrial. The pre-industrial one is based on a compact structure within the ancient walls. The urban form that developed between the 19th and 20th centuries in Turin, mainly due to the sudden growth of the automotive industry, was based on a less compact city. To meet the needs of this development, the city expanded beyond the medieval historic walls with the construction of residential neighbourhoods, industrial plants, and infrastructure.

The urban evolution of San Antonio has been partly similar to that of Turin in recent centuries. It also developed from a compact nucleus which, however, following the birth of the railway and the spread of cars, began to disperse, depending on the road axes and becoming increasingly characterized by a “sprawl” distribution.

In both cities, the push for this expansion was driven by strong migratory flows. In Turin especially during the industrial period, in San Antonio quite consistently due to its geographical position. In both San Antonio and Turin, immigrants tended to settle and live in specific neighbourhoods that were often isolated from the other citizens.

In San Antonio, this segregation has been studied in detail and in numerous studies that testify the fact that this division is a historical phenomenon that has been going on for at least a century. Divisions have in fact been exacerbated by factors such as the construction of the railway (a physical barrier), the disproportionate income distribution after the civil war, and zoning regulations.

A fundamental difference, however, between the two cities, is that in Turin there has been an increasingly homogeneous distribution of populations of different origins and ethnicities. Although economic and social divisions always remain, spatial ones have been significantly reduced. In San Antonio the divisions have persisted over time and have remained equally clear-cut and entrenched.

In both cases, however, the presence of different cultures manifests itself today with a multi-ethnic culture that brings and lives its own traditions and customs to these cities.

In San Antonio, field observations revealed a markedly different relationship between residents and public space compared to Turin. Daily mobility is predominantly organized around private vehicles and many residential neighbourhoods are characterized by wide roads, extensive parking areas, low-density and dispersed land uses. As a result, everyday activities often require travelling relatively long distances, reinforcing a strong dependence on roads and vehicles and limiting the role of streets as spaces for social interaction. Public life tends to concentrate in specific places, such as commercial centres, schools, recreational facilities, parks and community services, rather than along continuous pedestrian networks or neighbourhood streets.

The physical configuration of many urban areas reflects this mobility model. Large impervious surfaces, including roads and parking lots, are widespread and contribute significantly to heat accumulation during summer months. Thermal adaptation strategies, in this context, become strongly dependent on the design and transformation of public infrastructures. Interventions such as increasing tree cover along streets, introducing shaded pedestrian routes, redesigning parking areas, improving transit stops and replacing heat-absorbing materials with more reflective or permeable surfaces can play a crucial role in reducing heat exposure.



Figure 26: Views of San Antonio (Google Earth)

In the case of Turin, with the exception of the period of industrial expansion, efforts have always been made to maintain a fairly compact city structure. Especially in recent decades, much has been invested in proximity, in nearby places to experience on a daily basis. Thanks to pedestrianization projects, the requalification of squares and green spaces, and improved street furniture and lighting, Turin residents are increasingly experiencing the streets and squares for their social life and sustainable mobility.

Field observations conducted in Turin highlighted that in several districts, public spaces function as everyday social infrastructures, supporting a wide range of activities that extend beyond mobility and circulation. Outdoor markets, informal gatherings, children's play, recreational activities and intercultural interactions contribute to making these spaces important settings for daily social life.

The observations also revealed how the physical characteristics of the urban environment influence the way people adapt to summer heat. Tree-lined streets, shaded sidewalks, small public squares and green areas frequently become preferred locations during warm periods, concentrating pedestrian activity in thermally protected spaces (e.g. porticoes in the city centre).

From this perspective, even relatively small improvements in outdoor thermal comfort can have significant effects on the usability and attractiveness of public spaces. Reductions in heat stress may encourage longer stays, increase opportunities for social interaction and support the everyday functions that neighbourhood public spaces perform.



Figure 27: Views of Turin (Google Earth)

This dimension of proximity is difficult to project into the city of San Antonio. Its urban evolution has in fact continued to be based on a low density that leads to large distances between the different areas of the city. San Antonio is in fact a car-dependent city. Drivable road infrastructure therefore always has priority in open spaces as it is necessary for carrying out daily activities (Vanolo, 2008; Chiodi, 2017; Caine et al., 2017; Walter et al., 2017).

5.5.4.4 Effects of design scenarios on thermal comfort

This section examines the specific effects on outdoor thermal comfort of the two proposed design scenarios, in all the areas of interest of the case studies. The interpretation and analysis of the quantitative PET variations, is based on the relation of these values to the urban spatial characteristics, considering materials, streets configuration and open spaces design. The PET value are representative of the peak-discomfort hour for both cities, 2:00 PM for Turin and 4:00 PM for San Antonio, maintaining the same logic of the baseline (pre-design) analysis to guarantee the comparison of the three different cases: pre-design, scenario 1 and scenario 2). The aim of the discussion of the results is to hypothesize if and how urban form and income differences mediate or influence the behaviour of heat.

Table 9 presents the PET values (minimum and maximum) for all the areas selected in Turin and San Antonio. The analysis that follows refers to these data to discuss the thermal comfort patterns. These results are first examined in relation to the specific environment investigated and the differences between the configurations proposed in the same area. A part of the analysis will be also based on comparing the effects of the same strategies in different areas of the same city and finally to the two urban realities selected, Turin and San Antonio.

Table 9: PET values

CITY	Income level	Pre-design		Scenario 1		Scenario 2	
		Min	Max	Min	Max	Min	Max
Turin (2:00 PM)	Low	32,89	59,32	32,88	59,32	32,88	59,31
	Middle	31,46	59,47	27,17	59,20	27,33	59,33
	High	31,84	59,37	28,08	59,34	27,90	59,17
San Antonio (4:00 PM)	Low	42,39	59,78	31,64	59,14	33,07	59,73
	Middle	42,70	60,05	38,69	59,90	40,21	59,85
	High	42,05	60,11	40,40	60,01	40,50	60,10

The results highlight how the effectiveness of heat-mitigation strategies depends not only on physical and climatic conditions but also on the ways in which urban spaces are used, perceived and experienced in everyday life. While the quantitative analysis provides evidence of the thermal effects generated by the proposed interventions, field observations conducted during the research were fundamental for contextualizing and interpreting the simulation outcomes.

In Turin, the implementation of the design scenarios generates limited changes in thermal comfort values but some observations on these small variations can be interesting. The PET values have been reduced mostly in the minimum condition and not in the peak one. This pattern suggests that the neighbourhood-scale interventions can influence thermal comfort but not in a strong way in the moments of extreme heat. In high- and middle-income areas, the variation of PET values can be considered as significant with a reduction of up to 4° C. The presence of spatial conditions favouring the effect of extreme heat on human comfort such as tree-lined streets, vegetation buffers, and permeable surfaces, has demonstrated, in this case, its efficiency. On the contrary, in low-income areas there is an absence of significant changes but this can be attributed to the fact that, as already mentioned, this area is similar to a rural environment (large green areas, scattered and few houses) so it is not possible to extract useful information from its analysis.

Table 10: Turin PET

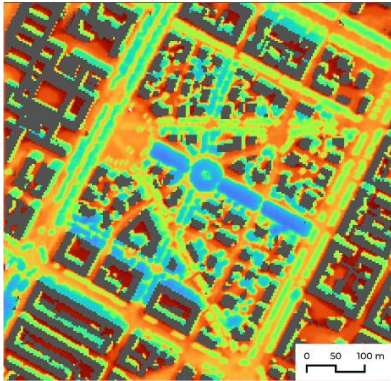
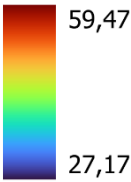
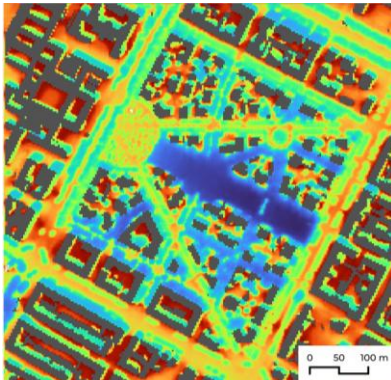
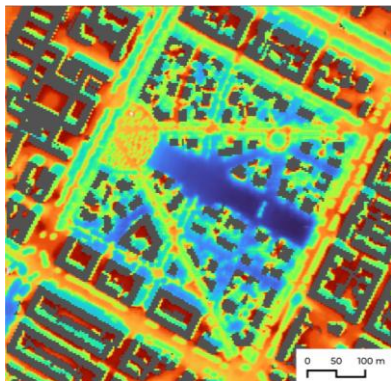
HIGH INCOME - PET Turin – 21.06.2023 – 02:00 PM		
Pre-design		
Design scenario 1		
Design scenario 2		

Table 11: Turin PET

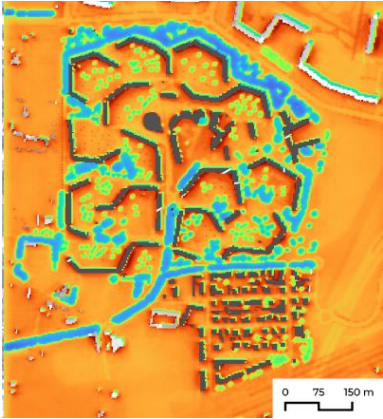
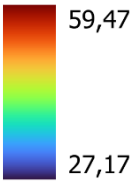
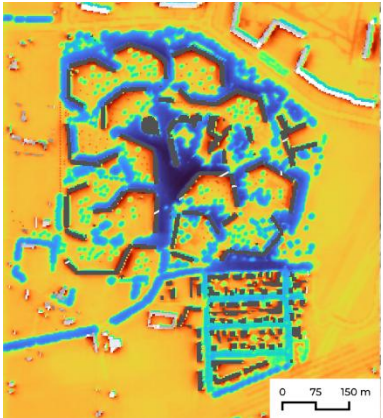
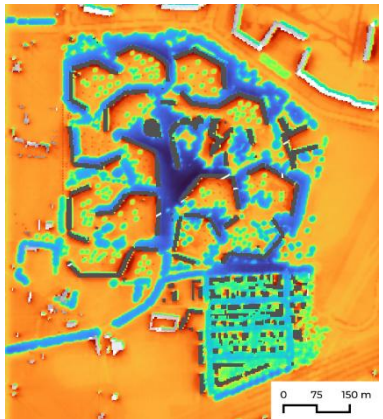
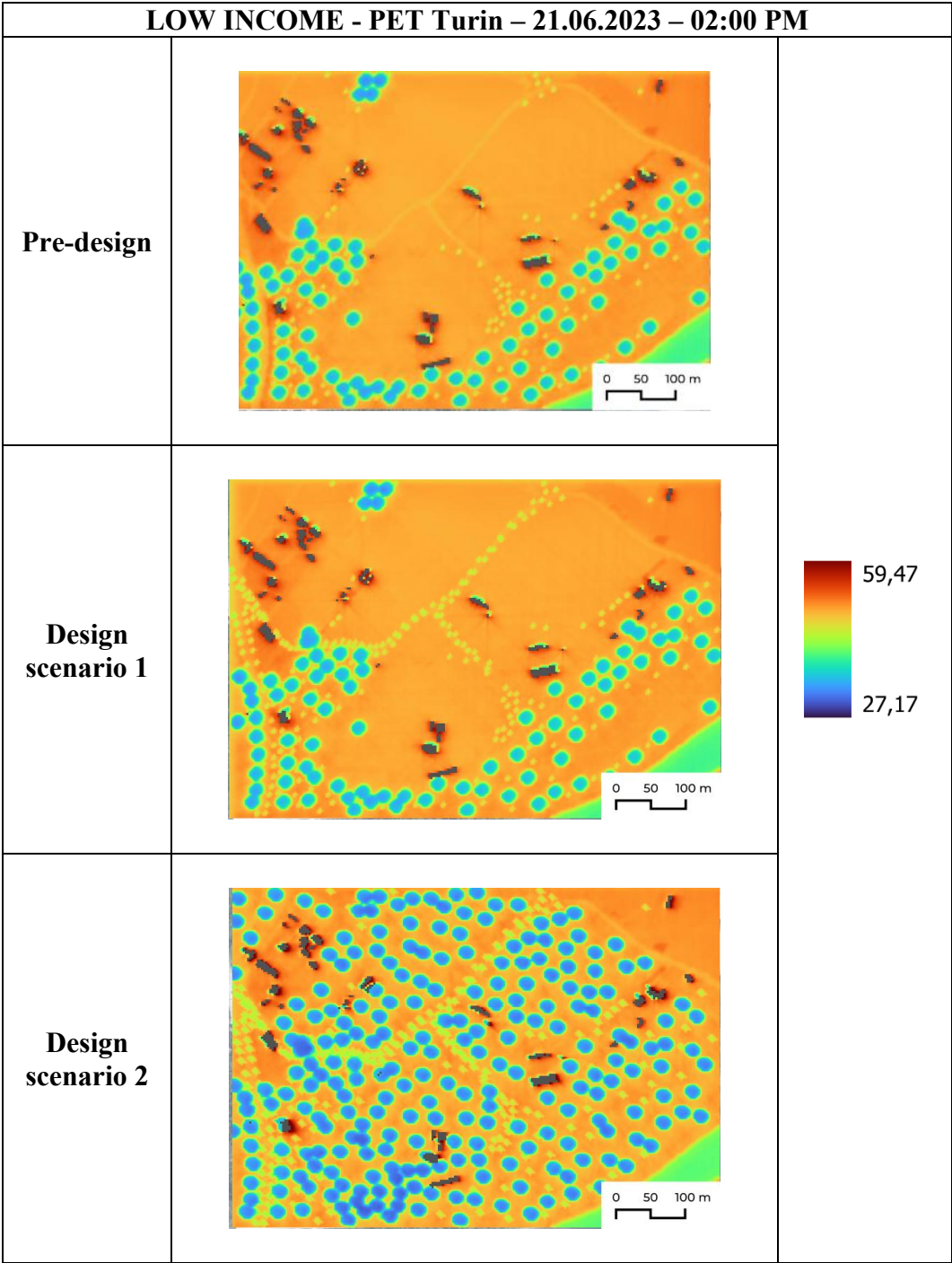
MIDDLE INCOME - PET Turin – 21.06.2023 – 02:00 PM		
Pre-design		
Design scenario 1		
Design scenario 2		

Table 12: Turin PET



In San Antonio, a similar situation can be observed. The effects of the design scenarios are more pronounced in the reduction of the minimum values of PET, especially in scenario 1, where the interventions were applied to public spaces (scenario 2 didn't lead to improvements). The maximum values are stable.

Table 13: San Antonio PET

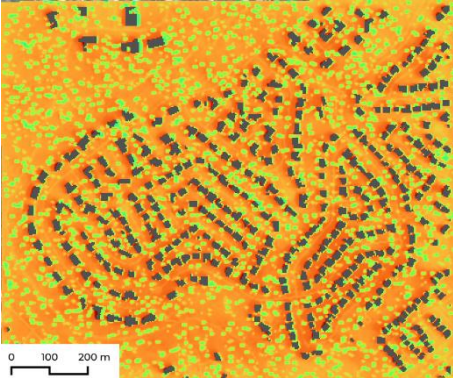
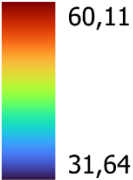
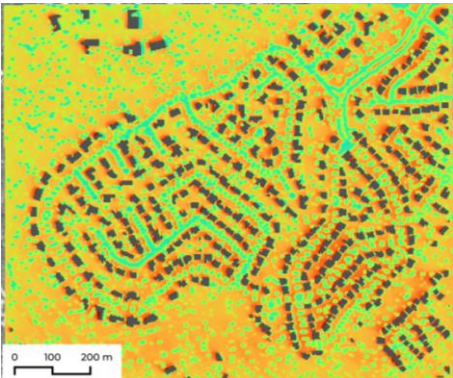
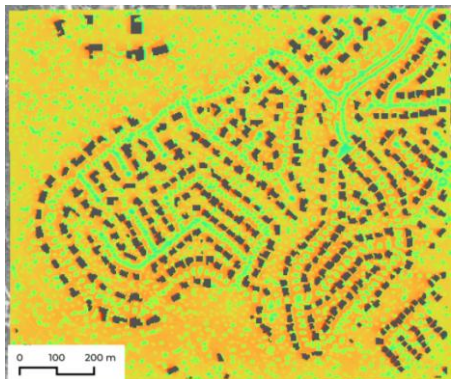
HIGH INCOME - PET San Antonio – 23.06.2023 – 04:00 PM		
Pre-design		
Design scenario 1		
Design scenario 2		

Table 14: San Antonio PET

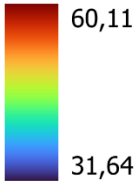
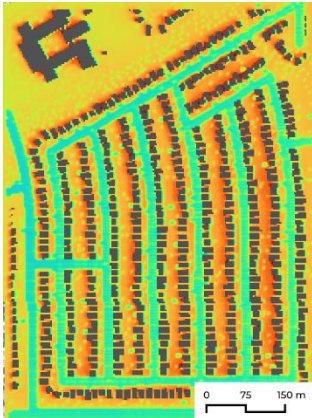
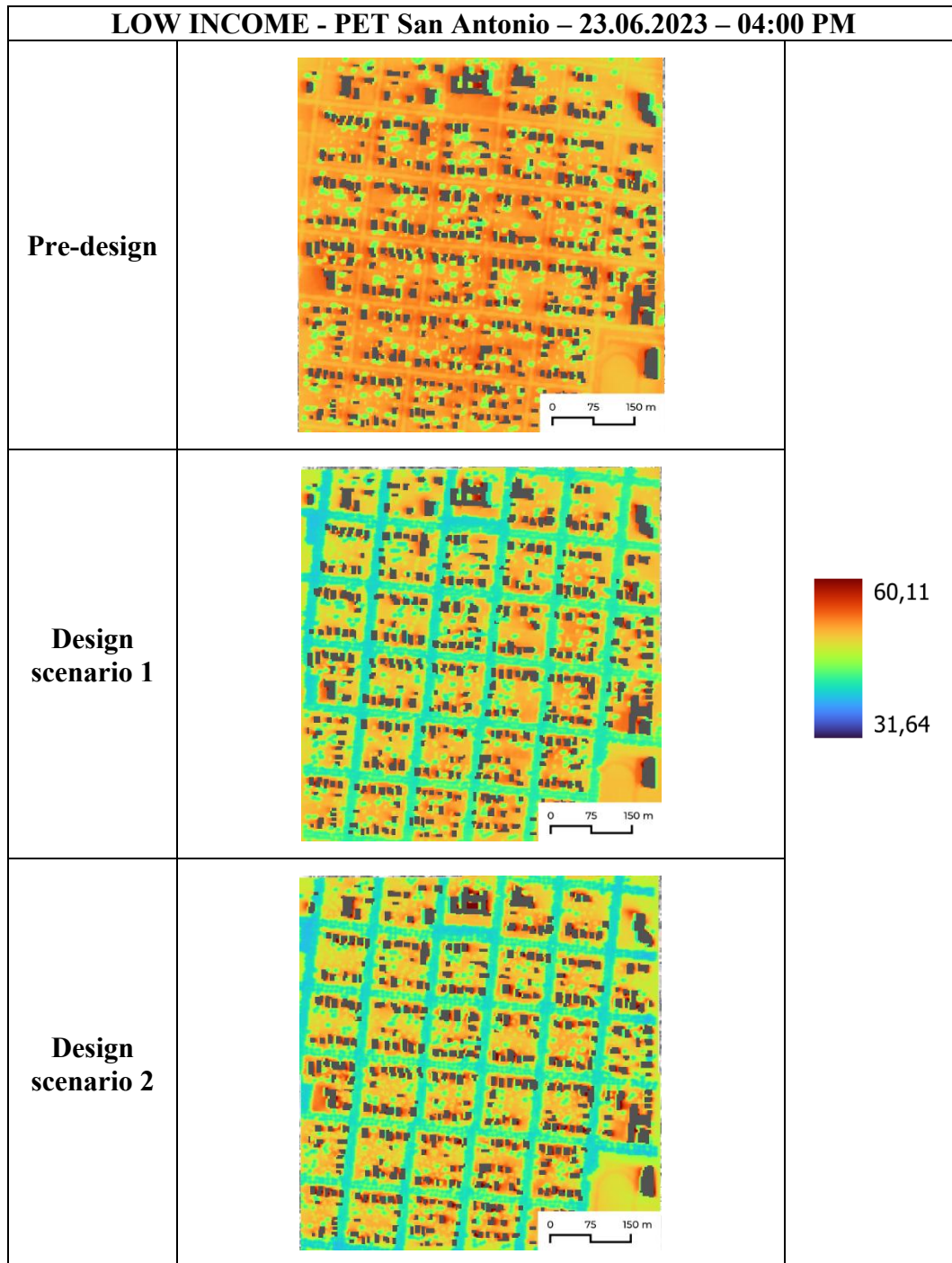
MIDDLE INCOME - PET San Antonio – 23.06.2023 – 04:00 PM		
Pre-design		
Design scenario 1		
Design scenario 2		

Table 15: San Antonio PET



The results highlight how the strategy's effectiveness in reducing heat stress depends on the interaction with the local urban cultures and spatial practices. In Turin, improvements in thermal comfort emerged with interventions aligned with an active use of the streets and public spaces, in a pedestrian-oriented urban structure. In San Antonio, the effectiveness of the interventions is strictly linked to the transformation of public infrastructures.

5.5.4.5 Synthesis and limitations

This study demonstrates that urban heat exposure and thermal comfort are context-dependent, even when neighbourhoods share similar morphological characteristics. The results indicate that income-related differences in thermal comfort emerge from the interaction between local urban form, surface characteristics, vegetation, and climatic conditions, and cannot be captured through generalized assumptions alone. These findings underscore the need for place-specific planning and design strategies when addressing heat-related inequalities within and across cities.

The use of a single simulation day, a single LCZs, and income as the sole indicator of vulnerability limit the analysis. Future research should extend the framework to multiple representative climatic conditions, additional LCZs, and broader vulnerability dimensions. Despite these limitations, the proposed workflow, integrating socioeconomic data, morphological classification, and microclimatic simulation offers a replicable and adaptable approach for assessing heat disparities and supporting equity-oriented urban climate adaptation strategies.

Chapter 6

Guidelines for the implementation of the proposed workflow

6.1 Introduction

The guidelines for the implementation of the land analysis workflow are the tool that this thesis brings as its final product. In this work, in fact, I have decided to develop guidelines that explain, step-by-step, how to carry out a territorial analysis with general objectives:

- Planning that prioritizes areas with greatest vulnerabilities
- Planning that is based on the integration of data of a different nature, put into a system and considered in their complexity and interaction
- Conscious design, aiming for effectiveness and efficiency, thanks to the evaluation of project scenarios during the decision-making phase

Of course, there will also be specific project objectives when these guidelines are used. The workflow will remain the same, but the data may vary depending on what you want to achieve from the final project, ensuring the replicability and flexibility of this methodology.

In our case, the specific objectives concerned extreme heat, vulnerabilities, urban morphology but this workflow can be used for other cases and with other variables. For example, climate data on extreme heat or cold could be integrated with health data to identify people with chronic diseases and the presence of climate shelters in those areas. The project, in this case, could consider which areas are lacking in such facilities and therefore prioritize their design depending on whether they are areas particularly subject to extreme heat or cold and, at the same time, there is a significant presence of vulnerable people who could be harmed by these climatic conditions. This is just one example of the adaptability of the workflow developed and explained in detail in these guidelines.

In general, the guidelines can be said to be an effective and consolidated tool in urban planning. In these contexts, in fact, the guidelines help to bring theoretical or strategic objectives to the level of design and direct application in the territory. This tool in fact provides a set of indications and prescriptions that regulate the transformations and management of spaces, according to parameters and with specific guidelines to follow (Trusiani and D'Onofrio, 2024). However, these are not simple recommendations, as they provide coherence and concreteness to policies, make them applicable to local realities, and guide planners and stakeholders in general in choosing and prioritizing projects to be developed. The guidelines are in fact characterised by design and operational guidelines (Giron and Punnoi, 2025).

The guidelines can be used by researchers and technicians dealing with territorial data to obtain mappings for territorial analysis that represent not only individual data but also their interaction and correlation. Planners and policy makers will be able to use them to operationalize policies, to carry out both preliminary land analyses and assessments of project scenarios.

The workflow described in detail in the guidelines (next paragraph) has characteristics that make it usable in different and interdisciplinary contexts. The principles on which it is based are in fact:

- multi-scalarity (ranging from the city scale to that of the block or even the building);
- the interaction of data (in this case climate-morphology-vulnerability, but can be replaced with others depending on specific planning needs)
- the systemic approach (the territory is considered as a complex system, made up of components that relate to each other, so to understand it it is necessary to reason in a complex way, considering every aspect that characterizes it and the relationships between them)
- decision-support orientation (this tool was designed to support planning decision-making processes)
- data transparency and replicability (the open, clear, and comprehensive step-by-step description of the workflow ensures that each step can be evaluated and replicated by other researchers, industry experts, and even people who have never used this type of tool)

6.2 Structure and logic of the guidelines

The guidelines refer to the operational steps to be conducted to apply the workflow, from data collection to project scenario analysis. In the different phases, QGIS, the ENVI-met plugin for QGIS and ENVI-met itself are used. Below are the steps, placed in the context of the workflow phases with a brief explanation (for more information: 6.3 Step-based guidelines for workflow implementation):

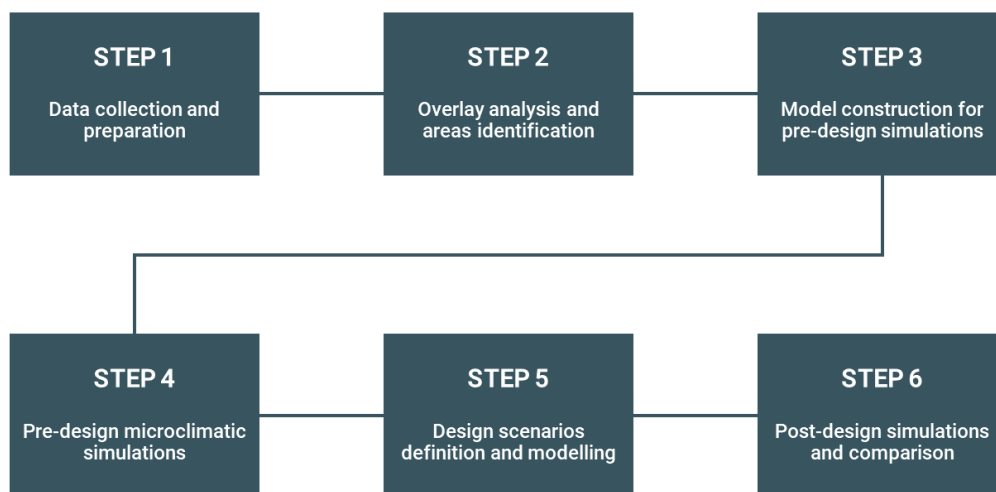


Figure 28: Workflow steps diagram

6.3 Step-based guidelines for workflow implementation

This sections describes the step-based guidelines for the implementation of the workflow proposed in this research. For each step, the specific objective, le required inputs, the main procedures and the expected outputs are discussed, highlighting the role within the overall workflow. The steps are described in a narrative way to clarify the logic of the process and the technical details and the software specific operations are intentionally reported in the Appendix (from page 146) simplify the comprehension of this section.

6.3.1 Step 1 – Data collection and preparation

The data collection and preparation represents the foundational phase of the entire process and it is essential to ensure the effectiveness of the subsequent analysis and simulations. The aim of this step is to collect and organize heterogeneous territorial data into a coherent and reliable spatial framework to support integrated analysis. This step is necessary to create the conditions for meaningful comparison and interaction between the different variables.

To achieve this objective, this step, relies on the integration of multiple datasets and different categories of spatial data, required to reflect the multidimensional nature of urban climate-related issues. The specific datasets may change according to the aim of the project, they can derive from different sources and they can be characterized by varying spatial resolutions and temporal references but their spatial compatibility remain a key requirement. The selection of the datasets is guided by their availability, their relevance to the objectives and their potential to be integrated in a unified spatial framework.

Data integration refers to the process of combining heterogeneous datasets within a common analytical framework in order to investigate their spatial relationships and reciprocal influences. Depending on the objectives of the study, the datasets may include climatic information (e.g. air temperature, surface temperature, heat stress indices), socio-demographic indicators (e.g. population density, age distribution, vulnerable groups), environmental data (e.g. vegetation cover, impervious surfaces), urban morphology descriptors (e.g. building density, sky view factor, street geometry) or infrastructure-related information (e.g. public services, cooling centres, healthcare facilities).

The interaction between these datasets does not necessarily imply a direct causal relationship but it allows the identification of spatial patterns.

The integration process is commonly performed within a GIS environment because of its capability to manage georeferenced information and perform spatial operations. The workflow is not strictly dependent on GIS software, any platform capable of managing spatial datasets, harmonising coordinate systems and supporting spatial analysis can potentially be adopted.

Once the relevant data have been identified and collected, the preparation process focuses on transforming these heterogeneous inputs into a coherent and interoperable dataset, ensuring their comparability. This process includes checking

spatial reference system, verifying spatial correspondence, assessing the adequacy of data spatial resolution, with respect to the intended scale of analysis. Data cleaning, aggregation or simplification can be required to ensure usability and clarity but it is necessary to maintain transparency regarding their original characteristics. This stage allows subsequent analytical steps to build upon a consistent dataset.

Throughout this step is possible to identify, assess and document data limitations, uncertainties, constraints and potential criticalities. Incomplete datasets with missing values, scale mismatches, outdated information must be recognized in this phase. The awareness on these problems can inform the interpretation of the results and allow the adaptation of the workflow to different territorial and data contexts, preventing the propagation of errors into later phases.

The final output of this step is a consolidated and harmonized set of spatial datasets that form the basis for overlay analysis and priority area identification in the next stage of the workflow.

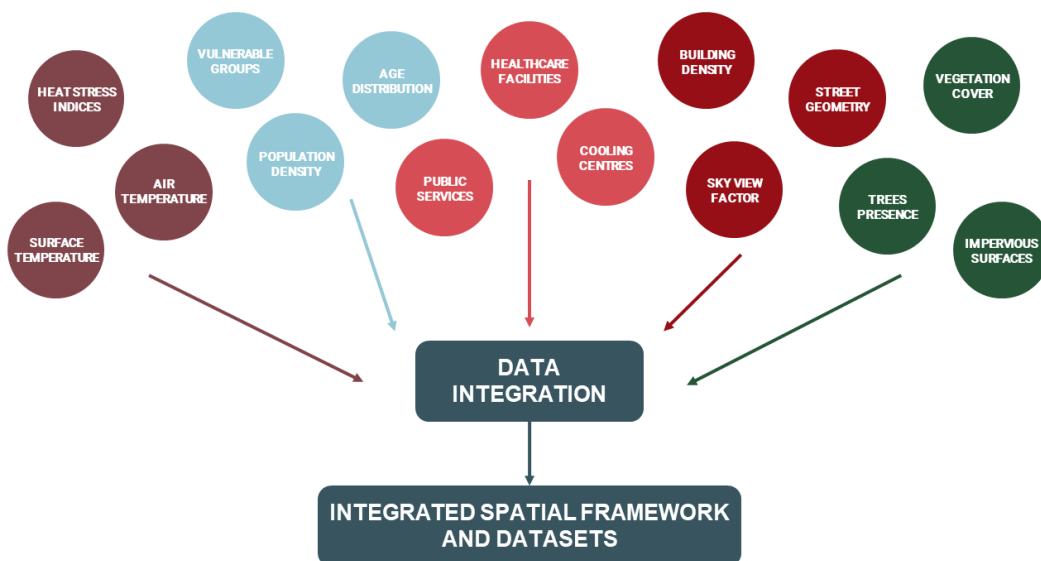


Figure 29: Data integration diagram (with some variables as examples)

6.3.2 Step 2 – Overlay analysis and areas identification

The second step of the workflow is dedicated to the interpretation of the overlay data and the identification of the areas that require particular attention in the planning process. The priority areas are identified by combining different types of information and highlighting where there are critical conditions converging spatially (in the research application described in this thesis, for example, where there were climatic stressors and vulnerabilities).

The overlay analysis is based on the integration of the spatial layers developed in the first step. Overlay is used to explore how the elements selected combine and interact with each other across the territory, allowing simultaneous consideration of different variables. This integrated approach where it is possible to read together multiple layers, makes it possible to move beyond a fragmented interpretation of the territory. In this way, areas with potential risks based on the cumulative effects of different conditions, can be identified.

The operation may involve simple visual comparison, weighted overlay procedures, spatial intersection, raster-based calculations or multicriteria analyses, depending on the nature of the available datasets and the objectives of the study.

For example, a layer representing thermal stress can be combined with socio-demographic vulnerability indicators to identify areas where environmental exposure and social fragility overlap. Similarly, climatic information may be integrated with data related to urban services, accessibility or environmental quality.

A central element of this step is the definition of the selection criteria. These criteria are established in relation to the objectives of the workflow use, the analysis to conduct, the study area. The choice of the criteria influence both the identification of the areas of interest and the analytical outputs. Making the selection criteria explicit is essential to ensure the process clarity, transparency and to support the replicability of the workflow to be adapted to different contexts and objectives.

This step is characterized by the change from a strategic territorial analysis to the more operational phases of the workflow; the focus is on passing from the city scale to a limited number of urban areas. In this stage and through the new scale, it is possible to conduct detailed investigations and analysis, for example, considering the neighbourhoods or the district.

The selected areas, outputs of this step, are used as input model construction and for pre-design microclimatic simulations in the next two steps.

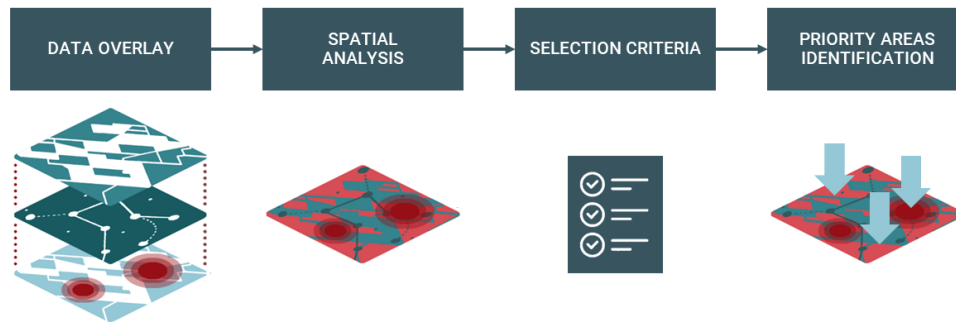


Figure 30: Step 2 process schematic diagram

6.3.3 Step 3 – Model construction for pre-design simulations

The parametric models' construction constitutes the main activity of this step. The objective is to develop models that represent existing conditions and can be used for the pre-design simulations.

Models' construction requires the definition of the main physical components that influence microclimate, including built form, surface material, vegetation and trees. To develop the model, these elements are derived directly from GIS layer datasets. In this phase, there is a translation of these spatial information into a model, semi-automatizing this process of construction.

A key aspect of this step is the use of the recent plug-in of ENVI-met on QGIS. Through this tool, spatial data are used to directly inform and create the structure of the parametric model. By using attribute tables and an identification mechanism linked to ENVI-met database (see Appendix), spatial data are used to directly inform the physical properties of the model. When the data are incomplete or not available, simplifications or different levels of detail can be defined in relation to the objectives of the whole workflow and the scale of the project that is using it.

Although the workflow presented in this thesis employs the ENVI-met plug-in for QGIS and the ENVI-met simulation environment, the methodological logic is not inherently dependent on these specific tools. Alternative modelling platforms can be adopted provided that they support the generation of spatial microclimatic

models and enable the integration of geospatial datasets into the simulation environment.

Potential alternatives may include software capable of importing GIS-based geometries, assigning physical and environmental properties to urban elements, managing vegetation characteristics and simulating microclimatic processes at neighbourhood or district scale. Depending on the selected platform, different levels of automation, model complexity and computational requirements may be available.

The parametric models generated are the outputs and serve as the basis for the pre-design microclimatic simulations described in the following step.

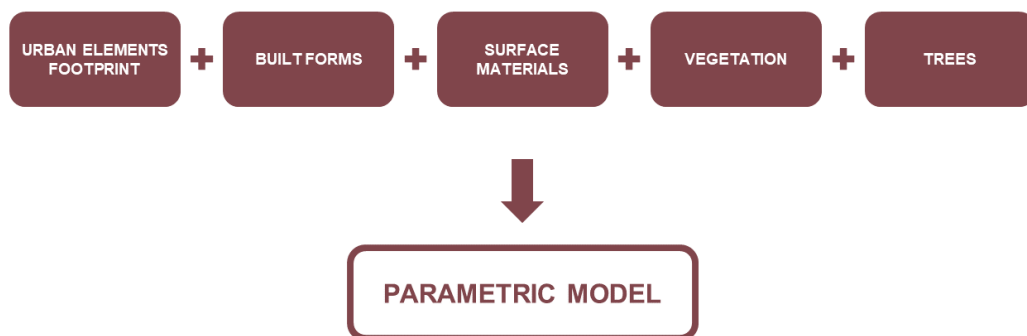


Figure 31: Parametric model construction schematic diagram

6.3.4 Step 4 – Pre-design microclimatic simulations

Step 4 is focused on running the pre-design microclimatic simulations. The objective of this step is to assess existing microclimatic conditions, understanding the local dynamics, to generate quantitative evidence to inform and influence the choices of the project scenarios design.

Using the parametric models developed in the previous phase, it is possible to carry out the simulations. To run them it is necessary to define specific settings, related to the objective of the analysis conducted through this workflow. The main parameters to define are model resolution, atmospheric conditions and simulation duration.

The simulations are conducted in ENVI-met (theoretically they can be launched directly from the QGIS plug-in but it is still having some bugs so it is possible to create both the model and the simulation files through it but not to run the simulation from it). It is also possible to visualize the simulation results in QGIS. In this way, they may become new layers for the integrated territorial mapping analysis.

The simulations are conducted through a microclimatic modelling platform capable of reproducing the interactions between urban morphology, surface materials, vegetation and atmospheric conditions. In the application developed within this research, ENVI-met was selected because of its suitability for neighbourhood-scale simulations and its recent interoperability with QGIS. Nevertheless, alternative simulation environments could also be employed.

Simulation results should be exportable and visualisable within a GIS environment or another spatial analysis platform, enabling their integration with the territorial datasets used throughout the workflow. In this way, simulation outputs can become additional analytical layers supporting evidence-based planning and decision-making.

The outputs of this step are maps and spatial distributions of environmental and thermal parameters and indices. This stage is fundamental to understand the microclimatic behaviour of each area, using simulations as an exploratory tool, allowing the identification of critical conditions. On one hand, the pre-design simulations guide the definition of the context-sensitive design strategies for the project scenarios (step 5), on the other, they are the reference against which those future design alternatives will be evaluated in the last step.

6.3.5 Step 5 – Design scenarios definition and modelling

Following the assessment of the existing microclimatic conditions, the fifth step is dedicated to the definition and modelling of the design scenarios aimed at addressing the criticalities of the selected areas. Starting from analytical evidence on the pre-design simulations, these evaluations are translated into design hypotheses and strategies, exploring the possible transformation of the built and not built environment.

The design strategies definition starts from the interpretation of the pre-design simulation so that the solutions are context-sensitive and not standardized. Multiple variables may influence microclimate and they need to be considered defining the design strategies. Some of these possible interventions involve modifications of urban form and surface materials, distribution of vegetation and trees, and other actions adequate to the local specific characteristics and to the workflow objective.

Design hypotheses are developed and also modelled in this step. Starting from the pre-design model, the strategies are added in QGIS and new model and simulation files are generated through the ENVI-met plug-in for QGIS.

The parametric models of each design scenario of the selected areas are the outputs of this step. They will be used in the next step to run the simulations and their results will be compared between them and with the current conditions.

6.3.6 Step 6 – Post-design simulations and comparison

The last step of the workflow is dedicated to the simulation of the design scenarios and their evaluation and assessment. The objective is to understand the effects and the potential of the alternative scenarios proposed in improving the microclimatic performance of the spaces in the selected areas.

Using the same framework and settings of the pre-design simulations, the design scenarios are simulated through ENVI-met. This coherence ensures their comparability and guarantees the outputs can be attributed exclusively to the design interventions effects.

This step, from a procedures point of view, is similar to the forth one, simulating in ENVI-met and visualizing the results in QGIS. The overlay of the different layers, in this case, is relevant because it allows to directly compare alternatives results, inserted in their urban context and with other variables and data.

The comparison is based on microclimatic behaviour changes providing explicit evidence of the potential improvements, the strengths, but also the remaining criticalities, the limitations and the trade-off of the design alternatives. This step supports and informs decision-making processes, through the integrated territorial mapping, providing an evidence-based evaluation of the design scenarios.

Chapter 7

Discussion and validation

7.1 Discussion

The development and application of the integrated territorial mapping workflow proposed in this research are critically discussed in this paragraph. The aim is to identify and analyse the results of the different workflow phases, interpreting their meaning, highlighting their scientific and practical contributions, methodological implications and limitations.

The workflow is the main focus of this discussion, considering both its conceptualization and application to the two case studies.

7.1.1 Interpretation of the results in relation to the research questions

The study findings achieve the goal to answer the questions exposed in Chapter 2. The main research question aimed to explore the potential of the use of integrated territorial mapping and digital tools in decision-making for urban planning, with a specific interest for extreme heat-related risks for vulnerable people at the micro-urban scale. The data suggest a strong relevance of these kinds of tools, particularly in planning contexts, where climate change has nowadays a key role. However, the use of digital tools to analyse the territorial conditions is limited. It seems that having more information and overlaying them to have a consistent frame of the territory reality would represent a relevant improvement and support for decision-making but it is not easy for these tools to be integrated in the planning process. This consideration invites a deeper examination of the contextual factors influencing these boundaries and suggests that the relationship between an informed way to plan and the real planning processes is not linear and simple to understand and change.

What emerged from the literature review, territorial maps analysis but also from the workshop involving some urban planners, is that planning is already very complex for its multidisciplinary, economic and cultural constraints, urgent requests to answer.

To understand how to enhance the use of this integrated mapping approach and digital tools, the second group of research questions were fundamental. They focused on how digital tools are currently used, for which purposes and in which way. The answers highlighted the complexity of this field that requires professional digital skills and continuous updates. Normally, the limited time available in planning processes, reduces the use of this type of analysis, preferring an immediate answer to specific problems.

The dynamics guiding the urban processes are complex and it is important to understand them to contribute to their efficacy. The third group of research questions insisted on the exploration of urban planning for extreme heat, analysing the existing experiences to understand their approaches, objectives and gaps. The findings indicate a notable variability across the different plans, depending on their main goal but also to their characteristics of the cities they were developed for. It is important to always contextualize the results and not treat them as universally applicable.

The findings of these research suggest that the topics addressed are not always immediate to be understood and to be interpreted in the right way. The real-world demands flexibility and context-sensitive approaches.

7.1.2 Workflow and case studies

The workflow proposed in this research can represent an attempt to bridge the gap between climate analysis and planning processes. Instead of proposing a new tool, the research showed how existing digital tools, datasets and indices, combined, can provide a coherent but flexible structure to support decision-making related to extreme heat and other correlated issues. The application of the workflow to two case studies allows the evaluation of its potential, technical feasibility and flexibility given by its organization, sequencing and scalarity. What emerged is that the workflow can have an interesting role in planning processes to reduce extreme heat risks, not as a protocol but as a structure to organize, analyse and use relevant information for intervention planning and design. Enabling comparative analysis, it

also allows planners to assess if the risks are distributed homogeneously or if they are causing inequalities. This characteristic is relevant to address the climate justice topic.

One of the strengths of this workflow, highlighted by the application to the case studies, is the multi-scale approach. It starts from the city-wide perspective to identify priority hotspots, combining different information and data, to arrive at the neighbourhood scale for specific analysis and project design and simulation. This characteristic proves its adequacy to the complexity of the planning decisions where one of these scales is not sufficient to understand all the dynamics of the urban context. Planning interventions for extreme heat needs to consider the city to understand the critical areas but a finer spatial resolution is necessary to guarantee effective and equitable projects.

In all the scales, the workflow and the analysis produced through it, has the aim to reduce arbitrary decision-making, proposing to ground planning priorities and actions on spatial evidence. In a first moment the evidence is provided by the integrated territorial maps developed in QGIS, supported in a second moment, through its interoperability with ENVI-met, by the maps resulting from the simulations (of the pre-design and the post-design conditions).

The opportunity to overlay purely analytical information of the current individuals, spatial and environmental conditions with future projections reinforces this workflow, allowing to consider the strategies not only for their climatic performances but also for their relationship with the other variables of the local territory in which they will be applied.

The application of the workflow proposed to the case studies plays a crucial role in the validation of these and other considerations. The main aim was to demonstrate that it can be applied in different contexts and using different data, proving its robustness, flexibility, transferability and replicability. This assumption doesn't eliminate the context specificity, on the contrary, it allows local conditions to be actively considered in the planning processes. It provides a common structure that can be adapted for specific-context interpretations and decisions, making the urban complexity more manageable. Another key concept of this workflow is that, enabling comparative analysis, it allows planners to assess if the risks are distributed homogeneously or if they are causing inequalities. This characteristic is relevant to address the climate justice topic.

7.1.3 Implications for planning practice and the role of the guidelines

The results of this research aim to support decision-making in the planning process particularly in relation to the use of digital tools to tackle extreme heat climate inequalities. In order to achieve this goal, it was necessary to have an output accessible to all the planners and actors of the planning sector, also for the non-specialist. For this purpose, the multi-step workflow has been translated into operational guidelines (Chapter 6) to be directly applied in planning practice. The guidelines are the bridge between the structure of the process (the workflow) and the practical application, allowing the workflow to be usable, readable and replicable. In this research the guidelines are intended as a structure to apply in a systematic and transparent way for spatial analysis and scenario evaluation, not as a prescriptive manual. They enable comparison, not giving standard design solutions but promoting a multi-objectives perspective rather than a simplification. The aim is not to have an automated decision-making process replacing expertise, but to give them support to plan and design.

The guidelines promote the integrated analysis and design approach. All the factors and variables involved in the specific projects, are considered as interconnected dimensions and not isolated. This framework permits to study and interpret the topics not just from a single point of view. For example, climate risks can't be considered just as an environmental issue but also as an expression of territorial inequalities.

To address the inequalities, not only caused by extreme heat, the workflow and the guidelines to apply it, can give a strong contribution by identifying planning priorities. The prioritization of the areas where multiple critical conditions overlap, can create a more informed decision process. The choice of the location for the interventions based on evidence on the risks, permits to redistribute attention and resources toward vulnerable areas, making inequalities visible and measurable.

7.1.4 Limitations of the workflow and its application

The research demonstrates the potential of using digital tools for integrated territorial mapping in climate-sensitive urban planning but there are some specific limitations that have to be highlighted. These considerations do not undermine the validity of the research, the process, the methodology and the results but define the

boundaries of this study. The limitations emerge in different moments, from the data collection to the modelling process, from the simulations to the interpretation of the results.

The first limitation to consider is related to data quality and availability. The datasets required by this research approach and workflow are noticeably varied and characterized by different sources, spatial resolution, time references, levels of completeness and accuracy. This can affect the use of the data when it is planned to use them together so when they need to be comparable. Data qualities and characteristics can change the results of a research like this and can require some simplifications or aggregations (as in the case of census-tract data). Data availability is the other side of this issue. The publicly available data are limited, particularly in the case regarding vulnerabilities (social, educational, health-related data), because of privacy constraints, but also the spatial ones do not always have the open access. This can limit the opportunities to analyze in a detailed way the most vulnerable people and risky situations. The difficulty in finding the data is also time-consuming and can also require some proxy data that can create biases in the analysis.

The use of ENVI-met for microclimatic simulations is another critical point. This software is widely validated in scientific literature but has some limitations. First of all, to develop the model and run the simulations, material properties, vegetation characteristics, boundary conditions and atmospheric input, are needed. Sometimes, as already mentioned, these data are not available, missing or incomplete, and simplifications are needed. These possible incoherence can influence the quantitative results of the simulations. Another issue regarding ENVI-met is linked to its time-consuming processes that also require good machines. This point can go in contrast with the planning timing. Finally, the software is available in a free version but it has strong limitations (especially for the size of the areas simulated) compared to the paid one.

Strictly linked to the limitations of the use of ENVI-met, there is the problem of the temporal dimension of the microclimatic simulations. In this research simulations were conducted on a representative summer day. This choice is coherent with the objective of the research, focused on the extreme heat, but it is statistically solid. Also, it is not considering factors like intra-seasonal, long-term climatic trends, cumulative effects over time. This simplification give the results of this study relevant from an explorative and comparative point of view but they assess urban thermal behaviour.

Further limitations emerged comparing the two case studies, Turin and San Antonio. For this research two cities were chosen deliberately with differences in climate, urban development patterns, governance and data infrastructure to test the flexibility and adaptability of the workflow. It is important to recognize that, while the comparison for the use of the workflow works in a good way, the comparison between the two cities from a quantitative point of view (considering the results of the territorial analysis and simulations) was not completely successful. This consideration, anyway, confirms the assumption that territorial analysis needs to be context-dependent to be significant.

In relation to this last consideration, one of the limitations emerging from this research is the use of LCZs classification in different contexts. The use of these allows to compare the two cities having the same morphological typology for all the case studies. The limits in this case were given by two main points: the same LCZ can represent a wide range of specific typologies; some LCZs are more appropriate for a city and less for another so using the same typology can give non-significant results. An example of these issues is visible in the two case studies used for this research. Even if the LCZ6 resulted the most common (considering the extension in squared kilometres) it is not representative for the city of Turin where citizens live in most of the cases in a compact urban environment. In this research, in particular, the LCZ6 was not representative for Turin for the low income households because normally, in Italy, this category of people lives in apartments. In San Antonio, on the contrary, LCZ6 is predominant and all the income classes usually live in single-family houses or in general low-rise buildings. These considerations reinforce again the importance of contextual interpretation and promote preliminary analysis to understand when a comparison at all levels can be applied.

Finally, the validation process of the workflow has limitations given by the involvement of stakeholder only in the final phase and not for the workflow definition. This tool is developed with the aim to support decision-making but planning processes are normally characterized by non-linear actions, fragmented responsibilities and limited resources. As it will be described in the validation paragraph (7.2) it emerged that even if the workflow is scientifically robust and relevant for this field, the adoption of these kinds of approaches depends on the political willingness, time constraints or computing priorities. From this point of view, it is important to consider government dynamics and stakeholder engagement for the future application of the workflow.

7.2 Validation

The validation process of my work is an important step towards the conclusion of my doctoral path. Validation was designed so that, by involving stakeholders and experts in the planning field, the plausibility, relevance and usefulness of the research and its outcomes could be verified (Creswell & Plano Clark, 2018).

Specifically, I decided to use the participatory workshop methodology, which is widely used in the field of urban planning. The workshop in fact gives the possibility to explore complex concepts through the interaction of participants who, as in this case, may have different backgrounds, skills and knowledge (Reed et al., 2010). The relevance of a workshop of this type in fact does not lie in the attempt to seek consensus among the participants but in bringing out different points of view and testing ideas and tools critically (Innes & Booher, 2010).

7.2.1 Framing of the workshop and participants

This phase of the work started from two objectives. The first objective is to test conceptual frameworks, compare expert knowledge and skills (Reed et al., 2010). The second objective instead concerned the validation of the workflow designed in the research to understand its comprehensibility, usability, relevance, adaptability to different contexts and situations.

The workshop was in fact composed of two phases, the first in which the participants carried out two activities without the thesis being explained to them in order not to create bias in their responses to the first objective, while the second phase was preceded by a short and concise explanation (5 minutes) of the main concepts of the thesis, to answer the second objective.

The total duration was one hour and thirty minutes and the participants carried out 4 different activities:

- 1) Priority ranking of urban planning issues
- 2) Brainwriting on factors influencing extreme heat
- 3) Future uses brainstorming: adaptability and transferability
- 4) Critical friends: collective reflection on the workflow

Seven professionals were involved who, in different ways, deal with the planning of urban spaces in their work. Specifically, as representatives of the administrative bodies of the city of Turin, I invited a representative of the Metropolitan City of Turin, Doctor Alessandro Bertello, of the Department of Environment and Environmental Surveillance, and one for the City of Turin, Doctor Giovanni Ferrero, who deals with urban regeneration. At the regional level, I involved a representative of IRES Piemonte (Institute for Economic and Social Research of Piedmont), Doctor Giovanna Perino, who directs research for the Health and Development Area of the healthcare system. For the health promotion sector in the area, I invited two representatives of the ASL, Doctor Alda Cosola (ASL TO3) and Doctor Morena Stroschia (ASL TO5). The field of academic research on this topic was represented by Professor Riccardo Pollo, who deals with the Technological and Environmental Design of Architecture, and PHD student Anja Pejovic, who works on topics similar to those of this research for her doctoral thesis.



Figure 32: Workshop

7.2.2 Activity 1 - Priority ranking of urban planning thematics

The first activity I asked the group to do was “priority ranking”. This participatory methodology allows us to understand the importance that people attach to concepts that concern complex situations such as climate change, creating hierarchies (de Bruin et al., 2009).

In this specific case, the goal was to understand whether extreme heat is perceived as a priority in planning or at least to understand what importance it has, according to experts, compared to other planning topics.

Participants were provided with a list of planning-related words or concepts (written on cards), and I asked them to rank topics by priority in this area. The cards reported a series of planning-related themes drawn from authoritative sources (IPCC, WHO, IPBES, UN-Habitat, OECD) as titles, a brief explanation (so that everyone understood and shared the same meaning), and an icon. The topics addressed and the explanations reported on the cards were:

- **EXTREME HEAT:** Increased frequency and intensity of heat waves, amplified in urban areas by the heat island, with impacts on the health, comfort and functioning of cities
- **FLOODS:** risk of urban flooding due to extreme rainfall, river or coastal events, with effects on settlements, infrastructure and essential services.
- **DROUGHT:** Prolonged reduction in water availability that impacts urban supplies, ecosystem services, and water management.
- **AT-RISK GROUPS:** Populations most exposed to urban climate impacts, such as the elderly, children, low-income people, or those with pre-existing health conditions.
- **DISEASES AND URBAN ENVIRONMENT:** influence of urban environmental conditions (air, water, climate) on the onset and worsening of diseases.
- **AIR QUALITY:** levels of air pollutants in urban areas and their effects on public health, influenced by traffic, production activities and climatic conditions.
- **URBAN GREEN:** A collection of green spaces and ecosystems in cities that provide ecosystem services, including climate regulation, well-being, and biodiversity support.

- **PUBLIC SPACE:** Accessible and shared urban spaces, such as streets, squares, and parks, that play a central role in social life, livability, and urban resilience.
- **URBAN MOBILITY:** a system of movement of people and goods in urban areas, which influences accessibility, social inclusion, environmental impacts, and quality of life.
- **HOUSING:** conditions of availability, quality and affordability of housing, with implications for social equity, health and urban safety.
- **COORDINATION BETWEEN ACTORS:** collaboration between public, private entities and civil society in managing urban and climate challenges.
- **ACCESS TO SERVICES:** ability for residents to reach essential services such as healthcare, education, transportation, and green spaces.

In the figure 18 you can see in what order the participants decided to place the individual cards. First of all, it is interesting to note how the participants immediately identified the fact that not all the elements were on the same level also in terms of meaning. It essentially emerged that some could be clustered under the same group, but also that some were a consequence of others. They all agreed that “coordination between actors” was the most important element, explaining that without it, one cannot even act on the issues below. There are two steps under this concept: risk groups, the most vulnerable people, and access to services. At the third level of priority, however, there are concepts well known in urban planning, “urban mobility”, “public space”, “urban greenery” and “housing”. The last level is instead characterized by very specific elements: “diseases and urban environment”, “extreme heat”, “air quality”, “drought”, “floods”.

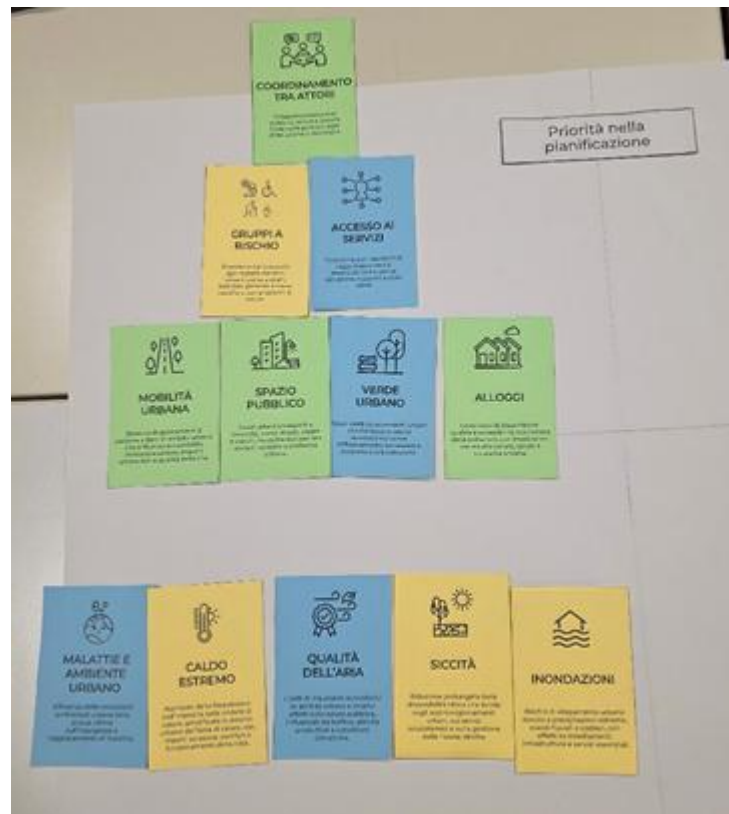


Figure 33: Priority cards

The positioning choices of the elements present in this activity can be interpreted from the perspective of connecting both horizontally, between those on the same level, and vertically, between different levels.

For a vertical reading, it can be considered that “coordination between actors” is an essential concept without which one cannot act on all the elements below. In this sense, it is a sort of necessary and essential condition for addressing the problems that planning poses to planners.

The second level, however, can be read horizontally, meaning both the items reported, both “risk groups” and “access to services”, as issues to be addressed with absolute priority because they are very problematic in the urban context. Vertically, this level can be understood both in relation to what is above and what is below. The link with the higher element consists in the fact that, without coordinating the actors, action can certainly not be taken either on making services more accessible or on supporting the most fragile categories of population. These two elements

instead connect to the bottom row as the latter are tools that the planner can deploy to address the aforementioned problems.

The third level connects to this vertically when the design and planning of “urban mobility”, “public space”, “urban greenery” and housing” can serve to address the problems of vulnerabilities and access to services. This level, in fact, reading it horizontally, is the one that most connects to the concrete actions that a planner can implement. In fact, it can be said that this level encompasses the different typologies of urban spaces on which design can be applied.

The fourth and final level, when considered horizontally, represents all risks that are linked to environmental and climatic phenomena that do not strictly depend on the configuration of urban spaces (“diseases and urban environment”, “extreme heat”, “air quality”, “drought”, “floods”). However, some urban spaces may influence their effect, they cannot eliminate them but only address them to reduce their negative consequences. In this sense, this level of connection to the higher one is also necessary because, by carrying out concrete actions on urban spaces, the effects of these extreme and negative phenomena can be mitigated.

7.2.3 Activity 2 – Brainwriting on factors influencing extreme heat

Regarding the second activity, I decided to propose a “brainwriting”, an idea generation technique that is based on having participants write their own contributions before interacting with the group (VanGundy, 2005). This collaborative technique lends itself to urban issues in that it is adequate for complex problems in which there is no single solution but it is necessary to consider several dimensions simultaneously (Geschka, 1987).

Through this second activity, I thought I would delve deeper into the topic of my thesis, always without talking about it directly, addressing the issue of extreme heat. Specifically, in fact, this activity aimed to identify which variables are considered important and influential on the effects of extreme heat.

I asked participants to answer a question “Why doesn't extreme heat affect all people and all urban areas in the same way? What factors and variables influence the effect of extreme heat?”. I provided each of them with post-it notes and markers, gave them 10 minutes to write on each piece of paper a factor that they believed

affects the effect of extreme heat, and asked them to place the post-it notes on the blank sheet of paper with the written question.

After this individual moment, the one of collective sharing began. We read the concepts, words, or sentences they wrote together, and I asked them whether there were the same or similar ones or whether they could be grouped into conceptual clusters to reason by groups.

Numerous concepts have emerged that can be traced back to both the city and the people. Four clusters emerged from the concept clustering work: vulnerability factors; individual variables; spatial characteristics; and the presence of natural elements.

Regarding the vulnerability group, participants identified factors related to social, economic and clinical conditions. In this context, most of them focused their attention on the health status factor, emphasizing the epidemiological issues and physiological characteristics of the individuals.

The individual variables highlighted concern lifestyle, which can be active or passive, and the activities performed by people in the city. For example, there may be jobs that carry greater risks if performed in extreme heat. The age and culture of the citizens were obviously also indicated among the factors. Another interesting element that emerged in this cluster is adaptive behavior that depends on the adaptive capabilities of the individual.

On the topic of spatial characteristics that influence the effect of extreme heat, numerous variables have been identified, often linked to each other. The variables in this group have different scales. The urban form and morphology have been identified and have a fairly large scale. At a smaller scale, materials and housing patterns that can enhance the effects of extreme heat have been identified. Finally, two variables that are less measurable but equally important were included: the quality of buildings and the quality of public spaces.

The last cluster connects strongly with the previous one because it always concerns urban spaces but, in this case, the focus is on natural elements. In particular, the importance of the presence of urban greenery and blue infrastructure was highlighted.

The breadth and multidimensionality of this phenomenon certainly emerged from the discussion among the participants. The variables to be considered are

numerous, certainly even more than what has been brought to light in this exercise. This speech confirms the complexity of this topic.

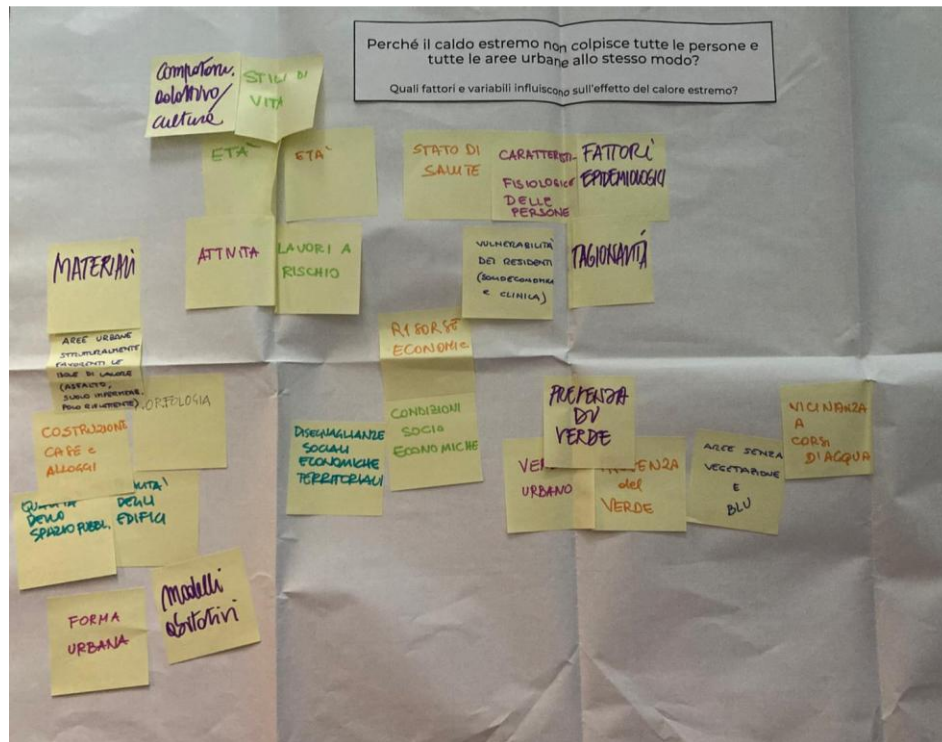


Figure 34: Brainwriting panel

7.2.4 Activity 3 - Future uses brainstorming: adaptability and transferability

The third activity is the first we did after I briefly explained my thesis. In this case I decided to use the “future uses brainstorming” technique. This methodology is based on individual brainstorming and it is a recognized approach to assess the adaptability, robustness, and applicability of a research or study to other contexts and situations (van der Bijl-Brouwer & Dorst, 2017).

The aim of this activity was to assess whether the proposed workflow was perceived as adaptable and transferable to cases other than extreme heat, other urban issues.

To do this task I prepared some cards to design custom integrated mappings. Each participant was then asked to individually reflect on questions such as: “For what other urban problems might this workflow be useful?”; “What additional or alternative data layers would be relevant?”; “In what decision-making contexts could it support planning activities?”. The workshop participants then completed a form thinking about what data they found most interesting and thus created a map with the same underlying workflow but different objectives and variables. Each card had blank spaces into which each participant could insert different layers, one for each piece of data they wanted to overlay in the mapping, and a space to insert the mapping objective. This individual moment was followed by a group discussion on the individual mappings created by the participants.

As a result of this activity I obtained 7 integrated territorial maps:

- Map 1

Objective: Opportunities to promote physical activity among the population

Overlapping layers: urban green (environment) + organized public spaces (health and social) + climate and microclimate + mobility + cultural initiatives + cultural spaces + health conditions + social risks + commercial spaces

- Map 2

Objective: To assess appropriate priorities and policies

Overlapping layers: land use + commerce + private spaces/public spaces + age groups + public green/private green + trees + condominium spaces + active mobility spaces (walkability) + third sector activities (social assistance, healthcare, education, culture, environment, civil protection, and research, carried out by private non-profit organizations for civic and solidarity purposes)

- Map 3

Objective: To demonstrate that real estate values are a proxy for both climatic and socio-economic variables

Overlapping layer: real estate values + climate risk + socioeconomic hardship

- Map 4

Objective: to define usable/recoverable urban space

Overlapping layers: TPL (Local Public Transport) offering + population density + parking + green areas

- Map 5

Objective: to know the conditions of the population and the services offered; knowledge framework

Overlapping layers: social conditions + economic conditions + territorial conditions + epidemiological conditions + greenery + materials + local public establishments + personal (health) services + information points

- Map 6

Objective: To map the health risk associated with urban heat islands

Overlapping layers: health data (mortality, hospitalizations, general practitioner visits) + heat islands + socioeconomic status + demographic data + availability of green or blue areas + access to services (walkability, proximity...) + availability of climate shelters

- Map 7

Objective: Accessibility of vulnerable populations to climate refuges

Overlapping layers: heat stress + social and economic vulnerability + accessibility + active mobility + climate shelters + possible climate shelters + urban greenery

From the discussion of the maps it emerged that there were similar ideas but also some different ideas. Participants envisioned the workflow as a flexible tool, adapting it to different objectives, scales, and areas, while maintaining the logic of integrated territorial mapping. Since “personalized” maps combine variables of different nature, the fact that urban issues are complex and interdependent phenomena is confirmed.

The objectives of the seven maps instead highlighted the fact that each map can have a different function. Some aim to build knowledge and evaluation frameworks while others aim to define operational support for public action.

7.2.5 Activity 4 - Critical friends: collective reflection on the workflow

The fourth and final activity I proposed to the participants was the “critical friends”, an evaluation tool that is based on offering critical and constructive feedback (Costa & Kallick, 1993). This methodology allows for external feedback that contributes to understanding the limitations and potential of methods and practices (Schuck & Russell, 2005).

At this stage of the workshop, the main objective was to critically evaluate the robustness, practical applicability, and adaptability of the proposed workflow through feedback from field professionals and experts. Identifying operational strengths and limitations for realistic implementation is critical for a product that is not limited to theoretical use.

I invited participants to assume the role of “critical friends” by commenting positively and negatively on the workflow proposed in the thesis with short and concise feedback.

The potential and positive aspects of the research were highlighted as being very useful for topics such as health promotion and prevention, to support decision-making in urban design and planning, and to map complex phenomena such as health risk and walkability. In general, the potential to “multiply maps” adapted to the phenomena to be studied and the objectives to be carried out, has been identified as the main positive aspect of the proposed workflow. Among the limitations, it has been highlighted that in planning contexts we often act according to the logic of “garbage can” in which problems, solutions and actors interact in non-linear and contingent ways (Cohen et al., 1972) so, including a process like the one proposed, is not always possible. A further point, linked to the first, is that, in the context of public planning, there is not always the will to take additional steps to have a scientific basis on which to base decisions. An interesting input on this last point, however, came from the observation that if these scientific bases, in the form of mappings, in our case, were correlated with cost-saving data, then decision makers would also be more likely to invest in this type of approach. The last major

limitation identified is that the construction of the workflow was carried out without interfacing with the decision-makers or the actors usually involved in these processes. Unfortunately, this was not possible because, both in Turin and San Antonio, we were given a willingness to talk about the work only when it was finished, following the production of the maps and guidelines.

Chapter 8

Conclusions

This doctoral research explored how digital tools can be used for integrated territorial analysis and mapping in a climate-sensitive and equity oriented urban planning. The main contribution of this thesis is a comprehensive digital workflow to support planning for extreme heat focusing on integrated territorial mapping. The aim is to support decision-making in identifying priority areas for interventions, conducting territorial analysis, pre-design and post-design simulations, strategies scenarios evaluation and choice. The workflow is a structured and operational tool to bridge the gap between scientific knowledge and practical urban design applications. The research also provided guidelines to guarantee workflow replicability, adaptability, transparency and flexibility in planning processes that have usually limited time, human and economic resources.

The contribution of this thesis to the scientific debate in the field of spatial planning and urban climate actions is the development of an approach that is analytical and operational in the same moment. This point of view promotes a consideration of the territory as a complex system composed by interdependent variables to be considered in their interrelations to not simplify the reality.

The thesis has been enriched by the application of the workflow to two case studies, Turin and San Antonio, demonstrating the potential of this tool across different contexts but also highlighting its limitations and future perspectives. The research has been enriched by analysis of the scientific literature, experts' consultation and collaboration, planning actors' involvement.

The research is also characterized by some important constraints and boundaries of the research as a whole, beyond the technical limitations discussed in relation to the workflow itself (see 7.1.4).

The scope of the thesis defines the boundaries of the research. The aim of the research was to create an analytical and decision-support framework to address heat stress in urban contexts focusing on vulnerable people.

The data used to test the workflow, applying it to Turin and San Antonio, were climatic, morphological and economic. These data are relevant for the topic but they are not the only useful information from this point of view. The choice of these variables excluded numerous others. Future research could address this limitation by using the workflow with other data. During the validation workshop, many other interesting possible map layers emerged, such as health and mobility data.

Future research should also further explore data integration as a central component of climate-sensitive and equity-oriented planning.

For this purpose, future developments should investigate the characteristics that make data suitable for integrated planning workflows. Particular attention should be given to data accessibility, interoperability, update frequency and spatial disaggregation.

At the same time, future research could explore whether the workflow should rely on pre-existing composite indicators, such as vulnerability indexes, or whether it would be more effective to identify and analyse correlations among multiple urban, environmental and health indicators. Similar approaches have recently been adopted in regional planning experiences that investigate the relationships between urban characteristics and public health outcomes at broader programming scales.

From a technical perspective, further research could also focus on the definition of data standards and technical specifications for the development of future plugins and extensions capable of facilitating data exchange among different GIS environments, planning support systems and institutional databases. Such developments would enhance the interoperability, transferability and long-term applicability of the workflow across different administrative contexts.

The other main topic of the research, the extreme heat, also excluded alternative climatic factors, equally and more relevant in other countries, like the extreme cold, air pollution, or other specific climatic conditions. In a future perspective the workflow could be applied to other climatic issues as well.

Another important choice that influenced the research results was the selection of two case studies. A larger number of case studies, considering additional cities and climatic contexts, would permit a more consistent comparison and give the opportunity to test the workflow in numerous different conditions. As a future perspective it would be interesting to apply the workflow in a wider range of cities

and climates to generate significant results and to change the workflow in relation to new limitations that would emerge from these new experiments.

A further limitation is connected to the involvement of planning stakeholders and actors working on urban planning. The workshop aimed at evaluating and validating the workflow proposed in this research. It would have been better to involve these professionals during the definition of the workflow to adapt it to their specific needs, not only in the final phase. A future researcher should apply what emerged from the workshop to change in some parts the workflow. Future research could therefore adopt co-design and participatory validation approaches, engaging planning practitioners throughout the entire research process.

This limitation is closely related to another concerning the dependence on institutional and organizational context for the replicability and the effectiveness of the workflow. The successful adoption and implementation of the workflow is influenced by multiple factors: data accessibility, technical expertise, administrative priorities, resources availability, policies, supportive institutional culture. Future research could investigate how the institutional and organizational dynamic can determine and affect the implementation of the proposed workflow. The application in cities with different institutional structures and administrative capacities would suggest further modifications to the workflow, providing guidelines and recommendations that enhance its transferability.

Some of the choices described in the previous points were motivated by an academic limitation, the duration of the PhD. Both the workflow definition step, the experimentation phase and the guideline development couldn't take more time so some activities were excluded in relation to a priority order.

The outputs of the thesis demonstrate the applicability of the structured digital workflow proposed. In this perspective the thesis should be read as a starting point for future research and experimentations, to improve the connections between climate knowledge, spatial analysis, projects and urban planning practice.

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Appendix A – Data collection and preparation in QGIS

APPENDIX A.1 – Open data search and dataset selection

A.1.1 Identification and download of required datasets

To develop integrated territorial maps in QGIS and a microclimatic model for ENVI-met, geospatial datasets describing the areas of interest are required.

Step 1 – Identify relevant open data sources

- Access official municipal and regional open data portals (for example writing in the search bar “open data” and the name of the city)
- Search for datasets using keywords such as buildings, land cover (the type of surface) and trees

Step 2 – Select essential model parameters

- For the integrated territorial maps, the parameters required depend on the aim of the analysis
- For ENVI-met modelling some specific datasets are required:
 - Building footprints (polygon format preferred) and height (meters values required but they can be converted directly in QGIS)
 - Land cover (raster format is usually used)
 - Tree inventory and, if possible, species and height (point format)

Datasets associated with map visualization and usually already georeferenced and, for these kind of research, preferred.

Step 3 – Verify data structure and format

- Confirm if the dataset is provided in vector or raster format

- If only tabular data (for example: CSV) are available:
 - Import in QGIS using “Layer” -> “Add Layer” -> “Add Delimited Text Layer”
 - Define geometry type: for example, point coordinates
 - Assign X (longitude) and Y (latitude) fields
 - Maintain the original coordinate reference system during import process

Step 4 – Resolution assessment (for raster datasets)

- Verify spatial resolution
- A resolution of approximately 1 m is recommended, as this correspond to the minimum grid cell size usually adopted in ENVI-met simulations

Step 5 – Alternative data sources

- If official datasets are unavailable, data may be derived from OpenStreetMaps, using dedicated plugins

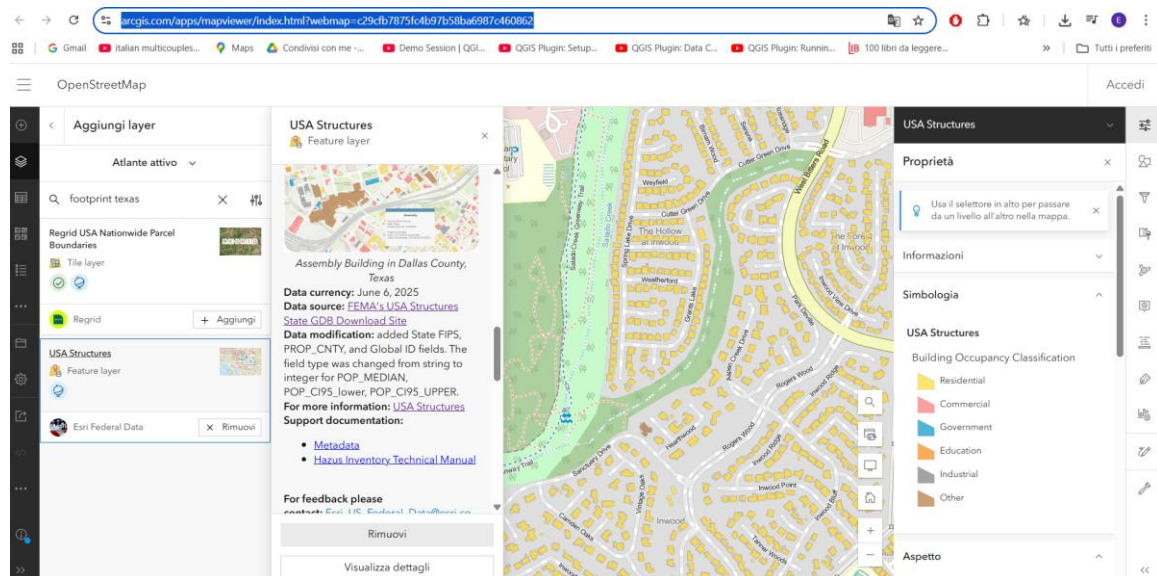


Figure 35: Data search in OpenStreetMaps

APPENDIX A.2 – Dataset visualization and preliminary verification

Step 1 – Create a new QGIS project

- Open QGIS
- Create a new project
- Import vector and raster datasets via drag-and-drop or the Data Source Manager

Step 2 – Select appropriate geometry

- When multiple geometry types are available (for example point and polygon layers), select the most suitable representation for modeling purposes

Step 3 – Verify coordinate transformation warnings

- If a notification appears (for example: transformation from “EPSG...” to another CRS), this indicates CRS inconsistency and requires a harmonization (see Appendix A.3)

Step 4 – Inspect attribute tables

- Open the attribute table of one layer (for example: building)
- Verify the presence of the information of interest (for example: height)
- Identify unit of measurement (for example feet of meters)

Step 5 – Verify raster classification

- Open layer properties -> “Symbology”
- Confirm class-value correspondence with the dataset documentation

APPENDIX A.3 – Coordinate Reference System (CRS) harmonization

Step 1 – Identify appropriate UTM zone

- Determine the UTM zone corresponding to study area
- Select the projected CRS

Step 2 – Reproject vector layers (if necessary)

- For each layer:
 - Right-click -> “Export” -> “Save as”
 - Select the appropriate CRS
 - Apply the recommended transformation parameters

Step 3 – Reproject raster layer (if necessary)

- Use “Raster” -> “Projections” -> “Warp (Reproject)”

Step 4 – Set project CRS

- Open “Project” -> “Properties” -> “CRS”
- Assign the selected projected CRS
- Remove non-harmonized layers
- All the layers must share the same projected CRS before proceeding with any analysis

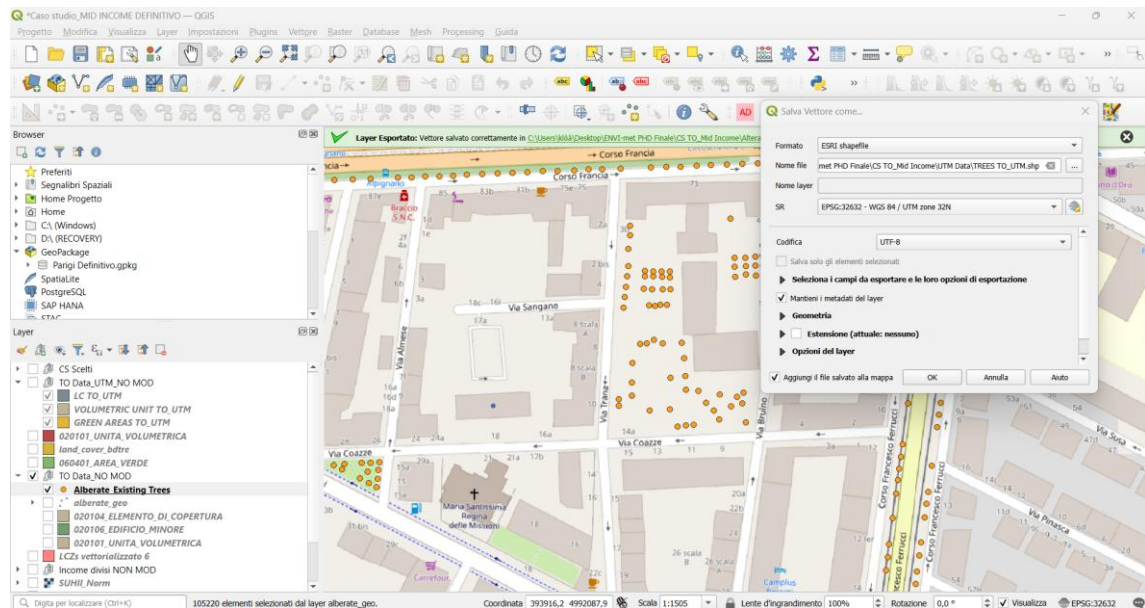


Figure 36: CRS harmonization process

APPENDIX A.4 – Definition of the Area of Interest (AoI) and data clipping

This step reduces computational load and improves maps and model performance. It is necessary to do it for all the layers to get smaller areas.

Step 1 – Create AoI layer

- Create a new polygon shapefile
- Assign the same CRS as the project
- Digitize a rectangular polygon representing the simulation boundary

Step 2 – Clip vector layers

- Open “Vector” -> “Geoprocessing Tools” -> “Clip”
- Set:
 - Input layer: dataset to be clipped
 - Overlay layer: AoI polygon

Step 2 – Assign classification colors

This step improves readability and visual verification.

- Select “Paletted / Unique values”
- Assign specific colors to each class (or example in the case of “land cover” the classification can be: “buildings, roads, paved surfaces, water, grass, tree canopy...”)

APPENDIX A.6 – Common data issues and pre-processing

Issue 1 – Height unit conversion

- If the heights are provided in feet for example:
 - Use “Field Calculator”
 - Create new field (Decimal)

Issue 2 – Missing height values (NULL)

- Possible solutions:
 - Assign statistical average values
 - Manually integrate missing data
 - Assign minimum plausible height values

Appendix B – ENVI-met conceptual model

APPENDIX B.1 – ENVI-met grid-based modeling logic

ENVI-met Database model/ENVIIDs

ENVI-met operated on a three-dimensional structured grid.

- Each grid cell stores information regarding:
 - Built structures
 - Surface materials
 - Vegetation (simple plants and 3D trees)
 - Soil properties

All physical properties are defined through ENVI_ID codes (six-character identifier linked to the internal ENVI-met database), which specify materials' composition, albedo, vegetation type, structural parameters.

Appendix C – GIS-ENVI-met integration via QGIS plugin

APPENDIX C.1 – Model grid definition

Step 1 – Define simulation sub-area

- Open ENVI-met plugin
- Navigate to “Gridding”
- Select AoI layer (must contain one rectangular polygon)

Step 2 – Define horizontal resolution

- Set grid resolution (typically 1, 2 or 3 meters, depending on the level of detail and precision needed for the analysis)

Step 3 – Define vertical resolution

- Set vertical grid size equal to horizontal resolution
- Determine the number of vertical cells based on the tallest building
- Ensure total model height is at least twice the maximum building height

Step 4 – Additional gridding settings

- Set default surface (walls and roofs) material (for undefined cells)
- Define “safety” cells at model borders (because the area to be simulated is enclosed within a rectangle that cuts through buildings on its sides; normally 5 is used as the value of the cells but, in case it doesn't work, the software will suggest it when using the “model inspector”)
- Enable removal of vegetation overlapping buildings

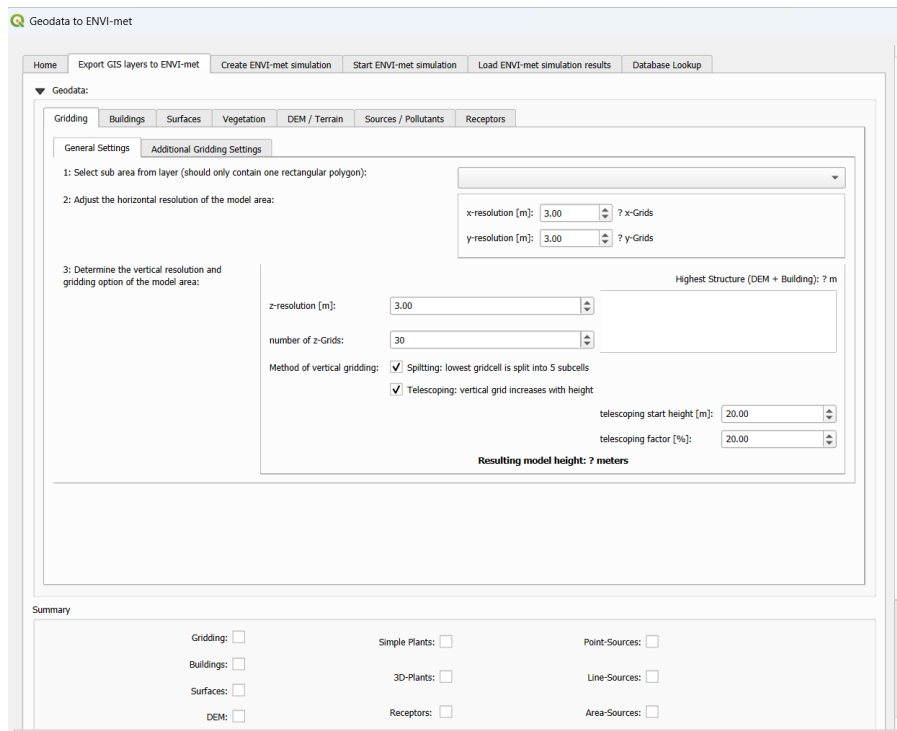


Figure 38: Plugin gridding settings' page

APPENDIX C.2 – Building modelling

All the following steps are referred to the attribute table of the building layer and to the plugin building page. Height and material assignment are the minimum required parameters.

Step 1 – Select building layer

- In plugin -> “Buildings”
 - Select clipped building layer
 - Assign height field (meters)

Step 2 – Convert units (if required)

- Use “Field Calculator” to convert feet to meters

Step 3 – Assign building heights

- Link height field in plugin under “Select field for building top [m]”

Step 4 – Assign wall materials

- Create new text field (for example naming it like “WallID”)
- Insert appropriate ENVI_ID from database
- Link field in plugin under “Select field for building walls [ENVI_ID]”

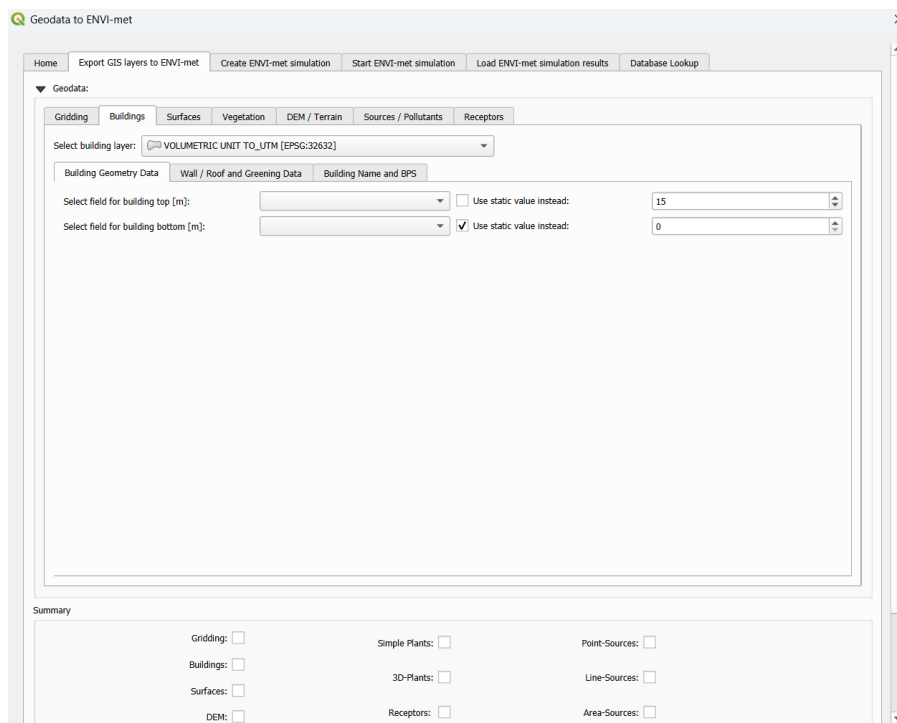


Figure 39: Plugin building page

APPENDIX C.3 – Trees and vegetation modeling

Step 1 – Select tree layer

- In plugin -> “Vegetation” -> “3D Plants”

Step 2 – Create ENVI_ID field

- Open “Field Calculator”
- Create text field (for example TreeID)
- Use conditional expressions (CASE) to associate species names with corresponding ENVI-met database IDs
- Define a default generic tree for unmatched species

Step 3 – Visual verification

- Compare modelled tree distribution with satellite imagery to ensure consistency

Step 4 – Simple plants (grass areas)

- If grassy areas are modelled:
 - Use “Vegetation” -> “Simple Plants from Vector Layer”
 - Assign static ENVI_ID where appropriate

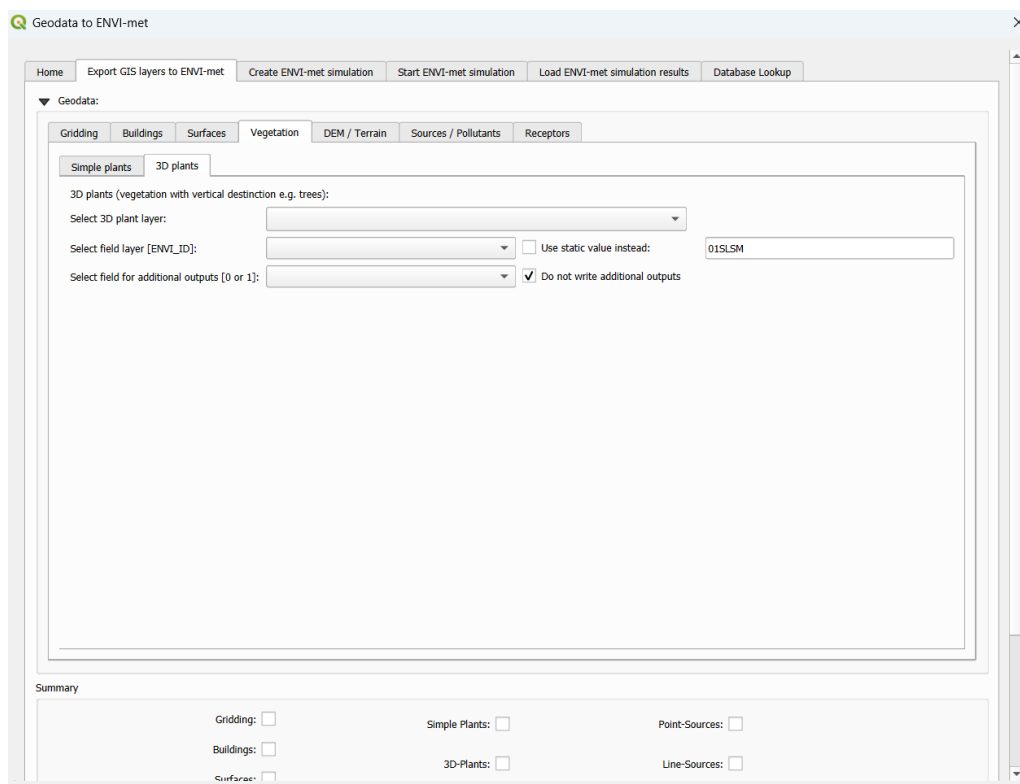


Figure 40: Plugin vegetation page

APPENDIX C.4 – Surface materials modeling

- Two approaches are possible:
 - Option 1 – Raster-based surfaces
 - Plugin -> “Surfaces from Raster Layer”
 - Assign ENVI_ID to each raster value
 - Option 2 – Vector-based surfaces
 - Create ENVI_ID field in the attribute table
 - Use plugin -> “Surfaces from Vector Layer”
 - Link ENVI_ID field
- If classification detail is insufficient for the intended simulation scale, additional layer, such as different typologies of roads, sidewalks, may be merged to increase spatial resolution
- Cells without any explicit material assignment, are automatically filled using the default material defined in the gridding settings (APPENDIX C.1 – Model grid definition)

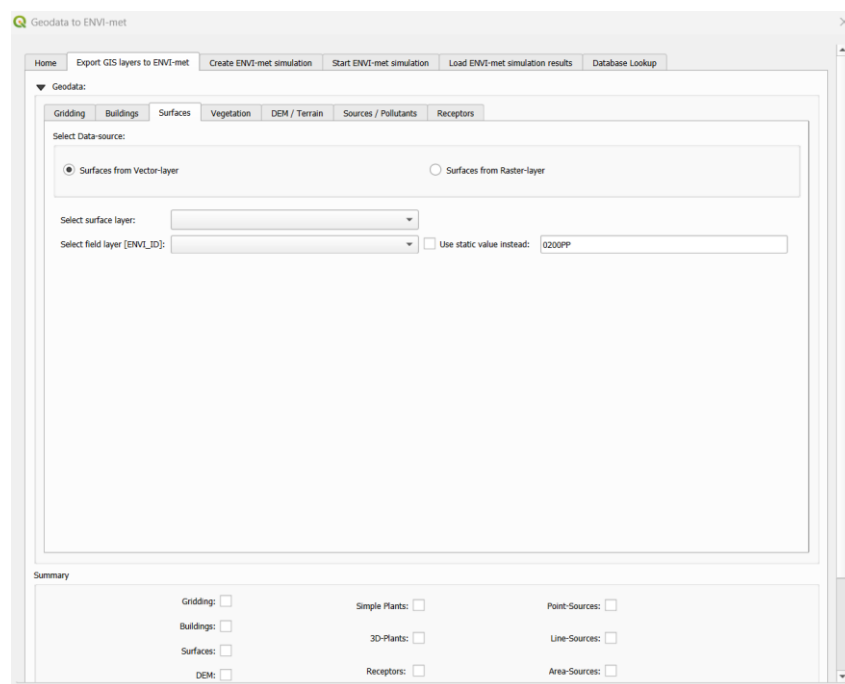


Figure 41: Plugin surface material page